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Technical Summaries

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Conference 8339: Bioinspiration, Biomimetics, and Bioreplication II

SPIE Smart Structures/NDE

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8339-01, Session 1

Nature as a model for technical sensors

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Nature has developed a stunning diversity of sensory systems. Humans and many animals mainly rely on visual information. In addition, they may use acoustic, olfactory, and tactile cues for object detection, object discrimination and spatial orientation. Beyond these sensory systems a large variety of highly specialized sensors have evolved. For instance, some buprestid beetles use infrared organs for the detection of forest fires. The infrared sensors of boid and crotalid snakes are used for prey detection at night. For object detection and spatial orientation all fish and aquatic amphibians use the mechanosensory lateral line. In addition to their mechanic sense, many species of nocturnal fish employ active electrolocation. This review describes certain aspects of the detection and processing of infrared, lateral line and electrosensory information. I will show that the study of natural exotic sensory systems can lead to discoveries that are useful for the construction of technical sensors and artificial control systems. Comparative studies of animal sensory systems have the power to uncover at least a small fraction of the gigantic untapped reservoir of natural solutions for perceptive problems.

8339-02, Session 1

Bioinspired hyperacuity vision sensors for robotic navigation

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The Wyoming Information, Signal Processing, and Robotics (WISPR) Laboratory has developed multiple generations of analog vision sensors inspired by the common housefly, Musca domestica. The fly's vision system exhibits features such as fast, parallel operation and hyperacuity. Hyperacuity is motion detection at resolutions less than that predicted by photoelement spacing, achieved in the fly using neural superposition. A small robot was equipped with an array of analog sensors incorporating neural superposition. The array exhibited a 50 fold increase in object resolution compared to a similar robot equipped with an apposition type analog sensor array. Apposition type compound eyes occur in diurnal insects and certain species of arthropods, and do not incorporate neural superposition. In addition to the significant increase in resolution measured for the neural superposition sensor, analog processing to mimic the "log transform-subtraction-multiplication" light adaptation features of the fly was also added. This provides light adaptation in a wide variety of lighting scenarios. The sensor allows fast analog detection of edge orientation and location. The sensor development is intended for obstacle avoidance applications including unmanned aerial systems, ground based robots and autonomous wheelchair navigation in both the visible and infrared wavelengths.

8339-03, Session 2

Learning from animal sensors: the clever "design" of spider mechanoreceptors

F. G. Barth, Univ. Wien (Austria)

No abstract available

8339-04, Session 2

Noise-exploitation and adaptation in neuromorphic sensors

T. Hindo, S. Chakrabartty, Michigan State Univ. (United States)

Even though current sensing technology has reached the cross-roads where biological scale devices can be fabricated, but the sensing and operational capabilities are still orders of magnitude inferior to those observed in neurobiology. For example, the filiform hairs in crickets operate at fundamental limits of noise, the power dissipation of a mammalian cell is less than pico-watt; and sensors in a parasitoid fly can overcome fundamental limitations due to size for localizing ultra-faint acoustic signatures. To understand how biological systems can achieve such a performance it is important to understand the underlying neuromorphic signal processing principles. One aspect is the inherent ability of neuromorphic sensors to adapt and learn at the sensing level. Learning will involve adaptation and altering the parameters or topology of the sensor over slow time-scales so that it can efficiently sense the signals of interest without dissipating too much energy and without requiring the use of precision computing or sensing devices.

Also, unlike man-made sensors which consider device and sensor noise as nuisances, neurobiology has evolved to use non-linear sensing techniques to exploit noise to its advantage and operate at or below fundamental limits. At a level of a single sensor, we will discuss stochastic resonance principle that exploits the combination of "device" noise with the system non-linearity to improve the system sensitivity. At the system level we will discuss "noise-shaping principle" which is a mechanism by which the energy contained in noise is shifted out of the spectral and spatial locations where information is present.

8339-05, Session 2

Formation and characterization of membrane based artificial hair cell sensor arrays

T. Young, Virginia Polytechnic Institute and State Univ. (United States); S. A. Sarles, The Univ. of Tennessee (United States); D. J. Leo, Virginia Polytechnic Institute and State Univ. (United States)

The mammalian ear is an amazing feat of evolution; using a series of vibration sensitive hair cells located in the inner ear canal it is able to pick up vibrations in the air and transmit them to the brain to be recognized as sound. Our research has been centered around the creation and testing of a setup that imitates the mechanotransducing processes found in these hair cells. Our initial experiments lead to the creation of a single artificial hair cell using a lipid bilayer as the artificial cell membrane and alamethicin peptides as transduction elements. Using capacitance measurements of the lipid bilayer and single channel measurements of the gating activity of transmembrane proteins we are able to measure the vibration response of the hair structure generated by an actuated fluid flow. Work has moved to creating arrays of the artificial hair cells that use hydrogel spheres to anchor the bilayer interface to a substraight, support the hair structure, contain the phospholipids and alamethicin peptides necessary for creating the artificial cell structure and better transmit vibration from the hair to the bilayer for measurement. Work is currently being done to characterize arrays in a parallel configuration where each artificial cell is measured independently and in a series configuration where multiple cell structures are measured as one unit. The effects of ionic liquid properties on lipid bilayer properties and protein gating events when incorporated into the hair cell system are also being studied.

8339-06, Session 3

A bioinspired aquatic flow sensor using an artificial cell membrane

P. Pinto, K. Garrison, Virginia Polytechnic Institute and State Univ. (United States); S. A. Sarles, The Univ. of Tennessee (United States); D. J. Leo, Virginia Polytechnic Institute and State Univ. (United States)

Receptors known as hair cells give many animals this ability to sense a wide range of stimuli, such as sound, orientation, vibration, and flow. Previous researchers have mimicked natural hair cells by building electromechanical sensor systems that produce an electric response due to the bending of artificial hairs. The biomimetic system used in our prior work was a hair cell airflow sensor that incorporated a gel-supported artificial lipid bilayer as the transducer element. Initial research demonstrated that the amplitude and frequency of the current response were directly related to the airflow over the hair, and that the vibration of the artificial membrane was responsible for the current flow induced by mechanical vibration.

Inspired by the roles of sensory hairs in fish, this work builds on previous research by investigating the flow dependent electrical response of our artificial hair cell in an aqueous flow. This study presents the design, fabrication, and characterization of a flow sensor that will help close the loop between the sensing mechanisms and control strategies that aquatic organisms employ for functions such as locomotion regulation, prey capture, and particulate capture. The system is fabricated with a durable, artificial bilayer that forms at the interface between lipid-encased aqueous volumes contained in a flexible encapsulated polyurethane substrate. Flow experiments are conducted by placing the hair cell in a flow chamber and subjecting it to various types of pulsatile and steady flow conditions. The sensor is characterized by measuring the current response as a function of the input flow conditions.

8339-07, Session 3

Fabricating neuromast-inspired gel structures for membrane-based hair cell sensing

N. Tamaddoni, S. A. Sarles, The Univ. of Tennessee (United States)

In the past few years, bottom up assembly of biological molecules has led to new forms of biosensors, drug-delivery vehicles and functionalized implant coatings. The recreation and stabilization of an artificial cell membrane is a common objective in these works as this material interface provides a suitable environment for hosting enzymes and proteins and for ensuring diffusion-resistant encapsulation of biochemical agents. In contrast to these uses, recent research has shown that a new class of mechanical sensor made from biomolecules and that features an artificial cell membrane as the sensing element can be used to mimic hair cell mechanotransduction in vertebrates. The sensor is comprised of a synthetic hair that features a water-swollen hydrogel at its base and which is connected via a lipid bilayer to a second lipid-encased hydrogel volume. Induced motion of the hair cause both the gel and membrane to vibrate. This oscillation produces changes in the capacitance of the membrane, thereby generating a voltage-dependent current on the order of 10-1000pA.

The work presented in this paper is part of an ongoing effort to better understand and improve the sensing mechanism of membrane-based hair cells and to fabricate arrays of sensors in a single device. Specifically, our efforts are focused on refining the methods used to fabricate and connect lipid-encased hydrogels. Gel structures that more closely mimic the ball-cup morphology of neuromasts found along the lateral lines of fish will be fabricated and tested for their ability to support the hair structure and enable bilayer formation.

8339-08, Session 3

Localization of a moving target using an IPMC-based artificial lateral line

A. T. Abdulsadda, X. Tan, Michigan State Univ. (United States)

Lateral line systems are an important sensory organ for fish that enable them to detect predators, locate preys, perform rheotaxis, and coordinate schooling. A lateral line system consists of arrays of neuromasts that effectively function as flow sensors. Motivated by the lateral line system of fish, arrays of flow sensors have been proposed as a new sensing modality for underwater robots. A vibrating sphere, also known as a dipole source, is often used in the study of biological and artificial lateral lines (ALLs) because it emulates the rhythmic movement of fins or body appendages. Most studies on ALL systems, however, have only considered localizing a dipole source fixed in space.

In this paper we examine the problem of localizing a moving dipole source using an ALL, which is of great interest in underwater robotics. First, we formulate a nonlinear estimation problem based on an analytical model for the moving dipole-generated flow field, where we assume that the source location, vibration amplitude, and moving speed are unknown and the amplitudes of flow velocities at the sensor sites are measured. The problem is solved recursively with the Gauss-Newton method. To evaluate the proposed approach, we have constructed an ALL prototype comprising an array of six ionic polymer-metal composite (IPMC) sensors. Each sensor measures 8 mm tall and 2 mm wide, with sensor-to-sensor separation of 2 cm, which is determined through an optimization process based on the Cramer-Rao bound analysis. A moving dipole source is created by a sphere attached to a mini-shaker that is mounted on a custom-built conveyor. A sliding digital Fourier transform (SDFT) algorithm is employed to extract the flow amplitudes from IPMC sensor outputs. Experimental results have shown that, with the proposed approach, the IPMC-based ALL system is able to track the moving dipole source successfully.

8339-09, Session 3

A multi-electrode biomimetic electrolocation sensor

K. Mayekar, Rheinische Friedrich-Wilhelms-Univ. Bonn (Germany); D. Damalla, Forschungszentrum Jülich GmbH (Germany); M. G. Gottwald, Rheinische Friedrich-Wilhelms-Univ. Bonn (Germany); H. Bousack, Forschungszentrum Jülich GmbH (Germany); G. von der Emde, Rheinische Friedrich-Wilhelms-Univ. Bonn (Germany)

We present the concept of a multielectrode catheter inspired by the electroreceptive system of the weakly electric fish, Gnathonemus petersii. The skin of this electric fish exhibits numerous electroreceptors which are capable of sensing a self induced electrical field. Our sensor is composed of a sending electrode and sixteen receiving electrodes. The electrical field is measured by the receiving electrodes and objects are detected by the perturbation of the electrical field they induce. The intended application of such a sensor is in coronary diagnostics, in particular in distinguishing various plaque types which are major causes of heart attack.

For calibration of the sensor system, finite element modeling (FEM) was performed. To validate the model, experimental measurements were carried out with two different systems. The first physical system was Plexiglas tubing with metal and plastic insertions as targets. For the control of the experiment and for data acquisition the software LabView, designed for 17 electrodes, was used. The second, more biological system was an artificial blood vessel made from Agarose gel and fat insertions. Different parameters of electric images were analysed for the prediction of the electrical properties and size of the inserted target in the tube. Comparisons of the voltage modulations predicted from the FEM model and the experiments show a good correspondence. It can be concluded that this novel biomimetic method can be further developed

for detailed investigations of atherosclerotic lesions. Finally, we discuss various design strategies to optimise the output of the sensor using different simulated models to enhance target recognition.

8339-10, Session 3

Formation, encapsulation, and validation of membrane-based artificial hair cell sensors

K. L. Garrison, Virginia Polytechnic Institute and State Univ. (United States); S. A. Sarles, The Univ. of Tennessee (United States); D. J. Leo, Virginia Polytechnic Institute and State Univ. (United States)

Hair cell structures are one of the most common forms of sensing elements found in nature. In nearly all vertebrates hair cells are used for auditory and vestibular sensing. In humans, approximately 16,000 auditory hair cells can be found in the cochlea of the ear. Each hair cell contains a stereocilia, which is the primary structure for sound transduction. This study looks to develop and characterize an artificial hair cell that resembles the stereocilia of the human ear.

Recently research our group has shown that a single artificial hair cell can be formed in an open substrate. Another study demonstrated that a flexible substrate with internal compartments for hosting biomolecules and mating cap can be used to create a fully encapsulated device for artificial membrane, or lipid bilayer, creation. These two studies have provided the foundation for our current work toward a fully encapsulated artificial hair cell.

In this study a test setup was created in order to consistently measure various properties of the encapsulated hair cell. An impulse force is applied to the tip of the hair and the corresponding current response is measured. A high frame rate camera was used to capture the motion of the hair due to the impulse input. A transfer function was calculated between the measured current response and the captured motion of the hair. By changing the physical parameters of the hair sensor, such as hair length and stiffness, we were able to alter the response of the sensor. The directivity of the artificial hair sensor was also found by taking measurements at several different sensor orientations.

8339-11, Session 4

Large area and high-speed reproduction of the Morpho butterfly's color for true practical applications

A. Saito, M. Yonezawa, T. Shibuya, M. Akai-kasaya, Y. Kuwahara, Osaka Univ. (Japan)

Morpho butterfly's brilliant blue is well known as an example of the structural coloration and attracts interest due to a metallic luster of natural beings. The blue originates from their scales almost transparent without pigment. The basis of the color with high reflectance (> ~60%) is then attributed to an interference based on a periodic microstructure. However, the interference contradicts the blue observed in too wide angle (> ± 40° from the normal). This mystery has been explained with a specific multilayer structure, which contains nano-randomness preventing the rainbow coloration. This principle has been proved successfully by emulating the 3D layered structures by deposition of multilayer film on a nano-patterned substrate designed with a specific randomness. Such artificial structural color has recently been found to have wide potential applications. However, a serious problem for application is too expensive nano-patterning process, which strictly limits the throughput. The problem was partly solved by use of nano-casting lithography that could replicate effectively the nano-structures. Furthermore, we have recently fabricated with high speed the specific nano-pattern using a self-organized propagation process of the femto-second laser ablation on the substrate surface. After the multilayer deposition, the film fabricated in large area (~85 mm square) was confirmed to reproduce the basic optical properties of the Morpho color, keeping both the high reflectivity and wide angular range of the blue. Since we have theoretically analyzed the optical role of the randomness using FDTD method, we could utilize the theoretical results to design the nano-randomness.

8339-12, Session 5

Arrays of bioinspired compound lenses (BCLs) for solar cells

F. Chiadini, Univ. degli Studi di Salerno (Italy); V. Fiumara, Univ. degli Studi della Basilicata (Italy); A. Scaglione, Univ. degli Studi di Salerno (Italy); A. Lakhtakia, The Pennsylvania State Univ. (United States)

Improving the efficiency of silicon solar cells is a crucial point for reducing the production costs of electric energy from photovoltaics and then enhancing its diffusion.

In previous works [1, 2] we suggested that a morphologically fractal prismatic lens, whose shape is inspired by the apposition compound eyes of some dipterans, could be mounted on the silicon slab to improve the solar harvesting capability. We showed that the best performing bioinspired compound lens (BCL) is a first-stage structure whose cross-section is a frustum of an infinitely long circular cylinder decorated with sections of smaller cylinders. We analyzed BCLs made of silicon as they may be textured directly on the surface of the silicon slab.

Moving towards the design of a high-efficiency photovoltaic module, here we analyze the light-harvesting capabilities of an array of silicon first-stage BCLs mounted atop the light-exposed silicon surface of a solar cell. By using ray-tracing, we evaluate the cell light-coupling efficiency on a large wavelength range of the solar spectrum and determine the array configuration maximizing the efficiency.

Despite the results obtained for the single BCL scheme [1,2], for which the best performing lens was the thickest one, we observed that a significant improvement of the efficiency is offered by arrays of thinner lenses. Indeed, results show that an array of thin adjacent BCLs can enhance the light-coupling efficiency by at least of 16% with respect to that of a flat surface silicon cell.

[1] Chiadini F, Fiumara V, Scaglione A, Lakhtakia A Simulation and analysis of prismatic bioinspired compound lenses for solar cells Bioinspir. & Biomim. 5 (2010) 026002

[2] Chiadini F, Fiumara V, Scaglione A, Lakhtakia A Simulation and analysis of prismatic bioinspired compound lenses for solar cells: II. Multifrequency analysis Bioinspir. & Biomim. 6 (2011) 014002

8339-13, Session 5

Biomimetic one-dimensional photonic crystals having black thin layers

H. Yabu, Y. Hirai, M. Shimomura, Tohoku Univ. (Japan)

We report a simple, novel method for obtaining structurally colored films consisting of poly(1,2-butadiene) (PB) and Os multi-layers that mimic the surface structure of jewel beetle elytra. Strong color reflection was achieved by interference of light at the interface between the multi-layers. Os has a much higher refractive index than PB, which causes the strong reflection at the interface between these two materials. As a result, strong reflection colors were observed because of the interference between the multi-layers. Active control of the reflection peaks was achieved by swelling the PB layers, and photopatterning of the composite film was performed. From these results, we conclude that black thin layers enhance the reflection of structural colors. Active control of the reflection peaks was achieved by swelling the PB layers with solvent, and photopatterning of the composite film was also performed. The simple, low cost fabrication of 1D photonic crystals can be achieved through this biomimetic approach. Furthermore, these findings provide new insight into the structural colors observed in nature.

8339-14, Session 5

Light transmission of the marine diatom Coscinodiscus wailesii

S. Hsu, C. Paoletti, M. Torres, R. J. Ritchie, A. W. D. Larkum, C. Grillet, The Univ. of Sydney (Australia)

Unicellular microalgae diatoms (Bacillariophyceae) abundantly found in aquatic environments have attracted a great deal of research interests in investigating the properties of their peculiar silica cell walls (frustules) which possess regular arrays of micro- to nanometer pores. Because they are important phytoplankton and contribute a large portion of photosynthesis in oceans, thorough studies of the optical properties of frustules are of great value. In this presentation, we report the results of a detailed investigation of light transmission behavior of a centric diatom species Coscinodiscus wailesii by optical microscopy. The 3-dimentional transmitted intensity distributions of both broadband and monochromatic light through individual valves of the diatom in air as well as in water were measured by acquiring transmission images at varying objective-sample distances. For several valves under investigation, at a certain distance from the valve, light intensities close to the optical axis are relatively higher than those in the surrounds, which is similar to the effect of lens focusing. At a longer distance from the valve, transmitted light intensities display ring-shaped profiles. The distances showing center- and ring-concentrated profiles are wavelength-dependent, which is believed to be the result of interaction between light and valves' micro- and nanostructures. However, for some other valves, the light concentration behavior was extremely weak or even indiscernible. The causes of the light transmission characteristics and the discrepancy between different valves will be discussed. These results may offer insight into the understanding of biological functions of diatom frustules' intricate structures and inspire optical biomimetic applications.

8339-15, Session 5

A mechanism of reflective camouflage in silvery fish as design inspiration for an omnidirectional broadband mirror

T. Jordan, N. Roberts, N. Linden, J. Partridge, Univ. of Bristol (United Kingdom)

Nanoscale reflective structures have evolved in many animals. Through their intricate organizational properties and structural efficiency these can offer design inspiration for optical technologies. The need for an effective mirror is especially acute in the open ocean where silvery pelagic fish use reflective camouflage to radiance-match their photic environment and render themselves invisible. This requires the sides of the fish to act as a vertical plane mirror that has a broad spectral bandwidth and is non-polarizing; an effect achieved by an elegant multilayer arrangement of birefringent guanine crystals in their skin. In this paper we characterize this structural mechanism and draw design inspiration for an efficient omnidirectional broadband mirror. Through the application of anisotropic multilayer theory we establish how the angle of maximum polarization is controlled by the orientation and birefringence magnitude of the guanine crystals, and for the first time demonstrate how an evolved structure is able to produce near omnidirectional reflectivity. We then perform structural optimization and establish that high broadband reflectivity is characterized by variation in nanoscale periodicity (the thickness and spacing of the guanine crystals). For a fixed amount of crystal layers, linear systematic variation in periodicity produces higher spectrally and angularly averaged reflectivity than random variation in periodicity and is near optimal in performance as a broadband mirror in the visible wavelength regime.

8339-16, Session 5

Toward pest control via mass production of realistic decoys of insects

D. P. Pulsifer, A. Lakhtakia, The Pennsylvania State Univ. (United States); J. Kumar, Univ. of Massachusetts Lowell (United States); T. C. Baker, The Pennsylvania State Univ. (United States); R. J. Martin-Palma, Univ. Autónoma de Madrid (Spain)

The Emerald Ash Borer (EAB), Agrilus planipennis, is an invasive Asian species presently threatening the ash trees of North America. EABs exhibit a mating behavior in which a flying male will spot a stationary female and then dive sharply onto her. This behavior is cued by some visual signal from the elytra of the female EAB. Here we present a method for reproducing the elytra of the EAB for the potential development of traps that utilize this visual cue as bait. Decoys of EAB elytra are mass produced by hot embossing a colored polymer with a nickel die that is a direct negative of the original biotemplate. The nickel die is fabricated by first coating the biotemplate with an ~250-nm thick evaporated nickel layer which is subsequently reinforced by electroforming. This industrially scalable bioreplication approach has been successful at producing high-fidelity replicas of blow-fly corneas, and its application to North America's EAB troubles may serve as an example of how the emerging engineering methodology of bioreplication can provide novel solutions to real-world problems.

8339-17, Session 6

The development of a closed-loop flight controller with panel method integration for gust alleviation using biomimetic feathers on aircraft wings

C. J. Blower, W. Lee, A. M. Wickenheiser, The George Washington Univ. (United States)

This paper presents the development of a biomimetic closed-loop flight controller that integrates gust alleviation and flight control into a single distributed system. Modern flight controllers predominantly rely on and respond to perturbations in the global states, resulting in rotation or displacement of the entire aircraft prior to the response. This bio-inspired gust alleviation system (GAS) employs active deflection of electromechanical feathers that react to changes in the airflow, i.e. the local states. The GAS design is a skeletal wing structure with a network of feather-like panels installed on the wing's surfaces, creating the airfoil profile and replacing the trailing-edge flaps. Each feather minimizes the effect of the disturbances experienced through airflow manipulation.

In this study, a dynamics model of the GAS-integrated wing is simulated to compute gust-induced disturbances. The system implements continuous adjustment to flap orientation to perform corrective responses to inbound gusts. MATLAB simulations, using a closed-loop LQR integrated with a 2D adaptive panel method, allow analysis of the morphing structure's aerodynamic data. Non-linear and linear dynamic models of the GAS are compared to a traditional single control surface baseline wing. The feedback loops synthesized rely on inertial changes in the global states; however, variations in number and location of feather actuation are compared. The bio-inspired system's distributed control effort allows more efficient response to gusts than the traditional wing by minimizing the magnitude and duration of the airfoil's deviation from its equilibrium position. Consequently, the GAS demonstrates enhancements to maneuverability and stability in turbulent intensive environments.

8339-19, Session 6

Measurement and estimation of thrust produced by flapping-wing systems with passive wing rotation mechanism

V. H. Phan, Q. Truong, V. Q. Nguyen, H. C. Park, D. Byun, N. S. Goo, Konkuk Univ. (Korea, Republic of)

Flyers less than palm size, which are named Micro Air Vehicles (MAV) or Nano Air Vehicle (NAV), have wide range of applications in many domains such as military intelligence, space exploration, areas of civil service, etc. For realization of such flyers, we need to learn secrets of insect flight, because these kind vehicles should fly in the low Reynolds number environment from 5,000 to 10,000, where viscous force becomes more important. For this reason, researchers have been paying attention to relevant studies on principle of insect flights.

Rhinoceros beetle, Allomyrina Dichotoma, is one of the flying insects. Its weight is about 6 to 10 grams and wing span is less than 130 mm, which is very close to the definition of MAV and NAV in terms of size and weight. The specific beetle flaps its hind-wings at 30 Hz to 40 Hz with angles of 165o to 180o during forward flight and hovering flight, respectively. It can rotate its hind-wings around 140o and adjust their cambered shape during up-strokes and down-strokes to generate sufficient aerodynamic forces. Recently, we have been developing a beetle-mimicking flapping-wing system, which has flapping angle of 145o and flap at 39 Hz. At this frequency, the flapping-wing system can produce a large enough thrust of about 7 grams to lift vertically its own weight.

In this work, we modified the system such that the hind wings were directly connected to the output links of the flapping mechanism without flexible hinges. Instead, the trailing edges of the hind wings near wing root were connected to the body, so that the hind wings can create semi-active wing rotation. Consequently, the wing rotation angle becomes variable from wing root to wing tip during flapping. The resulting wing rotation is quite different from that of previous flapping-wing, which is constant along from wing root to wing tip. Three-dimensional wing kinematics was measured by using two high-speed cameras. The wing kinematics was used for aerodynamic force estimation by an unsteady blade element theory (UBET). We also measured the thrust produced by a modified flapping-wing system and compare it with that of the previous flapping-wing with similar wing span, wing area, and flapping frequency. The measured and computed thrusts of the modified flapping-wing system were higher than those of the previous one. Thus, the semi-active wing rotation mechanism is proven to produce a higher thrust.

8339-20, Session 6

Dynamic characteristics of a beetle hind wing

N. Ha, N. Goo, H. Park, Konkuk Univ. (Korea, Republic of)

In this paper, a non-contact measurement method was proposed to determine the natural frequencies and mode shapes of beetle hind wings severed from thoraxes. The hind wings were glued with the cyanoacrylate adhesive at the wing base onto the Acrylic stand which was attached to the base of a shaker. The shaker produces the translation motion in the lateral direction of the wing plane. A non-contact laser sensor was used to measure the displacement history of the painted spots on the hind wing. A Brüel & Kjær FFT analyzer was adopted to calculate the frequency response functions where the natural frequencies and the mode shapes of the wing structure can be extracted. The first peak in the frequency response function (FRF) of beetle hind wings is 47.5 Hz that is close to the flapping frequency of the beetle was from 35 to 40 Hz. It was found that the natural frequencies of beetle hind wings were related to the flapping frequency of the beetle. To accurately identify the resonant frequencies, the mode shape at each peak in FRF was constructed. In addition, the wing structures were lightly damped with damping factor around 3%.

8339-21, Session 6

Micro-electro-mechanical flapping wing technology for micro air vehicles

A. Hall, Motile Robotics Inc. (United States)

This paper presents the fabrication and testing of a prototype micro-electromechanical (MEMS) flapping wing aerial vehicle. A flapping mechanism was developed that couples a 3cm PZT-5H bimorph actuator oscillating at 13Hz with two flexural wing joints at the distal end of the bimorph. Various bodies and wing frames of the MEMS flapping device were developed using 3D Prototyping technology. The 5cm wing span was manufactured utilizing a Fullcure820® resin as the wing frame and polyethylene as the airfoil. Joints were created at the wing root to allow for more freedom for the angle of attack of the wing. The flapping performance was experimentally investigated in terms of the flapping frequency, the stroke amplitude, the lift, the inertial forces, the instantaneous wing force, and the power requirements. Finally, a palm sized flapping wing micro air vehicle was produced to demonstrate successful tethered flapping.

8339-22, Session 7

Adaptive honeycomb structure with pneumatic muscle fibers

W. Yin, D. Tian, Harbin Institute of Technology (China)

The adaptive honeycomb structure actuated by pneumatic muscle fibers is proposed in this paper. The elastics modulus of the designed pneumatic muscle fibers is experimentally determined and their output force is tested. The results show that the contraction ratio of the pneumatic muscle fibers with inner diameter of 2mm could reach up to 26.8% and the force could reach to a value of 27N when the applied pressure value is 0.4MPa and the contraction ratio is zero. The FE model of adaptive honeycomb structure is developed by use of ANSYS. Future research will be focused on the manufacture and experiment of adaptive honeycomb structure with pneumatic muscle fibers.

8339-23, Session 7

Water uptake through an open capillary by wharf roach, Ligia exotica

M. Shimomura, Tohoku Univ. (Japan); T. Hariyama, Hamamatsu Univ. School of Medicine (Japan); D. Ishii, Y. Hirai, H. Yabu, Tohoku Univ. (Japan); K. Ijiro, Y. Matsuo, T. Shimozawa, Hokkaido Univ. (Japan); K. Tsujii, Consultant (Japan); H. Horiguchi, Hamamatsu Univ. School of Medicine (Japan)

Wharf roach, Ligia exotica, is an arthropod living at seaside but avoids water. Ligia exotica has a branchial respiration system, however, it requires water uptake to its gills from wet environments. Hariyama et al. have reported that Ligia exotica uses two pairs of legs, IV and IIV, for water uptake to the gills. On the side of the IV leg, there are open-channel structures possessing hair-like and paddle-like cuticular protrusions arrays from the second podites to the 5th podites of the leg. The open-channels are surrounded by the cuticular flat surface including small flat protrusions. Water from the wet ground is transported through the open-channels of the leg IV and flows to the gills via the 6th podites of the leg IIV. Wettability is affected mainly by chemistry and topology of the surface. Though the surfaces of the open-channels and outer area consist mainly of the cuticle, the intrinsic chemical components are not determined due to the individual difference of the animals. In order to focus the discussion of the water transport mechanism on the structural effect, surface of the legs are dried and modified with gold and self-assembled monolayer to identify and regulate the surface chemistry. Wettability of the outer area, the hair-like protrusions arrays, and the paddle-like protrusions array are largely different even if the surface

chemistry is identical. The modified legs with certain surface chemistry can repel water at the outer area, transport water via the hair-like protrusions arrays, and store water in the paddle-like protrusions arrays.

8339-24, Session 7

Biologically inspired highly efficient buoyancy engine

B. J. Akle, W. Habchi, Lebanese American Univ. (Lebanon); J. B. Blottman III, Naval Undersea Warfare Ctr. (United States); D. J. Leo, Virginia Polytechnic Institute and State Univ. (United States)

Undersea distributed networked sensor systems require a miniaturization of platforms and a means of both spatial and temporal persistence. One aspect of this construct is the necessity to modulate sensor depth for optimal positioning and station-keeping. Current approaches involve pneumatic bladders or electrolysis; both require mechanical subsystems and consume significant power. These are not suitable for the miniaturization of sensor platforms. Presented in this study is a novel biologically inspired method that relies on ionic motion and osmotic pressures to displace a volume of water from the ocean into and out of our proposed buoyancy engine. At a constant device volume the water displaced will alter the buoyancy leading to either sinking or floating. The engine is composed of an enclosure sided on the ocean's end by a Nafion ionomer and by a flexible membrane separating the water from a gas enclosure. Two electrodes are placed one inside the enclosure and the other attached to the engine on the outside. The semi-permeable membrane Nafion allows water motion in and out of the enclosure while blocking anions from being transferred. The two electrodes generates local concentration changes of ions upon the application of an electrical field; these changes leads to osmotic pressures and hence the transfer of water through the semi-permeable membrane. Some aquatic organisms such as pelagic crustacean perform this buoyancy control using an exchange of ions through their tissue to modulate its density relative to the ambient sea water. In this paper the authors provides an experimental proof of concept of this buoyancy engine. The efficiency of changing the buoyancy of the engine is calculated and optimized as a function of ionic species, electrode material, and electrode surface area. For example electrodes made of a 3mm diameter Ag/AgCl (surface area 70mm2) proved to transfer approximately 4mm3 of water consuming 1.7mAh of electrical energy. The speed of displacement is optimized as a function of the surface area of the Nafion membrane and its thickness. The 4mm3 in with the Ag/AgCl electrodes required approximately 380 seconds. The thickness of the Nafion membrane is 180μm and an area of 133mm3.

8339-25, Session 7

Mobile robot with retractable paws

B. Bahr, P. Safi, S. Varela, California State Univ., Long Beach (United States)

Nowadays Robots are widely used for tasks which cannot be done or is hazardous to be done by human being. Search and rescue operations are among these especially in a hazardous environment of Nuclear power plants or chemical or biological Plants. These rescue robots are expected to operate well in case of natural disasters e.g earthquake by overcoming unpredicted obstacles, rough and even slippery surfaces in case of the oil spill or snow storm. In this paper we have developed a novel paws on the when of a mobile robot which is normally in the retractable position, and can be activated when the robot encounter slippery surfaces or want to climb on a rough train. This combination takes advantage of the locomotion efficiency of wheels, while at the same time it uses the retractable paws as legs or even hooking it to objects that it want to climb. The results of simulation have been satisfactory and the goal is to have a working prototype with further test result at the conference.

8339-35, Poster Session

Controlling spontaneous emission in bioreplica photonic crystals

M. R. Jorgensen, M. H. Bartl, The Univ. of Utah (United States)

The strikingly colorful world of insects is in large part the result of interaction of light with precisely ordered, periodic bio-polymeric structures. Such biological photonic crystal structures have recently gained tremendous interest for use as templates in bioreplication with promising potential for applications in energy and information technologies. In this talk, I will present high-dielectric photonic crystals templated from photonic nanostructures located in exoskeleton scales of various beetles. Among these structures, the diamond-based photonic structures found in the weevil Lamprocyphus augustus are of particular importance, since their high-dielectric replicas (made out of titania) can possess a complete photonic band gap. Applying a range of structural characterization tools and theoretical modeling we evaluate the properties of these novel photonic architectures. In the current work, particular focus is directed on the ability of these bioreplica photonic crystals to modify the optical density of states. The most promising candidates were used for experimental studies. For these studies they were activated with internal light sources (nanocrystal quantum dots). The spontaneous emission decay rates of the internal light sources were then studied by time-correlated single-photon counting techniques. Depending on the photonic band structure, up to ten-fold variation of decay dynamics were observed, indicating strong density of states variations-a property of utmost importance for applications ranging from solar energy conversion to light amplification and quantum optics.

8339-36, Poster Session

Analysis of object properties of a tube wall by active electrolocation

M. G. Metzen, S. Krueger, I. Al Ghouz, Rheinische Friedrich-Wilhelms-Univ. Bonn (Germany); H. Bousack, Forschungszentrum Jülich GmbH (Germany); G. von der Emde, Rheinische Friedrich-Wilhelms-Univ. Bonn (Germany)

Weakly electric fish use 'active electrolocation' to orientate in their environment and to localize objects such as prey or obstacles. The fish discharge an electric organ, which emits brief electrical current pulses and sense the electric field that builds up surrounding the animal. Based on the electrical properties of the object under investigation (OUI), a characteristic signal modulation is measured by an array of electroreceptors in the fish's skin. The fish are able to gain important information about the OUI such as its size, shape, complex impedance and distance. Thus, active electrolocation is an interesting method to be used in biomimetic approaches including material identification or distance measurements.

We used the principle of active electrolocation to identify different insets within a plexiglas tube. The objects tested were composed of aluminium, brass and graphite and varied in size between 3 mm and 20 mm. A carrier signal was emitted and perceived via two poles of a commercial catheter used for medical diagnostics. The poles were separated between 6.3 mm and 50.5 mm during measurements. The measured image width of the OUI correlated with the separation of the sender and the receiver, whereas the object caused modulations of the received signal remained constant. We observed a first single peak when the sender was beneath the OUI, whereas two peaks occurred when the receiver approached and moved away from the OUI. The distance between the second and third peak strongly correlated with the size of the OUI.

8339-38, Poster Session

Effect of Gurney flap and fixed droop leading edge on dynamic stall

M. N. Mumtaz Qadri, S. H. R. Hamdani, K. Parvez, A. Shahzad, National Univ. of Science and Technology (Pakistan)

Dynamic stall vortex (DSV) arises near the airfoil leading edge after a rapid conglutination of unsteady vorticity. This vortex grows and moves downstream of the airfoil, finally shedding from the trailing edge into the wake contributing to high lift and negative pitching moment; a phenomena called Dynamic Stall. This phenomenon was encountered by the aerospace community, where large oscillations were attributed to the stalling and un-stalling of rotor blades causing abrupt fluctuations in aerodynamic forces leading to high torsional loads and flutter. The motivation behind this research paper is to investigate different control techniques by introducing passive devices, such as Gurney Flap and Droop, and varying their physical parameters to observe which combinations contribute towards efficient dynamic stall control. For this numerical investigation, a two-dimensional finite volume method Fluent was used to solve time dependent compressible Navier-Stokes equations using density based solver. Grid independence, domain independence, time step and turbulence model sensitivity studies were conducted and validation results are in good agreement with their experimental results. Further simulations were done where the location of Gurney Flap and Droop angle have been varied contributing towards increased lift and reduced negative pitching moment coefficient and aerodynamic damping respectively. Hybrid configurations of these two passive devices and their effect on dynamic stall have also been investigated, where it played a vital role in reducing hysteresis while maintaining a higher lift and reduced negative pitching moment throughout the pitching cycle.

8339-39, Poster Session

Investigation of fluids as filling of a biomimetic infrared sensor based on the infrared receptors of pyrophilous insects

T. Kahl, Rheinische Friedrich-Wilhelms-Univ. Bonn (Germany); N. Li, Forschungszentrum Jülich GmbH (Germany); H. Schmitz, Rheinische Friedrich-Wilhelms-Univ. Bonn (Germany); H. Bousack, Forschungszentrum Jülich GmbH (Germany)

The Beetle Melanophila acuminata is highly dependent on forest fires. The burned wood serves as food for the larvae and the adults copulate on the burned areas to put their eggs in the freshly burned trees. To be able to detect forest fires from great distances the beetle developed a highly sensitive infrared receptor which works according to a photo-mechanical principle.

The beetle has two pit organs, one on each lateral side, of which each houses around 70 domeshaped infrared receptors. These IR-receptors consist of a hard outer cuticular shell and an inner microfluidic core. When IR-radiation is absorbed, the pressure in the core increases due to the thermal expansion. This results in a deflection of a dendritic tip of a mechanosensitiv neuron which generates the signal.

This biological principle was transferred into a new kind of an uncooled technical infrared receptor. To demonstrate the functional principle and the feasibility of this IR-sensor a macroscopic demonstrator sensor was build. It consisted of an inner fluid filled pressure chamber, an IR-transmissive window and a membrane which deflection was measured by a sensitive commercial capacitve sensor.

In the experiments ethanol with added black ink, a mix of ethanol and glucose with additional absorber, air with additional absorber and water were compared against each other. Furthermore the experiments showed an important influence of the sensor housing material on the membrane deflection.

In order to understand the physics of the results of the experiments additional simulations using FEM methods and analytical calculations have been performed. The results showed that the compensation of ambient temperature changes is an important issue. Without such compensation the membrane works in a nonlinear range and the deflection of the membrane is not only influenced by the filling of the pressure chamber but also by the stress conditions of the membrane at the beginning of the experiment.

8339-40, Poster Session

Fabrication of bioinspired low-frictional surfaces by using honeycomb-patterned porous polymer films

Y. Saito, Y. Hirai, H. Yabu, M. Shimomura, Tohoku Univ. (Japan)

Surfaces of animal have unique nano and micro structures. Those surface structures have various functions. Above all, surface structures of Amazon tree boa have interesting tribological properties. When those structures are prepared on metal curved surfaces, smart surfaces for friction can be obtained. However common machining methods are difficult to make structures on those surfaces with surface smoothly. So the processing method of those surfaces is required. We have reported that self-organized honeycomb-patterned porous polymer films (honeycomb films), which have hexagonally-arranged uniform-sized pores ranging from submicron to micron size, can be prepared by simple casting method. In this study, we attempted to fabricate the aluminum surface having micro dimple arrays by using top layer of honeycomb films as wet-etching masks.

Honeycomb films with 8 μm pore diameter were prepared from Polystyrene and amphiphilic copolymer. After UV-O3 treatment, Poly(vinyl alcohol) (PVA) aqueous solution was spin-coated on top layers of honeycomb films, and honeycomb films were fixed upside down on aluminum surfaces. Bottom layers of honeycomb films were peeled off, and aluminum surfaces with honeycomb films were annealed at 200˚C for 3h. The aluminum surfaces were etched by soaking in the ethanol solution containing potassium hydroxide.

After etching, micro dimple arrays were formed on aluminum surfaces. These results suggested honeycomb films could be used as etching masks. By changing etching conditions, the dimple depth could be controlled from 400 nm to 1800 nm. Friction measurements of fabricated aluminum surfaces will be discussed.

8339-41, Poster Session

A biomimetic hydrophilic-hydrophobic patterned multi-functional surface

Q. Xu, F. Lin, B. Mondal, Y. Liu, A. M. Lyons, College of Staten Island (United States)

Animals and plant incorporate superhydrophobic surfaces to enhance adaptability. The Stenocara beetle, which lives in the Namib Desert, harvests water droplets from fog by using the hydrophilic-superhydrophobic patterned surface of its wings. Species of the floating water fern Salvinia also take advantage of a combination of hydrophilic and superhydrophobic materials to improve their air retaining ability in turbulent flows. Inspired by these natural smart surfaces, fabrication of multi-functional surfaces by patterning hydrophilic areas on superhydrophobic surfaces using semiconductor oxide materials such as TiO2, ZnO and V2O5, have recently been reported.[1-3] These surfaces are of interest because the semiconducting nanoparticles have applications in photocatalysis, solar energy conversion and sensors. Because the particles are intrinsically hydrophilic, surface modification has been required to achieve superhydrophobicity. However, these surface treatments adversely affect properties. Concurrently achieving high contact angle and low slip angle from semiconductor oxide coated materials without surface modification remains a technical challenge.

In this paper, we present a simple and inexpensive lamination templating method [4] that enables the fabrication of polymer nanocomposite superhydrophobic surfaces with regions of hydrophilic semiconducting

nano-particles exposed on the surface. The morphology and surface chemistry was characterized by TEM, SEM and EDX and the chemical composition of the surface before and after UV illumination was characterized by XPS. These surfaces exhibit excellent superhydrophobic and self-cleaning properties (Fig. 1a) immediately after lamination without any particle surface modification. In addition, these hydrophilic-hydrophobic patterned nanocomposite surfaces exhibit reversible wettability such that superhydrophobic properties can be degraded upon exposure to UV light and restored after heating (Fig. 1b).

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8339-42, Poster Session

Morphology of primary feathers in two falcon species

A. Schmitz, B. Honisch, Rheinische Friedrich-Wilhelms-Univ. Bonn (Germany)

Primary feathers have the important function to provide the flight of birds and differ in their morphology and material properties between different bird species. We tested the material properties, using scanning electron microscopy and nanoindentation, of the primary feathers of two raptor species: of the fastest known vertical flyer, the peregrine falcon (Falco peregrinus), and of the common kestrel (Falco tinnunculus).

The reduced E-modulus of the cortex of the rachis of the tenth primary, measured at different cross sections, continuously increased from the base to the third quarter of the rachis where it decreases again. In F. tinnunculus, values were significantly higher than in F. peregrinus (means: 7.8 - 8.55 - 7.35 GPa in F. peregrinus and 8.1 - 8.7 - 7.95 GPa in F. tinnunculus). Looking at the hardness, there were no significant differences between species and measuring points. In F. peregrinus, however, two distinct layers of the cortex exist which have E-moduli of about 7 GPa (outer layer) and up to 8-9 GPa (inner layer, measured in the third quarter of the rachis), whereas only one consistent layer was found in F. tinnunculus. Moreover, in F. peregrinus there are significant more ramuli per barbule (5.5) than in F. tinnunculus (3.2) and the length of the pennulum of the barbules (323 µm) is significantly greater in F. peregrinus than in F. tinnunculus (234 µm).

Because the given structures are responsible for the stability of the feather face it seems that the feathers of F. peregrinus are more robust than those of F. tinnunculus.

8339-26, Session 8

Micro- and nano-structured cantilevers for biomedical applications

B. Müller, Univ. Basel (Switzerland); P. Urwyler, J. Althaus, Univ. Basel (Switzerland) and Paul Scherrer Institut (Switzerland); H. Schift, Paul Scherrer Institut (Switzerland); U. Pieles, Univ. of Applied Sciences, Northwestern Switzerland (Switzerland); J. Gobrecht, Paul Scherrer Institut (Switzerland)

Cantilever sensors have become valuable diagnostic tools in a variety of biomedical applications. The cantilevers are mostly based on silicon technology and therefore rather expensive. To significantly reduce their price as necessary for widespread single use, we have applied micro injection molding to fabricate arrays of polymer cantilevers. These polymer cantilevers show characteristics well comparable with silicon arrays [P. Urwyler et al.: Surface patterned polymer micro-cantilever arrays for sensing, Sensors and Actuators A (2011) in press]. These polymer cantilevers can be straightforwardly microstructured with countless designs during the injection molding process or using nanoimprint technologies for post-processing. Such microstructures can reveal directionally defined periodicities, for example to guide and orient adhesive cells, or be replicates of natural bodies such as bony tissues. Further processing including plasma treatment, as necessary to chemically activate the polymer surface, is employed to add nanotextures. Hence surface morphologies as found in nature (and beyond) are engineered with reasonable effort. Such cantilever arrays permit the measurement of contractile cell forces [J. Köser, S. Gaiser and B. Müller: Contractile cell forces exerted on rigid substrates, Eur. Cells Mater. 21 (2011) 479-487], which provides a quantitative parameter to characterize the cyto-compatibility of load bearing implant surfaces. The applications of cantilever arrays in biomedicine ranges also towards the artificial sensory organs including olfactory and gustatory organs as well as DNA recognition of selected sequences.

8339-27, Session 8

Toward bioinspired parylene-C coatings of implant surfaces

L. Wei, A. Lakhtakia, The Pennsylvania State Univ. (United States)

The external surfaces of an implanted prosthesis must be biocompatible; otherwise, integration with the tissue does not occur but a foreign-body response is elicited, whereby the surrounding tissue produces a dense fibrous encapsulation of the prosthesis. As the properties of a biological surface vary, often gradually but also abruptly, the implant surface should be endowed with a gradient of surface roughness and wettability for good integration with proteins and cells. Parylene-C demonstrates excellent biocompatibility for implantable prostheses, for which purpose it has been approved by the US Food & Drug Administration. We have made free-standing, flexible, fibrous, micro/nano-textured thin films of parylene-C with thickness-controlled surface morphology and hydrophobicity; furthermore, varying degrees of hydrophilicity are displayed after oxygen-plasma treatment. The bioinspired thin films are mechanically robust and have been shown to support both protein binding and cellular attachment as well as growth. By conformally covering an implant surface with patches of these thin films of varying thickness and oxygen-plasma-treatment duration, gradients of protein/cell attachment can be tailored and thus tissue integration can be managed on different parts of the implant surface.

8339-28, Session 9

Biological adhesives and fastening devices

H. D. Wolpert, Bio-Optics (United States)

Many of today's manufacturing techniques rely on assembling components with adhesives. It is less time consuming, less expensive and eliminates fastening devices which are often physical points of stress. One of the riches sources of new adhesives comes from the sea because of their unique strength and insolubility in water. Sea water naturally breaks down even the strongest conventional adhesive, so an alternative is important that can be used in repairing or fabricating anything that might have regular contact with moisture such as: repairing and building ships, manufacturing plywood, use in the dental work, developing a surgical adhesive that would be less invasive than suturing, bonding agents for implants, or repairing bone fractures. The adhesive, binding abalone shell platelets together, is important for future materials development. The abalone matrix creates a sacrificial bond, initially looped or folded, that upon stress, breaks one fold at a time leaving

successive folds to take up the load until all the folds have been broken. This break and release in the uncoiling of the glue is nature's way of preventing or slowing fracture and is useful in developing stronger materials. Even ivy and spider glue droplets are under investigation for certain important properties. Biological adhesives are self assembling, rely on readily available materials, are non-toxic, and are made at low temperatures. As we learn about these adhesives we are also developing non-adhesive fasteners, such as "Gecko tape", which like the Gecko foot, relies on Waals forces to adhere to smooth surfaces.

8339-29, Session 9

Biologically inspired reversible adhesives: Where are we now?

S. N. Gorb, Christian-Albrechts-Univ. zu Kiel (Germany)

Biological hairy attachment systems demonstrate their excellent adhesion and high reliability of contact. The structural background of various functional effects of such systems is discussed in the present paper. Additionally, it is demonstrated here, how comparative experimental biological approach can aid in development of novel adhesives. Based on the broad structural and experimental studies of biological attachment devices, the first industrial bioinspired reversible adhesive foil was developed, which adhesive properties were characterised using variety of measurement techniques and compared with the flat surface made of the same polymer. The microstructured foil demonstrates considerably higher pull off force per unit contact area. The foil is less sensitive to contamination by dust particles, and after washing with water, its adhesive properties can be completely recovered. This glue-free, reversible adhesive is applicable in dynamic pick-and-drop processes, climbing robots, and other systems even under water or vacuum conditions. The foil represents therefore a considerable step towards development of industrial dry adhesives based on the combination of several principles previously found in biological attachment devices.

8339-30, Session 10

Biomimetic approach for multi-responsive water microdroplet adhesions on a superhydrophobic surface

A. Takahashi, Tohoku Univ. (Japan); D. Ishii, Tohoku Univ. (Japan) and CREST, JST (Japan); H. Yabu, Tohoku Univ. (Japan); M. Shimomura, Tohoku Univ. (Japan) and CREST, JST (Japan)

In nature, many functional superhydrophobic surfaces have been observed such as lotus leaves, rose petals and morpho butterflies. We focused the functions of rose petals composed of nano-micro structured surfaces, showing not only strong water repellency but also size-selective adhesion of water microdroplet. Our group has reported that superhydrophobic surfaces composed of polymer pillar arrays are obtained by peeling off the top layer of honeycomb-patterned porous films (honeycomb films) prepared by self-organization process. Furthermore, high adhesive superhydrophobic surfaces composed of metal-dome/polymer-pillar hybrid structures are obtained by metal deposition into several pores of the honeycomb film before peeling process. In this report, we fabricated a superhydrophobic structured surface showing multi-responsive water microdroplet adhesions prepared from the polystyrene honeycomb film. Multi-responsive polymer domains composed of polyallylamine skeleton severally modified with glycidyl isopropyl ether were introduced into the polystyrene superhydrophobic surface. Adhesions of water microdroplets on the surface were controlled by changes of surface temperatures; pinning at low temperature and rolling at high one (>30), and pH of water droplets; pinning at low pH and rolling high one (>8.3). Responsivity of water droplet adhesions on the surface was accurately regulated by components of the responsive molecules and surface microstructures such as amounts and sizes of the responsive domains. Such surfaces will be expected for novel application of microfluidics devices in order to manipulate water droplet under various environments by facile external stimuli.

8339-31, Session 10

Biomimetic superhydrophobic surfaces having gradients of a droplet adhesion property prepared by self-organization

D. Ishii, M. Shimomura, H. Yabu, Tohoku Univ. (Japan)

Accurate patterns used in device fields were easily and repeatedly prepared by top-down techniques such as photolithography and nano-imprinting. However, it is difficult rapidly to fabricate various kinds of surface structures because of one-by-one template methods. On the other hand, we have been reported honeycomb-patterned porous films having accurate arranged micron pores by self-organization that is one of the bottom-up techniques. Biomimetic high adhesive superhydrophobic metal-polymer hybrid surfaces have been prepared by electroless plating of the honeycomb films and simple peeling. In bottom-up fabrication, various structures were prepared by changing of the preparation conditions. In this report, we fabricate the hybrid surfaces having gradient of water droplet adhesion prepared by control of metal deposition into the honeycomb pores by self-organization. The honeycomb films fixed vertically in a plastic vessel were immersed in a 10mL catalytic solution at 323K. Then the same solution of 40mL at 298K was gradually added. After nickel electroless plating and peeling, we obtained metal-polymer hybrid surfaces composed of superhydrophobic hexagonally polymer pillar array and hydrophilic metal micro-domes with gradient density that give strong adhesion of water micro-droplet. The hybrid surface having gradient of the dome density was indicated gradient of water droplet adhesion from sliding to adhesion. Characteristic wetting behaviors such as invisible gates for water micro-droplets were demonstrated on the hybrid surface having gradient of water droplet adhesion. Control of the adhesion of water droplets will be applied to microfluidics devices, open-air lab-on-a-chip, and the other functional superhydrophobic surfaces.

8339-32, Session 10

Printed superhydrophobic surfaces that exhibit ratchet-like slip angle anisotropy

M. Barahman, A. M. Lyons, College of Staten Island (United States)

Superhydrophobic surfaces offer a valuable alternative to microchannel based microfluidic devices as individual droplets can be translated across a surface without using an oil phase. However few methods exist for manipulating these droplets along specific paths. A surface that enabled ratchet-like motion would facilitate targeted droplet motion since droplets could be preferentially translated in one direction, while limiting its ability to move backward along the same path. Some naturally occurring surfaces, such as the wing of the Morpho Aega butterfly1 , exhibit such ratchet-like droplet motion as do the leaves of rice plants2. This behavior is attributed to partial wetting of anisotropic surface features.

Based on insights gained from these naturally occurring surfaces, we report on the fabrication of superhydrophobic surfaces that exhibit ratchet-like slip angle anisotropy 3. A 3-axis robot was modified to print a polydimethylsiloxane (PDMS) pre-polymer. By controlling the rheological properties of the material as well as the dispense parameters, surfaces were fabricated composed of regular arrays of circular conical posts with slopes ranging from 0 to 50o. Slip-angle anisotropy values as large as 32o were observed as a function of droplet size and post slope. Droplets rolled more easily when tilted in the direction aligned with the posts compared to when the surface was tilted in the opposite direction. Optical microscopy was used to observe the triple contact line (TCL) and so determine that the slip angle anisotropy results from partial wetting of the surface features as well as changes in the TCL length as a function of tilt.

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8339-33, Session 10

Anisotropic frictional properties in snakes

M. Benz, A. Kovalev, Univ. of Kiel (Germany); S. Gorb, Christian-Albrechts-Univ. zu Kiel (Germany)

Since snakes keep their ventral body side in almost continuous contact with the substrate during locomotion, the snake skin is presumably adapted to generate propulsion (high friction) and simultaneously slide along the substrate at rather low friction. In this study, the microstructure of ventral scales from Lampropeltis getula californiae and its influence on frictional properties were analysed by the use of scanning electron microscopy and force measurements using microtribometer. To investigate the role of the material stiffness on the frictional anisotropy, two different types of sample cushioning (hard and soft) were tested while sliding in four different directions. The data demonstrate strong frictional anisotropy.

The soft cushioned skin samples showed a strongly anisotropic frictional behavior. The frictional coefficient in caudal direction (from head to tail) was much lower than in the opposite direction. In caudal direction, the frictional properties did not significantly differ from those measured in lateral directions. For the uncushioned sample preparation, the caudal direction showed the significantly lowest frictional coefficient compared to the other directions. There was no difference in the frictional behavior between the cranial (from tail to head) direction and the lateral direction. Based on these results we assume that the material stiffness of the snake surface has a big influence on its frictional anisotropy. This fact needs to be considered during the transfer of single parameters inspired by a biological model into technical applications. This work is funded by the Federal Ministry of Education and Research, Germany within the BIONA-program (01 RB 0812A).

8339-34, Session 10

Fabrication of wettability-patterned biomimetic surfaces for water-collection and water transportation

Y. Hirai, Tohoku Univ. (Japan) and CREST, JST (Japan); H. Yabu, Tohoku Univ. (Japan); Y. Matsuo, K. Ijiro, Hokkaido Univ. (Japan) and CREST, JST (Japan); M. Shimomura, Tohoku Univ. (Japan) and CREST, JST (Japan)

In nature, there are many functional water-controlling surfaces, such as a water repellency surface of a lotus leaf, a superhydrophobic water adhesion surface of a rose petal, a water harvest surface of a beetle's back, and so on. We have reported that honeycomb-patterned porous polymer films can be prepared by casting a solution of hydrophobic polymer and amphiphilic polymer on a solid substrate by using condensed water droplet arrays as templates. In this report, we show the preparation of the biomimetic wettability patterned silicon nano-structured surface by dry etching process with the top layer of self-organized honeycomb-patterned films as etching masks. We prepared honeycomb-patterned films from polystyrene and amphiphilic copolymer by casting their chloroform solution. Honeycomb-patterned films were fixed on silicon substrates up side down with poly(vinyl alcohol) solution as adhesive. After peeling off the bottom layer of the honeycomb-patterned films, porous polymer masks were formed. After reactive ion etching of the silicon substrate through the mask, the silicon nanospike-array structure was obtained. We measured water contact angles (CAs) on the silicon nanospike-array structures, and the maximum CA was over 170 degree. This superhydrophobicity is realized due to fluorocarbon absorbed on the surface during dry etching and their surface structures. After UV-O3 treatment with photo-masks, fluorocarbon was removed at irradiation area, and the area shows superhydrophilicity. These results suggest that we can easily design superhydrophobic and superhydrophilic patterned surfaces by UV-O3 treatment through photo-masks. By using this wettability patterned surface, biomimetic water-collection and water transportation surfaces can be obtained.

Conference 8340: Electroactive Polymer Actuators and Devices (EAPAD) XIV

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8340-01, Session 1

Bringing toys to life: toys today and unique opportunities for EAP sensors and actuators

J. Corsiglia, Spin Master Ltd. (Canada)

This paper will cover a brief explanation of how toys imitate life, which sometimes is predictive of future advances in technology. Development of toys involves significant quest for realism. The toy designers are increasingly making “smart” toys using Artificial Intelligence, Augmented Reality, Speech Recognition and Synthesis, etc. with the purpose of hopefully amaze and delight us all. For this purpose, such technologies as new battery and microprocessor are emerging that allow making toys very capable. The review will cover the business of marketing and manufacturing toys, as well as the important categories of toys. A description will be given on how toys are designed and selected according to market forces and children’s play patterns.

New actuator materials are also being incorporated into the latest toys and the Shape Memory Alloys are an example of such materials that are already being used. Toys of the future will be discussed including suggestion of potential applications of actuation technologies such as EAPs. The paper will be concluded with a summary and an appeal for a collegial search for applications that may drive EAPs into future consumer products.

8340-02, Session 1

Bio-integrated electronics

J. A. Rogers, Univ. of Illinois at Urbana-Champaign (United States)

Biology is curved, soft and elastic; silicon wafers are not. Semiconductor technologies that can bridge this gap in form and mechanics will create new opportunities in devices that adopt biologically inspired designs or require intimate integration with the human body. This talk describes the development of ideas for electronics that offer the performance of state-of-the-art, wafer-based systems but with the mechanical properties of a rubber band. We explain the underlying materials science and mechanics of these approaches, and illustrate their use in bio-integrated, ‘tissue-like’ electronics with unique capabilities for mapping cardiac electrophysiology, in both endocardial and epicardial modes, and for performing electrocorticography. Demonstrations in live animal models illustrate the functionality offered by these technologies, and suggest several clinically relevant applications.

8340-03, Session 1

The need for speed

S. Rosset, Ecole Polytechnique Fédérale de Lausanne (Switzerland); P. Gebbers, Ecole Polytechnique Fédérale de Lausanne (Switzerland) and Zürcher Hochschule für Angewandte Wissenschaften (Switzerland); B. M. O’Brien, The Univ. of Auckland (New Zealand); H. R. Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

Development of dielectric elastomer actuators has been mainly targeted towards achieving giant static strain with little attention paid to their response speed, which can, depending on materials used, be counted in seconds. However, most of the practical applications require actuators capable of changing shape quickly, therefore a careful choice of materials and technologies for the dielectric and electrodes must be made.

We have fabricated ø14mm circular actuators with a ø2mm active area in the center. A range of silicone membranes with Shore hardness between A5 and A25 were tested, and the compliant electrodes were made with different technologies: carbon powder, carbon grease, conductive rubber and metal ion implantation.

The transient response of each actuator to a voltage step input was characterized with a high-speed camera (>50’000 frames/s), and a laser Doppler vibrometer. Results show that by choosing the right silicone/electrode combination extremely fast actuation can be obtained, with rise/fall times shorter than 100 us.

Our experiments also show that the response speed of actuators is extremely dependent on the compliant electrodes. Several conductive rubber electrodes were prepared with different silicones as the dispersing matrix. The damping coefficient of the actuators made with these preparations was strongly dependent on the polymer used in the electrode formulation.

We conclude that the impact of electrodes on the dynamic properties of dielectric elastomer actuators cannot be neglected, and that the assumption of “perfect” electrodes often found in the literature is unfortunately a myth.

8340-04, Session 2

Multi-functional soft smart materials and their applications

J. Leng, Harbin Institute of Technology (China)

Smart materials can be defined as the materials that have the capability of sensing and reacting to environmental conditions or stimulus, such as heat, temperature, electricity, magnetic field, light or solvent. In recent years, a great wide range of novel smart materials have been developed in biomaterials, sensors, actuators, etc. And the applications of smart materials now cover many fields, including automobile engineering, medical treatment, and aerospace engineering. This paper presents some recent progress of soft smart materials and their applications. Special emphasis is focused upon shape memory polymer (SMP), electro-active polymer (EAP) for aerospace engineering, which has highlighted the need for development of these materials. A detailed overview of development in these soft smart materials, of which the undergoing and future applications are used in adaptive structures and active control, is presented. Recent advances in SMP and EAP systems are discussed and their composites filled with functional fillers such as conductive nanoparticles, short carbon fiber and ferroelectric ceramics are introduced. The paper concludes with a short discussion for multi-functional soft smart materials and their composites that are expected to extend the range of development and applications available to the related researches and engineers.

8340-05, Session 2

Actuators, biomedicine, and cell biology

E. W. H. Jager, Linköping Univ. (Sweden)

Conducting polymers such as polypyrrole are well-known for their volume changing capacity and their use as actuating material. Actuators based on polypyrrole have been demonstrated in dimensions ranging from centimetres down to micrometres as well as in linear strain and bending beam actuation modes. The polypyrrole (micro-)actuators can be operated in salt solutions including cell culture media and blood. In addition, polypyrrole is known to be biocompatible making them a good choice for applications within cell biology and medicine.

Applications of polypyrrole actuators within micromechanical devices,

such as microrobotics and valves, will be presented. Opportunities and devices for the medical device industry, especially vascular surgery will be shown. This includes a rotating PCTA balloon system and an implantable drug delivery system. In addition, novel mechanostimulation chips for cell biology will be introduced. Using these devices, we can stretch cells and show the cellular response to this mechanical stimulation. Since the dawn of eukaryotic cells many parallel molecular mechanisms that respond to mechanical stimuli have evolved. This technology allows us to begin the investigation of these mechanisms on a single cell level.

8340-06, Session 2

Electroactive skin: from high-energy-density polymer to antibiofouling

X. Zhao, Duke Univ. (United States)

In this talk, we will present a polymer skin (or coating) that can dynamically change its morphology under applied electrical voltages. The working mechanism for the polymer skin is a new type of voltage-induced instability recently discovered in our group. Subject to an electric voltage, a substrate-bonded polymer film initially maintains flat and smooth. Once the voltage reaches a critical value, regions of the polymer surface locally fold against themselves to form a pattern of creases. As the voltage further rises, the creases increase in size and decrease in density, and strikingly evolve into craters in the polymer. The critical voltage, morphology, and length scale of the instability patterns can be tuned by varying the dimension and modulus of the polymer.

We will discuss two examples of the electro-active skin's appliactions. The voltage-induced deformation and instability of the polymer film can be used to prevent the formation of biofilms (biofouling) and/or to detach existing biofilms on the polymer surface. As another example, the electro-active skin can be used to accurately control the adhesion and release of small objects, with potential applications in transfer printing. The electro-active skin is flexible, conformal to complicated geometries, and easy to use. Large-scale fabrication of the electro-active skin is simple and cheap.

8340-07, Session 2

Cutting the fat: artificial muscle oscillators for lighter, cheaper, and slimmer devices

B. M. O'Brien, The Univ. of Auckland (New Zealand) and Ecole Polytechnique Fédérale de Lausanne (Switzerland); S. Rosset, H. R. Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland); I. A. Anderson, The Univ. of Auckland (New Zealand)

Artificial muscles based on dielectric elastomers show enormous promise for a wide range of applications. The technology is adolescent but slowly moving from the lab to industry. One problem for industrial uptake is the expensive, rigid, heavy and bulky high voltage driver, sensor and control circuitry that artificial muscle devices currently need.

One recent development, the Dielectric Elastomer Switch(es) (DES), shows promise for substantially reducing auxiliary circuitry and helping to mature the technology. DES are piezoresistive elements that can be used to form logic, driver, and sensor circuitry. One particularly useful feature of DES is their ability to embed oscillatory behaviour directly into an artificial muscle device, which in many cases provides adequate control.

In this paper we will focus on how DES oscillators can break down the barriers to industrial adoption for a range of different artificial muscle devices. For example, with DES oscillator based control, artificial muscle;

1) Robots (rolling, crawling, hopping etc...) could enjoy substantially lighter control circuitry, and increased power to weight ratios;

2) Peristaltic pumps could be massively simpler to control, with a large reduction in interconnects;

3) Industrial applications such as rotary motors could enjoy reduced cost to the point of commercial viability.

In addition we will present a simple model of an artificial muscle ring oscillator and apply it to design a mechano-sensitive conveyor.

8340-08, Session 4

Navigating conjugated polymer actuated neural probes in a brain phantom

E. D. Daneshvar, Univ. of Michigan (United States); E. Smela, Univ. of Maryland, College Park (United States); D. R. Kipke, Univ. of Michigan (United States)

Neural probe insertion methods have a direct impact on the longevity of the device's useful life in the brain. Initial tissue and vascular damage caused by the probes entering the brain triggers a chronic tissue response that is known to ultimately encapsulate the probes and attenuate neural recordings. To provoke less reactive tissue response, we are developing probes with controllable articulated electrode projections, which would actuate with minimal insertion force. The objective of this study was to predict and analyze the navigation capability of conjugated polymer bilayer actuators to actuate neural electrode projections from the probe shank into an agarose gel brain phantom. The transparent agarose gel has similar viscoelastic consistency as brain matter, allows ion transport, and is a useful method to visualize the performance of the active devices.

Custom neural probes, having parylene electrode projections with varying widths (50 - 250 m), lengths (200 - 1000 µm), and thicknesses (10 - 20 m), were coated with Cr/Au. Polypyrrole (PPy) was potentiostatically polymerized onto the Au at 0.5 V in a solution of 0.1 M pyrrole and 0.1 M dodecylbenzenesulfonate (DBS) to varying thicknesses. Using cyclic voltammetry, the PPy(DBS) was cycled between 0 and -1 V in aqueous 0.1 M NaDBS. Using an electronic microdrive insertion device, the probes were inserted into a brain phantom consisting of a combination of 0.5% agarose gel and artificial cerebrospinal fluid while simultaneously activating the actuators. Video and scanning electron micrographs were taken and used to quantify thicknesses and deflections.

By using a transparent brain phantom, we present a method to visualize the navigation of active microfabricated neural electrodes. We demonstrate that integrating a small conjugated polymer actuator is sufficient to navigate neural probes and electrode projections through a brain tissue phantom on demand, and that we can control the final electrode projection location.

8340-09, Session 4

Designing micro- and nanostructures for artificial urinary sphincters

B. Müller, Univ. Basel (Switzerland); G. Kovacs, Swiss National Institute for Materials Testing and Research (EMPA) (Switzerland); F. Weiss, Univ. Basel (Switzerland)

The dielectric elastomers are functional materials that have promising potential as actuators with muscle-like mechanical properties. Consequently, such actuators should be realized to replace the currently available artificial urinary sphincters building dielectric thin film structures that work with several 10 V. The present communication describes the determination of the forces (1 - 10 N) and deformation levels (~10%) necessary for the appropriate operation of the artificial sphincter as well as the response time to master stress incontinence (less than 0.1 s). Besides the analysis of urodynamic data from patients, ex-vivo stress-strain measurements of the urethral tissue were performed to precisely correlate applied forces and tissue deformation (opening/closing). Aware the dimensions of the presently used artificial sphincters, these macroscopic parameters form the basis of the actuator design. Here, we follow two strategies. First, we start from high-voltage microstructures decreasing the film thickness towards one micrometer or even below

and, second, we start from organic nanometer-thin films maybe even monolayers, which should work with low voltages and provide the desired strain but only small deformations. In the latter case, actuators out of 1,000 or 10,000 layers will finally lead to the necessary motion. The suitable choice of elastomer and electrode materials as well as the appropriate processing technology is vital for the success. As the number of incontinent patients is steadily increasing worldwide, it becomes more and more important to reveal the sphincter's function under static and stress conditions to realize artificial urinary sphincters, based on sophisticated, biologically inspired concepts to become nature analogue.

8340-10, Session 4

Precession curvature control of a self-sensing IPMC actuator for active endovascular micro-catheters

Y. Bahramzadeh, M. Shahinpoor, Univ. of Maine (United States)

In recent years Minimally Invasive Surgery (MIS) procedures have been received a lot of attention due to several advantages over conventional open procedures. Less trauma involved in MIS, faster recovery and higher precision are some of the benefits of MIS procedures. The endovascular treatment of aortic aneurysms is an important minimally invasive procedure that involves the placement of an endo-vascular stent via a percutaneous technique through the femoral arteries into the diseased portion of the aorta. The catheter is inserted into the body through the femoral artery and is guided through the lumen of the blood vessel until it reaches a blockage. Conventionally the insertion procedure is performed manually which is a complex task mostly due to the high flexibility of catheter. In order to improve the insertion procedure, active catheters employing tendon driven stirrer and shape memory alloys have been investigated recently. In this research we investigate application of the Ionic Polymer Metal Composites (IPMC) actuators as the stirrer of the distal tip. Properties of IPMCs such as low electric potential driving, large deformation, high functionality in aqueous solution and above all their biocompatibility have made these materials highly promising for biomedical applications. The distal tip of the catheter is equipped with an electrically controllable ionic polymer-metal composite (IPMC) stirrer. The IPMC artificial muscle is connected to an external voltage. In order to increase the repeatability of IPMC stirrer a feedback controller is designed that assigns the required voltage for the IPMC stirrer. The controller input is the curvature of stirrer which can be assigned through a surgical robotic system similar to those used in master-slave robots. Unlike other proposed position controllers for IPMCs that the controller input is the deflection of IPMC cantilever, the controller input in this paper is the curvature of IPMC stirrer. The required curvature is dictated by the surgeon depending on the path of the veins. On the other hand, for precise control of curvature of the actuator, a curvature sensor is essential for feedback control. Herein we use another strip of IPMC as curvature sensor parallel with IPMC stirrer. It should be noted that other feedback methods such as camera or laser distance sensor is not applicable for active catheter inside the body. Also it has been already shown that IPMC curvature sensors demonstrate high linearity, repeatability and sensitivity which make the IPMC curvature sensor promising for this type of application.

In order to characterize the IPMC actuator, an experimental setup is provided which provides the step response of the actuator. Using the step response, the transfer function of the actuator can be derived. This transfer function gives the relation between applied voltage as input and curvature as output. The IPMC actuator could follow various commanded position trajectories such as sinusoidal, square and saw tooth position profiles. The control architecture presented includes a PID controller for tracking the desired curvature.

The performance of the IPMC strip is investigated under various commanded trajectories. Experimental results shows that the proposed integrated IPMC actuator/ sensor is able to track the desired curvature for precise navigation of IPMC stirrer inside the veins.

8340-11, Session 4

Molecular engineering of polymer actuators for biomedical and industrial use

M. Banister, Y. Geronov, Medipacs, LLC (United States); D. V. McGrath, The Univ. of Arizona (United States)

Smart polymers, electro-active polymer (EAP) gels, hydrogels, have all long been the subject of extensive development and investigation. The literature today tends to refer to each of these as if they were each a specific discipline or classification of materials. When, if looked at from a molecular engineering approach, there is a common mechanism of action in many of these materials: a physical swelling and deswelling of a 3-dimensional polymer matrix on which there are reactive and un-reactive molecular units or sites. We investigated structures, based on epoxide crosslinked gels that have been covalently linked at specific molecular sites allowing a systematic approach of specific OH to NH reactive site ratios.

The findings of our study demonstrate that the molecular reactive units provide the actual driving forces. The results demonstrate that the quantity, type and ratio of molecular reactive units can be tailored to produce forces needed for practical applications of the actuators. The ratio and the density of their electrostatic charges, as well as their affinity for the solvent or electrolyte used, play an important role in the gel's actuation performance. We also show that surprisingly these reactive units do not need to be part of the polymer chain, and can be simply placed or entangled within the matrix in order to have significant impact on the gels performance characteristics. Finally, we also demonstrate that binders are critical to maintain polymer matrix integrity under the increased performance stress loads of additional reactive units within the polymer matrix.

8340-12, Session 4

A rigid coupling tactile display

H. R. Choi, J. C. Koo, H. Moon, H. S. Lee, Sungkyunkwan Univ. (Korea, Republic of)

Currently, one of the major trends in consumer products is how to exploit haptic feel in the human machine interface. Many researchers concentrate on development of tactile displays which can generate displacement greater than 100um at 1HZ and 10um at 40HZ. Tactile displays need miniaturization, ease of fabrication, light weight, softness, flexibility, high power density, and cost effectiveness. In this paper, to satisfy all of these requirements, we propose a tactile display with rigid coupling based on Dielectric Elastomer Actuator. It consists of two parts, actuator layer and upper layer, and a rigid coupling is sandwiched between them. Because of this simple design, after making EAP actuator sheet and upper layer, the only process of fabrication is to bond upper layer to actuator layer. A new design of the tactile display is proposed and its basic operational principles are discussed. And we develop a tactile display device with multiple actuator arrays and confirm its effectiveness.

8340-13, Session 4

Dielectric elastomer vibrissal structure for active tactile sensing

A. T. Conn, Univ. of Bristol (United Kingdom); M. J. Pearson, A. G. Pipe, J. Welsby, Bristol Robotics Lab. (United Kingdom); J. Rossiter, Univ. of Bristol (United Kingdom)

In nature, animals such as rats and shrews dexterously navigate confined and unlit environments by extracting spatial and textural information with their whiskers. Whiskers, or vibrissae, form part of a sophisticated active tactile sensory system that contrasts the reactive tactile sensing typically found on existing robots. Vibrassal-based active touch is suited

to a variety of applications where vision is occluded, such as search-and-rescue operations in collapsed buildings. In this paper, a compact dielectric elastomer vibrissal structure (DEVS) is described that mimics the vibrissal follicle-sinus complex (FSC) found in rodents. Like the vibrissal FSC, the DEVS encapsulates all sensitive mechanoreceptors at the root of a passive whisker within an antagonistic muscular system. Typically, rats actively whisk arrays of macro-vibrissae at frequencies of 5-25 Hz and with amplitudes of up to ±25°. It is demonstrated that these properties can be replicated by exploiting the characteristic large actuation strains and passive compliance of dielectric elastomers. A prototype DEVS is developed using VHB 4905 and embedded strain gauges bonded to the root of a tapered whisker. The DEVS is demonstrated to provide tactile sensory information in response to external stimuli in the range ±25°. An electro-mechanical model of the DEVS is derived, which incorporates a hyperelastic material model and Euler-Bernoulli beam equations. The model is shown to predict 2-D experimental measurements of whisking stroke amplitude and vibrissal deflection. Finally, ongoing work towards harnessing the self-sensing capabilities and solid-state nature of dielectric elastomers to form inexpensive arrays of synthetic vibrissae is discussed.

8340-14, Session 4

Manufacturing issues around world first commercial EAP (electro-active polymer) based haptic actuator and its scale-up

D. S. Kim, D. H. Shin, J. I. Yang, ELK Corp. (Korea, Republic of)

Since the finding of EAP (electro-active polymer) by Stanford Research Institute, many researches and commercialization efforts have been conducted. ELK Corporation, which collaborates with Artificial Muscle / Bayer MaterialScience, developed and manufactured the world first commercial product for haptic actuator out of EAP technologies. This study deals with difficulties and issues to produce haptic actuators, and ways to overcome the low yield / performances.

Current production is based on proprietary silicone film as substrate material, which is extremely tacky and fragile. ELK chose screen printing for deposition method for facilitated scaling up efforts. Printing on silicone film caused lots of troubles, such as film sticking into mask screen, tearing during print or holding, curing issues, etc.

After series of attempts to alleviate the defects and failures during the manufacturing process, the completely different way of thinking showed the unexpected and exceptionally high performance and yield. This study will talk about how to manage the issues in production, and become successful. Also, retrospective view on the previous mistakes and way to realize fool-proven process setup will be highlighted.

8340-15, Session 4

A dynamic physics-based model for base-excited IPMC sensors

C. Y. Lim, H. Lei, X. Tan, Michigan State Univ. (United States)

In this paper, a dynamic, physics-based model is studied analytically and experimentally for an ionic polymer-metal composite (IPMC) sensor that is excited at the base. This work is motivated heavily by structural monitoring and energy-harvesting applications of IPMCs. The model combines the vibration dynamics of a flexible beam under base excitation and the ion transport dynamics within the IPMC.

The vibration dynamics of a base-excited IPMC beam is obtained from the Euler-Bernoulli beam equation incorporating damping and accommodating suitable boundary conditions. The charge dynamics is derived by analytically solving the governing partial differential equation, which captures electrostatic interactions, ionic diffusion and ionic migration along the thickness direction. In order to relate the mechanical dynamics to the sensing response, we assume that the charge density at the boundary is proportional to the stress. The derived model relating short-circuit sensing current to the base excitation is expressed as an infinite-dimensional transfer function, in terms of physical and geometric parameters, and is thus scalable. The model can be readily reduced to a finite-dimensional one for real-time signal processing.

Experiments have been performed to validate the proposed model. A mini-shaker is used to provide base excitation to a cantilevered IPMC beam in the frequency range of 10-150 Hz. Two laser displacement sensors are mounted to measure the applied displacement at the base and the resulting displacement at the beam tip, respectively. A two-tier amplification circuit is used to measure the short-circuit current generated by the beam motion. Experimental results have shown that the proposed model captures well both the beam dynamics and the overall sensing dynamics. The model is further validated in a structural monitoring setup, where an IPMC is mounted on a structure subjected to both impacts and periodic stimuli.

8340-16, Session 5

Applications of scanned pipette techniques for the highly localized electrochemical fabrication and characterization of conducting polymers

J. Travas-Sejdic, The Univ. of Auckland (New Zealand)

The limited toolbox for conducting polymer (CP) microscale fabrication and characterization hampers the development of device applications such as actuators and sensors. To address this, we present a robust methodology capable of electrochemical fabrication/characterization of CPs in a highly localized manner, allowing CP patterning and spatial mapping of their voltammetric response. This is enabled by a scanned probe microscopy (SPM) setup tipped with a micropipette to electrochemically polymerize and characterize CP.

Various applications of the SPM setup to electroactive CPs will be discussed, such as an application of this new type of SPM setup for the measurement of the ion fluxes associated with CPs. This is for the benefit of applications such as artificial muscles which require a better understanding of the ion flux that underpins the actuation of CPs.

These developments represent key steps towards the localized fabrication and characterization of small-scale CP structures.

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8340-17, Session 5

Patterning process and actuation in open air of micro-beam actuator based on conducting IPNs

C. Plesse, Univ. de Cergy-Pontoise (France); A. Khaldi, Univ. de Valenciennes et du Hainaut-Cambrésis (France); A. Maziz, Univ. de Cergy-Pontoise (France); C. Soyer, Univ. de Valenciennes et du Hainaut-Cambrésis (France); C. Chevrot, D. Teyssie, F. Vidal, Univ. de Cergy-Pontoise (France); E. Cattan, Univ. de Valenciennes et du Hainaut-Cambrésis (France)

Polymer actuators are considered to be promising alternative to conventional actuators due to their attractive properties, including, light weight, and low operating voltage.

We report on new method to obtain micrometric electroactive polymer actuators operating in air. High speed conducting Interpenetrating Polymer Network (IPN) microactuators are synthesized and fully characterized. The IPN architecture used in this work allows solving the interface and adhesion problems, which have been reported in the design

of classical conducting polymer-based actuators. We demonstrated that it is possible to reduce the thickness of these actuators by a specific synthetic pathway. IPN host matrixes based on polyethylene oxide / polytetrahydrofurane or polyethylene oxide / Nitrile Butadiene Rubber have been shaped by hot pressing or spin-coating techniques. Then, the resulting thin host matrixes (below 10 µm) are compatible with the micro-fabrication technologies. After interpenetration of poly(3,4-ethylenedioxythiophene) (PEDOT), these electroactive materials are micro-sized using dry etching process. A chemical and a "self degradation" mechanisms are proposed to explain the high etching rates which have been observed. Frequency responses, displacement and forces have been characterized by scanning electronic microscopy and Atomic Force Microscopy. These sized actuators (L*l*w=900*300*20µm3) can be considered as potential candidates in numerous low frequency applications, including micro-valves, micro-optical instrumentation and micro-robotics. Moreover, due to their response speed performances (above 100 Hz), these materials have been considered as the main actuator for the flapping wings of an artificial insect.

8340-18, Session 5

How to improve electrochemomechanical strain in conducting colymers

K. Kaneto, Kyushu Institute of Technology (Japan)

We have been studying electrochemomechanical strain (ECMS) of conducting polymers to realize artificial muscles or soft actuators, since 1993 [1,2]. The ECMS is generated by insertion and ejection of counter ions during electrochemical oxidation and reduction. To improve the performance, i.e., strain, stress, response time, cycle stability and creep, we have investigated the mechanism of ECMS and found a lot of interesting facts. In this talk, we will mention behaviors of ECMS in polyaniline and polythiophene in aqueous and non aqueous electrolyte solutions under tensile loads. Especially improvement of ECMS by using various morphology of conducting polymer films and electrolytes are mentioned. Novel features of ECMD such as training effect, shape retention by ionic cross links as well as creep under tensile loads will be also described.

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8340-19, Session 6

Equivalent circuit modeling of ionomer and ionic polymer conductive network composite actuators containing ionic liquids

Y. Liu, R. Zhao, S. Liu, J. Lin, M. Ghaffari, The Pennsylvania State Univ. (United States); H. Cebeci, R. Guzmán de Villoria, Massachusetts Institute of Technology (United States); R. Montazami, Iowa State Univ. (United States); D. Wang, Virginia Polytechnic Institute and State Univ. (United States); B. L. Wardle, Massachusetts Institute of Technology (United States); J. R. Heflin, Virginia Polytechnic Institute and State Univ. (United States); Q. Zhang, The Pennsylvania State Univ. (United States)

In this paper, we demonstrate electrical equivalent circuits that model the complex frequency-dependent impedance of 1-ethyl-3-methylimidazolium trifluoromethanesulfonate (EMI-Tf) containing electro-active polymer membrane and ionic polymer conductor network composite (IPCNC) devices, including Nafion membrane actuators, Nafion coated with layer-by-layer (LbL) Au nanoparticle/ poly(allylamine hydrochloride) (PAH) composite actuators and Nafion with Vertically Aligned Carbon Nanotube (VA-CNT)/Nafion composite actuators. It was found that the low frequency responses of these devices indicate Warburg diffusion; therefore Warburg impedance is utilized to model their low frequency behavior, while electrical double layer capacitance Cdl represents the drift of ions at higher frequencies. The electrical double layer capacitance Cdl for Nafion with 40 wt% EMI-Tf is 7.5 µF/cm2 and increases to 11.4 µF/cm2 with increased surface area from the LbL composite. The total electrical double layer capacitance further increases to above 3×103 µF/cm2 for an actuator with 12 µm of VA-CNT/Nafion composites, while the Warburg coefficient AW remains nearly the same for all the devices. It is shown that the actuation magnitude increases with charges accumulated, resulting from higher Cdl, without much increase in the contribution from the slow diffusion process.

8340-20, Session 6

Influence of micro- and nanofillers on electro-mechanical performance of silicone EAPs

A. G. Bejenariu, A. E. Daugaard, A. L. Skov, S. Vudayagiri, Technical Univ. of Denmark (Denmark)

Silicones are widely used in electroactive polymers formulation due to their favourable electro-mechanical properties, but they do, however, posses low mechanical breakdown strength and hence the mechanical properties must be improved1. A well-known technique to improve the tear strength of rubbers is to add micro- or nanofillers2.

The effects of different micro- and nanofillers on the electro-mechanical behaviour of silicone based dielectric elastomer are studied in this work. Several types of fillers and varied loadings are used to increase the overall permittivity of the silicone networks. The effect of particle size and particle size distribution on the electrical and viscoelastic properties is investigated. The dielectric properties are improved mainly by decreasing the particle size as was also shown by Kofod et al. for acrylic networks whereas the elastic properties are influenced in a less trivial way3. The filler particles result in an unfavourable increase of the storage modulus.

The presence of fillers also produces a highly inhomogeneous electric field in the materials and also increases the permittivity of the film, simultaneously with the increasing of mechanical breakdown. The aim of the paper is to find the right filler and the appropriate concentration for a suitable EAP material, such that an optimized formulation schema can be proposed.

8340-21, Session 6

Nanocomposites based on conducting polymers and multiwall carbon nanotubes

S. B. Kondawar, RTM Nagpur Univ. (India); D. K. Burghate, Shivaji Univ. (India); S. P. Agrawal, RTM Nagpur Univ. (India)

Conducting polymer nanocomposites (PANI-CNT and POAS-CNT) have been synthesized by polymerization of aniline (ANI) / o-anisidine (OAS) in the presence of functionalized multiwall carbon nanotubes (MWCNTs). These nanocomposites have been characterized by UV-VIS, FTIR, XRD and SEM to study the effect of incorporation of MWCNTs on the morphology, structure and crystalline of the conducting polyaniline and its substitute derivative poly(o-anisidine). UV-VIS spectra shows that polaron-π^* and π-π^* transition bands of the PANI/POAS chain shifted to longer wavelengths, indicating the interaction between quinoid rings and MWCNTs. FTIR spectra shows that the interaction between the MWCNTs and PANI/POAS may result in 'charge transfer', whereby the sp2 carbons of the MWCNTs compete with dopant ions [Cl-] and perturb the H-bond, resulting an increase in the N-H stretching intensity. XRD pattern shows that the prominent peak at 2 =26o in polymer became more intense indicating the uniform mixing of MWCNT with PANI/POAS. Electron microscopy reveals that the interaction between the quinoid ring of PANI/POAS and the MWCNTs causes PANI and POAS polymer chains to be adsorbed at the surface of MWCNTs, thus forming a tubular core surrounding the MWCNTs. The nanocomposites showed high electrical

conductivity compared to pure PANI/POAS. Further, PANI-CNT showed high electrical conductivity compared to that of POAS-CNT.

8340-22, Session 6

Influence of the counterions of ionic membranes on the performance of IEAP actuators

R. Montazami, Iowa State Univ. (United States); D. Wang, J. R. Heflin, Virginia Polytechnic Institute and State Univ. (United States)

The functionality of ionic electroactive polymer (IEAP) actuators is due to the mobility of ions within the ionic polymer-metal composite (IPMC). The ions are sourced by uptake of electrolyte (aqueous or ionic liquid) into the IPMC, and are mobilized when subjected to an external electric field. Thus far, the common understanding of the actuation mechanism in IEAP actuators has been that accumulation of ions provided by the electrolyte is the primary origin of the actuation. Nafion, used as the backbone structure of most IEAP actuators, is an ion permeable polymer with sulfonate end groups and proton counterions. In this work, we have shown that the counterions of Nafion have significant effect on the performance of IEAP actuators and that both actuation magnitude and temporal response are closely related to the type of counterions of Nafion. We have studied samples consisting of Nafion in its original (protonated) form and Nafion with 1-ethyl-3-methylimidazolium (EMI) counterions and have shown that the counterions participate in the actuation process and influence the performance of the IEAP actuators. The influence can be strong enough to reverse the bending direction, depending on the size of ions in the electrolyte. To further scrutinize the relation between polymer counterions and ions sourced by electrolytes, samples with proton or EMI counterions were tested with three different types of ionic liquids: 1-ethyl-3-methylimidazolium trifluoromethanesulfonate (EMI-Tf), 1-butyl-1-methylpyrrolidinium bis(trifluoromethylsulfonyl)imide (BMP-TFSI) and triethylsulfonium bis(trifluoromethylsulfonyl)imide (TES-TFSI).

8340-23, Session 6

Modeling and simulation of polyelectrolyte gels for the application as bending actuators

K. Keller, Univ. Stuttgart (Germany); T. Wallmersperger, Technische Univ. Dresden (Germany)

Polyelectrolyte gels are ionic electroactive materials. They have the ability to react as both, sensors and actuators. As actuators they can be used e.g. as artificial muscles or drug delivery control; as sensors they may be used for measuring e.g. pressure, pH or other ion concentrations in the solution.

In this research polyelectrolyte gels placed in aqueous solution with mobile anions and cations are investigated. Due to external stimuli the polyelectrolyte gels can swell or shrink enormously by the uptake or delivery of solvent.

The modeling of these gels is performed by a coupled 3-field approach consisting of a chemical, electrical and mechanical field. The chemical field formulation comprises diffusive and migrative terms; the electrical field is formulated by a Poisson equation. Finally, the mechanical field is realized by a momentum equation for the gel (network).

In the works by Gülch et al., the application of combined anionic-cationic gels as grippers was shown. In the present research for an applied electric field, the change of the concentrations in the complete polymer is simulated by the given formulation. These changes lead to variations in the osmotic pressure resulting in a bending of the polymer gripper. The obtained numerical results match quite well with the experimental results.

8340-24, Session 6

Physics based electromechanical model of IPMC considering various underlying currents

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Experiments indicate that the electrodes affect the charge dynamics, and therefore actuation of ionic polymer-metal composite (IPMC) via three different types of currents - electric potential induced ionic current, leakage current, and electrochemical current if approximately higher than 2 V voltage is applied to a typical 200 μm thick IPMC. The ionic current via charge accumulation near the electrodes is the direct cause of the osmotic and electrostatic stresses in the polymer and therefore carries the major role in the actuation of IPMC. However, the leakage and the electrochemical - electrolysis in case of water based IPMCs - currents do not affect the actuation dynamics as directly but cause potential gradients on the electrodes. These in turn affect the ionic current. A physics based finite element (FE) model was developed to incorporate the effect of the electrodes and three different types of currents in the actuation calculations.

8340-25, Session 6

Multi-physical modeling for electro-transport and deformation of ionic polymer metal composites

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A multi-physical model of ionic polymer metal composites (IPMCs) is presented in this paper when they deform under an applied voltage. It is composed of two parts, which describe the dynamic electro-transport and large deformation of IPMCs respectively. The first part describes the ion and water molecule transport, the equations of which are derived using the thermodynamics of irreversible process. Besides the gradient of the electric potential and the concentration usually considered in the previous models of IPMCs, the hydrostatic pressure gradient is confirmed to be one of the main factors induced the mass transport. The second states the strain induced by the redistribution of ion and water molecule and reveals the stress field from micro- to macro-scale by the method of micromechanics in IPMCs. The elastic stress balanced with the eigen-stress (including the hydrostatic pressure) can influence the distribution of ion and water molecule, which means that it influences the deformation further. Then to explore the mechanism of the relaxation phenomena, various kinds of eigen-stresses are discussed and preliminary numerical results are given based on the classical Na+ Nafion type IPMC. It's obtained that the osmotic pressure is an indispensable eigen-stress to explain the complicated deformation.

8340-68, Poster Session

Design and fabrication of an IPMC-based valve-less micro-pump

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IPMC (ionic polymer-metal composite), which is considered as a new member of artificial muscle materials, has been becoming a promising material candidate for micro-pump applications because of its unique advantages, such as low drive voltage, large deformation, and rapid response. This paper presents our work on the development a novel IPMC actuator-driven valve-less micro-pump. In this study, we used a type of self-produced Nafion-based IPMC (Pd-electrode) as the basic actuating element, and combined it with PDMS material to form the pump diaphragm for purpose of improving its tightness. The pump chamber, including the nozzle/diffuser elements, was integrally photo-etched on a SU-8 substrate. The two parts were bonded together utilizing a reversible sealing for PDMS. In order to get a better pumping

performance, a theoretical analysis for flow characteristics of the flat-walled nozzle/diffuser elements was performed, and two design schemes with different shapes in small end are analyzed and compared via numerical simulation. Based on this, a multi-parameter optimization model for determining key structural parameters of the elements, i.e., diffusion angle, tube length, and width of the small end, was established and solved, making use of fminsearch approach in MATLAB. Then, a flow performance test was carried out for the fabricated micro-pump prototype, in which the nozzle/diffuser elements adopted the proposed optimal geometry. The testing results showed that under the sinusoidal drive voltage of 3V in amplitude, and 2Hz in frequency, a maximum flow rate could be obtained, which was about 24μL/min.

8340-69, Poster Session

Adaptive absorber based on dielectric elastomer stack actuator with variable stiffness

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An interesting application for dielectric elastomer stack actuators (DESA) is the development of adaptive absorber. Adaptive absorbers are used to eliminate varying resonance frequencies of system for example caused by temperature change. The adaptive absorber consists of a mass, a spring and some internal material damping. Thereby the resonance frequency of an adaptive absorber can be changed by varying the mass or the stiffness of the spring.

In an adaptive absorber the mechanical stiffness and damping of DESA can be changed by applying different constant electrical voltages or charges. This effect allows to simplify the setup of adaptive absorbers.

In this paper we present the theoretical calculations for changing the mechanical stiffness and damping in the DESA and comparison with experimental results. Three configurations of adaptive absorber with different mounting have been set up. The DESAs with 50 dielectric layers and layer thickness of 50 μm have been fabricated in an automated process. Using a shaker experiment, the change of mechanical parameters has been measured and the resonance frequency has been determined. Thereby two different cases were investigated: constant voltage and constant charge.

The theoretical calculations have shown that the constant voltage applied reduces the stiffness of the absorber. These results have been proved experimentally. The amount of stiffness change is especially depended on the mounting of DESA. The mechanical stiffness of an adaptive absorber using DESA bonded between two stiff plates by applying constant voltage of 1000V has been reduced from 67 kN/m to 60 kN/m.

8340-70, Poster Session

Partial discharge analysis of prestretched and unstretched acrylic elastomers for dielectric elastomer actuators (DEA)

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Partial discharges (PD) occur in solid insulating materials when the insulating material is partially bridged by an electrical discharge in response to an applied voltage stress. PDs typically occur at localized points of high field stresses or at voids and other inhomogeneities within the insulator. The applied field's effect on the frequency of occurrence and intensity of PDs can be used to assess the electrical breakdown strength and aging characteristics of insulating materials. PD testing is therefore a promising characterization method to understand the insulating properties of the elastomers and geometries commonly used in DEAs. Prestretched (100% biaxial) and unstretched acrylic elastomers (3M VHB tapes) with solid metal and dusted carbon electrodes have been tested. Preliminary results have shown the number and intensity of PDs increase with applied field, and that a significant number of PDs are detected before any actuation was visibly observed, implying that the fields required for actuation will cause material aging and degradation over time. Carbon electrodes introduced additional PDs compared to solid metal electrodes, and so mitigation techniques will be investigated. Most interestingly, the number of PDs steadily increased as the un-stretched elastomers' applied voltage was increased, but at a certain voltage (~23 kV) the PDs suddenly ceased. Since internal voids can cause PDs, this may indicate that the Maxwell stress minimized the thickness of or eliminated these voids. This would increase the maximum voltage the film can withstand for an extended period of time, which could also explain how prestretching improves elastomer performance.

8340-71, Poster Session

PVDF-TrFe composite with methacrylate triblock copolymer elastomer for actuator application

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Well-defined PMMA-PDMA-PMMA (hard-soft-hard) polar triblock copolymers were synthesized by atom transfer radical polymerization. The triblock copolymers with BCC and cylinder self-assembled structures showed excellent actuation performances, which were much better than conventional triblock copolymer elastomer such as SEBS triblcok copolymers. Since these PMMA based triblock copolymers can be compatible with PVDF derivates, those block copolymers were then blended with PVDF-TrFe as a softer additive. Well defined morphologies from cylinder to lamella structures were obtained, of which actuation performance increased with increase of the block copolymer.

8340-72, Poster Session

Characteristics of nanostructured polyelectrolyte membranes incorporating imidazolium ionic liquids with varying cationic chain lengths for ionic transducer applications

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A nanostructured ionic thermoplastic elastomer, poly((t-butyl-styrene)-b-(ethylene-r-propylene)-b-(styrene-r-styrene sulfonate)-b-(ethylene-r-propylene)-b-(t-butyl-styrene)) (tBS-EP-SS-EP-tBS; SSPB) pentablock copolymer was selected as an ion-conducting matrix due to its high ionic conductivity and mechanical strength comparable to those of DuPont's Nafion. The SSPB copolymer membrane was impregnated with imidazolium ionic liquids (ILs) with varying cationic chain lengths, i.e. 1-ethyl-3-methylimidazolium [EMIm], 1-butyl-3-methylimidazolium [BMIm], 1-Hexyl-3-methylimidazolium [HMIm], and 1-octyl-3-methylimidazolium [OMIm] cations were combined with bis(trifluoromethylsulfonyl)imide [TFSI] anion to result in four ILs. Compared with the Nafion counterpart, the resulting nanostructured polyelectrolyte/IL membranes measured lower ionic conductivities for [EMIm][TFSI], however, higher ionic conductivities for the other ionic liquids with larger cationic sizes ([BMIm][TFSI], [HMIm][TFSI], and [OMIm][TFSI]) were revealed, due to a very limited conductivity decay with the increase in the cationic chain length. This may be originated from the big ion-conduction channels (ca. 20 nm) constructed with the SS middle blocks in the polyelectrolyte. While the longer cationic chain length of IL induced the weaker mechanical strength of the polymer/IL membrane due to the higher IL uptake, the selective impregnation of the ILs into the ionic SS phase considerably preserved the mechanical strength of the neat block copolymer without IL. Besides, the exceptional electrolytic

and thermal stabilities of ILs enable high-voltage and -temperature operations. This feature of the nanostructured polyelectrolyte/IL membranes is very promising in the fields of ionic transducers such as ionic polymer-metal composites as well as polymeric fuel cells and supercapacitors.

8340-73, Poster Session

Interpenetrating polymer networks based on no prestretch as basis for electrical actuators

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Several electrical actuators made from interpenetrating polymer networks (IPNs) coated on both sides with compliant electrodes have been thoroughly investigated in the literature. The actuators rely on the prestretch of the commercially available VHB tape (3M) followed by swelling of the VHB with the reactants for the additive network which is in then cured while the VHB is kept stretched. The system can be characterized as a system with two strain minima, namely the zero strain of the VHB tape and the zero strain of the additive network, which equals the prestretch. Such systems are, however, prone to significant stress relaxation and therefore they may not be applicable for long-time uses. Traditional IPNs (without any prestretching) allow for the use of polymer materials that would not otherwise have properties that would make them applicable for actuators or generators. In this work we focus on the mechanical and dielectrical properties of interpenetrating networks without any prestretch during the processing and show that parameters such as the mechanical breakdown strength can be improved.

8340-74, Poster Session

Fabrication of transparent active skin using few layer graphene

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We developed a transparent and stretchable dielectric elastomer actuator with electrode of few layer graphene (FLG). The developed active skin was consisted of elastomeric films sandwiched between compliant patterned electrodes. An individual FLG in 5 ~ 10 nm of thickness and containing 6.4 % of oxygen was obtained by expanding graphite with microwave followed by exfoliating the expanded graphite with sonication in N-methyl-pyrrolidone. Stacking FLG in the in-plane direction, the FLG film was obtained by the vacuum-assisted filtering and drying methods, and transferred to a silicone substrate by the way of transferring it on the water surface. Masking method was adopted in the fabrication of patterned electrode. The sheet resistance of the FLG film on the silicone substrate was 0.4 kΩ/sq with a thickness of 80 nm. The transparency and displacement of developed active skin were measured over 45 ~ 65 % with stretching and 100 μm with controlled frequency, respectively. Also, preliminary implementations on the embossed actuator are given to validate the proposed idea.

8340-75, Poster Session

Electroactive polymer blends of neoprene rubbers and conductive polyaniline nano-particles

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Polymer blends between polyaniline (PANI) nano/large particles and chloroprene rubbers (Neoprene) were fabricated and investigated as the electroactive materials. The effects of the chloroprene type, the particle size, the particle concentration, and electric field strength on the storage modulus sensitivity, and the dielectrophoresis force were studied. Chloroprene W provides the highest storage modulus sensitivity at 55% and was chosen as the matrix. The dielectric constant of the blends increase with increasing concentration of PANI nano/large particles. The storage modulus of the blends (with and without electric field) increase linearly with the PANI content. The maximum storage modulus sensitivities of the blends with PANI nano and large particles at E= 2 kV/mm are 73% at 0.01 %vol and 63% at 0.1 %vol, respectively. The dielectrophoresis force of all specimens increases monotonically with increasing electric field strength. The blends with PANI-nano and large particles at 0.01 %vol generate higher dielectrophoresis forces than those of the pure chloroprene W. For the 0.1 %vol of PANI nano and large particles, the resultant deflection angle and dielectrophoresis forces are lower than those of the 0.01 %vol systems and the pure chloroprene W, presumably due to the diminishing resultant dipole moments genarated with increasing PANI concentration.

8340-76, Poster Session

Electrical and temperature response of nanowire polypyrrole/gelatin hydrogel as an actuator

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In our work, we prepared Nanowire-Polypyrrole/gelatin hydrogels by dispersion of gelatin solution in an aqueous solvent with anionic surfactant sodium dodecyl benzene sulfonic acid (DBSA) toward electroactive application. The electromechanical properties, thermal properties and the deflection testing of the pure gelatin and Nanowire-Polypyrrole/gelatin hydrogels were investigated as a function of temperature, frequency, and electric field strength. The 0.01%, 0.1%, 0.5%, 1%v/v and the pure gelatin hydrogel possess the storage modulus sensitivity values of 0.75, 1.04, 0.88, 0.99 and 0.46, respectively in effect of electric field strength. The storage modulus (G') of Nanowire-Polypyrrole/gelatin hydrogels increase with increasing concentration at 0.1%v/v nanowire PPy as the applied electric field strength is increased to 800 V/mm. The effect of temperature, on electromechanical properties of pure gelatin and composite hydrogels, are studied between 30 and 80 °C.

8340-77, Poster Session

Electroactive ionic liquid-cellulose gel: effects of temperature and electric field strength

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Cellulose is piezoelectric material whose piezoelectric properties are responsible for the internal rotation of polar atomic groups associated with asymmetric carbon atoms based on non-centro symmetry. The 1-Butyl-3-methylimidazolium Chloride (BMIM+Cl-), a well-known room temperature ionic liquid (RTIL), was used to dissolve a micro-crystalline cellulose. The BMIM+Cl- - cellulose gels were prepared by the solvent casting method. The elctromechanical properties of the cellulose gels were investigated under the oscillatory shear mode at electric field strengths between 0 to 1kV/mm and as functions of temperature. The storage moduli (G') linearly increase with temperature up to 333 K at 1 rad/s in the absence of electric field strength. This is because temperature enhances the mobility of BMIM+-cation, the dipole-dipole interaction, and the cellulose chain alignment. The storage moduli (G') linearly increase with temperature up to 313 K at 1 rad/s in the presence of 1kV/mm of electric field strength and decrease above 313 K. This is presumably caused by the ionic association of ionic liquid, the premature transition temperature of BMIM+Cl- (fusion temperature=341.94 K), and the chain relaxation due to the imposed high electric field strength and temperature. In the deflection experiments, under the electric field, the deflection distances of the gels linearly increase with increasing electric field strength along with the dielectrophoresis forces beyond

the electrical yield strength of 100 V/mm. The back and forth swing was investigated under the electric field strength of 525-550 V/mm to be due to the competition between the anion and cation movements within the ionic liquid.

8340-78, Poster Session

Flexible autonomous scavengers: the combination of dielectric polymers and electrets

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Thanks to their high energy density and their flexibility, scavenging energy with dielectric polymer is a promising alternative to ensure the autonomy of various sensors such as in e-textiles or biomedical applications. Nevertheless, they are passive materials requiring the installation of a high-voltage source to polarize them. Thus, we present here a new design of scavenger using polymer electrets for poling the dielectric polymer which is a first step toward a fully autonomous system. Our scavenger is composed of commercial dielectric polymer (3M VHB 4910) with Teflon electrets developing a potential of -300V, and patterned grease electrodes. The transducer works in a pure share mode with a maximal strain of 50% at 1Hz. The typical “3D-textured” structure of the scavenger allows the electrets to follow the movement of the dielectric. A complete electromechanical analytical model has been developed thank to the combination of electrets theory (re-arrangement of electrical charges) and dielectric modelling (viscoelasticity and Maxwell contributions). For plane structures under main deformations, this model can calculate all the output value such as voltage V and produced power Ppro. Thus, our new autonomous structure on an optimal resistance can produce about 0.14mJ.g-1. This value is twice those obtained with piezoelectric polymer (active reference material), and can be improved by optimising the characteristics of the two main materials. The power management of our flexible autonomous structure is quite simple (diode rectifier) and let us hope a scavenged energy up to 60µJ.g-1. The manufacture and tests of these new scavengers are under development.

8340-79, Poster Session

High performance dielectric elastomer stack actuators with optimized electrical interconnection

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Dielectric elastomer stack actuators (DESA) with up to 100 layers are fabricated in an automated process. The resulting stack is composed of dielectric PDMS layers with a film thickness ranging from 80 µm down to 5 µm and compliant graphite electrodes (approx. 5 µm).

The challenge of the electrical interconnection of each enclosed electrode layer is not solved satisfactorily. So far thin copper wires pulled through the feeding lines are used for the interconnection. With this method typically 80 - 90 % of the electrode layers are connected, resulting in additional passive material and thus reduced actuator performance. Furthermore, first investigations suggest that the electrical interconnection of DESA plays a major role regarding actuator lifetime.

The interconnection of DESA is evaluated by analyzing the structure and the electrical loading of the single layer interconnection. The temperature distribution of a driven actuator shows a maximum at the contact area between the thin electrode and the copper wire. Hence several methods for optimization are developed and compared. To reduce the contact resistance and therefore the temperature increase at the interface between the graphite electrodes and the external feeding line, thicker electrode layers are used for the feeding lines as compared to the active region. Lifting the single dielectric layers in the feeding lines partially in a step profile and refilling with a conductive paste allows connecting the thin electrodes from the top rather than sideways. This results in an increased connection surface and therefore a reduced resistance as well.

Finally a new interconnection method with an increased yield of single layer connections and improved heat dissipation (life-time) is presented.

8340-80, Poster Session

Effect of temperature on electrostriction in dielectric elastomers

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Dielectric elastomers (DE) are electro-activated soft materials which can be used in high performance applications such as artificial muscles and electric generators. Subject to an electrical load, DE shows great deformation which has been analyzed by invoking stresses of two origins: the Maxwell stress and the electrostrictive stress. The electrostrictive stress results from the effect of change of dielectric constant. The dielectric constant of DE is closely related to the temperature as reported before; therefore electrostriction will be generated in the actuation and hence affects the stability of DE. In the past investigation, DE is assumed to operate in an isothermal environment. In this paper, we develop a free energy model in the thermodynamic system of electrostriction for DE involving thermo-elastic strain energy, electric energy and purely thermal contribution energy. By applying recent experiments with a VHB 4910 dielectric elastomer (3M, USA) where the dielectric constant changes obviously when the temperature changes, the equilibrium equations of electrostriction in this thermodynamic system at different temperatures are investigated and evaluated. In this free energy model, we couple this temperature dependence of dielectric behavior with nonlinear thermo-elastic behavior. The numerical results indicate that the effect of temperature-dependent dielectric constant partially removes the Maxwell stress, which consequently improves the actuation stress and the critical nominal electric field of DE. It was thus demonstrated that the increase of temperature could modify the electromechanical instability of DE, which consequently enhances the electromechanical stability of the DE. It is hoped that these conclusions will guide to select and design high-performance DE.

8340-81, Poster Session

Electric field induced deformation in dielectric

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Subject to a high electric field, the dielectric deforms. If the dielectric is hard, the voltage induced deformation is small and the deformation is determined by the breakdown voltage. If the dielectric is soft, the voltage induced deformation is large. The deformation is determined by the breakdown voltage together with electromechanical instability and snap-through instability. Based on the theoretical research proposed by Suo and Li, taking the dielectric elastomer soft material research object, we introduce three kinds of material limits: strain-stiffening, polarization saturation and breakdown voltage and analyze the effect of material limits on voltage induced deformation. The influence of the pre-stretch and material parameters is also investigated. For a specific soft dielectric material under certain pre-stretch, the theoretical maximum electrical actuation deformation can be determined.

8340-82, Poster Session

Design and modeling of dielectric elastomer actuators

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One of the main technical challenges in the development of EAP stack actuators is the design and realization of suitable electrodes. For the conventional actuator design the electrodes must be compliant and be able to undergo large strains without adding too much stiffness. Metal electrodes are therefore normally out of question due to their high stiffness, though their electrical properties are excellent. In this work a new design approach is presented which comprises rigid metal electrodes. Its functionality is proven by means of numerical simulations and experimental tests. It is shown to be convenient for a variety of application scenarios from active vibration control to haptic interfaces. It allows the customized tailoring of transducer elements due to the designable electrode structure. Various actuators are tested concerning their electrical, mechanical and electromechanical behavior. One of the main focuses is the reliability and durability of the actuators in different environmental conditions, an aspect that has hardly been considered so far.

For this new actuator type a full electromechanical model is developed. It contains all transfer functions in a nonlinear description and accounts for various physical effects arising from the special actuator design. Due to its standardized interface configuration it can well be used in combination with existing models for mechanical structures and electrical amplifiers to completely model active systems. It is shown to be capable of satisfactorily matching the experimental data and therefore applicable for the realistic simulation necessary in the development of active solutions.

8340-83, Poster Session

Novel DEA with organically modified silicone elastomer for permittivity enhancement

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Novel dielectric elastomer actuators (DEA) with high performance have been developed. For this purpose, silicone rubber was modified by the introduction of fluorinated propyl groups in order to enhance its permittivity and the actuation strain and stress. Mechanical and electric properties of the modified silicone elastomer were investigated. Elastomer films were coated with graphite electrodes and the actuation strain of the model DEA at variable field strength was studied as well. It was demonstrated, that the permittivity could be increased by ca. 70 % compared to the unmodified silicone. Simultaneously, the conductivity of the elastomer was not significantly enhanced and the Young's modulus was even diminished. As a consequence of all these properties, the actuation strain at fixed field strength was nearly doubled by the modification of the silicone elastomer. This strong gain in actuation performance gives the modified elastomer material a high potential for future applications.

8340-84, Poster Session

Electroactive nanostructured polymer materials for the next generation actuators

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Electrostriction facilitates electric field stimulated mechanical actuation of dielectric materials. The present work demonstrates that introduction of dielectric mismatched nanodomains to a dielectric nanostructured polymer results in an unexpected ultralarge electrostriction coefficient, enabling a large electromechanical strain response at a low electric field. This strong electrostrictive effect is attributed to the development of an inhomogeneous electric field across the film thickness due to the high density of interfaces between dielectric mismatched periodic nanoscale domains. The periodic nanostructure of the nanostructured gel also makes it possible to measure the true electromechanical strain from the dimensional change monitored via in-situ synchrotron small angle X-ray scattering (SAXS). The present work offers a promising pathway to design novel high performance dielectric elastomers as well as to understand the underlying operational mechanism of nanostructured multiphase electrostrictive systems.

8340-86, Poster Session

Optimal operation of dielectric elastomer generators

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Dielectric electroactive polymers are thin films made of elastomeric material coated with compliant and conductive electrodes offering a large amount of deformation. Beside of the actuator functionality, they can be used in the inverse operation mode as generators converting mechanical strain energy into electrical energy using the polymer's capacitive behavior. For the mechanical excitation of the energy harvesting device preferably ambient energy sources like wind or water are utilized, because large forces can be applied from an inexhaustible source in general. Since the excitation forces usually occur randomly distributed in amplitude und frequency, the controller of the device has to estimate these quantities and to adapt resp. optimize the energy harvesting cycle accordingly. In contrast to the integration of an additional strain measurement system, the motion quantities can also be estimated based on the already measured generator voltage under the condition that a few charges remain on the generator during relaxation, too. Based on this estimation of the fundamental oscillation of the excitation, the initial charging energy for the generator can be calculated in a first step. In a second step the current limitation of the power electronics is taken into account to determine the length of charging and discharging time. Based on this, the exact points in time for charging and discharging are determined, optimizing the conflict of objectives between maximizing the mechanical stretch ratio when fully charged and minimizing the electrical losses during charging. The estimation and optimization are described and demonstrated in detail in the final paper.

8340-87, Poster Session

Dual-axis hybrid type force sensor

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Robotic grasping requires not only force and touch sensors but also flexibility of such sensors because most of the sensors are attached to the finger tip. Many studies are underway in such sensors using polymer because polymer is flexible and affordable. Especially, Nitrile Butadiene Rubber (NBR) is one of primary materials because the dielectric constant of the NBR is about 3 times higher than that of silicon and its characteristic can be easily modified according to the requirements.

The principle of the capacitive force sensor using NBR is as follows; capacitance values will be changed by changes in the thickness of the dielectric under normal force or changes in the overlapping area of electrodes under shear force. The force and moment are measured by such changes. Conventional one-axis capacitive type force sensors measure normal or tangential force from one pair of electrodes. The increased number of electrodes can be used for multi-axis force sensors at the cost of complexity of wiring and the size of the sensor.

In this paper, we propose a dual-axis capacitive and resistive hybrid-type force sensor using dielectric elastomer with only one pair of electrodes. The electrodes are made with sputtering, to avoid breakage of the electrode due to the length variations. With only one pair of electrodes, the normal force is measured from the change of capacitance and resistance values and the shear force is measured from the change of only capacitance values. Experimental results verify the effectiveness of the proposed dual-axis hybrid type force sensor.

8340-88, Poster Session

Large electromechanical and electro-optical effects of polydomain liquid crystal elastomers

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Mechanical and optical effects of polydomain liquid crystal elastomers (LCEs, both side-chain and main-chain LCEs) in applied electric fields is investigated, when LCEs are swollen in a low molecular weight liquid crystal, 4-n-pentyl-4-cyanobiphenyl (5CB), a nematic solvent. The shape and optical intensity changes were measured as a function of the voltage. Large mechanical and optical effects in main-chain Poly-LCEs simultaneously arise in an applied electric field. The threshold for shape changes of swollen main-chain LCE, Vth, is about 10 V across 100 m and the maximum contraction is more than 20% at about 200 V. The electro-optical effect of main-chain Poly-LCEs is due to field induced poly-mono (PM) domain transition, and its optical transmission change is proportional to the contraction. This suggests the possibility of broad application as field-induced-optical actuator devices.

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8340-89, Poster Session

Reduction of the stress-relaxation of IPMC actuators by a fluctuating input and with a cooperative control

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Stress-relaxation phenomenon is commonly observed in the operation of ionic polymer-metal composite (IPMC) actuators.

In many applications, the stress-relaxation phenomenon of IPMCs is not a preferable feature.

The origin of the stress-relaxation is said that the diffusion of the solvent decreases the pressure, i.e. stress, in the polymer.

Therefore it is difficult to avoid the stress-relaxation phenomenon of a piece of IPMC due to the physical principle.

However, there are possibilities of reducing the stress-relaxation with some IPMCs.

In this study, we propose a control method using two (or more) IPMCs in order to reduce the stress-relaxation phenomenon.

In the experiment, the force generated by two IPMC strips is measured by a force sensor for feedback.

The proposed control signal consists of a small fluctuating signal which is oscillating independently of the command, in addition to a 2DoF controller with an I-PD feedback and with a feedforward gain.

In the experiment, in the case of the desired force is constant, the voltage reached its upper limit if the fluctuating signal was not added.

On the other hand, we have found that the time to reach the limit voltage became more than twice if the fluctuating signal was added.

We also observed that the amplitude of the fluctuating signal should be appropriate.

In contrast, the results were not sensitive to the frequency of the oscillation.

This phenomenon of reducing the relaxation is not reproduced in the simulation therefore it may because of the unmodeled non-linear nature of the actuators.

8340-90, Poster Session

A structure model for ionic polymer-metal composite (IPMC)

L. Chang, H. Chen, Z. Zhu, Xi'an Jiaotong Univ. (China)

IPMC has been widely pictured as a polyelectrolyte membrane sandwiched between two flat electrodes in most of its electromechanical models. However, over the past decade, several studies revealed that this structural idealization (ignorance of the interface) may lead to problematic predictions. A proper model to characterize IPMC structures are expected for a more sophisticated electrochemistry or deformation theory. This paper proposed a geometrical model for an electroless-plated palladium-electroded IPMC when it is treated as a composite containing three distinguished layers: upper electrode, interface layer, and the substrate membrane. Especially, fractal dimension was adopted to describe the rough contact surface between the upper electrode and the substrate membrane. And the interface was illustrated as a gradient structure with a linear decrease in the scales and the volume fraction of the palladium particles. Based on this model we consequently estimated the electromechanical properties of IPMC, including the elastic modulus and the capacitance. Then these properties of some IPMC samples with representative structures were measured to verify the model. The comparison of the experimental results with the modeling results well proved the applicability of the structure model.

8340-92, Poster Session

Characterization of longitudinal tensile force of millimeter thick IPMCs

V. Palmre, D. Pugal, K. J. Kim, Univ. of Nevada, Reno (United States)

Ionic polymer-metal composites (IPMCs) are an emerging class of electroactive polymers that display actuating and sensing capabilities. In this paper, a longitudinal tensile force of millimeter thick IPMCs is characterized. Both, 0.5 mm and 1 mm thick IPMCs with Pt electrodes are tested in tensile mode, by monitoring the change of tensile load in response to applied electric fields. The measurements are performed either under static pre-strain conditions or by dynamically increasing the tensile strain with constant rate, while switching the voltage on and off periodically. The tests under static pre-strain and constant voltage are performed in order to evaluate the maximum tensile force of the samples. Our results indicate that Pt-IPMCs which typically show blocking force in bending direction in range of 100 mN, are capable of generating tensile forces in longitudinal direction more than 1.5 N.

8340-93, Poster Session

Electrochemical impedance spectroscopy of the bucky-gel actuators and their electromechanical modeling

K. Asaka, T. Sugino, K. Kiyohara, K. Mukai, National Institute of Advanced Industrial Science and Technology (Japan); H.

Randriamahazaka, Univ. Paris 7-Denis Diderot (France)

In previous papers, we have reported the dry actuator that can be fabricated simply by layer-by-layer casting, using 'bucky gel', a gelatinous room-temperature ionic liquid (IL) containing single-walled carbon nanotubes (SWNTs). Our actuator (the bucky-gel actuator) has a bimorph configuration with a polymer-supported internal ionic liquid electrolyte layer sandwiched by bucky gel electrode layers - polymer-supported 'bucky gel' layer, which allow quick and long-lived operation in air at low applied voltage. In order to explore the electromechanical response of the bucky-gel actuator, it is important to study the kinetics of the electrochemical processes in the electrode layers. In order to do this, electrochemical impedance spectroscopy (EIS) method is a powerful analysis tool. The impedance for the bucky gel electrode layer can be considered to be presented a porous electrode model that consists of a conductive electrode layer containing electrolyte pores. In this paper, bucky-gel electrodes containing various ionic liquid species were prepared, and their impedance responses were measured and analyzed by means of the porous electrode model. Actuators were prepared from the bucky-gel electrodes, and the displacements were measured by applying sinusoidal voltages of various frequencies. The frequency dependence of the displacement responses is discussed in relation with the impedance properties of the bucky-gel electrodes. The electrochemical equivalent circuit of the bucky-gel actuator is discussed on the basis of the impedance analysis. Accordingly, we are able to develop an electrochemical model allowing to analyze the behavior of these actuators.

8340-94, Poster Session

Compliant composite electrodes and bistable electroactive polymers

S. Yun, W. Hu, X. Niu, Z. Yu, L. Li, Q. Pei, Univ. of California, Los Angeles (United States)

We will present our recent results in the development of compliant electrodes based on silver nanowires and carbon nanotubes. A facile in-situ composite synthesis and transfer technique is used, and the resulting composite electrodes retain the high conductivity of the conductive network and the mechanical flexibility of the matrix polymer. The composite electrodes have low surface roughness useful for the fabrication of polymer thin-film electronic devices. They have also been used for resistive heating and dielectric actuation. Bistable electroactive polymers employing the composite electrodes can be actuated to large strains via heating-actuation-cooling cycles.

8340-95, Poster Session

Bistable electroactive polymer with improved actuation stability and tunable transition temperature

X. Niu, P. Brochu, Q. Pei, Univ. of California, Los Angeles (United States)

Poly(t-butyl acrylate) is a bistable electroactive polymer (BSEP) capable of rigid-to-rigid actuation. The BSEP combines the large-strain actuation of dielectric elastomers with shape memory property. We have introduced a material approach to overcome pull-in instability in poly(t-butyl acrylate) that significantly improves the actuation lifetime at strains greater than 100%. The technique is further modified to tune the BSEP's glass transition temperature. In a specific example, the transition temperature was tuned to 35 ideal for haptic reading. Refreshable Braille display devices with of smartphone screen size have been fabricated to manifest a potential application of the BSEP. We will report the testing results of the devices by a Braille user.

8340-96, Poster Session

Ionic polymer-metal composites (IPMCs) as dexterous manipulators and tactile sensors for minimally invasive robotic surgery

Y. Bahramzadeh, M. Shahinpoor, Univ. of Maine (United States)

Robot-assisted surgery provides the surgeons with new tools to perform sophisticated surgical operations in a minimally invasive manner. Significant faster recovery, reduced hospitalization time and cost, less pain and enhanced precision are some of the benefits of robotic surgery.

The key features in robotic surgery that distinguishes it from other minimally invasive surgery techniques such as laparoscopic surgery are dexterity and operation of modified forceps , bowel grasper, curved scissor, suture-cut needle drivers, curved needle drivers, and Cadiere forceps that are robotically manipulated during surgery by cable-driven antagonist actuations. This provides the surgeons with more degrees of freedom to control and manipulate the surgical tools and end-effectors during robotic surgery with higher dexterity. However, the current mechanism of robotic forceps have some drawbacks because of their cable driven actuation mechanism and relatively complex design of robotic forceps, graspers, cutters, needle-drivers, burners and scissors. It has been reported that the rigidity and the durability of wires are poor. Furthermore, cleaning and sterilization of the wires are problematic during surgery. On the other hand the rigid nature of the robotic linkages, forceps and other surgical end-effectors significantly reduce the workspace and dexterity.

Reported here are applications of IPMCs as flexible actuators with embedded tactile and force-feed-back sensors in minimally-invasive robotic surgery. Properties of IPMCs such as low actuation voltage , large bending deformation, high functionality in aqueous solution and alkaline environment in the body and above all their biocompatibility have made these materials highly promising for sensing and actuation in robotic surgery. Theses polymeric actuators offer advantage over conventional cable driven rigid actuators because they have biomimetic flexibility which is a crucial parameter in manipulating the robotic surgical end-effectors especially in the convoluted parts of organs, tissues and vasculature.

In this paper, several possibilities for application of IPMCs in robotic surgery are investigated. It is shown that with a special design, IPMC actuators can be used for different surgical tasks such as holding the tissue or bending the tip of the forceps. Experimental result is presented to assess the maximum output force of IPMC actuators and tactile and force-sensing capabilities of IPMCs. These results are compared with the required forces involved in conventional surgical tools during surgical operations on biological tissues and organs. On the other hand, the range of deformation and frequency response of IPMCs are also analyzed and compared with the speed of the surgical tasks.

Result:

The study shows that IPMC actuators and sensors are promising for applications in robotic surgery because they maintain all the necessary properties and characteristics suitable for the future generation of surgical robots.

8340-97, Poster Session

Zipping it up: DEAs independent of the elastomer's electric breakdown field

P. Gebbers, Ecole Polytechnique Fédérale de Lausanne (Switzerland) and Zürcher Hochschule für Angewandte Wissenschaften (Switzerland); C. Grätzel, Optotune AG (Switzerland); L. Maffli, Ecole Polytechnique Fédérale de Lausanne (Switzerland); C. Stamm, Zürcher Hochschule für Angewandte Wissenschaften (Switzerland); H. Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

The maximum force generated by dielectric elastomer actuators (DEAs)

is limited by the electric breakdown field of the elastomer, and scales linearly with the membrane's dielectric constant.

We demonstrate here an alternative electrostatic actuator structure, which relies on the compliant nature of elastomer membranes, but does not require any electric field in the elastomer. Our device is a macroscopic version of the electrostatic zipping actuators common in silicon MEMS. It consists of a cm-sized metallic bowl-shaped bottom electrode, covered by a thin insulator, on which the elastomer membrane is bonded, enclosing a tapered air gap. A compliant electrode is patterned on the lower face of the membrane. Applying a voltage between solid electrode and compliant electrode leads to controlled pull-in in a movement comparable to the closing of a zipper, thus giving large strokes and forces with no electrical requirements on the elastomer since no voltage is applied across the membrane.

The compliant electrodes (5 to 20 mm diameter) are produced by gold ion-implantation into silicone membranes. The bottom metal electrodes are coated with 10 to 30 µm of Al2O3. We modeled the actuators semi-analytically and with finite elements. We report on our experimental study of membrane deflection and dynamics and discuss the effect of design parameters such as elastomer mechanical properties and actuator geometry.

The membrane deformation achieved with this zipping actuation can be applied to pumps or tunable liquid lenses. The out-of plane movement of the membrane can be used for linear actuation.

8340-99, Poster Session

Pump it up

L. Maffli, B. M. O'Brien, S. Rosset, H. R. Shea, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

Microfluidic Large-Scale Integrated (MLSI) chips are matrix of independently controlled fluidic actuators. These software-reprogrammable microfluidic chips enable applications such as high-throughput screening, systematic mixing and even displays. By replacing their conventional pneumatic actuation with directly driven active chambers, MLSI chips can be more than 10 times smaller, and one can avoid complex off-chip pneumatic controls.

Miniaturized Dielectric Elastomer Actuators (DEA) are excellent candidates to make these "smart" chambers because of their combination of compliance, large strains, and high energy density.

Using micropumps made from DEAs as basic building blocks, we explored several actuation schemes in order to determine the optimum geometry and fluidics to build a matrix of actuators.

The tested actuation architectures are out-of-plane diaphragm, zipping, and a combination of both. The use of simultaneous squeezing of the elastomer and zipping enhances the actuation force, and allows forcing the deflection towards the bottom of the fluidic channel, which is mandatory for peristaltic pumping.

Thanks to the low Young's modulus of the elastomers, excellent stroke volumes can be achieved. However this softness leads to increased response time. Additionally, the displaced mass of liquids is large compared to the actuator mass, and viscous dissipation takes place. The performance of miniaturized pumping DEAs have been studied by building an analytical model, validated with the measure of the response time of mm-size DEAs coupled with hydraulic impedances.

Cm-size devices were used as first proofs of concept, and we also report on the performance of chip-scale microfabricated mm-size DEA pumps with ion-implanted electrodes.

8340-100, Poster Session

Product oriented DEA design and characterization

M. Matysek, R. van de Molengraaf, F. Crompvoets, Philips Research Nederland B.V. (Netherlands)

Dielectric elastomer actuators (DEA) are flexible, smart materials due to an inherent combination of many advantages. For instance for user interfaces they offer breakthrough functionality by enabling freely programmable, free-form surfaces that combine sensing and actuation capabilities.

For industrial realization the aspect of manufacturing-complexity is important. In most cases the simplicity of the setup determines the realizable potential of the DEAs. To allow easy and efficient mass production we worked on new setups like the "duck mode" which was recently published [1]. Finding an efficient way to incorporate the actuators in a product is crucial, because the configuration of the outside world-actuator interface affects the performance of the actuator.

In this paper we will focus on the characterization of parameters influencing the actuator's behavior in a close to product environment. Different conditions like the clamping and bearing of the actuator as well as additional covering layers are investigated.

Using product concepts like tactile displays we will characterize those effects: Free bending films, for example, will underlie position dependant deformation as the increased actuator area will always be captured by gravity, as shown in Fig.1. Solid fixtures on the other hand will at least partially block movements and hence strongly decrease the actuator's performance. The typically soft silicone elastomer is disadvantageous for tactile applications as it is extremely sticky and hinders an easy exploration of the user's finger. Different approaches to overcome this mechanical impedance mismatch, like modifying the top silicone layer itself or adding additional covering layers, are investigated.

1 F. M. H. Crompvoets, D. Brokken, H. de Koning and W. M. Martam, "Accurate free-form surface actuation using a non-pre-stretched silicone dielectric polymer actuator", Proc. SPIE 7976, 79761F (2011)

8340-101, Poster Session

Electromechanical properties of P(VDF-TrFE)/graphene nanocomposites

S. M. Hong, S. S. Hwang, K. H. Min, C. M. Koo, Korea Institute of Science and Technology (Korea, Republic of)

Electromechanical properties of poly (vinylidenefluoride) (P(VDF-TrFE)) /graphene (Gr) nanocomposites have been investigated. The electromechanical thickness strain of the nanocomposites increased with the filler content. P(VDF-TrFE)/Gr showed the larger sz than P(VDF-TrFE) composites with other carbon based nanofillers at the same filler content. Such actuation properties of the nanocomposites with conductive fillers are discussed in the view point of filler shape and filler dispersion state.

8340-102, Poster Session

Bimorph and trimorph actuators based on polyaniline nanofiber reinforced PVA nanocomposites

A. Kumar, S. Banerjee, Tezpur Univ. (India)

Electroactive polymer (EAP) based actuators have high actuation strain (> 300 %), very high reaction speeds (micro-sec to min) requires less power for operation and can be used in space applications where limited power is available for use [1, 2]. Conducting polymers are an important class of electroactive materials; however, actuators based on them synthesized using electrochemical deposition puts constraints in their possible designs for the actuators [3]. In the present work, we have synthesized polyaniline (PAni) nanofiber reinforced PVA nanocomposites by rapid mixing polymerization. The nanocomposite films can be cast in any possible shape and thickness as desired. The nanocomposites have been characterized using XRD, FTIR and SEM. The mechanical properties of the PAni nanofiber reinforced PVA nanocomposites have been investigated. Actuators have been fabricated in two configurations viz., bimorph and trimorph configurations. It has been observed that the actuators operate both in acidic medium and in air. The actuation of the

nanocomposite films have been measured using a laser displacement system and the data has been acquired in a computer using a MATLAB program. The bimorph actuator operates in acidic medium without the application of any voltage, while a very small voltage is required for the operation of the trimorph actuator.

References:

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[3] E. Smela, Adv. Mater, 15 (2003) 481.

8340-103, Poster Session

Nanocrystalline nickel ferrite reinforced conducting polyaniline composites

S. B. Kondawar, A. I. Nandapure, RTM Nagpur Univ. (India)

A Nanocrystalline nickel ferrite ($NiFe_2O_4$) powder with average particle size 20nm was synthesized by refluxing method. Magnetic and conductive polyaniline-nickel ferrite (PANI/$NiFe_2O_4$) nanocomposites in different weight proportion (5 to 15%) have been synthesized by chemical oxidation polymerization method. These nanocomposites were subsequently characterized for morphological, crystalline, structural, electrical and magnetic properties by TEM, XRD, FTIR, UV-VIS, four-probe resistivity and VSM. UV-Visible and Fourier Transform Infrared spectra showed that there was strong interaction between ferrite and PANI chains, but the backbone chains of PANI- $NiFe_2O_4$ were hardly changed compared with PANI. The X-ray diffraction (XRD) pattern and transmission electron microscopy (TEM) image showed that nanocrystalline Co_3O_4 embedded into polycrystalline PANI to form crystalline nanocomposites. The electrical conductivity of nanocomposites decreases from 1.0 S/cm to 0.2 S/cm as ferrite content increases from 5 to 15%. The electrical conductivity of nanocomposites decreased with decreasing temperature, exhibiting typical semiconductor behavior. Nanocomposites showed weakly ferromagnetic behavior as compared to that of pure nickel ferrite. But, the saturation magnetization of nanocomposites was drastically increased as ferrite content changed from 5 to 15%.

8340-104, Poster Session

Sensing capabilities based on dielectric electro active polymer's: feasibility and potential state-of-art application

Y. H. Iskandarani, H. R. Karimi, Agder Univ. (Norway)

This paper will present the work in the area of sensing using smart materials, more specific Dielectric Electro Active Polymer's (DEAP's). Sensing is one of the main trio-characteristics of the DEAP's, the trio-formations as applicable use are actuator, transducer and last but not least sensor. It is noted here that one of the main value propositions whenever DEAP material is used is the dual characteristics as the sensing/actuating capability.

In the following work, the material will be modeled and the relation between the key variables (pressure & capacitance) will be determined. Hence, such a relation depends on the geometrical shape of the used membrane. So on, conceptualization is carried out to propose alternative solution for the sensor design using the DEAP and the laminate material. Test methodology, pressure based test rig, prototypes and software is developed afterward to evaluate the prototypes.

In general, the DEAP material has proven to be a very good sensor for pressure taking the advantage of flexibility, wide range of operation and last but not least the sensitivity. The theoretical model is benchmarked against the acquired data from the tests, good correlation has been recorded. The desired requirements for accuracy and measuring intervals (30mmHG-180mmHG)are satisfied, showing a promising application for the DEAP material in pressure sensing in general, and blood pressure sensing in specific. Moreover, a conceptual design for a blood pressure system has been developed.

8340-105, Poster Session

Effect of Janus particles as filler materials for acrylate-based dielectric elastomers

H. Chen, I. Kretzschmar, The City College of New York (United States); A. Maliakal, LGS Innovations Inc. (United States)

A dielectric elastomer is a polymer that charges when it is exposed to an electric field. Owing to the electrostatic attraction, films of dielectric polymers are able to compress by reducing their thickness along the direction of electric field and by elongating in the transverse direction. The compression mechanism can be described by the Maxwell equation, in which the compressive strain is proportional to the square of the electric field. The proportionality factor is the electrostrictive coefficient.

In our research, we modified an acrylic elastomer with gold-capped silica Janus particles to enhance the electrostrictive coefficient of the polymer film. Their heterogeneous properties enable Janus particles to carry a high local dipole moment in an electric field thereby increasing the dielectric constant of the composite. Further, the interactions of the gold and the silica halves with the polymer are different potentially affecting the mechanical properties of the films.

Here, we will report our dielectric, elastisity and stress-strain characterization of Janus silica and plain silica particle loaded acrylate polymers. We find that the addition of Janus particles improves the electrostrictive coefficient by an order of magnitude. Based on the Maxwell equation, such films should show a ten times larger strain response than pure acrylate films.

8340-26, Session 7

Electrical actuation and control of shape memory polymer carbon nanocomposites

F. Liang, R. Sivilli, J. Gou, Y. Xu, Univ. of Central Florida (United States)

Shape memory polymers (SMPs) are one of the most popular smart materials due to their fantastic properties and greatly potential application in recent years. This paper presents a study on the synergistic effect of carbon nanofiber (CNF) and carbon nanofiber paper (CNFP) on shape memory polymer (SMP) nanocomposites actuation by applying electric current. Shape memory effect has been greatly improved due to the significant increase of electrical conductivity by combining CNF and CNFP into SMP composites. CNFP is used to facilitate the actuation by electrical resistance heating. In order to accelerate the electro-active response, the bulk thermal and electrical conductivity of SMP nanocomposite is increased by mixing CNFs with SMP. A vision based 3D coordinate prediction system is designed to precisely obtain the deformation information of the SMP composites with current and voltage applied. Compared with baseline material, the recovery speed of SMP nanocomposites is increased up to 1000%. In order to investigate the themomechanical property of SMP composite, Dynamic Mechanical Analysis (DMA) test has been carried out as well. Furthermore, the control tests of SMP nanocomposites show that they had a reasonably fast response of ~90 seconds, also could be repeated over 100 times and commanded to the desired angle within 5%.

8340-27, Session 7

CNT/conductive polymer composites for low-voltage driven EAP actuators

T. Sugino, Y. Shibata, K. Kiyohara, K. Asaka, National Institute of Advanced Industrial Science and Technology (Japan)

We recently succeeded to provide low-voltage (< ±3 V) driven electroactive polymer (EAP) actuators which show large deformation and quick response in air. Actuators consist of single-walled carbon nanotube (SWCNT), ionic liquid (IL), and base polymer (BP). Our CNT-

actuators have a three-layered configuration in which one electrolyte layer composed by IL and BP is sandwiched by two electrode layers produced by SWCNT, IL, and BP. Actuators, in general, are requested their large deformation, quick response, and strong actuation power. But it is very difficult to find fabrication condition to improve these three parameters at the same time. For example, increasing of thickness of actuators to improve the mechanical stress provides decreasing of actuation displacement and speed. We have investigated the effect of some kinds of additives incorporated into the electrode layer to improve the actuation performance. In particular, the addition of nano-particles of polyaniline (PANI) or polypyrrole (PPy) as conductive additives is a good strategy to improve actuation. Addition of conductive nano-particles such as PANI and PPy induced larger capacitance and higher conductivity and larger Young's modulus, which are leading to larger deformation, faster response, and stronger actuation, respectively. For example, a CNT-actuator with PANI nano-particles shows more than 3 times larger deformation with more than 4 times higher electromechanical generated stress compared with a CNT-actuator without PANI nano-particles.

In this paper, we present the effects of applied voltage, species of IL, amounts of IL, thickness of actuator to optimize actuation performance and the potential of improved CNT-actuators for thin and light Braille display.

8340-28, Session 7

Giant torsional actuation from carbon nanotube yarns

J. Foroughi, G. M. Spinks, G. Wallace, Univ. of Wollongong (Australia); J. Oh, M. E. Kozlov, S. Fang, The Univ. of Texas at Dallas (United States); J. D. W. Madden, The Univ. of British Columbia (Canada); T. Mirfakhrai, Stanford Univ. (United States); M. K. Shin, S. J. Kim, Hanyang Univ. (Korea, Republic of); R. H. Baughman, The Univ. of Texas at Dallas (United States)

Actuator materials capable of producing a rotational motion are rare and, yet, rotary systems are extensively utilized in mechanical systems like electric motors, pumps, turbines and compressors. Rotating elements of such machines can be rather complex and, therefore, difficult to miniaturize. Rotating action at the microscale, or even nanoscale, would benefit from the direct generation of torsion from an actuator material. We have discovered that the electrochemical charging of helically wound multiwall carbon nanotubes in the form of a twisted yarn generates such rotational action. Large scale rotations are produced from small voltage stimuli. The rotation angles are orders of magnitude larger than piezoelectric or shape memory alloy torsional actuators. The torsional strain, torque, speed and lifetime have been evaluated under various electrochemical conditions to provide insight into the actuation mechanism and performance. Finally, the rotating motion has been coupled to a mixer for use in a prototype microfluidic system.

8340-29, Session 7

Ionic EAP transducers with amorphous nanoporous carbon electrodes

F. Kaasik, J. Torop, I. Põldsalu, I. Must, A. Aabloo, Univ. of Tartu (Estonia)

There is still emerging need for more effective and technologically simple electrode materials for low voltage ionic EAP materials. In the field of actuator production, the performance characteristics of the device such as stress, strain and speed can be controlled by changing the electrode conductivity and packing density of the active material in electrode layer. Most extensively used carbon materials for bending and linear actuators are different types of carbon nanotubes. We have used for the electrode layers carbide-derived carbon (CDC), which can be considered as template carbon. However, this material differs from the other porous amorphous carbons by its well-defined structure and narrow distribution of micropores. Also, several carbon aerogels were proposed as new materials for the fabrication of nanoporous electrodes for EAPs.

The differences in actuation performance were analyzed in the context of pore characteristics of carbons, electromechanical and electrochemical (EIS) properties. Quantum chemistry and molecular dynamics simulations were used to analyze in detail the actuation/sensor processes in material.

It will be a talk invited by organizers.

8340-30, Session 7

A new twist on artificial muscle: metal yarns that wiggle!

J. D. Madden, W. Sikkema, D. Sim, G. Russell, T. Mirfakhrai, The Univ. of British Columbia (Canada); S. Nafici, Univ. of Wollongong (Canada); R. H. Baughman, The Univ. of Texas at Dallas (United States); G. M. Spinks, Univ. of Wollongong (Canada); C. Sinclair, The Univ. of British Columbia (Canada)

Artifical muscle technologies have long been known to change in length and volume, but twisting has been rare, and generallly achieved by converting linear actuation into rotary motion. Very recently it has been demonstrated that carbon nanotube yarns twist when electrochemically charged - showing large and fast rotations. Here we show that generating rotation is not unique to carbon nanotubes - yarns composed of metal nanofibres can also produce twist when charged. To demonsrate this charging we employed a yarn composed of niobium nanofibres that are twisted into a yarn using a magnetic stir bar. Although the wires are bundled into strands that appear to have a diameter of approximately 1 micrometer, which is much larger than in CNTs, application of a voltage to a submerged section of the yarn in electrolyte nevertheless led to an untwisting of about 1 degree in a specimen that is several centimeters long. Although the rotation is small, it suggests that any form of electronically conductive yarn composed of small diameter fibres can be employed to generate rotary motion.

8340-32, Session 8

Novel DEA materials by chemical grafting of silicone networks on molecular level

H. Krueger, B. Kussmaul, M. Wegener, Fraunhofer-Institut für Angewandte Polymerforschung (Germany); S. Risse, G. Kofod, Univ. Potsdam (Germany)

Dielectric elastomer actuators (DEA´s) enable a wide range of interesting applications since they are

soft, lightweight and have direct voltage control. Demonstrators already exist for an arm wrestling robot, miniaturized pumps, optical adjustment actuators, an electro-mechanical logic gate for distributed multielement smart systems, etc..

However, one of the main obstacles to their wide-spread implementation is their high operating voltage, which tends to be several thousand volts. In principle, the operating voltage can be lowered by reducing the thickness of the elastomer film, increasing the permittivity or lowering the mechanical stiffness. Permittivity generally can be increased by inorganic filler particles with high dielectric constant or by modifying the chemical structure of the elastomer.

Therefore, a novel chemical method is established to enhance the permittivity of a silicone matrix, which prevents agglomeration and give elastomer films that are homogeneous even at molecular level. A push-pull dipole is synthesized to be compatible with the silicone crosslinking chemistry, allowing direct grafting to the crosslinker molecules in a one-step film formation process. The chemical, thermal, mechanical and electrical properties of films with dipole containing a range between 0 wt% to 13.4 wt% were thoroughly characterized.

The grafting of dipoles increases the relative permittivity and simultaneously decreases the stiffness, resulting in the actuation

performance being improved by a factor of six compared to the non-modified silicone.

Furthermore the applicability of this new method to improve the actuation properties by dipole integration on molecular level is demonstrated for several silicone matrices.

8340-33, Session 8

Modeling and characterization of stiffness controlled robotic legs using dielectric elastomers

J. Newton, J. T. Morton, J. Clark, W. S. Oates, Florida Ctr. for Advanced Aero-Propulsion (United States)

A new robotic leg design is presented that utilizes dielectric elastomers (3M VHB) to rapidly control stiffness changes for enhanced mobility and agility of a field demonstrated hexapod robot. A set of electro-mechanical test are utilized to obtain up to 20% change in stiffness. The quasi-static and transient response is quantified using a benchtop 10 kV/10 mA amplifier versus a smaller portable amplifier with a comparable voltage output, but lower current capacity. The results are compared to a finite deformation membrane finite element model to quantify how to optimize the electrode configuration to avoid dielectric breakdown while improving stiffness changes for real-time robotic applications.

8340-34, Session 8

A framework to investigate instabilities of homogeneous and composite dielectric elastomer actuators

M. Gei, S. Colonnelli, R. Springhetti, Univ. degli Studi di Trento (Italy)

Predictive models for Dielectric Elastomer Actuators require to be based on nonlinear solid mechanics theory of soft dielectrics. This is certainly true for homogeneous systems, but also for devices made of composite materials, where the insertion of high conductive particles in the soft matrix may help to improve the overall actuation performance.

In the talk, we present a complete theoretical framework to investigate instabilities in both homogeneous and composite actuators: electromechanical instability, band-localization failure, buckling-like modes are analyzed for currently employed actuator geometries and discussed taking into account:

i) nonlinearities associated with large strains and the employed material model;

ii) initial prestretched applied to the system;

iii) dependency of the permittivity on the deformation (electrostriction);

iv) the type of composite layout (layered and particle disperse);

v) occurrence of electric breakdown.

In particular, we highlight band-localization instability, where at a certain stage of the electromechanical loading process, deformation and electric field concentrate along an inclined narrow band, thus leading to possible electric breakdown failure of the material.

8340-35, Session 8

Complex 3D motion of a planner dielectric elastomer actuator with distributed stiffeners

W. Lai, A. F. Bastawros, W. Hong, Iowa State Univ. (United States)

A new design for a multi-layer dielectric elastomer actuator (DEA), reinforced with periodic stiffeners is presented. The resulting actuator enables complex 3-dimensional motion without the need of the DEA prestretch. An in situ optical imaging system is used to capture the complex deformation pattern to evaluate the surface curvatures. It is found that the actuator force-stroke characteristics can be greatly changed by varying the size and periodicity of the stiffeners, while maintaining the overall actuator stiffness. A material model coupling the applied electric field to the elastomer deformation is developed within Abaqus finite element software. The model is used to analyze the interaction between the dielectric elastomer and the stiffeners. The numerical results showed a band of localized deformation around the stiffeners. By disturbing the stiffeners across the actuator span, the actuator curvature and thereby its stroke can be greatly altered. It is conceivable to continue in this distributed structure down to a stiffener width in the order of the film thickness. In this range, the localized deformation band width appears to be independent of the stiffeners periodicity. Such observation sets the limit on the stiffeners spacing to achieve the highest actuator curvature. The shown actuator deformation mechanism and the developed numerical framework would enable the exploitation and optimization of many actuator designs without the need for trail and errors to explore their best load-stroke performance.

8340-36, Session 9

Compliant electrodes for large strain actuation

S. Yun, Q. Pei, Univ. of California, Los Angeles (United States)

Dielectric elastomer actuators (DEA) require compliant electrodes that exhibit rubbery elasticity and maintain high conductivity at strains as large as 100 %. Many materials such as carbon grease, sprayed-on CNT and graphite powder, and corrugated metal coating have been investigated as compliant electrodes enabling large actuation strains without electrical failure, but these materials have shown poor mechanical adhesion with DEA and unsuitable for miniaturization. Recently, a few approaches toward mechanically robust, stretchable compliant electrodes have been employed to dielectric elastomers in order to improve durability of performance under large strain actuation. We have been developed novel approaches to build not only mechanically robust and stretchable, but also Joule heatable compliant electrodes on shape memory polymer actuators for promising Braille application. This report is a review of the latest developments in the area of compliant electrodes including our approaches.

8340-37, Session 9

Super-compliant metallic electrodes for electroactive polymer actuators

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Electroactive polymer (EAP) actuators are very promising candidates for the ambitious aim of developing soft actuator systems for “artificial muscles”. In particular dielectric elastomer transducers benefit of important advantages compared to other electro-mechanical actuators: they have a high energy density, large and noise-free deformation capability or consist of low cost materials. However, if EAP devices have to be cheap, they usually work at high voltage (> 1000 V) leading to need for expensive electronics. Such operating conditions preclude their use in or close to the human body as such high voltages cause obvious safety problems. The electrode material is also a challenge, since clean and fast processes suited to miniaturization of EAP devices are still missing. To solve these drawbacks, we are developing a new fabrication process aiming at reducing the dielectric layer thickness down to <20µm and to increase the efficiency using highly conductive electrode materials deposited by magnetron sputtering. Moreover multilayer stack actuators will be produced in a continuous processing mode under contamination free conditions. Thus the entire manufacturing facility is placed in a large vacuum chamber offering cleanest environment and sputtering option. In this work, we show how we succeed in finding the conditions for deposition of compliant metallic thin films of 50 nm thickness that are able to maintain high conductivity at more than 10% stretching, using a

reproducible and clean process. The films are characterized by X-Ray Diffraction, electrical conductivity measurements and Atomic Force Microscopy. The film properties and their implications for new EAPs will be discussed.

8340-38, Session 9

Highly stretchable silver film electrodes for dielectric elastomer actuators in excess of 100% areal strain

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Metallic thin films have not often been used as electrodes in dielectric elastomer actuators (DEAs) as the reported actuated strains of metallized DEAs have been small. This is especially so when in comparison to commonly used conductive greases and powders. In this paper, we demonstrate that thin silver film electrodes can allow DEA for an actuated areal strains of up to 125% at a relatively low driving voltage of 1.9 kV. Here, stretchable electrodes of thin silver films is formed by electroless deposition on a pre-stretched substrate of acrylate elastomer (VHB F9473 PC). Such electrodes can be made thin, at less than 1 m, yet still maintain a low resistance of less than 100 Ω. DEA using this stretchable silver electrodes was optimised for maximum areal strain by tuning the thickness of the silver electrodes, the prestrain ratio of the dielectric layer and the morphology of both the silver film electrodes and the dielectric layer.

As electroless deposition involves only the use of chemicals, expensive equipment is not needed. That, coupled with the fact that the thin silver electrodes require only a small amount of silver per unit area, means that such electrodes are simple and inexpensive to fabricate. In addition, unlike conductive powders and greases, these silver films adhere well to most substrates that are or have been made hydrophilic. This is especially useful in maintaining structural integrity of the actuator, such as when DEA units need to be stacked up one on top of each other. Most importantly, thin silver film electrodes have the ability to self heal. Self healing not only averts actuator failure brought about by localised breakdowns, it also enables actuation to resume, even allowing higher driving voltages to be reached.

8340-39, Session 9

Transferring electrical energy between dielectric elastomer actuators

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Unlike electromagnetic actuators, Dielectric Elastomer Actuator(s) (DEA) can exert a static holding force without consuming a significant amount of power. This is because DEA are electrostatic actuators where the electric charges exert a Maxwell stress. A charged DEA stores its electrical energy as potential energy, in a similar way to a capacitor. To remove or reduce the Maxwell stress, the stored charge with its associated electrical energy must be removed. Current DEA driver electronics simply dispose of this stored electrical energy. If this energy can be recovered, the efficiency of DEA would improve greatly. We present a simple and efficient way of re-using this stored energy by directly transferring the energy stored in one DEA to another. An energy transfer efficiency of at least 70% has been achieved.

8340-40, Session 9

Self-clearing dielectric elastomer actuators using charcoal-powder electrodes

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Recently, there were reports on self-clearing dielectric elastomer actuators (DEAs) using submicron film of silver or single walled carbon nano tubes (SWCNT). Keys to successful self clearing of dielectric elastomer actuator lie with sub-micron electrode thickness and localized oxidization of electrode faults. However, the submicron electrode thickness is susceptible to non-uniform electrode coverage during high-strain dielectric actuation. An increased electrode thickness could improve electrode coverage, but may substantially suppress dielectric actuation of soft elastomer as a result of increased electrode stiffness. This motivates the present research to explore other electrode materials capable of self-clearing property while being compliant and having good coverage. This study found that charcoal powder, being the same class of material as carbon nano tubes and graphite, make a good compliant electrode while being capable of self clearing. Charcoal powder is applied as compliant electrodes by smearing on a 100% bi-axially pre-stretched dielectric elastomer membrane (VHB 9473), with nominal pre-stretched thickness of 62.3 µm. This DEA using charcoal-powder electrodes can sustain up 10 kV without terminal breakdown, while those using graphite or silver grease break down at about 2 kV. It is noted that this DEA using charcoal-powder has maximum areal strain at about 45 % at 4 kV. But, its actuation strain does not increase further beyond 45% at a higher voltage because charcoal electrode loses electrical conductivity at a higher strain. Nevertheless, the DEA using charcoal is rugged against electrical shortings and sparks, without terminal failures.

8340-41, Session 9

Low-voltage bending actuators from carbide-derived carbon improved with gold foil

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Carbide-derived nanoporous carbon (CDC) based polymeric actuators have been designed and fabricated in combination with gold foil. The gold-foil-modified actuators exhibited high frequency response and required remarkably low operating voltage (as low as ±0.25 V). Hot-pressed additional gold layer (thickness 100 nm) ensures better conductivity of polymer supported CDC electrodes, while maintaining the elasticity of actuator. Energy consumption of gold-foil-modified (CDC/gold) actuators increased only at higher frequency values ($f > 1$ Hz), which is in good correlation with enhanced conductivity of CDC/gold actuators. Electrochemical measurements of both actuators performed at small operatig frequency values ($f < 0.01$ Hz) confirmed that there was no difference in consumed charge between conventional CDC and CDC/gold actuators. Due to enhanced conductivity of CDC/gold actuators at higher operating frequency values the accumulated charge increased, while initiating larger dimensional changes of actuator. CDC/gold exhibited same deflection rate at much lower potential applied. Electrochemical impedance measurements confirmed that relaxation time constant of gold-foil-modified actuator decreased more than one order of magnitude, thus allowing faster charge/discharge cycles. Gold-foil-modified actuators obtained the strain level of 2.2 % when rectangular voltage ±2 V was applied with frequency 0.5 Hz. The compact design of multi-layered actuator also provides opportunity to use actuator concurrently as energy storage device. From practical standpoint, this device concept can be easily extended to actuator-capacitor hybrid designs for generation of energy efficient actuation.

8340-42, Session 9

Bidirectional power electronics for driving dielectric elastomer transducers

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Beside of the actuator functionality, dielectric electroactive polymers

can be used in the inverse operation mode as generators. To control the energy harvesting cycle of the dielectric elastomer generators or to control the actuation strain of an actuator, the feeding high-voltage power electronics (HVPE) is an essential part of the overall transducer system. In order to supply the generator with initial charges and to harvest the generated energy, the HVPE must enable a bidirectional energy transfer, a controllable high-voltage feeding the capacitive load, a robust behavior allowing significant changes of the capacity and minimum energy losses caused by semiconductors and wires. The same requirements hold for actuators to provide a high dynamic and energy efficient operation.

High voltage DC-DC converter topologies in various power ranges can be found in the literature. However, most of the applications provide only unidirectional energy flows. To meet the abovementioned requirements, either dual active full-bridge (DAB) or flyback topologies are suitable.

Flyback-converters are realized with only a few components and provide a large output voltage range, while the transferred energy is stored in a two-winding transformer affecting the efficiency. The DAB converter consists of H-bridges, is very versatile and can be cascaded easily due to its modular design. Since the energy is transferred continuously, its efficiency is improved. Both topologies are analyzed based on predefined requirements first and realized afterwards. The two converter concepts will be presented in the final paper and its appropriateness for DEAP transducers will be evaluated experimentally.

8340-43, Session 10a

Carbon-polymer-ionic liquid composite as a motion sensor

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High surface area carbon, ionic liquid (IL) and polymer are incorporated in an electromechanically active composite. Two layers of carbonaceous electrodes are separated by a thin non-ferroelectric poly(vinylidene fluoride-co-hexafluoropropene (PVF-HFP) separator. The whole laminate contains 1-ethyl-3-methylimidazolium tetrafluoroborate (EMImBF4) IL as an electrolyte. This composite, referred as Carbon-Polymer Composite (CPC) , bends when low voltage (typically < 3 V) is applied between the electrodes and can in consequence be used as an actuator in microrobotics.

When the CPC is bent with an external force, the material behaves as a motion sensor. The effect of charge formation on bending of electroactive polymers is well-known in case of ionic polymer as a separator layer; however, the current CPC material has properties of similar type. The bending of the composite causes the difference of strain between concave and convex electrode. The strain results in the formation of hydraulic pressure on IL, and the IL is enforced to change its conformation in the micropores in acitivated carbon and dislocate to and from the swollen PVF-HFP separator. The charge formation effect is achieved by matching the porosity of the carbon material with the sizes of ions in an ionic liquid. The ions are likely to be trapped in the micropores with diameters close to the ion sizes. As a result, voltage and current can be registered between the electrodes and the device also operates as an energy harvester.

By suitable optimization, the material can be used either as an actuator, energy storage element (supercapacitor), or motion sensor.

8340-44, Session 10a

Microfabrication of IPMC cilia for bio-inspired flow sensing

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The lateral line system for fish consists of arrays of micro neuromasts, and as the primary flow sensing organ for fishes, it plays a critical role in various fish behaviors. In this paper we report, to our best knowledge, the first microfabricated, ionic polymer-metal composite (IPMC) cilia-based artificial lateral line system, targeting flow sensing for underwater robots and vehicles.

IPMCs form an important class of electroactive polymers, and comparing to many existing sensing techniques, an IPMC has a number of desirable properties that make it ideal for flow sensing. For example, its direct mechanosensory capability minimizes the complexity in both the sensor construction and signal processing. It works well in aqueous environments and automatically captures flow polarity. However, existing fabrication methodologies for IPMCs are all inherently planar and are thus not amenable to the creation of arrays of free-standing, micro IPMC beams for effective flow sensing.

In this work we present a novel process flow for the batch-fabrication of IPMC cilia using MEMS technologies. Instead of using commercial Nafion membranes, we pattern high-aspect-ratio molds using SU-8, followed by casting Nafion solution to form Nafion posts. Several chemical and thermal processing techniques are introduced to overcome challenges induced by surface tension and volume contraction during solidification of Nafion. We then combine parylene deposition and selective plasma etching to expose future electrode surfaces. Finally, ion-exchange and electrode plating processes are conducted as in planar IPMC fabrication. Prototypes of IPMC cilia-based flow sensors have been fabricated and characterized, which demonstrates the feasibility of the proposed microfabrication approach. In addition to flow sensing, the developed fabrication process is expected to enable micro IPMC actuators and sensors for many other applications.

8340-45, Session 10a

Simultaneous sensing characteristics of a biomimetic polypyrrole based triple layer actuator exchanging cations

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Conducting polymers are soft, wet and reactive gels capable of mimicking biological functions. A first time report on a conducting polymer based triple layer sensing-actuator device exchanging cations is presented. The actuator configuration corresponds to polypyrrole-dodecyl benzene sulfonate (pPy-DBS) film/tape/ pPy-DBS film in which one of the films acted as anode and the other as cathode simultaneously when describing angular movement in one direction. The films interchange their role when move in the opposite direction. Sensing characteristics of the actuator were studied as a function of its working conditions in lithium perchlorate aqueous solution by recording chronopotentiometric responses while describing angular movements of ± 45º during one complete cycle, consuming constant anodic and cathodic charges of 60 mC. The direction of the movements indicated a prevalent exchange of cations between the films and electrolyte. The evolution of the muscle potential is a function of chemical and physical variables acting on the polymer reaction rates and found to decrease with increasing electrolyte concentrations, increasing temperatures or decreasing driving electrical currents. The electrical energy consumed to describe a constant angle, is a linear function of the working temperature or of the driving electrical current and is a double logarithmic function of the electrolyte concentration. Thus, it is a sensor of the working conditions. This simultaneous and self-sensing properties of the actuators derive from the reactions taking place in dense and biomimetic gels of conducting polymer, pPy. We propose that any reactive device based on the same material and reaction will sense surrounding conditions.

8340-46, Session 10b

Large amplitude oscillatory measurements as mechanical characterization methods for soft elastomers

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Mechanical characterization of soft elastomers is usually done either by traditional shear rheometry in the linear viscoelastic (LVE) regime (i.e. low strains) or by extensional rheology in the nonlinear regime. However, in many commercially available rheometers for nonlinear extensions the measurements rely on certain assumptions such as a predefined shape alteration and are in most cases very hard to perform on soft elastomers. The LVE data provides information on important parameters for DEAP purposes such as the Young's modulus and the tendency to viscous dissipation (at low strains only) but provides no information on the strain hardening or softening effects at larger strains, and the mechanical breakdown strength. Therefore it is obvious that LVE can not be used as the single mechanical characterization tool in large strain applications. We show how the data set of LVE, and large amplitude oscillating elongation (LAOE) and planar elongation make the ideal set of experiments to evaluate the mechanical performance of DEAPs. We evaluate the mechanical performance of several soft elastomers applicable for DEAP purposes such as polyethylene oxide networks and traditional4 and bimodal silicone networks.

8340-47, Session 10b

Oscillatory dynamics of a flexoelectric membrane in viscoelastic media

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Flexoelectric membranes are actuators that bend under the action of external electric fields, a phenomenon of interest to the development of emerging adaptive materials as well as biological auditory transduction. Within the inner ear, flexoelectricity plays a well-documented role in the lateral wall of Outer Hair Cells (OHC) and is consequently an integral part of the auditory system, allowing varying OHC lengths - about 10um-80um - to resonate in the auditory range (20-20,000Hz). This contribution develops an actuator model for flexoelectric membranes with particular application to the OHC, where Viscoelastic effects are integrated into the model to account for OHC nonlinear response observed experimentally. Governing equations are applied to a "ring" model of the OHC to account for dynamic modes of the OHC, and the physical parameters of these resonant modes depend on membrane bending and tension, polarization and dielectric energies, and viscoelastic interfacial effects. The model is analyzed for varying OHC lengths and with externally imposed steps and oscillating electric fields. The presence of harmonics are analyzed and discussed within the context of previously documented results.

8340-48, Session 10b

Biodegradable poly(lactic acid)/ multi-walled carbon nanotube composites and its potential application for electroactive shape memory actuator

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Poly(lactic acid)/multi-walled carbon nanotube (PLA/CNT) composites were successfully prepared by solution blending process. Crystallinity of the nanocomposites was studied by using differential scanning calorimetry and X-ray diffraction. The modulus increased by addition of CNT content in the nanocomposites. Morphological characterizations were studied by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The electrical conductivity of PLA/ESO/ CNT nanocomposites showed higher values compared to PLA/CNT nanocomposites and it also responded well upon voltage addition and thus enabled its potential application as an electroactive shape memory polymer. This revealed the addition of soybean oil facilitated the dispersion of the CNT in the PLA matrix.

8340-49, Session 11a

Electroactive polymer based force sensor for robotic fingertip tactile sensing

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In this article, a multi degree of freedom force sensor made with electroactive polymer is introduced. The most notable advantage of developed sensor is material flexibility so that it can be affixed onto various different surface geometries including a robot hand finger tip.

Seeking for a true definition of biomimetic functionality of a robotic hand, the current attempt of elastomer based flexible multi degree of freedom force sensor implementation should not be an option. Selection of elastomer for the finger tip is discussed along with a series of tests for defining the viable fabrication process. A study on a flexible electrode formation method is mentioned which insures both material flexibility of the sensor structure and reliability of electrical and mechanical electrode functions. In order to verify the multi DOF functionality and repeatability of a thin flexible film sensor, a dedicated test method for sensor calibration is to be also designed. Some exemplary force measurement system level implementations for robotic applications are mentioned.

8340-50, Session 11a

Acoustic transducer for automotive applications based on dielectric elastomers

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Conventional loudspeakers utilize voice coil actuators connected to a diaphragm mounted on a rigid frame to generate sound waves based on the electromagnetic principle. These kinds of loudspeakers require additionally a certain resonating sound box, are heavy due to the magnetic material and cover only a limited frequency range. Dielectric electroactive polymers are thin films made of silicon, acrylic or polyurethane material coated with compliant and conductive electrodes. By applying an external electrical field, the actuator performs large deformations, which can be utilized to generate sound waves based on the electrostatic principle.

When using these so called electrostatic loudspeakers (ESL) several advantages can be utilized. Since the membrane of the ESL is already made of active material, no additional space demanding sound boxes are required and because no voice coil is required the ESL is very lightweight. Both aspects result in an excellent impulse response and wide-band frequency response.

To generate sound waves, the loudspeaker has to be operated with both an electrical bias voltage and a mechanical bias stress. It is shown that the electrical bias voltage can be used to linearize the actuator's behavior and to adjust the loudness. The audio signal voltage is amplified to a certain level first and superimposed with the bias voltage. The mechanical bias stress can either be applied by air pressure (high / low pressure) or by means of an adapted mechanical design. The performances of the realized ESLs are evaluated in an anechoic room.

8340-51, Session 11a

Active high temperature polymers and polymer nanocomposites for aerospace applications

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New generation of aerospace structural components requires materials which not only possess the physical, mechanical, reliability and durability for the specific task, but also can undergo shape change with application of an external stimulus as active materials. Shape change potentially impact improved airfoil aerodynamics, maneuverability, reduced fuel consumption, and remote control in space extreme environment. Adaptive materials will enhance air vehicle maneuverability such as bio-inspired moving wings, where airplane wings could change depending on the altitude and mission.

Active polymer nanocomposites consist of nanoparticles and host polymer matrix are materials that exhibit physical and mechanical deformation in an induced external energy field such as electrical field, electro-resistive heating and ionic polymer metal composite, thermal gradient, light radiation, and electrochemical media. Magnetic actuation is wireless remote actuation method which generates mechanical deformation by inducing magneto-static or electromagnetic field on magnetic polymer nanocomposites. Magneto-active polymer nanocomposites have been prepared from superparamagnetic nanoparticle exhibited large deformation which is correlated to saturation nanoparticle saturation magnetization.

Thermal shape memory polymers have a permanent shape, but can be reshaped above a critical temperature and fixed into a temporary shape when cooled under stress to below the critical temperature. When the polymer is reheated above the critical temperature, the material reverts to the permanent shape. Novel high temperature shape memory polymers based on polyimide and SPEEK organo-metallic complexes with a switching temperature range of 240 °C were prepared. These shape memory polymers exhibited switching temperature that is adjustable based on the type of organo-metallic compound and the degree of polymer's chemical treatment. This shape memory polymer exhibited shape recovery of as high as 90%, while maintaining high temperature stiffness and excellent mechanical properties.

Polymer nanocomposite electro-mechanical actuators have been prepared based on ion transport mechanism operating at low voltage and frequency. These actuators based on ionic liquid doped high temperature triazine poly(arylene ether sulfone)s polymers posses high stiffness, high thermal stability, and fast response time which make them excellent candidate for aerospace structural components and space environment.

8340-52, Session 11a

Design and optimization of small-sized actuator for driving optical lens with different shapes based on IPMCs

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Ionic Polymer Metal Composites (IPMCs) are one of most promising smart materials which produce large deformation for low voltage in the range of 0-5V. Since the materials were found, IPMCs have often been studied as actuator for its large deformation and inherent flexibility. Recently, IPMCs is applied to the optical lens drive system, in order to meet the requirements for low power, high stability and simple structure. In this paper, we have designed miniature optical lens actuators, and optimized the output force, the displacement, the response speed of the actuators and other properties are also investigated. Firstly, according to its structure and performance requirements of the optical lens drive system, two kinds of the actuating structure are confirmed: the petal-shaped and annular actuators. After that, a brief description of the IPMCs material preparation process and manufacturing method of the actuators is presented. Then five kinds of petal-shaped and annular actuators respectively are manufactured, and their performances are tested. Finally, the basic performance of the actuators is analyzed and optimized by utilizing finite element analysis software and an equivalent thermal model. Meanwhile, we compare and discuss with the experimental results as well. Experimental results indicate that the petal-shaped actuator displacement performance overall is better than the annular actuator; Under actuation voltage of 3V, the displacements both can exceed 200μm; experimental tests and theoretical analysis have shown that the inner diameter is 2mm for annular actuator, the petals number 8 for petal-shaped actuator, the displacement and response speed can both obtain better results. In conclusion, it can basically satisfy the system requirements of the output force, displacement and response speed requirements.

8340-54, Session 11b

Hydraulic actuated artificial muscles

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Hydraulically Actuated Artificial Muscles (HAMs) consisting of polymer tube constrained by nylon mesh are presented in this paper. Despite the actuation mechanism being similar to it's popular counterpart which are pneumatically actuated (PAM), HAMs are not very frequently studied. Muscle characteristics to both static and dynamic input are discussed and compared to PAMs. A model to explain the non-linearirty and dynamic response is also reported. HAMs offer the advantage of compliance, large force to weight ratio, low maintenance, and low cost over traditional hydraulic cylinders. HAM application in mess-scale robotics system is also presented.

8340-55, Session 11b

Synthesis and characterization of multiwalled carbon nanotube/IPMC actuator for imitating locomotion of gecko's toes

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Ionic polymer metal composite (IPMC) is an electrically activated polymer (EAP) actuator, which is composed of a perfluorinated polymer membrane coated with a noble metal on both sides. And it has been widely applied to the artificial muscle, since it has great advantages such as large deformation, low noise, light weight, flexibility and low driving voltages. However, IPMC has the major drawback of a low generative blocking force. In this paper, a multi-walled carbon nanotube (M-CNT)/ Nafion nanocomposite was fabricated by dispersion of treated M-CNTs in a Nafion solution. The multi-walled carbon nanotube (MCNT) filler was prepared with the cationic surfactant cetyl trimethyl ammonium bromide. Starting from cast Nafion membranes, IPMCs were manufactured by electroless plating. The current and the blocking force were measured with an IPMC actuation testing apparatus. Compared with a bare Nafion-based IPMC, the blocking force of the new IPMC improved 1-1.4 times, and the current increased by 33%-67%. The clearly enhanced performance of the new MCNT filler-based IPMC is attributed to the well-distributed MCNTs that improved the electrical properties of the IPMC. Geckos are known to extend or crimp their toes (when peeling from a terminal) to attach to or detach from a substrate. These reptiles have been studied and imitated to develop climbing robots. However, traditional actuation technologies cannot reproduce the high flexibility, high degree of redundancy, and high bearing capacity to weight ratio of geckos. The IPMC strip behaving like biological muscles (such as gecko toes) bends toward the anode under an imposed electric potential. Therefore, the new IPMC was employed to directly actuate gecko-inspired adhesive arrays, imitating the locmotion of gecko's toes.

8340-56, Session 11b

Tracking electrical and mechanical energy currents in dielectric elastomer generators to assess the aptitude of special elastomers for energy harvesting

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Dielectric elastomer generators reverse the principle of dielectric elastomer actuators and generate electrical energy from mechanical input work. High energy density and the option to use low cost materials make them promising candidates for powering mobile electronic devices, as well as for large scale ocean wave energy harvesting.

We present a setup to assess the aptitude of different elastomers for energy harvesting. The setup separately measures mechanical and electrical energy currents. We operate the generator between two large capacitors serving as low voltage input and high voltage output charge reservoirs. Monitoring the voltage of the reservoirs allows for measuring the amount of charges transferred to and from the generator. An electrostatic voltmeter is used to avoid charge loss due to measurement of generator and reservoir potentials. Mechanical energy is supplied to the system by inflating the elastomer membrane into a balloon shape. Pressure and volume of the balloon are tracked to examine the flow of mechanical energy.

The path of the generator state is depicted in planes spanned by electrical (voltage, charge) and mechanical (pressure, volume) work-conjugate variables. The advantage of this type of illustration is that an area enclosed by a contour describing a generator cycle directly quantifies the mechanical and electrical energy currents, thereby revealing the specific electrical energy generated per cycle and the mechanical to electrical energy conversion efficiency. Consideration of the cycle duration yields the specific average power of the generator. The commonly used 3M VHB 4910 elastomer is analyzed, revealing significant disadvantages of this material.

8340-91, Session 11b

Enhanced IPMC actuation by thermal cycling

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IPMCs are bi-polar actuators capable of large, rapid actuation in flexural configurations. The limit of actuation is defined by the maximal voltage that can be applied to the IPMC, above which electrolysis of the electrolyte and damage to the IPMC occur. In this paper we present preliminary results that indicate how this actuation limit could be tuned and even exceeded through controlled thermal cycling. Electro-less gold-plated Nafion IPMCs are used. Thermal cycling is employed to move, under internal or external forcing, the centre point of the actuation stroke. Subsequent voltage stimulation actuates the structure around this new centre point. It is shown that by further thermal cycling this centre point returns to its initial position without any external forcing. We discuss the possible underlying electro-mechanical mechanism behind this property. By exploiting this feature as part of a control system it is expected that more sophisticated IPMC actuation will be achievable. Applications likely to benefit from this new property include swimming robots and deployable structures.

8340-98, Session 11b

Novel approach to enhancement of mechanical and electrical properties of carbon nanotube yarn

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Hybrid multi walled carbon nanotube (MWNT) reinforced conducting polymers (CP) yarns were obtained by chemical and electrochemical polymerization of pyrrole, EDOT (ethylenedioxythiophene) into and/or on the MWNT yarn surface. The material was characterized by SEM imaging, electrochemical, mechanical and electrical measurements. It was found that the hybrid MWNT-CP yarns possessed significantly higher mechanical strength (over 740 MPa) and Young's modulus (over 54 GPa) than the pristine MWNT yarn. The hybrid yarns also exhibited substantially higher electrical conductivity and their specific capacitance was found to be in excess of 60 F/g. Measurements of temperature dependence of electrical conductivity revealed semiconducting behaviour, with a large increase of band gap near 100 K. The collected low temperature data are in good agreement with variable range hopping model (3D-VRH). The improved durability of the yarns is important for electrical applications. The composite yarns can be produced in commercial quantities and used for applications such as actuators, batteries, sensors and bionics.

8340-57, Session 12a

Contractile electroactive materials and actuators

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Electroactive polymers (EAPs) that bend, swell, ripple (first generation materials), and now contract with low electric input (new development) have been produced. Ras Labs also produces EAP materials that quickly contract and then expand, repeatedly, by reversing the polarity of the electric input. Using applied voltage step functions produces varying amounts of contraction, which has enormous potential. A combination of high and low voltages could produce gross and fine motor skills, respectively, with both large motor control and fine motor control (fine manipulation) within the same actuator unit. The mechanism of contraction is not well understood. Radionuclide-labeled experiments were conducted to follow the movement of electrolytes and water in these EAPs. In addition, other experiments were conducted to determine how and why contraction and expansion occurs. Plasma treatment of the electrodes, along with other strategies, allows for the embedded electrodes and the EAP material of the actuator to work and move as a unit, with no detachment, by significantly improving the metal-polymer interface, analogous to nerves and tendons moving with muscles during movement. Challenges involved with prototyping a 2-link actuated device using contractile EAPs will also be discussed.

8340-58, Session 12a

Multi-layer beam with variable stiffness based on electroactive polymers

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The contribution describes a new kind of multi-layer beam with a variable stiffness based on electroactive polymers (EAPs). These structures are supposed to be components of new smart, self-sensing and -controlling composite materials for lightweight constructions. Dielectric Elastomers

from Danfoss PolyPower are used to control the beams' stiffness.

The basic idea is to change the area moment of inertia of bending beams. These beams are built up as multi-layer stacks of thin metal or polymethyl methacrylate (PMMA) plates. Its internal structure can be changed by the use of electroactive polymers for controlling the area moment of inertia. So it is possible to strongly change the stiffness of bending beams up to two orders of magnitude. Thereby, the magnitude of varying the stiffness can be scaled by the number of layers and number and type of electroactive polymers used in the bending beam.

The detailed mechanisms for controlling the moment of inertia are described. Modeling of the mechanical structure including the EAPs uses a pseudo rigid-body model, a strain energy model as well as a finite element analysis. The theoretical calculations are verified by an experimental set-up. The prototype consists of two structural layers. First results show the feasibility of the proposed structures with stiffness control corresponding to the analytical and finite element analyses.

8340-59, Session 12a

A bio-inspired bell kinematics design of a jellyfish robot using ionic polymer metal composites actuators

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The interest in developing underwater vehicles that mimic jellyfish, especially for their high locomotive efficiency and simple design, has arisen with the recent demand for novel types of autonomous underwater vehicles. In our previous work at Virginia Tech, two generations of jellyfish robots were built using ionic polymer metal composite (IPMC) actuators. The first generation served as a proof of concept and proved that a jellyfish robot based on IPMC actuators is achievable. The second generation represented a biomimetic jellyfish robot that mimics the shape and swimming style of the Aurelia aurita species. This design was able to swim vertically at an average speed of 1.5 mm/s with an average power consumption of (3 W). However, since we did not re-create the swimming motion of the jellyfish, there is significant energy loss due to unwanted deformation of the bell.

This study represents the re-creation of the bell deformation cycle by focusing on the design, fabrication and characterization of the bio-inspired bell kinematics of the IPMC jellyfish robot. In order to understand how the deformation is distributed along the bell and how this motion causes the jellyfish to propel itself, the swimming behavior and the bell kinematics of different jellyfish species are studied. Different methods of implementing the actuators underneath the bell with less IPMC material are investigated to replicate the natural jellyfish bell deformation. Assuming the motion to be symmetrical in the bell, these different methods are tested using one eight of the bell. Videos of the studied bell section are recorded and are analyzed using a MATLAB computer vision code that tracks the bell profile and compares it with the natural jellyfish profile. Results demonstrate that proper placement of the IPMC actuators results in a bell configuration that more accurately represents the deformation properties of the natural jellyfish.

8340-60, Session 12a

Stretching cells with DEAs

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Cells regulate their behavior in response to the mechanical stresses present in their organisms. Most of the available cell cultures designed to replicate the in-vivo environment are cm2 area, far too large to monitor single cell response. We have developed two sets of single cell stretcher devices based on dielectric elastomer microactuators. The first device consists of an array of 100 µm x 200 µm actuators on a non-stretched PDMS membrane. Compliant 100 µm wide electrodes are patterned one side of the membrane and a blanket electrode is patterned on the other side. To limit displacement of the membrane to one axis, the membrane is bonded to a Pyrex chip with 200 µm trenches perpendicular to the microelectrodes. In response to a voltage, the membrane expands over the trench. 4.7% uni-axial strain is recorded at the electric field of 96 V/µm.

The second device contains an array of 100 µm x 100 µm actuators on a 160% uniaxially prestretched PDMS membrane suspended over a frame. Two perpendicular arrays of 100 µm wide electrodes are patterned on top and bottom layer of the membrane. When a voltage is applied, at the intersection of the electrodes, membrane expands uniaxially due to anisotropic stiffening of the membrane. 37% strain is recorded at the electric field of 114 V/µm. The performance of these devices as a cell stretcher is assessed by comparing their static and dynamic behavior.

8340-61, Session 12a

Smart artificial muscles for soft machines

T. A. Gisby, T. C. H. Tse, B. M. O'Brien, I. A. Anderson, The Univ. of Auckland (New Zealand)

The key electrical parameters of a DEA are its capacitance, the resistance of its electrodes, and leakage current through its dielectric membrane. By being able to estimate these parameters during actuation, inferences can be made regarding the mechanical state and the health of the DEA without the need to couple the DEA to an external sensor. In this paper we describe improvements we have made to our self-sensing system that enables all three parameters to be estimated simultaneously, and demonstrate its application using flexi-drive: a soft, bearing-free artificial muscle motor. We present a simple proof of concept to demonstrate closed loop control of the angle of deflection of a cantilevered beam supported by an artificial muscle membrane when varying masses are suspended from the end of the beam.

8340-62, Session 12b

Efficiency prediction of energy harvesters of IPMCs based on the streaming potential method

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Ionic polymer metal composites (IPMCs) are a kind of intelligent, multi-functional materials which exhibit a promise as both actuators and sensors. Recently, IPMCs have often been studied as energy harvesting devices for its mechano-electric coupling and inherent flexibility, which are great candidates for harvesting energy in low frequency regime. However, to date, by reason that the ion transport mechanisms inside IPMCs can't be well understood, no theoretical model can be established to explain all observed phenomenon. Of all existing models, the gray-box model which includes two resistors and two capacitors is widely applied to design the specific devices, which does not reveal the physical natures of the materials. So far, little research has been done on efficiency prediction of energy harvesters of IPMCs. Lately, the streaming potential hypothesis which is proposed by F GAO and L M Weiland is able to explain a range of experimental observations. In this paper, we try to analytically predict the harvesting efficiency of energy harvesters of IPMCs by being improved the streaming potential method. Then, as a comparison, an energy harvesting system is designed and set up to verify that whether the method is feasible. Quasi- static harvesting and dynamic harvesting is considered. Furthermore, Transfer functions are constructed including the open-circuit voltage and the closed-circuit current. The impedance of the device is quantified as well. By utilizing the voltage function and the current function, it is possible to calculate the power produced by the device. The results clearly indicate that the theoretical prediction and experimental values of efficiency for energy harvesting reach a great agreement.

8340-63, Session 12b

Energy harvesting with dielectric elastomer generators based on natural rubber

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Dielectric elastomer generators are deformable capacitors, assembled by coating an elastomer membrane with compliant electrodes on both sides. They are capable of converting mechanical into electrical energy with attributes such as high energy density, low cost and light weight. Applications in small scale energy harvesting will enable the charging of mobile electronic devices from the excess energy available while walking, whereas large scale energy harvesting applications will provide clean energy from renewable sources such as wind or ocean waves.

One of the most essential and urgent challenges for research on dielectric elastomer generators is to identify or design materials with ideally suited properties. Therefore we perform experiments with an experimental setup that allows for assessing the aptitude of different materials for energy harvesting. We depict the cyclic path of the generator state in electrical and mechanical work-conjugate planes to enable a visual assessment of material performance and calculate the specific electrical energy generated per cycle, the mechanical to electrical energy conversion efficiency and the specific average power of the generator. This procedure is used to compare the generator performance of the commonly used acrylic elastomer (3M VHB 4910) with cheap and sustainable natural rubber. Based on a theoretical and experimental analysis of the region of allowable generator states in mechanical and electrical work-conjugate planes, we operate a generator utilizing a commercially available natural rubber membrane (Zrunek ZruElast A1040) near the limits of safe operation. The natural rubber membrane outperforms the acrylic elastomer membrane with respect to each monitored figure of merit.

8340-64, Session 12b

Dielectric elastomer energy harvesting undergoing polarization saturation

L. Liu, Y. Liu, J. Leng, Harbin Institute of Technology (China)

Mechanical energy can be converted into electrical energy by using a dielectric generator. The elastomer is susceptible to various models of failure, including electrical breakdown, electromechanical instability, loss of tension, and rupture by stretch. The models of failure define a cycle of maximal energy that can be converted. On the other hand, when subject to a voltage, the charge will be induced on a dielectric elastomer. When the voltage is small, the charge increases with the voltage. Along with the continuously increase of voltage, when the charge approaches a certain value, it won't increase and become saturated. This paper develops a thermodynamic model of dielectric elastomers undergoing polarization saturation. We obtain an analytical solution of the constitutive equation of dielectric elastomer undergoing polarization saturation The model may guide the search for high-performance dielectric elastomer transducers. We studied the typical failure model with two variables of Mooney-Rivlin type and Gent Model silicone energy harvester, illustrated the allowable area under equal-biaxial and unequal-biaxial conditions, calculated the energy generated in one cycle of an energy harvester. These results can be used to facilitate the design and manufacture of dielectric elastomer energy harvesters.

8340-65, Session 12b

Efficiency limits of dielectric elastomer energy harvesters

P. Brochu, H. Stoyanov, Q. Pei, Univ. of California, Los Angeles (United States)

A simple analytical relationship for the efficiency of a constant charge dielectric elastomer energy harvesting cycle is derived. The relationship takes into account the non-linear nature of elastomer materials and the effects of electrically induced strains during relaxation. It is explicitly shown that efficiency is dependent the combination of applied electric field, stiffness and permittivity, as well as the applied strain and the shape of the stress-strain curve.

8340-66, Session 12b

Modeling guided design of dielectric elastomer generators and actuators

T. Li, S. Qu, Zhejiang Univ. (China); C. Keplinger, R. Kaltseis, R. Baumgartner, S. G. Bauer, Johannes Kepler Univ. Linz (Austria); Z. Suo, Harvard Univ. (United States); W. Yang, Zhejiang Univ. (China)

Dielectric elastomer is assembled by sandwich an elastomeric membrane with compliant electrodes on both sides. They are capable of converting mechanical into electrical energy or electrical into mechanical energy. It was discovered a decade ago that an applied voltage may cause dielectric elastomers to strain over 100%. Because of this large strain, dielectric elastomers are often called artificial muscles. In addition to large voltage-induced strains, other desirable attributes of dielectric elastomers include fast response, no noise, light weight, and low cost. The discovery has inspired intense development of dielectric elastomers as transducers for diverse applications such as soft robots, adaptive optics, energy harvesting, and programmable haptic surfaces.

A challenging research on dielectric elastomer generators and actuators is to enhance the performance of device with mechanical design. In this paper, based on certain device, we build up mechanical model and design experimental setup guided by simulation, which allows for enhancing the performance of both generator and actuator. We model the membrane inflation device in both actuator mode and generator mode. In actuator mode, we get designing parameters to vary the voltage-deformation response of the device, and realize giant voltage induced deformation with appropriate parameter group. In generator mode, energy flow in a device with inhomogeneous deformation is demonstrated. General methods of Modeling guided Design of dielectric elastomer generators and actuators are proposed.

8340-67, Session 12b

Self-priming dielectric elastomer generator design

T. G. McKay, B. M. O'Brien, The Univ. of Auckland (New Zealand); E. P. Calius, Industrial Research Ltd. (New Zealand); I. A. Anderson, The Univ. of Auckland (New Zealand)

Dielectric elastomer generators (DEG) provide an opportunity to harvest energy from biomechanical motions with greater mechanical simplicity than previously possible. This simplicity is enabled by their good impedance matching to natural muscle and ability to operate efficiently when coupled directly to large stroke, low frequency motions.

A typical generation cycle requires electrical charge to be supplied and removed from the DEG at appropriate times as it is mechanically deformed. The recently developed self-priming circuit can provide this functionality using electronics integrated directly onto the DEG membrane. One advantage of the self-priming circuit is that it enables the generator to boost its operating voltage through the accumulation of generated energy. Although it is well understood that energy production increases with the DEG operating voltage, there is a lack of understanding of the self-priming circuit design's influence through the manner in which it controls the charge state of the DEG. In this paper an analysis of the self-priming DEG cycle is performed and design rules for optimal energy production are presented. As a case study, a self-priming circuit was optimised to rapidly increase the voltage of a hand pumped DEG through the accumulation of generated energy. The optimised generator voltage climbed from 30 V up to 1500 V in 27 cycles, whereas the same generator required 37 cycles when a suboptimal self-priming circuit was used.

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8341-01, Session 1

Performance analysis of frequency up-converting energy harvesters for human locomotion

B. Anderson, A. M. Wickenheiser, The George Washington Univ. (United States)

Energy harvesting from human locomotion is a challenging problem because the low frequencies involved are incompatible with small, light-weight transducers. Furthermore, frequency variations during changing levels of activity greatly reduce the effectiveness of tuned resonant devices. This paper presents the performance analysis and parameter study of energy harvesters utilizing magnetic interactions for frequency up-conversion. Ferrous structures are used to periodically attract a magnetic tip mass during low-frequency oscillations, producing a series of impulses. This technique allows resonant structures to be designed for much higher natural frequencies and reduces the effects of excitation frequency variation. Measured vibrational data from several human activities are used to provide a time-varying, broadband input to the energy harvesting system and are recreated in a laboratory setting for experimental validation. Geometric and material parameter variations are studied using simulations with real-world accelerations and compared to steady-state power optimization results. Under various size and mass constraints, the optimal design is presented for each input signal, and an estimation of the maximum average power harvested under idealized conditions is given. The frequency up-conversion technique is compared to linear, resonant structures to determine the impact of the nonlinearities. Furthermore, an analysis is performed to study the discrepancies between the simulated results and the predicted performance derived from frequency response functions to determine the importance of transients.

8341-02, Session 1

Harvestable vibrational energy from an avian source: theoretical predictions vs. measured values

M. W. Shafer, R. B. MacCurdy, E. Garcia, D. Winkler, Cornell Univ. (United States)

The research in the field of vibrational power harvesting has moved the technology to a point that small microcontroller based systems could be powered through ambient vibrations. In this work we investigate the power available from piezoelectric energy harvesters used to power long life wildlife tags on various avian species. Specifically, we look at the differences between the available power predicted from conventional bird flight models with the power predicted from direct measurements flight accelerations. Experiments on multiple species were performed while measuring acceleration in three orthogonal directions. Measurements were taken both with and without additional laden mass, beyond that of the tag. In doing so, we were able to extrapolate to the baseline acceleration of the bird with no payload present. These measurements were decomposed and principle axes calculated for maximum and minimum RMS acceleration directions. Based on these acceleration magnitudes and frequencies, piezoelectric energy harvesting beams were designed and optimized to these input parameters. The power output predictions for these beams are compared to the power predictions developed through the use of a conventional bird flight power model in order to verify the flight model predictions. Available power is assessed through the use of the upper payload limit for long duration bird flight. Based on both the theoretical predictions and experimental measurements, guidelines are established for expected power from a piezoelectric vibrational energy harvester for various bird species.

8341-03, Session 1

Vibration energy harvesting using the nonlinear oscillations of a magnetostrictive material

C. Lee, E. Tsutsumi, Z. Del Rosario, Franklin W. Olin College of Engineering (United States)

A novel magnetostrictive-material-based device concept to convert ambient mechanical vibration into electricity has been designed, fabricated, and tested. In order to harvest energy over a greater frequency range (as compared to the harvesting frequency range of state-of-the-art devices), a tuned L-shaped beam is used as a mechanical transducer to generate nonlinear oscillations. The first two natural frequencies of the L-beam, corresponding primarily to the first bending modes of the horizontal and vertical legs of the L-beam, are tuned to a (near) 2:1 ratio. Under harmonic base excitation, an autoparametric, dynamic response in which one externally excited vibration mode parametrically excites a second vibration mode results in significant displacement of both modes over an extended frequency range. A series of demonstration devices are used to study how this nonlinear response can be exploited to generate more electricity than state-of-the-art (linear-dynamics-based) vibration harvesters.

A magnetostrictive material, Metglas 2605SA1, is used to convert vibration into electricity. Vibration-induced strain in the Metglas changes its magnetization which in turn generates current in a coil of wire. Metglas is highly flexible so it can undergo large displacement and does not fatigue under extended excitation. Tests are conducted to measure the displacements of the vertical and horizontal legs of the harvester along with the current generated in the wire coil in response to single-frequency, harmonic and white-noise, random base excitation.

8341-04, Session 1

A statistical linearization approach to optimal nonlinear energy harvesting

I. L. Cassidy, Duke Univ. (United States); J. T. Scruggs, Univ. of Michigan (United States)

In this study, an extension of linear-quadratic-Gaussian (LQG) control theory is used to determine the optimal state feedback controller for a nonlinear energy harvesting system that is driven by a stochastic disturbance. Specifically, the energy harvester is a base-excited single-degree-of-freedom (SDOF) resonant oscillator with an electromagnetic transducer embedded between the ground and moving mass. The electromagnetic transducer used to harvest energy from the SDOF oscillator introduces a nonlinear Coulomb friction force into the system, which must be accounted for in the design of the controller. As such, the development of the optimal controller for this system is based on statistical linearization, whereby the Coulomb friction force is replaced by an equivalent linear viscous damping term, which is calculated from the stationary covariance of the closed-loop system. It is shown that the covariance matrix and optimal feedback gain matrix can be computed by implementing an iterative algorithm involving linear matrix inequalities (LMIs). Results are presented for the SDOF energy harvester in which the power generation resulting from the optimal state feedback control law

is compared to the power generation resulting from the optimal static admittance for various disturbance bandwidths.

8341-05, Session 2

A snap-through oscillator for increasing damping and providing adaptability

D. R. Johnson, M. Thota, F. Semperlotti, K. Wang, Univ. of Michigan (United States)

This research investigates a snap-through oscillator to increase energy dissipation loss factor and to provide damping adaptivity with respect to loading amplitude and frequency in a passive manner. This snap-through device consists of a lumped mass, damper, and nonlinear spring with a negative stiffness region. This configuration gives the device two stable equilibria and one unstable equilibrium. Under low amplitude cyclic loading, the mass oscillates about one of the stable equilibria, similar to a linear oscillator. When the loading amplitude crosses a certain threshold, the device snaps back and forth between the two stable equilibria, passing through the unstable equilibrium with high velocity. This increase in motion during snap-through leads to an abrupt increase in energy dissipated by the damper and the corresponding loss factor. The device can be tuned such that the snap-though threshold occurs at a certain forcing amplitude for a given forcing frequency. In other words, the device can be programmed to passively adapt to changes in the loading environment. This behavior is demonstrated via computer simulation and laboratory experiment.

8341-06, Session 2

New method of negative capacitance shunt tuning for vibration control

B. S. Beck, K. A. Cunefare, Georgia Institute of Technology (United States); M. Collet, FEMTO-ST (France)

A negative capacitance shunt is a specific active feedback control circuit that is used to reduce the amplitude of vibrating structures. When the circuit is connected to a piezoelectric patch bonded to a flexural system, the shunt effectively reduces the stiffness of the piezoelectric material and increases the damping thereby lowering the spatial average response. The selection of the shunt parameters for maximum control has been found using two numerical tuning theories. Yet, the values obtained theoretically cannot be implemented experimentally due to circuit instability. A new method for obtaining the shunt parameters based on circuit response is presented. This method selects the series resistor to obtain maximum control at a specific frequency by measuring the frequency with the largest phase difference between the open circuit case and a when the control is turned on. The parameters chosen by the new method are compared to previous negative capacitance tuning methods.

8341-07, Session 2

Optimization of a passive piezoelectric damper for a viscously damped main system

S. M. Schwarzendahl, M. Neubauer, J. Wallaschek, Leibniz Univ. Hannover (Germany)

Structural vibrations can be reduced by shunted piezoelectric elements. The passive piezoelectric damper considered here, consists of a piezoelectric element and an inductor-resistor network which are connected to a host structure.

The paper gives an in depth analysis on the tuning of the inductor and resistor parameters of the electric network with regard to different optimization goals. The calculations are based on a 2-degree-of-freedom model of the host structure and the shunted piezoelectric element. Three optimization goals are studied: The objective of eigenvalue optimization is to get both pairs of eigenvalues to be equal. Then the damping ratio of the host structure is maximized, leading to a minimized decay time of the free vibration. In the H-2 optimization the total vibration energy within the host system is minimized, leading to optimal results in case of a broad-band excitation. In the H-infinity optimization the objective is to minimize the maximum amplitude of the host structure over the whole frequency spectrum. Analytical solutions for these optimization goals are already known in the special case of a host structure without damping. In the more general case of a viscously damped host structure analytical solutions for the eigenvalue and H-2 optimization goal are derived. In case of the H-infinity optimization goal an analytical solution cannot be found and perturbation theory is used to calculate an analytical approximation. The approximation is compared to the numerical solution in order to check its accuracy. With these new solutions the distribution of energy dissipation between host structure and piezoelectric damper is analyzed.

8341-08, Session 2

Novel controller design demonstration for vibration alleviation of helicopter rotor blades

F. D. Ulker, F. Nitzsche, D. Feszty, Carleton Univ. (Canada)

This paper presents an advanced controller design methodology for vibration alleviation of helicopter rotor blades. Particular attention is given to the flight regime where blades experience periodically varying aerodynamic loading. When the aerodynamic loading varies at each azimuth angle along one full rotation, the coupled aeroelastic system becomes time-periodic. For these systems, in general, time-invariant controllers fail to provide desired performance and stability characteristics; time-periodic controller design methodologies are required. With this paper, we demonstrated the first application of time-periodic H-2 and $H-infinity controller design methodologies to alleviate the rotor blade vibration. The controller synthesis problem is solved based on both periodic Riccati and Linear Matrix Inequality (LMI) formulations, where the closed-loop stability is analyzed using Floquet-Lyapunov theory. For the validation of the controller design methodology, first, H2 and H-infinity controllers were designed using the time-periodic reduced-order models that were obtained from high-fidelity aeroelastic analysis. In the analysis, trailing edge flaps are used as control actuators. However, we stress that the methodology is applicable for any control actuation; twist, pitch link and swash plate actuation. The controllers' performance was evaluated by using both the reduced-order models and high-fidelity aeroelastic simulations. For real-time closed-loop control validations, whirl tower tests are scheduled to be completed in November 2011 on the Smart Hybrid Active Rotor Control Systems (SHARCS) blade. The tests will be conducted at the Carleton University whirl tower facility where an air blowing unit was installed to generate a periodic aerodynamic loading.

8341-09, Session 2

Macro composites with non-classical inclusions for vibration damping in wind turbine blades

F. Agnese, F. Scarpa, Univ. of Bristol (United Kingdom)

We have developed a biphase composite structure with non-classical (i.e., non circular) inclusions able to dissipate energy under harmonic loading for the vibration damping of the fundamental modes featured by large-scale wind turbine blades. The composite layouts have been designed and simulated using classical homogenization theory of periodic structures coupled with estimation of the equivalent loss factors based on strain energy criteria. The biphase macro composite structures do exhibit increased levels of strain energy dissipated through the matrix in particular under shear loading, with equivalent loss factors enhanced by 30 % compared to classical cylindrical solutions having equal surface contact area with the surrounding matrix. The numerical results are

validated against experimental measurements carried out in a Dynamic Mechanical Analyser (DMA), and with a new testing technique developed to measure the equivalent viscoelastic properties under simple shear harmonic loading.

8341-10, Session 3

Energy harvesting of vortex-induced vibrations

A. M. Baz, Univ. of Maryland, College Park (United States); O. J. Aldraihem, King Saud Univ. (Saudi Arabia); M. Nouh, Univ. of Maryland, College Park (United States)

In this study, piezoelectric patches bonded to the surface of the vibrating flexible cylinders are utilized to convert the vortex-induced vibrational energy directly into electrical energy. The theory governing the interactions between the periodic vortex shedding, the structural vibration, and the piezoelectric conversion of the vibrational energy into electrical energy is presented using the finite element method. The predictions of the developed finite element model are validated experimentally using a prototype of the cylindrical structure/piezoelectric harvester system which is placed inside a wind tunnel. The theoretical and experimental performance characteristics of the energy harvester are determined at different flow speeds and for various resistive electrical loads. The optimal theoretical and experimental operating conditions are determined and compared in order to demonstrate the accuracy and the utility of the developed finite element model.

The developed theoretical and experimental tools can be invaluable in designing wind-induced energy harvesters for numerous applications such as smart street light pole systems.

Keywords: Energy harvesting, vortex-induced vibration, piezoelectric harvesters

8341-11, Session 3

Nonlinear dynamics of the bi-stable piezoelectric wind energy harvester

M. A. Karami, Univ. of Michigan (United States); J. R. Farmer, Virginia Polytechnic Institute and State Univ. (United States); D. J. Inman, Univ. of Michigan (United States)

The nonlinear dynamics of the novel piezoelectric windmill is numerically and experimentally investigated. Wind energy can be used to power up the sensor nodes in hard to reach environments. The wind energy is of special importance in places that do not have access to sunlight. The focus of attention in wind power generation has mainly been on wind turbines, which can produce large amounts of power from strong winds. There have been few attempts to scale down the wind turbines and make them suitable for small scale wind energy harvesting [1]. The main problem with using the same configuration as large wind turbines and utilizing gearboxes and DC generators is the friction inside the power transmission. The friction prevents power generation when the wind speed is small. Recently contactless windmills which use piezoelectric mechanism to convert the motion of the blades to electrical energy have been proposed for energy harvesting from mild winds [2]. To enhance the power production of the piezoelectric energy harvesting we incorporate a repulsive magnetic force (Fig. 1). One set of magnets are radially placed at the bottom surface of the rotating blades. At the tip of each of the vibrating beams a magnet is placed that faces the rotating magnets. The repulsive magnetic forces between the tip and rotating magnets continuously vary as the rotating magnets pass over the tip magnets. The rotation of the blades and consequently the rotating magnet not only excites the beams, but also periodically changes the parameters of the governing differential equations. Numerical and experimental investigations are performed on the vibrations of the beams, power output of the devices, and the rotational speed of the blades in response to the wind flow. It is shown that the proposed devices can generate about 10 mw of power and the start up speed is 2 m/s. The device shows distinct nonlinear behaviors such as bi-stability and jump phenomenon, which are predicted by the numerical simulations and are observed in the experimental investigations. It is illustrated that the nonlinear wind turbine is relatively insensitive to wind speed and can generate power from very mild gusts.

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8341-12, Session 3

Reconfigurable wind blades

B. Bahr, S. May, California State Univ., Long Beach (United States)

This research paper describes a novel approach to the design of a wind turbine based on reconfigurable control surface blades. The mechanical action of the blades and blade elements will be illustrated in CAE and a model of this product will be illustrated. Using adaptive control surface design and an improved blade shape can be very useful in harnessing the wind’s energy in low wind speed areas. The new design is based on a series of smaller blade elements to make any shape, which changes to reduce a negative resistance as it rotates and thus maximizing the useful torque. The idea is based on many smaller blade elements that make the actual wind Blade. The individual blade elements will adjust their direction based on the direction of the incoming wind to provide the turbine with the maximum desired torque.

An implementation of this idea can be for a Savonius wind turbine, first proposed in the early 20th century, is a device known for its ability to harness the available wind energy at low tip speed ratios in a simple, cost efficient, low maintenance fashion. Its blade design simplicity, usually characterized by a 55 gallon barrel cut in half, may also be its downfall, in that it is known for operating rather inefficiently. However, by implementing an reconfigurable control surface design and adjusting the blade shape, the discovery may be made that by sacrificing just a little design simplicity, the Savonius wind turbine may be able to improve quite considerably upon its original design’s performance. The source of power for any vertical axis wind turbine of this type is a function of pressure differential on the retreating, driven blade (the blade going in the direction of the wind). However, as the blade makes the return trip against the wind, power is lost due to a negative, resistant torque. Therefore, with the new blade design it is possible to reduce the resistant torque to near zero, we could achieve a much more efficient wind turbine performance.

8341-13, Session 3

Power and efficiency analysis of an aeroelastic flutter energy harvester

M. J. Bryant, M. W. Shafer, E. Garcia, Cornell Univ. (United States)

This paper will present analysis of a novel energy harvesting device for powering wireless sensors or other low power electronics by extracting energy from an ambient fluid flow. In particular, a device driven by aeroelastic flutter vibrations has been designed to extract vibratory energy from the flow and then transduce these vibrations to electrical current via cyclically straining piezoelectric patches. The aeroelastic flutter energy harvesting device consists of a piezoelectric beam cantilevered from the trailing edge of the host structure with a small flap attached to the tip of the beam by a flexible joint. Above a critical flow speed, a modal convergence flutter instability occurs causing the flap to oscillate with coupled pitching and heaving vibrations. This paper will examine the physical mechanism by which the flutter energy harvester extracts energy from the ambient fluid flow. The flow-induced vibratory motion of the device will be examined to determine the time-varying

character of the energy transfer from the flow to the device, including cases where the incident wind speed varies and drives structural oscillations away from resonance. This analysis will be used to quantify the efficiency of the energy transfer stages occurring between the concurrent aerodynamic, elastic, and electrical aspects of the energy harvester system. Understanding these interactions will facilitate study of the differing roles of the piezoelectric coupling, aeroelastic coupling, and system parameters in determining the overall efficiency and performance of the energy harvester.

8341-14, Session 3

A short investigation of the effect of an energy harvesting backpack on the human gait

E. Papatheou, P. Green, V. Racic, J. M. Brownjohn, N. D. Sims, The Univ. of Sheffield (United Kingdom)

Exploiting human motion for the purpose of energy harvesting has been a popular idea for some time. Many of the approaches proposed can be uncomfortable or they impose a significant burden on the person's gait. In the current paper a hardware in-the-loop simulator of an energy harvesting backpack is employed in order to investigate the effect of a suspended-load backpack on the human gait. The idea is based on the energy produced by a suspended-load which moves vertically on a backpack while a person walks. The energy created from such a linear system can be maximised when it resonates with the walking frequency of the person. However, such a configuration can also cause great forces to be applied on the back of the user. The system which is presented here consists of a mass attached on a rucksack, which is controlled by a motor in order to simulate the suspended-load backpack. The advantage of this setup is the ability to test different settings, regarding the spring stiffness or the damping coefficient, of the backpack harvester, and study their effect on the energy harvesting potential, as well as on the human gait. The present contribution describes the preliminary results and analysis of the testing of the system with the help of nine male volunteers who carried it on a treadmill while ground reaction forces, heart rate and perception data were recorded.

8341-69, Session 3

An evaluation of novel transducer materials for low-level vibration energy harvesting applications

S. R. Anton, K. M. Farinholt, Los Alamos National Lab. (United States)

Energy harvesting technology is critical in the development of self-powered electronic devices. Over the past few decades, several transduction mechanisms have been investigated for harvesting various forms of ambient energy. This paper provides an investigation of some of the lesser studied materials used for vibration energy harvesting including novel ferroelectret foams, which are thin, flexible polymeric materials that exhibit piezoelectric properties, as well as dielectric elastomers, which are typically used in actuation. The basic operational principle behind cellular ferroelectrets involves the deformation of internally charged voids in the polymer, which can be represented as macroscopic dipoles, resulting in a potential developed across the material. Dielectric elastomers, on the other hand, operate as compliant capacitors in which deformation causes the distance between conductive surfaces to change, thus developing charge on the material surfaces. Both the mechanical and electromechanical properties of these materials are investigated in this work and comparisons are made to more conventional materials. Mechanical testing is performed using traditional tensile techniques to obtain experimental measures of the stiffness and strength of the materials. Electromechanical testing is performed in order to establish a relationship between input mechanical energy and output electrical energy for both materials. Lastly the properties of ferroelectret foams are compared to those of polyvinylidene fluoride (PVDF), a polymer based piezoelectric material whose crystalline phase exhibits piezoelectricity through dipole orientation, and similarly, comparisons are made between dielectric elastomers and a simple parallel plate variable capacitor design.

8341-15, Session 4

Fabrication and characterization of fluidic artificial muscles having millimeter-scale diameters

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This paper presents the manufacturing process, experimental characterization, and modeling of fluidic artificial muscles (FAMs) with millimeter-scale diameters that have been actuated both pneumatically and hydraulically. In order to best capture the behavior these devices, FAMs of three different active lengths (2cm, 4cm, and 6cm) and with five different overall diameters (ranging from 2.67mm to 4.17mm) were constructed. Experiments were performed on these actuators to determine blocked force and free contraction over a range of internal pressures, supplied by both air and water. Like full-scale pneumatic artificial muscles (PAMs), these devices possessed very high force to weight ratios. For example, the 4.17mm diameter FAMs were able to achieve a maximum blocked force of 163N and a free contraction up to 8% when pressurized with air to 0.62MPa. This paper will present experimental actuator load lines for these FAMs that demonstrate the evolution of force with displacement for a range of internal pressures (provided by both air or water), highlighting the differences between hydraulic and pneumatic actuation. Furthermore, it is the goal of this work to compare the data from these experiments to previously developed models for full-scale PAMs and incorporate necessary adjustments for the small size of these actuators. Potential applications for the FAMs include small-scale robotic manipulators, as well as actuation packages for biomimetic structures such as flippers or fins on an autonomous underwater vehicle.

8341-16, Session 4

Haptics using a smart material for eyes free interaction in mobile devices

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In this paper we present a novel proof of concept (POC) using a shape memory alloy (SMA) in interactive mobile devices for haptic interaction when audio or visual feedback is not possible or practical. This POC is an electro-mechanical system that realizes a shape changing haptic display for information communication. A two-way SMA spring will change its dimensions due to the thermal effect as current travels through it and recovers to its original shape by itself when the current is off. The spring can operate at a lower voltage (less than 3.7V of a mobile device battery) and temperatures which are compatible with requirements for mobile devices. The POC consists of the addressable arrays of the SMA springs with different dimensions which are deformable to different shapes with proper handling or customization. When mobile devices receive information signals, the original shape of the POC will change to another shape related to the specific sender or types of information sources. This interactive POC can simultaneously realize multiple methods for conveying haptic information such as dimension, force, texture and temperature due to the flexible array design. We conduct several studies of user experience to explore how users' respond to changes in the dimension, force, temperature and texture or different types of information. Currently, we are developing applications with different POC designs for human to digital world tangible interactions.

8341-17, Session 4

Experiments on the focusing and use of acoustic energy to accelerate polymer healing

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This research seeks to use stress-wave time reversal to accelerate the self-healing tendencies of a polymer. This could be advantageous when used in hard-to-reach areas such as space where manual repair would be difficult. Studies to date include one dimensional time reversal experiments and the use of acoustic energy to accelerate the molding of an epoxy polymer mixed with a curing agent (the curing reaction can be considered analogous to self-healing process). Studies reported herein investigate the effect of focused acoustic energy at a mold discontinuity during curing, and experiments under time reversed focusing on crack sealing in polymer dog-bone specimens. Tensile testing is carried out in the latter tests to monitor sealing progress.

Epoxy Curing Tests

Tests have been conducted on a curing two-part epoxy, both with and without acoustic excitation. Cure progress is measured via vibration response. Via fast Fourier transformation, frequency and amplitude shifts are tracked, and by monitoring these the epoxy's cure status can be quantified. In recent tests, several variables have been eliminated or reduced and consistent results are being achieved. While these confirm that acoustic excitation does accelerate the cure process, further research is needed in order to define the associated material and operational prerequisites.

Tensile Testing

The paper will also discuss results on iterative time reversal application on cracked nylon specimens mounted within a tensile testing machine and provided with transducers to enable time reversed focusing at the crack. Crack healing progress is monitored through continual measurement of the specimen's stress-strain response.

8341-18, Session 5

Design of smart composite platforms for adaptive trust vector control and adaptive laser telescope for satellite applications

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This paper presents design of smart composite platforms for adaptive trust vector control (TVC) and adaptive laser telescope for satellite applications. To eliminate disturbances, the proposed adaptive TVC and telescope systems will be mounted on two analogous smart composite platform with simultaneous precision positioning (pointing) and vibration suppression (stabilizing), SPPVS, with micro-radian pointing resolution, and then mounted on a satellite in two different locations. The adaptive TVC system provides SPPVS with large tip-tilt to potentially eliminate the gimbals systems. The smart composite telescope will be mounted on a smart composite platform with SPPVS and then mounted on a satellite. The laser communication is intended for the Geosynchronous orbit. The high degree of directionality increases the security of the laser communication signal (as opposed to a diffused RF signal), but also requires sophisticated subsystems for transmission and acquisition. The shorter wavelength of the optical spectrum increases the data transmission rates, but laser systems require large amounts of power, which increases the mass and complexity of the supporting systems. In addition, the laser communication on the Geosynchronous orbit requires an accurate platform with SPPVS capabilities. Therefore, this work also addresses the design of an active composite platform to be used to simultaneously point and stabilize an intersatellite laser communication telescope with micro-radian pointing resolution. The telescope is a Cassegrain receiver that employs two mirrors, one convex (primary) and the other concave (secondary). The distance, as well as the horizontal and axial alignment of the mirrors, must be precisely maintained or else the optical properties of the system will be severely degraded. The alignment will also have to be maintained during thruster firings, which will require vibration suppression capabilities of the system as well. The innovative platform has been designed to have tip-tilt pointing and simultaneous multi-degree-of-freedom vibration isolation capability for pointing stabilization.

8341-19, Session 5

Uncertainty quantification of acoustic emission filtering techniques

B. A. Zarate, J. M. Caicedo, P. H. Ziehl, Univ. of South Carolina (United States)

This paper proposes to quantify the uncertainty of three different Acoustic Emission (AE) filtering techniques, using Bayesian inference. The three filtering techniques are based on Swansong like filters that have been defined at different amplitude and duration ranges. Acoustic Emission data from a compact tension specimen tested under cyclic load is filtered using all three filtering techniques. The AE is linked to crack growth using an equivalent relationship to the Paris law that relates the rate of absolute energy AE with respect to the number of cycles with the stress intensity range. The stress intensity range is calculated as a function of the cumulative absolute energy of the AE data. The filtered sets of data are used to determine the probability distribution of the fracture mechanics and AE parameters that defines crack growth in the specimen tested for the specific filter. Then the weight of the models is updated using the filtered AE data. The methodology is especially useful in cases where several filtering protocols are available and there is not reason to choose one over the others.

8341-20, Session 5

Optimal design of viscous damper connectors for adjacent structures using Genetic Algorithm and Nelder-Mead Algorithm

K. Bigdeli, W. L. Hare, S. Tesfamariam, The Univ. of British Columbia (Canada)

Passive dampers can be used to connect two adjacent structures in order to mitigate effects of earthquakes. Theoretical and experimental studies have confirmed efficiency and applicability of various connecting devices, such as viscous damper, MR damper and etc. However, few papers employed optimization methods to find the optimal mechanical properties of the dampers. In most papers, dampers are assumed to be unique throughout the building. In this study, we find the optimal damping coefficients of viscous dampers considering a general case of non-uniform damping coefficients. Since the derivatives of objective function to damping coefficients are not known, to optimize damping coefficients, a heuristic search method, i.e. the genetic algorithm, is employed. Each structure is modeled as a multi degree of freedom dynamic system consisting of lumped-masses, linear springs and dampers. In order to examine dynamic behavior of the structures, simulations in frequency domain are carried out. A pseudo-excitation based on Kanai-Tajimi spectrum is used as ground acceleration. Result show that the assumption of uniform dampers is not reliable and removing this assumption can generate significant improvement in coupling effectiveness. To investigate efficiency of genetic algorithm, solution quality and solution time of genetic algorithm are compared with those of Nelder-Mead algorithm from a previous study.

8341-21, Session 5

A modified command feedforward tracking control system applied to the PRRR-RR parallel mechanism

J. A. Parkins, J. F. O'Brien, Univ. of Wyoming (United States)

The development of a prototype two degree-of-freedom parallel mechanism for application to unmanned ground vehicle target tracking is presented. The mechanism is extremely simple, decoupling the two end-effector degrees-of-freedom (DOFs) with an easily fabricated and inexpensive connection of passive joints. A summary of the parallel mechanism's kinematic design and singularity analysis is provided. It is shown that the mechanism is singularity-free in its workspace. The tracking system sensor is a digital camera with significant time delay, restricting the feedback bandwidth to 4 Hz. Stability of the 2x2 feedback system is assessed using Gershgorin analysis. The performance of the feedback controller is insufficient to reject vehicle disturbances expected to have significant energy to approximately 10 Hz. Command feedforward systems, while useful in improving tracking performance in frequencies where feedback is negligible, violate causality when implemented on plants with time delay. A modified command feedforward system is presented that improves the tracking performance by a factor of 2.4 compared to the feedback system, despite the plant time delay, without violating causality.

8341-22, Session 6

High shear rate characterization of magnetorheological fluids

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Magnetorheological energy absorbers (MREAs) are an attractive option for use in occupant or payload protection systems due to their ability to adapt their stroking load over a broad range of operating speeds and occupant or payload mass. Shear mode or rotary drum-type MREAs typically operate at shear rates ranging well over γ =25,000/s. The design of these MREA-based systems is still, however, performed using material properties measured using low-shear rate characterization techniques, that is, for shear rates less than 1000/s. In our magnetorheometric testing, the MR effect is observed to persist for tested shear rates as high as γ = 25,000/s. This paper details a method for characterizing MR fluids at high shear strain rates using a custom rotary drum magnetorheometer (Searles cell), and presents characterization results for several commercially available MR fluids. The test method is validated at low shear rates (γ = 1,000 /s) by comparing experimental results with published material properties over this shear rate range. Many prior efforts to characterize MR fluids used a Bingham-plastic perspective for the shear stress vs. shear rate behavior. The Bingham-plastic (BP) model assumes that the measured stress is the sum of a passive viscous stress and a field dependent active yield stress. The BP approach fits a high shear rate asymptote to the flow curves (stress vs. high shear rate data). The slope of the asymptote is the post-yield viscosity, and its intercept with the shear stress axis is the dynamic yield stress. This perspective works well for low shear rate data, but due to measurement noise and other experimental practicalities at high shear rate (in particular, shear thinning), estimates of yield stress and post-yield (differential) viscosity of the MR fluid tend to have large error. Instead, it is proposed to utilize the perspective of apparent viscosity (the ratio of shear stress over shear rate) vs. shear rate. The apparent viscosity is a measureable quantity at high shear rates, is also field dependent and illustrates the MR effect at high shear rates quite well. Good agreement between the measured data and predictions of the MR fluid behavior are achieved using the apparent viscosity vs. shear rate diagram. By expanding the knowledge of MR fluid behavior to these high shear strain rates, the design of MREAs is enabled for occupant protection systems for crash and mine blast events.

8341-23, Session 6

Realization of a MRF-Safety-Clutch for high torsional moments based on a novel Ball-Clutch design

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A big potential for technical applications based on magneto rheological fluids (MRF), beside adjustable dampers, switchable engine mounts, etc., are so called smart clutches.

There are two common designs of these clutches, the disk- and the bell-design. Both consist of two rotatable parts, the input or drive side and the output or power take off side, with a small gap in between. This gap is filled with MRF that transmits subjected to its viscosity and interaction with the surfaces the torsion moment from the input to the output side. These concepts allow influencing the power transmission and realize an adjustable slip torque.

To activate the MRF a high magnetic field, generated by an electromagnet is necessary. Therefore a clutch based on these designs need relatively high power consumption and is critical for energy limited applications. Due to the shear Stress applied on the fluid both designs have the disadvantage to lead to self-heating effects of the fluid as well of a limitation of the relation between minimal and maximal transmittable torque. The minimal torque is, beside a question of the dimension of the clutch, mainly a result of the basic viscosity of the MRF. Caused by this basic viscosity a minimal torsional moment will always be transmitted, which turns out to be limiting for some applications.

With respect to safety critical applications, where a fast reacting clutch to switch the power transmission on or off completely and a adjustable slip torque is not needed, a new MRF-Clutch-design was developed at the Fraunhofer LBF. This design based on a combination of a ball safety coupling mechanism and an axial operating MRF-actuator and was named "MRF-Ball-Clutch". Compared to the described common clutch designs where the torque is transmitted friction locked by the MRF, here mechanical coupling devices, realized with Balls which are circularly located in countersinks on the front of two opposite placed discs, act interlocking to transmit the power. By the geometrical interaction of these balls and the two disks an applied torque produces a force in the direction of the rotational axis which lets increase the distance between input and output disk. If the torque exceeds a certain level the balls are no longer able to rest in their countersinks and the power transmission is stopped immediately. To adjust the maximum transmittable torque, a variable counter force is required that hinders the axial movement of the clutch disks. This force is generated by an axial operating MRF actuator, which is designed similar to a common single-tube damper were a solenoid coil generates a magnetic field in the fluid gap and by this the flow through of the MRF can influenced and the reaction forced to open the clutch can be tuned.

This paper describes development and tests of a safety-MRF-Ball Clutch to switch the transmission torque between motor and generator in a bus-like vehicle.

The work was done within the Fraunhofer System Research for Electromobility founded by the German Federal Ministry of Research and Technology.

8341-24, Session 6

Feasibility study of self-powered magnetorheological damper systems

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Magnetorheological (MR) dampers are one type of semi-active control devices, which are applicable to various dynamic systems. In the current MR damper system, extra power supply is required to power the electromagnet of the MR damper. This paper is aimed to investigate a self-powered MR damper system, which could convert vibration and

shock energy into electrical energy to power itself under control. The self-power feature could bring great merits such as higher reliability, simpler system structure and less maintenance for the MR damper systems, and advance the technology of various dynamic systems such as smart prostheses and suspension systems.

In this paper, modeling of a versatile self-powered MR damper system was developed. The interactions between the power generation and MR damping were investigated. The relations between the generated power from the generator and consumed power by MR damper were discussed. The general criteria whether the MR damper system is self-powered or not was proposed. The effect of the damping force generated from the power generator on the vibration mitigation performance was also considered. Design guidelines of MR dampers with power generation were provided, to make the systems to be self-powered. Effects of key design factors were investigated.

A prototype of MR damper with power generation was designed, fabricated, and tested. The modeling of this damper was experimentally validated. Then a 2 DOF vehicle suspension system was established. The damper was applied to the suspension system under on-off controller, to validate the self-powered criteria and obtain the self-powered working range.

8341-25, Session 6

Model reference adaptive control of the intelligent above-knee prosthesis with MR damper

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Above-knee prosthesis is an important apparatus for a trans-femoral amputee. For amputee, the prosthesis not only restored to health, but also rebuilds their mind. Compare to the passive above-knee (AK) prosthesis with constant mechanical properties such as friction, spring, and damping coefficients, the active AK prosthesis is more intelligent, but more expansive and consume large energy. So the semi-active prosthesis is a wonderful alternative because of its lower power consumption and its performance of trajectory tracking in the swing phase. On the other hand, with the rapid development of the smart materials and structures, magnetorheological (MR) fluids, one kind of materials that can reversibly change from the viscous fluid to the semisolid with controllable yield strength when exposed to a magnetic field, is widely used as the damper of the semi-active prosthesis because the MR damper is stepless adjustable and its response time is shorter compare to the other dampers.

In order to realize the natural gait, the tracking control of the knee angel is utilized for the semi-active prosthesis. Because of the simplicity and stability of the Proportion-Derivative (PD) control law, the PD control law or the Compute Torque (CT) control plus PD control (CT+PD control) ,whose control gains are constant, is the mainly approach for the tracking control of the intelligent above-knee prosthesis. Nevertheless, the performance of a control system, with the constant control gains, for the above-knee prosthesis is greatly impaired due to some uncertain factors, such as the un-known system parameters, the various walking speed, the surrounding disturbance, and the nonlinearity of the dynamical model of the above-knee prosthesis.

In this paper, according to the Lyapunov stability criterion, a model reference adaptive control (MRAC) law for the tracking control of the semi-active above-knee prosthesis with a MR damper, is proposed and realized to promote the adaptability and performance of the intelligent above-knee prosthesis. The adaptive controller is composed of an adjustable controller and an adaptation mechanism (refer to Figure 1). Using the tracking error between the desired motion trajectory and the practical trajectory, the adaptation mechanism can adjust the control gains of the adjustable controller to produce the desired torque driving the knee joint of the prosthesis. The desired motion trajectory is the output of a linear reference model and the adaptation mechanism is determined by the Lyapunov stability criterion. The current applied to the MR damper can be solved in accordance with the inverse model of the MR damper. Moreover, the rapid control prototype of the semi-active above-knee is built based on the DS 1103 (a real-time simulation system from the dSPACE) and the Matlab/Simulink.

The experiments on the semi-active above-knee prosthesis include the comparative experiments between the MRAC and the PD control, and the adaptability experiments of different control laws. The simulation and experimental results indicate that the proposed control law is stable, and its tracking error is lower than those by the PD control law and the CT+PD control law. What the most worth mention is that the controller is adaptable to the walking speed.

8341-26, Session 6

Structural damping using encapsulated shear thickening fluids

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Smart structures with tunable damping and stiffness characteristics are of high interest to aerospace applications, but often require an external power source to be activated. This can be avoided by using highly concentrated silica suspensions, which exhibit a shear-thickening behavior, linked to a dramatic increase in viscous dissipation. These materials are however liquid at rest, and sensitive to humidity, so they are difficult to implement into structural applications.

In the present work, highly concentrated solutions of monodisperse silica particles in PEG were selected for their strong thickening effect at rather low critical shear strain. Damping properties were characterized by measuring the energy dissipated per cycle at low frequency (<2Hz) during oscillatory tests using a rheometer. Damping is higher than for elastomeric damping materials for high frequencies, high strain applications.

STF were then encapsulated into a RTV-silicone to produce patches that can be handled easily, and protect the STF against outgassing or humidity pick-up. Activation of the encapsulated STF was measured using dynamic compression tests. Several configurations of the STF distribution in the patches were investigated, to evaluate the effect of local shear strains. Finally, these patches are integrated into CFRP structure to provide enhanced damping at high strains.

8341-27, Session 7

Investigating the energy harvesting potential of ferro-fluids sloshing in base-excited containers

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During the last decade, a significant body of research has been directed towards the modeling and design of vibratory energy harvesters for powering remote sensors and other low-power consumption electronics. Piezoelectric, electromagnetic, electrostatic, and magnetostrictive transduction mechanisms are the most commonly exploited for that purpose. In this work, we investigate a new approach based on the motion of a ferrofluid in a seismically excited tank for the purpose of transforming mechanical motions directly into electricity and harnessing energy from low-frequency excitations.

Ferrofluids are colloidal liquids made of nanoscale permanent randomly-oriented magnetic dipoles. When an external magnetic field is applied, the dipoles rotate and produce a net magnetic moment such that the average direction of the fluid magnetization is parallel to the external field. The principle of the generator is based on variation of the fluid magnetization caused by mechanical vibrations, whereby the motion of the sloshing liquid tends to change the orientational order of the magnetic dipoles and create a varying magnetic flux. This flux induces an electromotive force in a coil wound around the container thereby generating an electric current according to Farady's law.

Several experiments were performed on a cylindrical container of volume 5.65 x 10-5 m3 carrying a ferrofluid and subjected to different base

excitation levels. Results illustrate that, under non-optimal conditions, the harvester can generate around 1.2 μW of power using a base excitation of 3.5 m/sec2 at a frequency of 7 Hz and a resistive load of 50 Ohms.

8341-28, Session 7

Electromechanical and statistical modeling of turbulence-induced vibration for energy harvesting

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Extensive research has been done on the topics of both turbulence-induced vibration and vibration based energy harvesting; however, little effort has been put into bringing these two topics together. Preliminary experimental studies have shown that piezoelectric structures excited by turbulent flow can produce significant amounts of useful power. This research could serve to benefit applications such as powering remote, self-sustained sensors in small rivers or air ventilation systems where turbulent fluid flow is a primary source of ambient energy. A novel, robust solution for harvesting energy in these turbulent fluid flow environments was explored by the authors in previous work, and a harvester prototype was developed. This prototype, called piezoelectric grass, has undergone extensive experimental analysis. In this paper the authors present a theoretical analysis of the piezoelectric grass harvester modeled as a single unimorph cantilever beam exposed to turbulent cross-flow. This distributed parameter model is developed using a combination of both analytical and statistical techniques. The analytical portion uses a Rayleigh-Ritz approximation method to describe the beam dynamics, and utilizes piezoelectric constitutive relationships to define the electromechanical coupling effects. The statistical portion of the model defines the turbulence-induced forcing function distributed across the beam surface. The model presented in this paper will be validated using the results of several experimental case studies. Preliminary results have shown that the model agrees quite well with experimental data. A parameter optimization study will be performed with the proposed model. This study will demonstrate how a new harvester could be designed such that maximum power output can be achieved in a given turbulent fluid flow environment.

8341-29, Session 7

Energy harvesting using piezoelectric/shape memory alloy composites containing spatially oriented inclusions

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Energy harvesting from ambient vibrations in civil and mechanical structures has been given a growing attention in recent years. Piezoelectric vibration harvesters have been widely used given their energy conversion ability and relatively high mechanical to electrical coupling properties. Several efficiency improvement techniques have been previously investigated, including the optimization of the piezoelectric material itself, the alteration of the electrode pattern and system configuration, the use of matching networks to increase the power transfer, and most importantly, the tuning of the harvester's resonant frequency to match the fundamental frequency of the base insuring a maximum response.

In this paper, energy harvesting using a composite containing piezoelectric and shape memory alloy inclusions is studied. A model, based on linear piezoelectricity and Brinson method, is developed to describe the effect of SMA inclusions on the time and frequency response of the composite. An analysis of the variations of the frequency response, the power output, and the efficiency of the device with respect to temperature, SMA fraction, and level of prestrain is presented. The active self-tuning concept of the piezo harvester is discussed for different applications. Preliminary experimental verification of the developed model using a simplified apparatus is also performed. The time and frequency domain responses of the built device are measured under different temperatures and compared to theoretical results.

8341-30, Session 7

Impedance optimization of wireless electromagnetic (EM) energy harvester for maximum output efficiency at μW input power

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Two planar 434 MHz Printed Circuit Board antennas (efficiency 20 % at 26 cm2) are presented for wireless EM energy harvesting. Neglecting specific transmitting frequency, ambient EM power density at far field is 0.3μW/cm2 [1]. At this power density, about 1.5μW is induced by the presented antennas at 434 MHz. Hence the presented wireless harvester circuit; radio frequency (RF) to direct current (DC), is optimized for microwatt RF input power. The presented wireless energy harvester circuit consists of RF power to DC converter using schottky diode voltage doubler. Since diodes have non-linear impedance which varies as a function of input power level, frequency and connected load, most RF to DC harvester circuits [2] [3] neglect the complexity of matching the diodes impedance to the antenna impedance. This approach results in power losses in the wireless EM harvesting transmission lines and ultimately less efficiency. Ungan [4] presented a loosely matched RF source to diode impedance at 300MHz with a simulated reflection coefficient of more than 0.9 (-0.4 dB). The reflection coefficient of the RF harvester circuit must be zero for optimum performance. This work presents simulated and measured results of matched antennas impedance to the diodes input impedance at 434MHz by optimizing the transmission lines and using an L-circuit and PI-circuit matching. The L-circuit is optimized for broadband antenna/diode impedance matching while the PI-circuit takes advantage of the possibility to define the desired RF to DC circuit quality factor (voltage gain) to possibly improve diodes detection and better efficiency at the load. At 434 MHz, L-circuit input reflection coefficient of 0.03 (see Figure 3) and impedance 50 Ω are measured. An efficiency of 17 % at antenna supplied power of -35dBm and more than 45 % at -10dBm are obtained for the presented L-circuit (see Figure 4) and PI-circuit RF to DC circuit.

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8341-31, Session 7

Performance evaluation of multiple piezoelectric energy harvesters endowed with different interfacing circuits

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This talk presents both modeling and experimental studies developed for investigating the electrical behavior of multiple piezoelectric energy harvesters endowed with several interfacing circuits. It is motivated by small amount of power output generated by a single energy harvester and significant power reduction at off-resonance. Here, the energy harvesters are connected in series and to either AC/DC standard or SSHI (synchronized switch harvesting on inductor) interfacing circuit. The analytic results are obtained by our recent development of equivalent impedance approach suitable for nonlinear circuits. They are validated by both numerical simulation and experimental justification. The results

are obtained for standard, parallel-SSHI and series-SSHI circuit systems. First if the deviations in the system parameters of each piezoelectric energy harvester are small, DC power output increases significantly for each case. Second, if the deviations are relatively large, DC power output changes from power-boosting mode to wideband mode. In addition, the parallel-SSHI system exhibits much more significant bandwidth improvement than the other two cases. Surprisingly, the electrical behavior of the series-SSHI system does not outperform the standard circuit system for the present array system. Such a result contradicts to what we observe in the case of a single piezoelectric energy harvester, and the explanation is under investigation.

8341-68, Session 7

Design and analysis of a new type of electromagnetic vibration energy harvester with high power density

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The electromagnetic vibration energy harvesters have been used in large-scale vibration energy harvesting applications, such as energy harvesting from vehicle suspensions and civil structures. However, one of the main drawbacks of the current electromagnetic vibration energy harvesters is that they usually have very large size with low power density as well as low damping density. So far, most the electromagnetic harvesters in literature are too large for retrofit or can't extract sufficient power to provide sufficient damping. In another word, the power density of these harvesters is not as large as the energy dissipation rates of current oil dampers. In this paper, a new type of electromagnetic vibration energy harvester with remarkably high power density is developed. The magnets are assembled in a way such that high magnetic flux density with high compactness is achieved.

An analytical model based on the electromagnetic theory for this type of energy harvester is proposed. The finite element analysis (FEA) is carried out to predict the magnetic field and power density. A prototype will be developed, and experiments will be conducted to verify the he analytical model and FEA predictions. This designs can be also used for simultaneous vibration control and energy harvesting of buildings (for instance, electricity-generating Tuned Mass Dampers (TMDs)), as well as smaller size energy harvester for portable electronics.

8341-82, Poster Session

Topology optimization design of actuation voltage in plates with active constrained layer damping treatments

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The Active Constrained Layer Damping (ACLD) treatment has been used successfully for controlling the vibration of various flexible structures. The treatment provides an effective means of augmenting the simplicity and reliability of passive damping with the low weight and high efficiency of active controls to achieve high damping characteristics over broad frequency bands. This paper invesitigates the optimal spatial distribution of single-channel actuation voltage in vibration control of plates with Active Constrained Layer Damping (ACLD) treatments. It is pointed out that single-channel actuation voltage input for ACLD plates gives a new means of vibration control for plates with ACLD treatments due to its flexible and ease of electrical implementation.A finite element model for plates with ACLD treatments is presented and used along with an optimization algorithm in order to determine the optimal topologies of single-channel actuation voltage distribution. The optimal distribution of the actuation voltage is formulated as a discrete optimization problem with two-level control voltage design variables, where the structural modal damping ratio is to be maximized under a constraint on the control effort. Such a optimization problem is then transformed into a continuous one by introducing element-wise artifical design variables defining the topological feature of the actuation voltage distribution in piezoelectric constrained layer. A power-law function relating the design variables and the applied control voltages is proposed to penalize intermediate values of the design variables. The optimization problem is solved effectively by using the Method of Moving Asymptote (MMA) algorithm based on the sensitivity analysis. Numerical examples demonstrate the validity of the proposed problem formulation and numerical approach.

8341-84, Poster Session

Peeling stress analysis of piezo-bonded laminated composite plate

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A stress function based method is proposed to analyze the interlaminar stresses at the free edge of a piezo-bonded composite laminated structure. Two piezoelectric actuators are symmetrically surface bonded on composite laminate. Same electric fields are applied to the two symmetric piezoelectric actuators which can generate induced strain, resulting in pure extension on the laminated plate. The stresses that satisfy the traction-free boundary conditions at the free edge and at the top and bottom surfaces of the laminate are obtained by using the complementary virtual work principle. Cross-ply, angle-ply and quasi-isotropic laminates are analyzed. To verify the proposed method, the stress concentrations predicted by the present method are compared with those analyzed by the finite element method. The results will provide that the stress function based analysis of piezo-bonded laminated composite structure is an efficient and accurate method for initial design stage of piezo-composite structure.

8341-85, Poster Session

Cyclic behavior of damaged RC short columns confined with superelastic shape memory alloys wires

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Superelastic Shape memory alloys have the ability to undergo large deformations, while reverting back to their undeformed shape by removal of load. The unique property enables their great potentials in seismic design and retrofit of structure members. The goal of this paper is to assess the cyclic behavior of damaged reinforced concrete short columns confined with superelastic SMA wires subjected to strong earthquakes. Four circular RC columns specimens were tested under cyclic loading. The first one was regular RC short column, while the others were wrapped with superelastic SMA wires, CFRP bars and SMA-CFRP, respectively. The behavior of the four specimens under reversed cyclic loading, such as the maximum drifts, residual drifts and energy dissipation were compared. The results showed that the SMA-confined RC column specimen was able to recover most of its post-yield deformation and have significant increase in the ability to dissipate energy.

8341-86, Poster Session

An inter-crosslinking network gels that has both shape memory and high ductility

Y. Amano, R. Hidema, H. Furukawa, Yamagata Univ. (Japan)

Emergency medical treatment should be easy and quick for everybody to give it for patients in disaster areas such as earthquake-affected area, or for men in sports accident, or for old peoples in daily life. In such a case, plaster and bandage are used as common treatment, which needs to wrap and fix affected area. If plaster or bandage can cool the affected area, and it can be removed during washing the area, and be used repeatedly, it will be quite useful. Here we propose

innovative biocompatible material, that is, nontoxic high-strength shape-memory gel as a new medical material. The gels were prepared from two monomers (DMAAm and SA), a polymer (HPC), and a crosslinking agent (Karenz-MOI). In the synthesis of the gels, 1) a shape-memory copolymer network is made from the DMAAm and the SA, and 2) the copolymer and the HPC are crosslinked by the Karenz-MOI. Thus the crosslinking points are connected only between the different polymers. This is our original technique of gel preparation, of which gel is named Inter-Crosslinking Network Gels (ICN gels). The ICN gels achieve high ductility, which go up to 600% strain in tensile tests, while the ICN gels contain about 44% water. Moreover the SA has temperature dependence due to its crystallization properties; this is the key for shape memory properties of the ICN gels. The Young modulus of the ICN gels is larger below their crystallization temperature and becomes smaller above the temperature. Thus the ICN gel can memorize the original shape in the gelation process, it can deform largely and turn back to the original shape by heating. This novel material will let it possible to make fascinating medical products for emergency treatment.

8341-87, Poster Session

Soft and wet actuator developed with responsible high-strength gels

S. Harada, R. Hidema, H. Furukawa, Yamagata Univ. (Japan)

Novel high-strength gels, named double network gels (DN gels), show a smart response to altering external electric field. It was reported that a plate shape of the DN gel bends toward a positive electrode direction when a static (DC) electric field is applied. Based on this previous result, it has been tried to develop a novel soft and wet actuator, which will be used as an automatically bulging button for cellar phones, or similar small devices. First, a bending experiment of a hung plate-shape DN gel was done, and its electric field response was confirmed. Second, the response of a lying plate-shape DN gels was confirmed in order to check the bulging phenomena. The edge of three plate-shape gels that was arranged radially on a plane surface was lifted 2mm by applying DC 8V. This system is a first step to make a gels button. However the problem is that electrolysis occurs simultaneously under electric field, that is, water seep out from gels, and gels is shrinking, which cause the separation between aluminum foil working as electrode and gels. This means we should improve the setup of the bulging experiment to suppress the electrolysis in future.

8341-88, Poster Session

P-delta effect of high bridge pier considering performance-based design

Z. Wu, North China Univ. of Water Conservancy and Electric Power (China); D. Wang, Zhengzhou Univ. (China)

No abstract available.

8341-89, Poster Session

Research on mode classification and quantization

Y. Li, North China Univ. of Water Conservancy and Electric Power (China); Z. Wu, Zhengzhou Univ. (China)

No abstract available.

8341-90, Poster Session

Active vibration control of submerged cylindrical shell by piezoelectric sensors and actuators

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This paper is concerned with the active vibration control of cylindrical shell submerged in water by means of piezoelectric sensors and actuators. The dynamic model for the cylindrical shell was derived using Sanders theory and the fluid domain was modeled by fluid potential theory. To verify the dynamic model, experiments on the submerged cylindrical shell were carried out. It was found that added virtual mass due to the presence of water affects the dynamic characteristics of the shell to a great extent. Active vibration controller was then designed to cope with persistent harmonic disturbance using the modified higher harmonic control theory. The DSP controller was used to implement control algorithms. The macro fiber composite actuators were attached to the shell and were used as either actuators or sensors. It was found both from theory and experiment that the active vibration controller can effectively suppress vibrations and sound radiating from the shell.

8341-91, Poster Session

A rapidly realized test platform for trans-femoral prosthetic knees

D. Wang, L. Xu, Chongqing Univ. (China)

Test platforms which can simulate the movement of the thighs of normal human beings are essential for the research and development of above-knee prostheses. In order to avoid using complicated mechanical structures and only modeling the fixed height and weight, the principle of a test platform, which can supply both the vertical and horizontal movements of the thigh part utilizing two set of ball screws, is proposed. According to the proposed principle, the test platform with a simple mechanical structure, which can be realized quickly, can be adjustable for the height and weight. One set of ball screws vertically installed in the test platform, is used to simulate the up-and-down movement of the hip. Another set of ball screws horizontally installed in the test platform, is used to simulate the swing movement of the thigh. In addition, the pressure between the leg to the ground can by controlled by the test platform with a force loading module in the vertical direction. In this case, the developed test platform can simulate human beings with different weight. According to the proposed structure, the test platform is developed and tested. The experimental results show that the test platform can simulate the movement of the thigh in swing phase and the weight of a normal human being in stance phase.

8341-92, Poster Session

A novel method for piezoelectric energy harvesting from keyboard

L. Beker, A. Muhtaroglu, H. Kulah, Middle East Technical Univ. (Turkey)

Computers have an average daily usage of 6 hours per day. Keystrokes used to interface computers can be mechanically converted to vibration, and further can be converted to electrical power through piezoelectric transducers. This paper presents a novel method and apparatus for converting keystrokes to electrical energy using a resonant energy harvester which can be coupled with keyboards. The state-of-the-art dome-switch design is modified to excite the tip of the energy harvester beam. Piezoelectric transduction converts vibrations to electrical power. Due to low frequency operation, a unimorph harvester with tip mass is implemented. Instead of single-degree-of-freedom and distributed parameter approaches, finite element method is used for design and optimization purposes. ANSYS is used due to capability of simulating

piezoelectric materials. The energy harvester design is optimized to give highest voltage output under use conditions, and is fabricated. A close match is observed for the first modal frequency. When the piezoelectric energy harvester is excited at 7.62 Hz with tip excitation to emulate keyboard use, 16.95 μW of power is generated.

8341-93, Poster Session

Maximizing PV module harvested output power using a computer based automatic sun tracker

A. Abou-Elnour, Ajman Univ. of Science & Technology (United Arab Emirates)

Due to the increasing interest in renewable energies as the main source for future energy, an enormous number of researches are now considering renewable energy generation and applications. In all of these researches, increasing the efficiency (decreasing the costs) of the renewable energy generation is a must to compete with conventional energy resources. Photovoltaic cells are considered as important renewable solar energy elements which convert solar energy into electrical energy in an easily, directly, and environmental friendly way. The amount of the energy generated from a solar energy system depends to a large extend on the relative position of the solar energy module (collector) with respect to the sun position. The sun position with respect to the earth is continuously varying with the time of the day and with the season and consequently the amount of generated energy from a fixed solar module (collector) will be also affected. The initial costs and the output power of fixed solar sun modules are lower than those of movable modules, known as sun trackers, which are designed to follow the movement of the sun to maximize the output power of the module. The cost and the complexity of sun trackers depend on if the tracking is done in one or two dimensions. Although many tracking systems have been designed and implemented in one and two dimensions, the performance of hardware circuits and software programs of these systems can be further enhanced.

The aim of the present work is to design and implement a reliable two-dimensional photovoltaic module sun tracker which is fully compatible with standard platforms and operating system. Monitoring, controlling, and recording features are fully obtained in the present system using an efficient programming environment Design equations which are implemented allow the usage of the system anywhere anytime without extra hardware tracking circuits. A carefully design hardware motor deriving circuit is designed and implemented to simplify the controlling program without scarifying the required accuracy. The system generates the motors' controlling signals to allocate the photovoltaic module to receive the maximize amount of the solar energy on its surface from sunrise to sunset. The proposed system is successfully implemented for photovoltaic modules under realistic operating conditions.

8341-94, Poster Session

On the dynamic control of beams, subjected by multiple moving masses in resonance state, using piezo-ceramic actuators

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In this article the constitutive equation of an Euler-Bernoulli beam, excited by multiple moving masses is considered. A novel critical velocity is proposed in terms of the modified fundamental period, span length and spacing of moving masses in which resonance occurs. A set of multiple piezo-ceramic actuators is used to harness the dynamic response of the beam. In this regard the beam response is suppressed by utilizing a linear control algorithm with a time varying gain matrix and displacement-velocity feedback. The efficiency of the control algorithm, applying different number and length of piezo-actuators is investigated and the results of numerical analysis are demonstrated.

Problem formulation

A uniform and continuous Euler-Bernoulli beam with arbitrary boundary condition is assumed, Fig. (1). The arbitrary loading f(x, t) acts on the system. The index ,b, represents the beam properties while the index, p, indicates those properties which are related to the piezo-ceramic actuators. The bending stiffness and the mass per unit length of the beam are EI and , respectively, both constant throughout the beam Z(x, t) stands for the beam deflection. It is also assumed that n piezo patches are attached to the beam each with the length of lpi, such that lpi = x2i-x2i-1

The constitutive governing equation for piezo-electric materials for one-dimensional problems reads:

[Sigma] = [E][Epsilon] (1)

In Eq.(1) , E, denotes the elastic modulus of piezo-electric material, the piezo-electric constant and the dielectric constant, respectively.

Kinetic and potential energy along with the work done by non-conservative forces of the beam-piezo system could be expressed as below:

T = T(RO, A, b, h, l) of beam + [T (piezo)]*H(x2i- x2i-1)] (2)

U = U(RO A, b, h, l) of beam + [U (piezo)]*H(x2i- x2i-1)] (3)

And

W = Integral (f(x, t) dx)

In the above relations RO,A,b,h and l represent mass per unit volume, area, width, thickness, length respectively and stands for the Heaviside's function.

Using the Hamilton's principle, the governing partial differential equation for vibration of the beam with moving masses and piezo system after simplification and proper arrangements, can be presented as the following matrix form:

[dX(t))/dt] = A(t) * X(t) + E(t) * f(t) + D(t) * u(t) (5)

Where: X = { Z, dZ/dt} Transpose, u = {V1, V2,....}, the input voltage to the piezo layer, and [A], [E] and [D] are 2x2 required mass, material and other properties matrices (i.e. z(x, t) = Phi(x) * Z(t))

Control algorithm

The applicability of active structural control in reducing the maximum response of a continuous system under the effect of moving mass is investigated using a number of discrete piezo-actuators. A linear classical optimal control algorithm with displacement-velocity feedback is used to determine the required control voltages. Considering the Riccati type matrix equation, re-arrangement and simplification of the Eq. (5), shall lead into:

[dX(t))/dt] = [A(t) + DG] * X(t) + E(t) * f(t) (6)

Where, G is the resulting control gain matrix. Solving Eq. (6) shows the way to determination of the system's controlled response [1-8].

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8341-96, Poster Session

Three-dimensional base-isolation system using thick rubber bearings

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To render nuclear power plants a larger seismic margin from design earthquakes and standardize the seismic design for locations with various seismic fortification intensities, a three-dimensional base isolation technique is developed in this study. It was first examined by simplified single-degree-of-freedom models to search for the suitable parameters for the base isolation layer. From the rigid model, it is found that the vertical frequency of the base-isolated plant shall be larger than 1.0Hz to avoid the dominated rocking mode. If the vertical frequency is as low as the case with 0.5 Hz, the rocking mode is always dominated regardless of the aspect ratio. For other cases, with the increase of the aspect ratio, the horizontal frequency decreases at first then increases, while the rocking frequency keeps decreasing. The flexible model is simplified as a single-degree-of-freedom model with a mass at the top of a flexible column. Three springs were inserted in the base isolation layer to represent the isolators, two in vertical and one in horizontal. The periods in both horizontal and vertical direction are 0.2s and 0.07s, respectively. Time history analyses using a set of 20 near fault ground motions were conducted to find the influence of damping ratios. It is observed that the damping within the reasonable range, commonly less than 30%, is helpful to suppress structural displacement, velocity and acceleration.

8341-97, Poster Session

Optimization of bond transducer vibrations using active and semi-active control

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In ultrasonic wire bonding the required vibrations are generated by an ultrasonic transducer driven in its longitudinal mode. Asymmetries lead to additional orthogonal motions, which result in unwanted fluctuating normal forces in the friction contact. In this publication, a novel design of an ultrasonic transducer with control actuators is presented. The parasitic vibrations are damped in an active control and by the semi-active piezoelectric shunt damping technique. A Finite-Element model is developed to optimize the dimensions and the placement of the piezoceramics and to tune the electrical networks. The FE model includes the piezoelectric actuators that generate the vibrations of the transducer and the additional control actuators.

Passive inductance-resistance networks are utilized to damp the parasitic vibrations of the transducer. The inductance forms an electrical resonance network together with the capacitance of the piezoceramics. By tuning the resonance to the excitation frequency, an absorbing effect can be observed, similar to a mechanical tuned mass damper. The damping performance is proportional to the generalized coupling coefficient of the overall system.

Additionally, an active open-loop control is tested. In this case, the voltage amplitude and phase of the control actuators are set in such a way that the vertical vibrations of the wedge tip are totally cancelled out.

Measurements are conducted on a prototype transducer which are in good agreement with the simulation results.

8341-98, Poster Session

Optimal vibration control of a rotating plate with self-sensing active constrained layer damping

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Abstract: This work presents the optimal control on the vibration of a rotating plate with active constrained layer damping. Instead of modeling the rotating structure as beams as in most existing research, this work develops a single layer plate finite element model for rotating structures to improve in both accuracy and versatility. The frequency dependency of viscoelastic material in the damping layer is also taken into account by using the anelastic displacement fields (ADF) model. Concurrently, existing research shows that the damping of the active constrained layer can provide more damping than the damping of the passive constrained layer. Therefore, in this work the constraining layer is made of piezoelectric material and thus, will work as both the self-sensing sensor and the actuator. Then, the linear quadratic regulator (LQR) method is implemented as the control algorithms to effectively control the damping in the rotating plate. Additionally, a parametric study is presented to show the impact of some design parameters such as the thicknesses of constraining and the damping layers on structure’s modal characteristics.

8341-99, Poster Session

Development of cantilevered energy harvesters coupled with a topologically optimized piezoelectric layer oscillating in vortex

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An efficient design analysis method for cantilevered beam-type piezoelectric energy harvesters was developed for the prediction of the electric power output, based on the finite element method and the design optimization of piezoelectric materials. The optimum topology of a piezoelectric material layer could be obtained by a newly developed topology optimization technique for piezoelectric materials which utilized the electromechanical coupling equations, MMA (method of moving asymptotes), and SIMP (solid isotropic material with penalization) interpolation. Using the design optimization tool, several cantilevered beam-type piezoelectric energy harvesters which fluctuated in the region of vortex shedding were developed, that consisted of two different material layers - piezoelectric and aluminum layers. In order to obtain maximum electric power, the exciting frequency of the cantilevered energy device must be tuned as close to the natural frequency of the beam as possible. Using the method, the effects of geometric parameters and several piezoelectric materials (PZT, PVDF, and PZT fiber composites) attached to the beam device on power generation were investigated and the electric characteristics were evaluated. The three kinds of material coefficients such as elasticity, capacitance, and piezoelectric coupling are interpolated by element density variables. Then, the shape and size design optimizations for the cantilevered beam geometries with an optimum piezoelectric topology have been performed for a base model.

8341-100, Poster Session

Piezoelectric energy harvesting experiments using distributed high-polymer films

T. Nishigaki, Kinki Univ. (Japan)

In recent years, wind energy harvesting systems using piezoelectric materials have been studied by a lot of researchers. In most studies, piezoelectric ceramics were used to construct the energy harvesting structures. However, energy harvesting methods using flexible thin piezoelectric films had not been well developed. The main reason is

due to the extremely small electric power generation by using these materials. In this study, a piezoelectric wind energy harvesting method using high-polymer piezoelectric films was investigated experimentally. At first, the feasibility of the systems was shown in laboratory preliminary experiment by using various shapes, sizes, methods of lamination, and boundary conditions of piezoelectric films subjected to the artificial wind airflow from consumer air blower. Then, based on the results of preliminary experiments, a flag-type piezoelectric wind energy harvester was manufactured. This “piezoelectric banner” was developed based on the commercially available advertising flags and was much larger in size compared to the flag used in the laboratory experiments mentioned above. Finally, the characteristic of power generation of this banner against natural winds was verified by outdoor experiments. The results of these experiments and optimum design method of the proposed method was discussed.

8341-101, Poster Session

Metrological characterization of piezoelectric material as energy harvesting for health structural monitoring based on embedded sensors

M. Borotto, F. Braghin, F. Resta, G. Tomasini, Politecnico di Milano (Italy)

The interest in smart structures is greatly increased in recent years: the possibility of creating composite materials with outstanding lightness, strength and stiffness, with integrated sensors in place for monitoring the state of stress, strain, temperature or structural integrity, represent a very attractive goal for many different engineering applications. The integration of sensors within composite materials provides significant benefits such as greater security for the measurement system by external agent as well as the possibility of structural health monitoring directly within the material itself.

The project aim was to create a smart material independent from external energy sources with totally embedded sensors: since a large amount of mechanical components are subjected to harmonic generic loads, the study was directed to energy harvesting systems based on piezoelectric materials that can provide electric energy when properly excited.

The project was then focused on the design of an embedded measurement system that can provide informations about health of an hybrid joint (composite material - metal), evaluating possible damages, delaminations or not standard behaviors which can be associated to malfunctioning.

In order to obtain an adequate overview of possible sensors and energy harvesting systems based on metrological performances and the electrical power consumption and production, an experimental characterization of piezoelectric vibrating systems was performed as a function of frequency and amplitude of input.

To better understand the complex behavior of the hybrid joint (composite material - metal), a finite element model was implemented to simulate the consequence of a structural damage, providing important informations about the monitoring device and set up to use.

8341-103, Poster Session

Optimization of piezoelectric bistable composite plates for broadband vibrational energy harvesting

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In the past decade there has been a dramatic increase in the use of wireless sensor networks and electronics requiring a portable energy source. As a result energy harvesting solutions have emerged to convert electrical energy from ambient mechanical vibrations via electrostatic generation, electromagnetic induction and the piezoelectric effect. Vibration based harvesting devices are often tuned to operate near resonance to maximize their power generation however, resonant devices are not easily scalable and their performance falls significantly when operated outside their resonant frequencies. This renders the linear resonant systems unsuitable for ambient conditions where vibrations generally exhibit multiple time-dependent frequencies. Recent studies suggested that broadband harvesting could be achieved by exploiting non-linearity in bistable cantilevered beams. Bistability was induced by exciting a ferromagnetic beam with two permanent magnets located symmetrically near the free ends. Whilst this system has been demonstrated to perform effectively over a range of frequencies, it requires an obtrusive arrangement of external magnets to provide the electromagnetic field.

Bistable composite plates with bonded piezoelectric patches have been recently demonstrated to be effective for broadband vibration-based energy harvesting. It is well-known that the asymmetry can give rise to two stable equilibrium states in a thin laminate plate, leading to large amplitude oscillations between the two states when subjected to mechanical vibrations. These non-linear devices have improved power generation compared to conventional resonant systems and due to the inherent structural bistability, can be designed to occupy smaller volumes than bistable magnetic cantilever systems. To date only a [02/902]T laminate has been studied and in this paper, we exploit the wide scope for tailoring the design of a piezoelectric bistable composite laminate to optimize the mechanical to electrical energy conversion.

This paper presents results based on optimization of bistable composites that enables improved electrical power generation by discovering the correct geometric configuration for harvesting. The optimal device aspect ratio, thickness, stacking sequence, and piezoelectric area are considered for the arrangement shown in Fig. 1. Increased electrical output is found for geometries and piezoelectric configurations, which have not been considered previously.

8341-32, Session 8

Steerable adaptive bullet (StAB) piezoelectric flight control system

R. M. Barrett, R. Barnhart, R. B. Bramlette, The Univ. of Kansas (United States)

This paper outlines a new class of piezoelectric flight control actuators which are specifically intended for use in guided hard-launched munitions from under 5.56mm to 40mm in caliber. In March of 2011, US Pat. 7,898,153 was issued, describing this new class of actuators, how they are mounted, laminated, actuated and used to control the flight of a wide variety of munitions. This paper is the technical companion to the Patent. A Low Net Passive Stiffness (LNPS) Post Buckled Precompressed (PBP) piezoelectric actuator element for a 0.40 caliber body, 0.50 caliber round was built and tested. Aerodynamic modeling of the flight control actuator showed that canard deflections of just ±1° are sufficient to provide full flight control against 99% atmospherics to 2km of range while maintaining just 10cm of dispersion with lethal energy pressure levels upon terminal contact. Supersonic wind tunnel testing was conducted to Mach 3 to demonstrate control authority levels for resisting both gravity downrange and high level atmospherics. A sweep of axial compression shows the effect of the PBP configuration with an amplification factor of 3.8 while maintaining equivalent corner frequencies in excess of 100 Hz and deflection levels of ±1° with excellent correlation between theory and experiment. The paper concludes with a fabrication and assembly cost analysis on a mass production scale. Because the element is made with essentially the same kinds of methods that million-piece-per-day mass-produced uni- and bimorph elements are made, it is shown that the material costs are just pennies a piece with the total actuator element running under a single dollar in million+ lot volumes.

8341-33, Session 8

Elementary morphing shells: their complete behaviour

E. G. Loukaides, Univ. of Cambridge (United Kingdom); C. Maurini, Univ. Pierre et Marie Curie (France) and Ctr. National de la Recherche Scientifique (France); K. A. Seffen, Univ. of Cambridge (United Kingdom)

In this paper, we present a complete overview of possible stable geometries for multistable shells under the uniform curvature assumption. Based on previous work by Seffen & Guest (2011), and by Vidoli & Maurini (2008) and using some aspects of Catastrophe Theory we have identified the boundaries between monostable, bistable and tristable regions and isolated the relevant material and geometrical parameters. The boundaries themselves represent regions of neutral stability, which in turn allow for an infinity of shapes. We believe these exhaust the possibilities for multistable shells, putting a practical ceiling at a maximum of three states with absolute stability. We show what those stable geometries are for each region and explain the requirements and consequences of this behaviour. Finally, some issues of actuation that arrive from this work are discussed.

8341-34, Session 8

Miniaturizable high voltage control system for piezo-composite self-actuating flapping wing micro air vehicle

A. B. Harish, S. S. Kudli, A. Sridhar, A. M. Kulkarni, S. Honnungar, D. Harursampath, Indian Institute of Science (India)

In the recent past there has been a sudden surge in interest to mimic the flight and flight patterns of insects, birds etc. The problem of interest poses a lot of challenges in several domains including low Reynold's number aerodynamics of small and slow vehicle flight, multi-field governed anisotropic non-homogeneous material technology for self-actuating flapping wings, miniaturized and light weight electrical circuitry and fully autonomous robust individual and cooperative swarm control systems. One of the latest focus groups in the category of Unmanned Air Vehicles (UAVs) is the Micro Aerial Vehicles (MAVs). UAVs and especially MAVs have several military, civilian and commercial applications. Working prototypes of fixed, flapping and rotary wing MAVs have been built to date. Compared to the other types of MAVs, flapping wing MAVs, by virtue of being the closest in mimicking natural flyers, have shown better performance, capability for obstacle avoidance and manoeuvrability. One of the novel solutions in this direction is the concept of self-actuating flapping wing MAVs. With the advent of Piezoelectric Fiber Reinforced Composite (PFRC) materials, dynamic applications like self-actuating flapping wing have evolved into a reality. One of the challenges in using piezo-composites (like Macro Fiber Composites [MFC]) is their requirement of high operating voltages. The elastic operation voltage range of MFCs is between -500 V to +1500 V. In this work, we propose and implement a, first of its kind, miniaturizable high voltage multi-stage electrical control system for conversion of low voltage DC to a high voltage positively biased AC output to power the self-actuated PFRC flapping wings. The control system developed is transformer-less, uses purely analog components and hence miniaturizable. The implemented circuits are compared with suitable simulations for electrical outputs and also mechanical deformations.

8341-35, Session 9

An algorithm to optimize the morphing parameters in structures

A. M. Motlagh, W. W. Clark, Univ. of Pittsburgh (United States)

The concept of morphing generally implies changing the shape of a structure from its natural shape to one or several desired shapes. Morphing of structures has received attention in several areas (e.g. aerospace, automotive, biomechanics, etc.) with the objective of improving performance indexes, such as reduced fuel (energy) consumption, reduced noise and vibration, increased fatigue durability and improved ergonomic comfort. Conventional materials (metals, plastics and polymers) have constant properties and hence cannot provide high spatial precision when a complex morphed shape is expected. Therefore, it is beneficial to exploit smart materials whose properties can be altered with external stimuli (heat, electrical current, light or electrochemistry). To morph the structure to its programmed shape, certain regions of the material must be stimulated to transform to a softer (lower modulus) material phase. These regions can be thought of as hinges so that lower magnitude total force will be required for morphing. There are several competing factors that determine an optimal morph. For example, presumably transformation to a lower modulus reduces the work required to reshape the structure, but the phase transformation of material requires energy. In addition there is a shape error between the morphed and desired pattern. Time is also a very crucial parameter in many morphing applications and needs to be adjusted such that the cumulative time required for phase transformation and mechanical deformation meets the objective time. In this work, by combining MATLAB® and ABAQUS platforms, a framework is defined with which to optimize the parameters for morphing a beam structure with a two-phase material (neglecting heat transfer effects) into any continuous shape.

8341-37, Session 9

Material characterisation for morphing purposes in order to match flight requirements

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As a result of the national and European projects HIT-Smart-LED and JTI-SFWA a 2m long 3 dimensional demonstrator of a gapless smart droop nose was successfully tested. The device was tested under different flight similar conditions to prove the functionality during operation. The droop nose was mainly designed of structural optimised, commercial available glass-fiber reinforced plastics (GFRP, Hexcel Hexply 913).

Parallel to the functionality airplane structures have to meet several operational requirements therefore the tested laminate has to be improved in impact-strength and multifunctional issues like de-icing and lighting.

This paper presents elementary, comparable experimental set-ups of different droop nose integrable de-icing systems and their potentials due to efficiency and service stability.

The moreover experimental investigations of material characterisation referring to aging and temperature stability of the basis GRFP-material are shown. According to the mechanical requirements of impact-strength improvements reached by material modification of the GFRP build-up are presented and will be discussed.

It can be concluded that the main material (GRFP) has the potential for improvement by surface and resin modification. Facing the various requirements reveals that only a combination of different task specialised materials can be successful. Within those composites the material junctions require particular attention due to their ability of force-transfer and task specialised performance.

8341-102, Session 9

Experimental validation of simultaneous gust alleviation and energy harvesting for multifunctional composite wing spars

Y. Wang, Virginia Polytechnic Institute and State Univ. (United States)

No abstract available

8341-38, Session 10a

Piezoelectric low net passive stiffness (LNPS) flutter test vane

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This paper outlines the design, fabrication and testing of a new, high performance piezoelectrically driven aircraft flutter test vane. Unfortunately, the vanes of today suffer from high weight and the inability to control force phasing with respect to time. The associated change in mass balance results in deviations from true vibrational mode frequencies of the aircraft. The relatively high accident rate among small aircraft classes can be partially attributed to this discrepancy and presents the need for a more effective means of flight flutter testing. This paper describes a new, very light weight vane which is capable of full force and phase control through 50Hz. This device takes advantage of the post-buckled precompressed (PBP) effect to drive the vane to deflection levels unattainable in its unmodified configuration. Bench and wind tunnel tests were conducted at deflection levels up to ±8° and speeds of 100 ft/s. These results represent a 5-fold increase in angular deflection levels from the original configuration with no degradation in blocked moments. Comparisons between quasi-static and dynamic bench and wind tunnel tests have shown no susceptibility to performance degradation with changing test parameters. Analytical modeling using Classical Laminated Plate Theory with Low Net Passive Stiffness (LNPS) kinematic relations accurately captured the behavior of the vane in all test conditions. The use of piezoelectric actuators in this device reduces the total component weight by an order of magnitude when compared to the vanes on the market today and allows for less than 1W peak power consumption at max. actuation frequency.

8341-39, Session 10a

Mechanical and vibration testing of carbon fiber composite material with embedded piezoelectric sensors

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As part of the Fundamental Aeronautics program, researchers at NASA Glenn Research Center (GRC) are investigating new technologies supporting the development of lighter, quieter, and more efficient fans for turbomachinery applications. High performance fan blades designed to achieve such goals will be subjected to higher levels of aerodynamic excitations which could lead to more serious and complex vibration problems.

Piezoelectric materials have been proposed as a means of decreasing engine blade vibration either through a passive damping scheme, or as part of an active vibration control system. For polymer matrix fiber composite (PMFC) blades, the piezoelectric elements could be embedded within the blade material, protecting the brittle piezoceramic material from the airflow and from debris.

Before implementation of a piezoceramic within a PMFC blade, the effect on PMFC mechanical properties needs to be understood. This study attempts to determine how the inclusion of a piezoelectric element affects the material properties of the PMFC. Panels are made of commercially available piezoelectric “patches” embedded into PMFC material. Test articles are then cut from the panels so that the piezoelectric material forms a full layer within the composite (not fully surrounded by composite). These articles are then tested in four-point bending, short beam shear, and flatwise tension configurations. The patches include a monolithic-type piezoelectric patch, a macro-fiber-composite (MFC) patch with fibers made of diced piezoelectric material, and a piezoelectric fiber composite (PFC) with extruded piezoelectric fibers. The piezoelectric patches all incorporate Navy Type-II PZT (PZT-5A) piezoelectric material.

The short beam shear test results show that the specimens with embedded piezoelectric material had strength of 71-81% as compared to the baseline specimens. The piezoelectric specimens failed in interlaminar shear at the interface between the PMFC and the piezoelectric material.

In the four-point bending test, the embedded specimen strength was 53-69% of the baseline specimen strength. The Aramis image clearly shows a shear strain increase locally at the piezoelectric patch during the test. Failures in the embedded specimens occurred on the compression side, where there was delamination at the piezoelectric patch.

In flatwise tension, the embedded samples showed the most severe reduction in strength as compared to the baseline samples - only 13-17% of the baseline strength. Additionally, the baseline samples failed at the adhesive between the sample and the test fixture; it is likely that the FWT baseline material strength would have been even higher. Embedded samples failed within the piezoelectric patch, often within the piezoelectric material itself.

A second goal of this research is to measure the sensing and actuation properties of piezoelectric patches that are embedded into PMFC beams. Cantilever beam samples were tested in vibration to determine the sensing, actuation, and vibration damping abilities of the three kinds of piezoelectric patches. The beam width was chosen to be at least twice as wide as the PZT patch. Two piezoelectric patches were placed on either side of the beam, either surface-mounted or embedded 0.30 mm (0.012”) or 1.52 mm (0.060”) under the beam surface. Results show that the patches function as expected.

8341-40, Session 10a

Vibroacoustic studies on sounding rocket bulkheads

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This paper discusses ongoing work on the modeling of the vibroacoustic response of a sounding rocket as it proceeds through launch, with specific attention on the forward bulkhead. The work presented here discusses laboratory experiments and theoretical calculations, with an emphasis on experimental development. The goal of this project is to gain an understanding, with a view to designing the sounding rocket structure such that it mitigates the vibroacoustic loading felt by the payload. A major part of this work is devoted to studying the dynamic coupling between the components within the rocket, especially the forward bulkhead and the acoustic cavity within the fairing. The forward bulkhead is known to create damaging acoustics, and along with fairing design is the focal point of this research. The natural frequencies within the overall test system are found through component-wise tests, and theoretical calculations are performed component-wise on the tested system. These are found to agree within a few percent. Theoretical and experimental work was focused on gaining an understanding of the 2 components, independently, before pursuing the coupled state system. This was done so that a quality understanding of the natural frequencies of each part was obtained before attempting to tackle the more complex coupled system. Once there is an adequate understanding of the interaction between components an ideal geometry design will be proposed in order to minimize bulkhead and fairing vibroacoustic response.

8341-41, Session 10a

Development of smart seismic bridge bearing using fiber optic Bragg-grating sensors

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After a bridge was completed, a faulting at supporting point may occur because of the un-expected loads to bridge bearing. Serviceability of bridges could be impaired by the faulting which had caused structural damage. Therefore, it is needed for a smart bridge bearing which can observe the supporting points continuously. Some of bridge bearings have been developed for measuring vertical load and vertical displacement by installing sensors in the bearing. However in those systems, it is not easy to be replaced with new sensors when repairs are needed. In this study, the smart bridge bearing of which sensors can be replaced has been de-veloped to overcome such a problem.

In this study, strain signals were used for measuring both vertical displacements and loads. FBG sensors(fiber optic Bragg-grating sensors) preventing electronic noise due to mediating light, which enable the simplification of the measuring cable due to multiple measurements and are easy to place due to lightweight and small, has been used for measurement of the strain signals.

Smart bridge bearings based on FBG sensors consist of EQS(Eradi Quake System) which has been commercially used for seismic bridge bearings. Experiments were carried out to prove applicability of the smart bridge bearing based on FBG sensors that can measure vertical displacements and loads. Tests for field application of smart bridge bearing based on FBG sensors will be executed on an existing bridge as further work of this study.

8341-42, Session 10a

Mathematical modelling of postbuckling in slender beam column for active stabilisation control with respect to uncertainty

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Buckling of load-carrying column structures is an important design constraint in light-weight structures as it may result in the collapse of an entire structure. When a passive column is loaded above its critical buckling load, it may buckle. In addition, if the actual loading is not fully known, stability becomes highly uncertain. To control buckling uncertainty, an approach is presented to actively stabilise a slender flat column.

The active stabilisation is based on the idea to force a slender column, clamped vertically at the base and pinned at the upper end, into its second bending deflection shape. This results in a critical load three times higher than the critical buckling load of the column for the given boundary conditions, theoretically. For this purpose, actively controlled forces applied by piezoelectric actuators located close to the column's clamped base may increase the column's strength against buckling.

To design a stabilising controller for the actuators, a non-linear mathematical model of the postcritically loaded system is needed. Within this non-linear postbuckling model, different kinds of uncertainties may occur: a) error in estimation of model parameters as mass, damping and stiffness, b) non-linearities e.g. in the assumption of curvature of deflection shapes, and c) errors in model order which may lead to spillover effects. In this paper, numerical simulations based on the mathematical model for the postcritically loaded column are compared to measurement results from a real built column system and subject to active stabilisation.

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8341-43, Session 10b

Performance of a shear-mode piezoelectric energy harvester

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An energy harvester operating in the thickness-mode (TMH) consists of a piezoelectric element which is sandwiched between a proof mass and a base. The piezo-element is poled along a direction perpendicular to the electrodes. When the base is subjected to a sinusoidal excitation, along the poling direction, a relative motion is generated between the proof mass and the base producing mechanical strain in the piezoelectric element. The resulting strain is converted into electrical power by virtue of the direct piezoelectric effect. In this study, a shear-mode harvester (SMH) is considered as a viable alternative to the TMH to enhance the harvested output power. The enhancement is generated by capitalizing on the fact that the strain constant of the piezoelectric in shear is much higher than those due to thickness or longitudinal deflections. To achieve such an enhancement, the piezoelectric element is poled along a direction parallel to its electrodes and is sandwiched between a proof mass and oscillating base in a design similar to that of the TMH. Sinusoidal excitation of the base, along the poling direction, makes the piezo-element experience mechanical shear strain which when converted into electrical power produces outputs that are larger than those of the TMH. The theory governing the operation of this class of SMH is developed for simple resistive electrical loads. The theoretical predictions are validated experimentally to illustrate the optimal performance characteristics of the SMH in comparison with the TMH. The effect of the excitation frequency and electrical load on the harvested power is presented. The obtained results demonstrate the feasibility of the SMH as a simple and effective means for enhancing the power output characteristics of conventional TMH.

8341-44, Session 10b

Stabilization of a wide-band nonlinear vibration energy harvester by using a nonlinear self-excitation circuit

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To overcome the narrow resonance band of conventional vibration energy harvesters, nonlinear vibration energy harvesters have been designed by some researchers to widen the resonance frequency band by folding the resonance peak toward the higher (lower) frequency direction by introducing a hardening (softening) spring instead of the linear one. This type of nonlinear oscillator, however, can have multiple stable solutions with different amplitude in the resonance band when it is subjected to a sinusoidal excitation. Therefore, in order to maximize the energy harvesting performance, some mechanism is desirable that ensures the stable manifestation of the largest amplitude solution regardless of initial conditions and disturbances. In this paper, a concept of an electromagnetic nonlinear energy harvester is proposed, in which only the largest amplitude solution is activated. This is done by unstabilizing other possible solutions by utilizing the mechanism of entrainment. To this end, we introduce a nonlinear self-excitation circuit involving a variable resistance to control the equivalent input resistance varying from negative to positive in function of the amplitude of the response. As a preliminary study, a simplified mathematical model of the nonlinear energy harvester with a magnetic hardening spring is presented. Theoretical analysis using averaging method and numerical analysis are conducted focusing on the steady-state solutions, the generated power and matching of the load resistance, to show the effectiveness of the proposed concept in the sense of comparison with the linear energy harvester. A proof-of-concept experimental device will be developed for the demonstrative purpose.

8341-45, Session 10b

Energy harvesting device for power generation onboard gravity-dropped weapons

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The generator designs presented use a combination of piezoelectric elements and an electromagnetic generator to provide a safe, reliable source of electrical energy onboard gravity-dropped weapons such as aerial bombs. As the weapon falls away from the aircraft, a tethering cable is put in tension. This cable loads a spiral power spring, storing mechanical potential energy. When the spring has been loaded to a predetermined level, a mechanical trigger releases the energy in the spring, driving a rotary electromagnetic generator. In addition to loading the spring, the tension in the cable loads a piezoelectric element, providing a quantity of energy somewhat faster than from the electromagnetic generator. As the tethering cable reaches its limit, a break-away mechanism is overcome and the physical link between the aircraft and the weapon is severed. The coincidence with the severing of the tether cable and initiation of electrical power generation can provide a valuable signal to the aircraft that the weapon was successfully deployed, in addition to the power generated. Additionally, because the mechanical potential energy is not released and converted into electrical energy before the weapon is free and clear of the aircraft, the approach illustrated here represents an ultra-safe power source.

The design is highly scalable, depending on the energy budget for a particular weapon. For the bench-top prototype which was constructed, approximately 80 Joules of mechanical energy is stored in the spiral power spring which requires approximately 25 pounds of cable tension to fully actuate. Naturally, the power spring for any particular design may be parameterized to dovetail with the energy budget and the mechanics of releasing the weapon for any particular application.

8341-46, Session 10b

Improved pen harvester for powering a pulse rate sensor

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With the continued advancement in power electronics the power requirement for micro-sensors has been decreasing opening the possibility for incorporating on-board energy harvesting devices to create self-powered sensors. The requirement for the energy harvesters are small size, light weight and the possibility of a low budget mass production. In this study, we focus on developing an energy harvester for powering a pulse rate sensor. We propose to integrate an inductive energy harvester within a common pen to harvest vibration energy from normal human motions like jogging and jumping. An existing prototype is reviewed which consists of a magnet wedged between two mechanical springs housed within a cylindrical shell. A single copper coil surrounds the cylindrical shell which harvests energy through Faraday's effect during magnet oscillation. This study reports a design change to the previous prototype providing a significant reduction in the device foot print without causing major losses in power generation. By breaking the single coil in the previous prototype into three separate coils an increase in power density is achieved. Several pulse rate sensors were evaluated to determine a target power requirement of 0.3 mW. To evaluate the prototype as a potential solution, the harvester was excited at various frequencies and accelerations typically produced through jogging and jumping motion. The improved prototype generated 0.36 mW at 5 Hz and 1.14 grms. The design change allows for a reduction in total volume from 8.59 cm3 to 2.26 cm3 while maintaining the sensor power requirement.

8341-47, Session 10b

Analysis of a multiple-DOF system for piezoelectric energy harvesting

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Conventional vibration energy harvesters have been usually designed as single-degree-of-freedom (1DOF) systems. The fact that such harvesters are only efficient near sole resonance limits their applicability especially in frequency-variant and random vibration scenarios. In this paper, a novel multiple-DOF system is developed for broadband piezoelectric energy harvesting, which comprises a primary mass and several parasitic masses, connected by springs and dampers. The piezoelectric element is placed between the primary mass and the base for energy generation. The parasitic masses are independent of each other but attached to the primary mass to tune the response of the system. Through parametric analysis, it is found that the resonance frequencies of the system can be close to each other with a small parasitic mass to primary mass ratio. In addition, the multiple peaks in the voltage response can be tuned to have significant magnitudes by carefully selecting the stiffness of the springs. These results imply that useful multimodal energy harvesting is implementable with slight increase of overall weight to the original 1DOF harvester (without parasitic masses). Besides, the equivalent circuit representation of the proposed multiple-DOF system is presented, with which circuit simulation can deal with more sophisticated energy harvesting circuit interfaces than a simple resistor. Finally, a prototype of the proposed system is devised for proof of concept.

8341-48, Session 11

Seismic fragility assessment of concrete bridge pier reinforced with shape memory alloy considering residual displacement

A. H. M. Muntasir Billah, M. Shahria Alam, The Univ. of British Columbia (Canada)

Post earthquake recovery of bridges is one of the prime objectives for performance based design. Shape Memory Alloy (SMA) has the unique ability to undergo large deformation, but can regain its undeformed shape through stress removal (i.e. superelasticity), which brings about an added advantage in seismic regions. In an attempt to reduce permanent displacements and damage, and enhance the corrosion resistance capacity of concrete bridge columns, a hybrid RC bridge pier configuration is presented here. In the proposed configurations of bridge piers, the plastic hinge region is reinforced with SMA and the remaining portion regular steel. Residual displacement is a very important parameter for performance based earthquake engineering as it dictates the functionality of a member after an earthquake. This paper focuses on developing fragility-based seismic vulnerability assessment procedures for SMA reinforced concrete bridge pier considering residual displacement. Fragility curves will be also used to assess the relative performance of SMA with conventional steel RC bridge pier. Probabilistic Seismic Demand Model (PSDM) will be used in generating the fragility functions. This study will combine residual drift and ductility demand as demand parameter for developing fragility curves obtained from non linear time history analysis. The development of these fragility curves for bridge piers will aid in expressing the potential impact of SMA on the bridge pier vulnerability.

8341-49, Session 11

Design of piezoresistive-based sensors with distribution of piezoresistive material through topology optimization

L. A. Motta Mello, E. C. N. Silva, Escola Politécnica da Univ. de São Paulo (Brazil)

A piezoresistive sensor is usually made of a piezoresistive membrane attached to a flexible structure. It has been used in several applications and it has been widely studied. Several works have been published regarding sensor manufacturing and analysis, but only a few papers that focuses on systematic methods for designing piezoresistive transducers have been published. In this work, a topology optimization formulation for the design of piezoresistive plate-based sensors, for which the piezoresistive membrane disposition is also optimized, is proposed, which has not been addressed so far. Results suggest that the performance of sensors can be substantially improved by using the proposed approach. The objective is to maximize the sensor sensitivity to external loading, as well as the stiffness of the sensor to particular loads, which depend on the case (application) studied. We showcase the proposed approach by studying the optimization of an atomic force microscope cantilever.

8341-50, Session 11

Vibration reduction on a nonlinear flexible structure through resonant control and disturbance estimator

F. Ripamonti, G. Cazzulani, F. Resta, Politecnico di Milano (Italy)

Large mechanical and aerospace structures are often characterized by high flexibility and low damping ratio. In this sense, to prevent structural faults, many active control techniques have been developed in recent years. Several control logics are based on a modal approach since it allows to describe the system behaviour considering a reduced number of degrees of freedom. Many of these logics are designed to increase the damping of specific system modes.

The damping increase in fact allows to reduce the resonant peaks and the settling time during transient motion; anyway it does not improve the system behaviour far from its natural frequencies. For this reason the controlled system can still be critical if it is heavily forced far from its natural frequencies. Moreover in many cases these forces are unknown and, to compensate their effect on the structure, they need to be estimated.

In this paper a control strategy combining a resonant controller and an estimator of the external forces is proposed. The resonant controller increases the system damping, while the disturbance estimator allows to reject the external force acting on the system. A detailed description of the control logic and numerical/experimental results on a non-linear flexible test rig are provided.

8341-51, Session 11

Semi-active control of a scaled building structure with a magnetorhelogical elastomer isolator device

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This paper presents the use of a novel semi-active variable stiffness and damping isolator (VSDI) for vibration mitigation of structures. The proposed VSDI system consists of a traditional steel-rubber vibration absorber, as the passive element, and a magnetorhelogical elastomer (MRE), with a controllable stiffness behavior. To demonstrate the feasibility of utilizing the MRE base isolation for seismic control of structures, a scaled, three-story building supported by four VSDIs, is constructed. The scaled building is supported by the MRE base isolation system is installed on the shaking table. The VSDIs can be regulated in real time by varying the applied magnetic field. The displacement, velocity, and the accelerations of each floor are measured by displacement sensors and accelerometers, respectively. A feedback control system is used to develop and validate algorithms for the control of the MRE base isolators in reducing structural response.

8341-52, Session 11

Measurement of strain distribution of smart materials by electron Moiré method

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It is very important to measure the local strain distribution for understanding the mechanical properties of structural materials. Especially smart materials are fabricated by some different kind of materials which mechanical properties are different. Therefore the measurement method for micro-deformation in a very small area is required.

There are a lot of techniques to measure the strain or stress distribution such as strain gage method, photo elasticity, optical Moiré method, etc. In these methods, the optical Moiré method is one of the convenient methods to measure the deformation of the materials. However, these methods are difficult to be applied for deformation measurement on a microscopic aspect.

To measure the micro-deformation in a very small area, authors are developed an electron Moiré method. This method keeps the main advantages of moiré and laser moiré interferometry methods, and has an additional ability of measuring deformation in a micro-area with high sensitivity. A model grid is prepared on the surface of the specimen before deformation. An electron beam scan, whose space is almost same as that of model grid, can be used for a master grid. The difference amount of secondary electrons per a primary electron makes Moiré fringes (Electron Moiré fringes) that consists bright and dark parts.

In order to pursue the application of electron moiré method, some typical experiments were performed. The residual strain around the fiber and thermal expansion of the fiber and matrix in the smart materials (an aluminum alloy with shape memory alloy (Ti-Ni alloy) fibers) were investigated.

8341-53, Session 12a

The concurrent suppression of and energy harvesting from surface vibrations: experimental investigations

R. Harne, Virginia Polytechnic Institute and State Univ. (United States)

Vibrating surfaces can be a nuisance for a number of reasons: inducing fatigue failure of the surface itself; shaking of sensitive attached components; the generation of airborne sound by means of structural-acoustic coupling; and so forth. The passive suppression of this vibration has long been pursued. Mass-spring-damper devices, vibration absorbers", are one means of achieving this end.

Energy harvesting objectives pursue the conversion of ambient energy, here vibrational, into useful electrical power. This is accomplished by means of converting captured potential or kinetic energy through an electromechanical coupling|piezoelectric materials, electro-magnetics, etc.|into an electrical signal. Mass-spring systems are frequently used whereby piezoelectric materials serve as the spring.

Despite the implementation of the very same device, the gap between the two elds is apparent in modeling methodology. Energy harvesting tends to interpret the excitation of the mass-spring system as an innite source of vibrational energy, i.e. base excitation.

Studies in vibration and noise control of surfaces interprets the structural vibration response to be naturally aected by the attached absorbers or treatments.

This presentation introduces a distributed device constructed for the dual purposes of passive vibration suppression and energy harvesting. Several experimental results are presented which demonstrate that both objectives may be achieved simultaneously and also serve to validate

earlier numerical models having suggested this possibility. A novel application on a city bus is considered for a realistic assessment of capability and experimental results from this scenario are provided.

Thus, for a lightly-damped structural panel, for example an aircraft panel, such electromechanically coupled devices may be attached in order to reduce the panel vibration but also yield useful electrical power for charging or powering on-board sensors. This poses a unique opportunity to unify what, at rst glance, appear to be incompatible objectives, and calls for a strident eort to develop innovative devices for this purpose.

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8341-54, Session 12a

Multimodal vibration harvester combining inductive and piezoelectric mechanisms

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With increasing demand for wireless sensor nodes in automobile, aircraft and rail applications, the need for energy harvesters has been growing. In these applications, energy harvesters provide a more robust and inexpensive power solution then batteries. In order to enhance the power density of existing energy harvesters, a variety of multimodal energy harvesting techniques have been proposed. Multimodal energy harvesters can be categorized as: (i) Multi-Source Energy Harvester (MSEH), (ii) Multi-Mechanism Energy Harvester (MMEH), and (iii) Single Source Multi-Mode Energy Harvester (S2M2EH). In this study, we focus on developing MMEH which combines the inductive and piezoelectric mechanisms. The multi-mechanism harvester was modeled using FEM techniques and theoretically analyzed to optimize the performance and reduce the overall shape and size similar to that of AA battery. The theoretical model combining analytical and FEM modeling techniques provides the system dynamics and output power for specific generator and cymbal geometry at various source conditions. In the proposed design, a cylindrical tube contains a magnetic levitation cavity where a center magnet oscillates through a copper coil. Piezoelectric cymbal transducers were mounted on the top and bottom sections of the cylindrical shell. In response to external vibration, electrical energy was harvested from the relative motion between magnet and coil through Faraday's effect and from the piezoelectric material through the direct piezoelectric effect. Experimental results validate the predictions from theoretical model and show the promise of multimodal harvester for powering wireless sensor nodes in automobile, aircraft, and rail applications.

8341-55, Session 12a

Novel motion-doubling mechanism for improved piezoelectric energy-harvesting performance

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A novel technique is presented for transmitting forces to piezoelectric elements in electrical energy harvesting applications. The approach results in amplifying any force transmitted to the piezoelectric element. Additionally, the frequency of any cyclical input force is doubled. This is achieved by exploiting the large axial tension induced in a cable or other tensile member which is transversely deflected by an applied force. The increased performance and scalability of the technique make possible its employment in a wide variety of energy harvesting applications. The methods and designs may be mated to a number of intermediate energy harvesting techniques. Examples include mating the system to a spring-mass system which may be excited by an impulse, or a similar system which may be excited into resonance by cyclic motion, or a "single-shot" system which merely exploits the force amplification properties of the approach.

The designs presented are sufficiently robust to allow use in harsh environments such as projectile weapon platforms or onboard gun-fired munitions. The specific case of employing the technique to a mortar tube for providing electrical energy for the fire-control system is discussed in detail, as well as possible applications onboard projectiles and the associated design challenges and possible solutions.

8341-56, Session 12b

Smart hybrid SMA-steel rotary dampers

C. W. Yang, Georgia Institute of Technology (United States)

After a major earthquake, significant damage to the primary lateral load-resisting system of buildings or bridges is often observed in the form of permanent residual deformations. As a result, there is a need to develop smart hybrid devices that combine energy-dissipating and re-centering systems to effectively respond to a large seismic event. This paper develops a smart hybrid rotary damper using a re-centering smart shape memory alloy (SMA) material as well as conventional energy-dissipating metallic plates that are easy to be replaced (steel is used in this paper), the schematic configuration of which is shown in Fig. 1a. The ends of the re-centering SMA plates and energy-dissipating steel plates are inserted into slots in the hinge plate 1 and hinge plate 2, respectively to fix the plate ends. When the damper rotates, both the energy-dissipating steel plates and re-centering SMA plates bend, providing the rotary damper with efficient full-loop hysteretic energy dissipating and re-centering characteristics, respectively. Such smart hybrid rotary dampers can be installed in structures (e.g., moment-resisting building frames (Fig. 1b), where the rotary dampers are additionally installed in the lateral sides of the W-shaped steel beams) to mitigate structural responses and to re-center automatically after an external excitation. Especially, the damaged energy-dissipating metallic plates can be easily replaced promptly after an external excitation, reducing repair time and costs. A more sophisticated ABAQUS model was established for better understanding the behavior of the smart hybrid rotary damper. The seismic performance of the 3-story SAC model buildings with smart hybrid rotary dampers in the Los Angeles area was also evaluated through nonlinear time-history analysis.

8341-57, Session 12b

Multifunctional smart material system (MSMS) using shape memory alloys and shape memory polymers

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A Multifunctional Smart Material system (MSMS) consists of two or more different smart material phases in the form of a hybrid system, in which every phase performs a different but necessary function. In this work, we show how thermally responsive Shape memory alloys (SMA) and Shape Memory Polymers (SMP) can be combined to form a MSMS. These kinds of systems exhibit a system level response that is different from the individual constituents when subjected to the same external stimuli. The transformation temperatures Mf, Ms, As & Af of SMA and the glass transition temperature Tg for SMP play a critical role in designing such a MSS. We illustrate how varying Tg of SMP between the Mf and As of SMA results in a multi-state system with varying stiffness in different temperature ranges. We describe a fabrication methodology for a general MSMS considering the overlapping range of properties of the constituent materials, their interfacing options and possible system level feature outcomes with their combinations. With these considerations, we establish guidelines for the volume fractions of the individual constituents of such MSSs to overcome issues like debonding. We further propose various SMA-SMP based MSSs and also suggest suitable applications in the form of smart tools such as bistable configurations (continuous and discontinuous SMP matrix with SMA reinforcements) and automatic thermal cycling systems (mechanisms and composite structures).

8341-58, Session 12b

Reducing vibration in carbon fiber structures with piezoelectric actuators and fiber Bragg grating sensors

S. Cinquemani, L. Comolli, G. Cazzulani, A. Gardella, Politecnico di Milano (Italy)

Carbon fiber structures are claimed to offer several advantages such as contained mass and high stiffness. However, these structures are characterized by a very low mechanical damping and, therefore, they are easily subjected to potentially dangerous vibratory phenomenon. Active control techniques have been widely developed to suppress vibration and great progresses have been achieved. On the other hand the research on sensors and actuators to be used is still a research field of interest. The paper discusses the opportunity to use piezoelectric actuators (PZT) and Fiber Bragg Grating sensors (FBGs) to realize a smart structure including in itself both the sensing and the actuating devices. Fiber optic strain sensors, such as Fiber Bragg Gratings (FBG), have a great potential in the use in smart structures thanks to their small transversal size and the possibility to make an array of many sensors. They can be embedded in carbon fiber structures and their effect on the structure is nearly negligible. Such a structure is able to measure its state of excitation and to reduce the amplitude of vibration using the embedded actuators.

Different control strategies have been implemented on a test rig consisting on a carbon fiber cantilever beam with 14 FBG sensors and 3 PZT actuators. Control forces are designed to increase the damping of the structures, allowing to increase of damping of the first modes of vibration of about 10 times.

8341-59, Session 13a

Design and analysis of a 10GHz VCO using MEMS inductor

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Wireless communication is now moving forward to a high-frequency range greater than 10GHz for a high-speed data communication. However, the key and critical building block in the wireless communications transceiver are the voltage controlled oscillators (VCO). Sensitivity and selectivity of the transceiver depend on the VCO performance and the battery life such as oscillation frequency, phase noise, and power consumption. The primary challenge in designing VCO is to minimise the phase noise while maintaining the low-power consumption. The most important factor which causes a low noise and power oscillator is the quality (Q) factor of the inductor in the LC tank. Therefore, this paper presents a 10GHz VCO using on-chip high Q-factor of MEMS inductor to improve the VCO performances. The high Q-factor of air suspended MEMS inductor is designed on a high resistivity sapphire substrate to reduce the metal and substrate losses. Due to the reduced of these losses, the Q-factor and self-resonant frequency (SRF) is improved and extended. In this work, Q-factor of 189 was obtained for a 1.13nH MEMS inductor at 10GHz, where the SRF is greater than 50GHz. However, the proposed VCO is designed using 0.25µm silicon-on-sapphire (SOS) technology. The MEMS inductor is implemented in a 10GHz VCO and consumes only 4.725mW power. The VCO achieves a phase noise of -116.27dBc/Hz and -126.19dBc/Hz at 1MHz and 3MHz offset frequencies respectively resulting in a Figure of Merit (FOM) of -189.5dBc/Hz.

8341-60, Session 13a

Design and analysis of film bulk acoustic wave resonator in Ku-band frequency range for wireless communication

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Film Bulk Acoustic Wave Resonators (FBARs) have been used in the synthesis of filter at microwave frequencies. This paper presents the design, simulation and analysis of air-gap FBARs in Ku-Band frequency range. The FBAR has extremely thin film thickness to operate in the Ku-band frequency and has an air-gap beneath the resonator to acoustically isolate from the substrate. The FBAR consists of piezoelectric film, aluminium nitride (AlN) and top and bottom electrodes of ruthenium (Ru) were designed in the fundamental thickness extensional mode. Mason model and lumped Butterworth-Van Dyke (BVD) Circuit are employed to investigate the theoretical harmonic response and parameter extraction of the FBAR. A three-dimensional (3D) Finite Element Method (FEM) is used to evaluate the electrical performance of the FBAR. The one-dimension (1D) numerical and the FEM results of the FBAR are analysed and compared. These results would be useful for optimizing FBAR designs and performances. The value of electromechanical coupling coefficient (keff2) up to 7.0% can be obtained with appropriate thickness ratio of electrode/piezoelectric layers. Higher keff2 results in lower quality factor (Q) thus optimization of both parameters by one figure of merit (FOM) was employed. The size of FBAR in this frequency range is extremely small when the characteristic impedance is set to 50 Ω. The FBAR size is 1600µm2 and the active filter area size of the FBAR filter is 225µm2. The centre frequency of the Ku-band filter is 15.5 GHz and bandwidth of 1 GHz. This filter is widely used today for the telecommunication satellite in the Ku-Band transceivers.

8341-61, Session 13a

Homogenization and micromechanical analysis of piezo-fiber reinforced composites

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Development of Piezoelectric Fiber Reinforced Composites (PFRC) has enabled new applications towards electro-thermo-mechanical sensing, actuation and power harvesting. The conformability of PFRC enables them to be conveniently incorporated on or into many real-life structures whose surfaces, in general, are curved. They have a strong, voltage dependent actuation authority and can interact with dynamic systems at frequencies from about 1Hz to 1MHz. Because these piezoelectric fiber diameters are much smaller than the typical wavelengths of interest, homogenization techniques become both necessary and useful to describe the behavior.

Through this work, an asymptotically correct model will be presented for the micro-electro-mechanical analysis of PFRC, using Variational Asymptotic Method (VAM). VAM is a mathematical tool developed by Berdichevskii [1979]. This method enables solutions in closed form even to some complex problems with inherent small parameters. VAM has been employed in the current work as a tool to split the original 3D electro-mechanical problem of a representative volume element into a 1D problem tangential to the length of the piezo-fiber and a 2D cross-sectional problem. Apart from splitting the problem for dimensional reduction and computational efficiency, VAM also directly provides accurate solutions to the 2D cross-sectional problem, incorporating the influence of both the primary material constituents in an asymptotically correct fashion. Thus VAM enables one to analyze the original problem in a mathematically rigorous and yet computationally tractable manner.

The unit cell of the PFRC considered here, consists of a single piezo-fiber of circular cross-section surrounded by a piezoelectrically inactive polymer matrix. The size of the matrix sleeve is based on the volume fraction. This unit cell is treated as a slender beam. To simplify the analysis and provide certain insights, mechanical and electric effects were studied independently first, then they were rigorously coupled. Hence, this work consists of three broad sections. First section deals with the mechanical analysis of PFRC. The structure is homogenized and effective material constants are obtained. Second section deals with the electric effect of PFRC and effective dielectric coefficients are obtained. Third section deals with the fully coupled analysis of the PFRC and effective piezoelectric coefficients are obtained as a function of the piezoelectric coefficients of the constituent fiber. The analytical results obtained are then used to explore possible implications for design and analysis as well as numerical studies.

8341-62, Session 13a

Photo-responsible gel actuator developed with scanning microscopic light scattering

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Sensitive deformation of polymer gel actuator induced by various stimuli has been intensively investigated for over two decades. The utilization of light however will significantly broaden their applications. Photo-responsible deformations have already been reported by using photochemical ionization, or photo-stimulated volume phase transition. Notwithstanding, the introduction of photo-responsive molecules such as azobenzene into polymer gels, has not been utilized so far to realize the reversible macroscopic deformation of isotropic gel actuators. It is probably due to the flexibility of polymer gels absorbing the molecular-level shape change. Here we show that novel photo-responsive gels prepared from rigid poly(amide acid) chains having azobenzene moieties in main chains can undergo a macroscopic deformation induced by photoisomerization. A rod-shape gel can sharply and swiftly bend by blue laser irradiation and reversibly straighten when exposed to visible light. This implies that the trans-to-cis isomerization of the azobenzene moieties can successfully deform the rod gel macroscopically. By using a scanning microscopic light scattering, the optimal preparing condition of the gels was determined and the reversible change in mesh-size between 2.1 nm and 0.83 nm was observed.

8341-63, Session 13b

Power enhancement of piezoelectric transformers by adding thermal pad

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It was known that power density of piezoelectric transformers is limited by the stress. The power density of the piezoelectric transformer calculated by the stress boundary can be reached 330Watt/cm3. However, the piezoelectric transformer never reaches such a high power density in practice. The power density of the piezoelectric transformer is only 33 Watt/cm3 typically. This fact implies that there is another physical limitation in the piezoelectric transformer. In fact, it was also known that the piezoelectric material has the constraint of the vibration velocity. Once the vibration velocity is too large, the piezoelectric transformer generates heat unstably until crack.

To explain the unstable of the piezoelectric transformer, we will model the relationship between vibration velocity and generated heat of the piezoelectric transformer by a feedback loop first. It will be shown that the loop gain is determined by the vibration velocity as well as the heat generation. Large vibration velocity and heat may lead the feedback loop entering into the unstable state. Therefore, to enhance the power capacity of the piezoelectric transformer, the heat requires to be dissipated. The simplest way to dissipate the heat is to add the thermal pad on the surface of the piezoelectric transformer.

We added the commercial thermal pads on the piezoelectric transformer to dissipate the heat. In our experiments, the passing current of the piezoelectric transformers can move from 0.3A/4W to 0.9A/11W. It implies that the power capacity possibly increases 3 times in the piezoelectric material. Most importantly, the piezoelectric transformer is typical suitable in the application of the high voltage/ low current, but the most power supply is in low voltage/high current mode. This technique not only increases the power capacity of the piezoelectric transformer but also move the piezoelectric transformer into the practical application. In the final paper, the theoretical modeling will be detailed and be verified by the experiment.

8341-64, Session 13b

Piezoelectric sensors for non-linear systems identification in mechanical applications vibration suppression

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During the last years, more and more mechanical applications saw the introduction of active control strategies. In particular, the need of improving the performances and/or the system health is very often associated to vibration suppression. This goal can be achieved considering both passive and active solutions. In this sense, many active control strategies have been developed, such as the Independent Modal Space Control (IMSC) or the resonant controllers (PPF, IRC, ...). In all these cases, in order to tune and optimize the control strategy, the knowledge of the system dynamic behaviour is very important and it can be achieved both considering a numerical model of the system or through an experimental identification process. Moreover, dealing with non-linear or time-varying systems, a tool able to online identify the system parameters becomes a key-point for the control logic synthesis.

The aim of the present work is the definition of a real-time technique, based on ARMAX and neural network models, that estimates the system parameters starting from the measurements of piezoelectric sensors. These parameters are returned to the control logic, that automatically adapts itself to the system non-linearity. The problem is investigated both numerically and experimentally considering a non-linear multi-link flexible manipulator.

8341-65, Session 13b

Development of a d33 mode piezo-composite generating element

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As an improvement of piezo-ceramic wafer, a piezo-composite generating element (PCGE) has been proposed recently. The residual stress in PZT layer after curing process is one of the main reasons of PCGE's good performance and the outer epoxy based composites protect brittle PZT. In this work, we propose a d33 mode PCGE possibly used in energy harvesting. First of all, the d33 mode coefficient of generating element is introduced as a measure of generating performance. We fabricate several PCGEs and do energy harvesting tests to verify the concept of the d33 mode coefficient of generating element.

8341-66, Session 13b

Experimental study on repair of a notched beam with piezoelectric patches

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An experimental study on an effective repair of a notched cantilever beam structure subjected to dynamic loading by use of piezoelectric patches is realized. In the experiment, a small piezoelectric patch used as a sensor is placed on the notch position to monitor the severity of the stress concentration around the notch area by measuring the charge output on the sensor, and a patch used as an actuator is located around the notch area to generate a required bending moment by employing an actuation voltage to reduce the stress concentration at the notch position. The actuation voltage on the actuator is designed from a feedback circuit process. Experiment results show that the developed practical structural repair technique for notched beams with piezoelectric patches is effective and efficient.

8341-67, Session 14a

Two member piezoelectric structure for vibration energy harvesting

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Work in piezoelectric vibration energy harvesting has generally focused on single member cantilevered structures with transverse tip displacement, taking advantage of the optimal coupling characteristics of piezoceramics in the 3-1 bending mode (e.g. A. Erturk et. al 2009). Multi-member designs could be advantageous in delivering power to a load in environments in which vibration is not transverse to the structure.

The design presented in this work consists of two, hinged piezoceramic (PZT-5A) beams x-poled for series operation. Each beam measures 3.18cm x 1.27cm x 0.0381mm and consists of two layers of nickel-plated piezoceramic adhered to a brass center shim. The hinge device consists of two custom-machined aluminum attachments each epoxied to the end of a beam and connected using a 1.59mm diameter alloy steel dowel. Two stainless steel torsion springs capable of producing .0053 N-m of torque are placed over the pin and attached to the aluminum body to provide a restoring torque when under rotation. The design is modeled and simulated using FEA methods and the piezoelectric constitutive equations to solve for charge, voltage, and power for a set of electromechanical boundary conditions (M.S. Weinberg, 1999). Measurements of the electrical characteristics of the design are ongoing and achieved by bolting one end of the structure to a vibration shaker and fixing the other to rigid aluminum framing material. For a given frequency of vibration, power output of the structure can be obtained by measuring voltage drop across a resistive load in series with a full wave rectifier and a piezoelectric beam.

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8341-70, Session 14a

Optimized energy harvesting from mechanical vibrations through piezoelectric actuators, based on a synchronized switching technique

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Increasing demand in mobile, autonomous devices has made energy harvesting a particular point of interest. Systems that can be powered up by a few hundreds of microwatts could feature their own energy extraction module. Energy can be harvested from the close environment of the device. Particularly, the ambient mechanical vibrations conversion via piezoelectric transducers is one of the most investigated fields for energy harvesting. A technique for optimized energy harvesting using piezoelectric actuators called “Synchronized Switching Harvesting” is explored. Comparing to a typical full bridge rectifier, the proposed harvesting technique can highly improve harvesting efficiency, even in a significantly extended frequency window around the piezoelectric actuator’s resonance.

In this paper, the concept of design, theoretical analysis, modeling, implementation and experimental results using CEDRAT’s APA 400M-MD piezoelectric actuator are presented in detail. Moreover, we suggest design guidelines for optimum selection of the storage unit in direct relation to the characteristics of the random vibrations.

From a practical aspect, the harvesting unit is based on dedicated electronics that continuously sense the charge level of the actuator’s piezoelectric element. When the charge is sensed, to come to a maximum, it is directed to speedily flow into a storage unit. Special care is taken so that electronics operate at low voltages consuming a very small amount of the energy stored.

The final prototype developed includes the harvesting circuit implemented with miniaturized, low cost and low consumption electronics, a storage unit consisting of a super capacitors array and a wireless link, forming a truly self-powered system drawing energy from ambient random vibrations of a wide range of characteristics.

8341-72, Session 14b

Dynamic behavior of thick magnetorheological elastomers

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Experimental studies are conducted to investigate the dynamic shear properties of thick Magnetorheological Elastomers (MREs) which are affected by increasing the thickness, as well as the percentage of iron particles contained in these materials. MREs are made with various thicknesses and different amounts of iron particles. These include thicknesses of 25.4mm, 19.05mm, 12.7mm, 6.25mm and 3.05mm with iron particle percentages of 30%, 50%, 60% and 70% by weight. A double shear test setup is designed and built to test the MRE samples. All samples are tested over a range of frequencies from 200Hz to 800Hz. Experiments are performed at peak accelerations of 0.25g, 0.5g and 0.75g. The 25.4mm samples are also tested under pre-strains of 1% and 2%. Since all tests are performed at constant acceleration the strain amplitude varies according to the frequency. The results demonstrated that the thickness of MRE significantly affects the material properties in the “off” state, that is, when no magnetic field is applied. However, in the “on” state, when the material is activated by a magnetic field, the thickness of the sample does not show a significant effect on the change in storage modulus induced by a magnetic field. This change remains constant for all samples with different thicknesses under the same magnetic field.

8341-73, Session 14b

MRF actuators with reduced no-load losses

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Magnetorheological fluids (MRF) are smart fluids with the particular characteristics of changing their apparent viscosity significantly under the influence of a magnetic field. This property allows the design of mechanical devices for torque transmission, such as brakes and clutches, with a continuously adjustable and smooth torque generation. A challenge that is opposed to a commercial use, are durable no-load losses, because a complete torque-free separation due to the permanent liquid intervention is inherently not yet possible.

In this paper, novel concepts are proposed that allow a controlled movement of the MR fluid system and thus a almost separation of the fluid engaging surfaces is possible. Measurement results of a realized prototype show that the viscous induced drag torque can be significantly reduced. Based on these novel approaches, it possible to realize MRF actuators for an energy-efficient use in the drive technology or power train, which avoid this inherent disadvantage and extend additionally the durability of the entire component.

8341-75, Session 14b

A bi-annular-gap magnetorheological energy absorber for shock and vibration mitigation

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For magnetorheological energy absorber (MREA) based semi-active shock and vibration mitigation systems, the field-off damping force of the MREA at high speed is of particular significance. In order to decrease the field-off damping force and keep damping force range of the MREA for shock and vibration mitigation, the principle of a bi-annular-gap MREA with an inner-set permanent magnet is presented and the bi-annular-gap MREA prototype is designed, fabricated, and tested in this paper. Two concentric annular gaps for MR fluid flow and an inner-set permanent magnet for providing a magnetic field offset in magnetic circuit are assembled as the piston of the MREA. After establishing the model of the MREA, including magnetic circuit model and damping force model, principle and magnetic properties of the MREA is validated and analyzed via electromagnetic finite element analysis. The developed bi-annular-gap MREA is experimentally tested based on MTS servo-hydraulic testing machine and rail-guided drop test rig. The experimental results are analyzed from various ways, including characteristics of force-displacement and force-velocity, dynamic range, and equivalent damping. The research results indicate that the MREA can provide: (1) an initial damping force for fail-safe case of the mitigation system, and softer/harder damping by decreasing/increasing current applied to the exciting coil, and (2) a relatively large dynamic range, particularly low damping force at high velocity (up to 2 m/s), and a wide damping force range.

8341-76, Session 14b

Active vibration control through magnetostrictive layers

S. Cinquemani, F. Braghin, F. Resta, Politecnico di Milano (Italy)

Carbon fiber structures are claimed to offer several advantages such as contained mass and high stiffness. However, these structures are characterized by a very low mechanical damping and, therefore, they are easily subjected to potentially dangerous vibratory phenomenon. Active control techniques have been widely developed to suppress vibration and great progresses have been achieved.

The paper deals with the opportunity to reduce vibration in structures by using distributed magnetostrictive layers embedded in carbon fiber structures. The magnetostrictive layer is used to induce the actuating force to control vibration in the structure, based on a negative velocity feedback control law. The control input is the current to the solenoid surrounding the layer.

The magnetostrictive layer material studied is Terfenol-D, which is an alloy of terbium, iron and dysprosium. The magnetostrictive layer responds to the magnetic and mechanical stimuli. The magnetostrictive layer expands when excited with a magnetic field, allowing it to be used as embedded actuators.

Vibration reduction in the plate by positioning the magnetostrictive layer and its current carrying actuating coil pair along the plate is investigated. Issues associated with different control strategies are highlighted.

8341-77, Session 15

Multiband damping of resonant vibrating piezo-elastic structures by using digital adaptive passive shunting

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This contribution is concerned with passive vibration damping via a digital shunting device. This device is capable to simulate arbitrary R - L input / output - phase behavior and is able to adjust these parameters in real time to fulfill the underlying structural demands. The virtual resonator is coupled with a capacitive piezo electric patch bonded on the vibrating structure. The software implementation of the R-L circuit offers the possibility of adaptive adjustment and frequency tracking in case of eigenfrequency shifts on the vibrating structure that can happen due to temperature and structural stress changes. The multiband damping is realized by increasing the number of virtual R-L shunts connected in parallel. In order to separate the individual resonators and decrease the mutual influence, an additional virtual capacitor for each R - L section is needed. The algorithms are evaluated on the mathematical model of a Kirchhoff plate equipped with a piezoelectric patch. To demonstrate the capabilities of the system tests were carried out on a steel plate, whereas for the source of disturbance vibration a MFC - patch is used. By placing the patch on a common anti-node of different frequencies the digital shunting device is able to damp selected eigenfrequencies. The effectiveness of the passive shunting device was demonstrated during tests, where a reduction of the vibration level up to 20 dB was achieved.

8341-78, Session 15

Integrated framework for jitter analysis combining disturbance, structure, vibration isolator, and optical model

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Micro-vibration that results from actuating components of the satellite can severely degrade the optical performance of high precision observation satellites. In this paper, an integrated analysis framework combining disturbance, structure, vibration isolator and optical system model is developed for evaluating the performance of optical payloads in the presence of micro-vibration and the effectiveness of using vibration isolator for performance enhancement. Reaction wheel generated disturbance, usually the largest anticipated disturbance, is modeled including the disturbances' interaction with the structural modes of the wheel. A finite element program is used to solve for eigenvalues and eigenvectors of structure model which are then used to create a state space model in modal form in Matlab. A vibration isolator model capturing dynamics of an active isolator utilizing piezoelectric based actuator and load cell for feedback control is included to reduce the transmission of reaction wheel disturbances to the base structure. Dynamic response of the structure to reaction wheel disturbances is calculated with and without vibration isolator. The resulting line of sight jitter is used to obtain modulation transfer function (MTF) of diffraction limited optical system model and the obtained MTF is used as spatial frequency filter for image simulation.

8341-80, Session 15

Development and performance study of a magnetic aerostatic vibration isolation platform

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This paper presents the development of a magnetic aerostatic vibration isolation platform, which is integrated with electromagnetic and aerostatic bearing principles. For the aerostatic bearing, the concept of cap-shaped aerostatic bearing is applied to combine radial and axial bearings inside a cap-shaped air film to enhance its bearing capacity. The axial aerostatic bearing provides the supporting force of the vibration isolation platform, and the radial aerostatic bearing creates frictionless guide to increase its positioning accuracy. The electromagnetic coil is used to generate magnetic attractive force to counterbalance the axial aerostatic bearing force. Through this force counterbalance, not only the axial bearing stiffness can be minimized but also the axial position of the platform can be precisely controlled. For realizing axial positioning control, a hall element and a magnet are integrated to achieve non-contact displacement measurement with less loading effect. Besides, the classic PID control algorithm is the main core of the active positioning control. The finite element analysis and experiment are carried out to comprehend its electromagnetic and aerostatic effects; and the performances of the passive and the active vibration isolations are also experimentally verified. The developed vibration isolation platform can be applied in both passive and active vibration isolation modes .The total stroke of the vibration isolation platform is 6 mm. The sensitivity of the integrated Hall displacement sensor is about 5V/mm. By charging radial inlet pressure of 6 bar, the bearing capacity reaches 20 N. The nature frequency of the passive type is 1 Hz, and the active type can effectively damp vibration lower than 1.5 Hz.

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8342-01, Session 1

Finite element simulation of poling processes in ferroelectrics taking into account weak electric conductivity

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Piezoelectric devices made of ferroelectric ceramics have to be poled to induce the macroscopic inverse and piezoelectric effect for sensor and actuator applications. For the corresponding simulations, the material is usually assumed to be electrically insulating while, in fact, there exists a non-vanishing electric condutivity.

We present a constitutive model taking into account all ferroelectric and ferroelastic hysteresis effects together with weak electric conductivity. A hybrid finite element formultation and a customized integration algorithm is used resulting in a non-linear problem. For the corresponding Newton iteration, he consistent tangent operator is implemented by automatic differentiation. We present examples demonstrating the relevance of considering weak electric conductivity while computing poling processes.

8342-02, Session 1

A homogenized energy model for the relaxor ferroelectric lead lanthanum zirconate titanate

J. Crews, Z. Hu, R. Smith, North Carolina State Univ. (United States)

The homogenized energy model (HEM) is a multiscale model that has been applied to numerous smart materials, including shape memory alloys, ferroelectrics, and ferromagnetics. The HEM advantages include accurate characterization of material inhomogeneities and interaction fields, computational efficiency, and the capability for estimating parameters from experimental data. In this paper, we incorporate temperature dependence in the ferroelectric model to quantify the behavior of lanthanum doped lead zirconate titanate (PLZT), a relaxor ferroelectric. PZT is a common actuator in applications requiring precise positioning and high bandwidth. The addition of lanthanum to PZT has a significant effect on the material's strain-electric field and polarization-electric field behavior. At low temperatures, the material exhibits the characteristic butterfly-shaped strain-electric field hysteresis loops of PZT. At high temperatures, the strain-electric field behavior is quadratic with little hysteresis. This behavior is modeled by incorporating temperature dependence on the coercive field and remanent polarization. The model is validated using experimental data available in the literature. Methods for estimating the model parameters are described in detail, and the parameters are optimized to fit the experimental response.

8342-03, Session 1

Plane wave dynamics in multiferroic materials using maxwell's equation and equation of motion

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Plane Wave dynamic modeling of multiferroic materials typically use assumption of either electrostatic (mechanical dynamics) or decoupled constitutive relations (electromagnetic dynamics). To date researchers have not analyzed the 3D plane wave modes of linear multiferroic (i.e. magnetoelectroelastic) materials from a complete electromagnetic point of view and this is needed prior to design antenna with these novel materials. In this presentation we analytically show that the electromagnetic behavior is strongly influenced by the mechanical properties of the material as well as the coupling terms and thus these terms cannot be ignored. The model assumes a homogenized multiferroic containing cross-coupling parameters representative of a laminated piezoelectric and piezomagnetic multiferroic material. The mechanical dependence (i.e. stress and strain) in the electro-magnetic constitutive relations is eliminated by employing equation of motion (equilibrium) and strain-displacement relations combined with the magnetoelectroelastic constitutive equations. This produces a new set of constitutive relations involving only electric and magnetic field parameters, i.e. stress and strain have been eliminated. However, while stress/strain terms do not appear in the constitutive relations the other terms still contain the appropriate coupling through other parameters and thus there is no loss of generality. Plane wave solutions are provided and the influence of mechanical properties on electromagnetic plane wave behavior is discussed.

8342-04, Session 1

Quadrupole effects on modeling piezoelectric and ferroelectric materials

W. S. Oates, The Florida State Univ. (United States)

Piezoelectricity is often modeled using polarization as the order parameter within a phenomenlogical constitutive model that is based on measurable coupling coefficients within a free energy function. Similarly, nonlinear models based on modified electromechaical crystal plasticity, micromechanics or phase field methods are used to incorporate polarization switching and hysteresis from externally applied electromechanical loading. Here, polarization is extended to include the next higher order term, the quadrupole tensor order parameter. The electrostatic and mechanical governing equations are reviewed for the finite deformation case. A Landau-De Gennes free energy function is implemented numerically and compared to recent time-resolved piezoelectric x-ray data given in the literature which shows unusual coupling behavior in lead-zirconante titanate. The coupling behavior within the model is solely based on the Landau-De Gennes parameters and nonlinear mechanics. The results are shown to match recent unusual anisotropic piezoelectric measurements and the classic ferroelectric electric displacement-electric field hysteresis loops and strain-electric field butterfly hysteresis loops. Additional coupling phenomenon based on the quadrupole and strain gradients is also discussed.

8342-05, Session 2

High energy density nanocomposites based on high aspect ratio surface-functionalized BaTiO3 NWs

H. Tang, Univ. of Florida (United States); Y. Lin, The Univ. of Texas at El Paso (United States); H. Sodano, Univ. of Florida (United States)

High energy density capacitors have received a great interest in advanced electronic devices and electric power systems due to reduce the weigh, size and cost to meet a desired application. Nanocomposites combining of high dielectric permittivity ceramic with high dielectric

strength polymer matrix offer a potential of obtaining capacitor with high energy density. However, the design of nanocomposite capacitors poses certain challenges due to the reduced dielectric strength resulting from the integration of typically high dielectric fillers into polymer. Previously, the model and experiment have demonstrated that the high aspect ratio nanowires (NWs) can be used to improve the energy density of nanocomposites compared to low aspect ratio samples. Herein, the high energy density nancomposite is prepared by using the high aspect ratio surface-functionalized barium titanate nanowires. The BaTiO3 NWs are synthesized by hydrothermal ion-exchange reaction using sodium titanates as synthetic precursor. The functionalized BaTiO3 NWs are used to improve the breakdown strength of nanocomposites. The Fourier transform infrared (FTIR) shows the surface of BaTiO3 NWs have been functionalized. LCR meter and Sawyer-Tower circuit are used to determine dielectric permittivity and energy density of the nanocomposites, respectively. It shows that the nanocomposites with high aspect ratio functionalized BaTiO3 NWs have higher dielectric permittivity compared to nanocomposite with BaTiO3 nanoparticle. The breakdown strength is also tested and used to calculate the maximum energy density of nanocomposites. This work will show that high energy density nanocomposites can be obtained through high aspect ratio functionalized BaTiO3 NWs. The findings of this research could lead to broad interest due to the potential for fabricating next generation energy storage devices.

8342-06, Session 2

Nano-enhanced polymer composites for energy storage applications

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Polymer nanocomposites containing high dielectric permittivity ceramic particles embedded into a dielectric polymer represent promising candidates to overcome the limitations of monolithic materials in both energy storage and energy conversion. Indeed, monolithic materials are hitting a plateau in terms of high energy storage capabilities due to the trade-off between the dielectric constant, the dielectric loss and the dielectric breakdown. Since ceramics have high dielectric constant but low dielectric breakdown, while polymers have high dielectric breakdown and low loss but low dielectric constant, the strategy of simply filling a polymer with ceramic particles will only yield incremental and limited success. In this study, we investigate the effect of adding commercial metal oxide nanoparticles, TiO2, to a ferroelectric polymer on the dielectric constant, breakdown, ferroelectric behavior and energy density of the system; specifically, we focus on impact of the particles size, aspect ratio, and interaction with the polymer dipole. We find that at a very low TiO2 content, namely 4.6vol%, the energy density increased by more than 400% as compared to the pristine polymer, with an enhancement in both the dielectric constant and the dielectric breakdown while the dielectric loss remained in the same range as that of the pure polymer. We also investigate the mechanism for this large improvement and demonstrate that the high aspect ratio particles have a planar distribution in the nanocomposite film, resulting in a low local field, and therefore a high dielectric breakdown.

8342-07, Session 2

Electromechanical actuation response of PVDF-based SWNT/GO hybrid films

N. Sigamani, Z. Ounaies, The Pennsylvania State Univ. (United States); H. Sodano, Univ. of Florida (United States)

Both ionic (or IPMCs) and electronic EAPs have shown great potential as actuators. Current IPMC technologies are unrealistic due to their slow response time and the low forces produced which places severe limitations on their use. Also, due to the ion transport-based mechanism, presence of an electrolyte is necessary, further complicating issues of packaging and lifetime use. Despite the many advantages of electronic EAPs such as lightweight, good energy densities and high bandwidth, there are major obstacles facing their transition to application. Notably they require high actuation voltages, have low blocked stresses and low operating temperatures. The goal of this project is to induce significant electromechanical response in nano-modified EAPs by exploiting the increasingly dominant role of interfaces at the nanoscale. Our previous research showed SWNT-based PVDF nanocomposites to exhibit an electrostrictive response. However, due to the high electrical conductivity and dielectric loss, their operating voltage is very limited. In this study, we synthesize and characterize PVDF-based SWNT/GO hybrid nanocomposites as potential EAPs. The films are synthesized by solution casting the SWNT/GO-PVDF mixture in DMF solvent. These hybrid nanocomposites show better dispersion of both SWNT and GO in the PVDF, thus resulting in an enhanced effective dielectric constant. We show that electrical conductivity of this nanocomposite can be controlled by varying the ratio of SWNT/GO. The thickness and bending actuation response of the hybrid films in response to electrical field is discussed. The effect of the presence of hybrid SWNT/GO on the morphology of PVDF and the mechanism driving this actuation are discussed. In addition, both static and dynamic thermo-mechanical properties are measured and analyzed.

8342-08, Session 2

Piezoelectric and piezoresistance performance of PZT/PVDF composites with carbon nanotubes

X. Guan, Y. Zhang, H. Li, J. Ou, Harbin Institute of Technology (China)

PZT/PVDF is one kind of composite mainly composed of polyvinylidene fluoride (PVDF) matrix and lead zirconate titanate (PZT) particles. Because containing functional phase PZT, PZT/PVDF also possesses piezoelectric effect and can be made to sensors. Compared with pure PZT ceramic, PZT/PVDF possesses lower piezoelectric effect but better flexibility. As the dielectric permittivity of PVDF is much higher than that of PZT, during the process of polarization, most voltage will drop on the PVDF polymer instead of PZT particles; consequently, the PZT particles cannot be polarized at ideal voltage. Moreover, using piezoelectric effect, PZT/PVDF can only sense dynamic strain signal. In this paper, one kind of new composite was put forward. Compared with traditional PZT/PVDF, the main difference is that proper content of carbon nanotube particles was mixed in the PVDF matrix. As carbon nanotube possessing excellent electric conductivity, the dielectric permittivity of PVDF will reduced to proper value which is in favor of polarizing PZT particles. Moreover, the enhanced electric conductivity made the new composite also has piezoresistance effect and can be used as static sensor. In this paper, the detailed producing process of the new composite and its performance will be introduced.

8342-09, Session 2

Investigation of particle diameter and interphase effects on mechanical properties of SiO2/epoxy particulate composites

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This study involves the investigation of spherically shaped filler diameter and interphase effects on the mechanical properties of micro and nano size silicon dioxide (SiO2) particle reinforced epoxy composite materials. Specifically, 10μm and 20nm size SiO2 particles, and the diglycidyl ether of bisphenol A (DGEBA) are chosen as fillers and a matrix material, respectively. While 10μm SiO2 particles are dispersed in the epoxy through a direct shear mixing method, nano-composites are fabricated by using commercially available Nanopox F400 (nanoresins AG, Germany) with hardener at desirable ratios. Both micro- and nano-composites are prepared at a wide range of particle loading fractions (up to 40% weight fraction) for tensile testing. It is observed that the nano-composites show

significant increase in Young's modulus over micro-composites, showing a linear increase as weight fraction increase. This could indicate that for nano-composites interphase region between the particle and matrix can considerably affect their mechanical properties. Here, we develop a FEA model to investigate the interphase effect on the mechanical properties of both micro- and nano-composites. This model demonstrates how to determine effective material properties of a particle as filler, which is shown to be more important in predicting the mechanical response of nano-scale particles reinforced composite materials.

8342-10, Session 3

Biological ion transport driven conducting polymer actuators

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Biological processes and electromechanical function in ionic polymers share ion transport as the fundamental processes for sensing, actuation and energy harvesting. Inspired by the similarity in protein-bound cell membranes and polypyrrole membrane (an ionic polymer), our group is developing a hybrid device that provides the template for integrating biology and electronics. The integrated device, referred to as a bio-derived ionic transistor (BIT), consists of a bilayer lipid membrane (BLM) formed on a polypyrrole membrane and has two inputs that regulates the output of the device. The lipid bilayer is formed with sodium conducting voltage-gated channel (alamethicin) and supported on a polypyrrole membrane doped with dodecylbenzenesulfonate. The assembly measuring 50 microns long, 10 microns wide and 0.5 microns thick is mounted in a cantilever configuration to demonstrate actuation and characterize the mechanical work done in the conducting polymer by biological transport. Our preliminary work to fabricate the hybrid has demonstrated that the actuator is capable of generating 100 microstrain for a gate potential of 100 mV and source to drain potential of 1V. The work presented in this conference will report ongoing work and recent developments in characterizing this actuator and finding the constitutive relations for this novel actuation method.

8342-11, Session 3

Optimizing the photomechanical performance of glassy azobenzene liquid crystal polymer networks

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Azobenzene liquid crystal polymer networks have recently drawn significant attention due to their novel photomechanical actuation characteristics for developing remotely actuated morphing structures. The photoisomerization of the azobenzene liquid crystal leads to unusual polymer network deformation as the liquid crystals undergo polarized light induced shape change and subsequently, work on the host polymer network. Given these interesting properties, it is critical to understand photomechanical efficiencies based on the underlying chemistry of the polymer network and the volume fraction of liquid crystals. To more fully understand this behavior, a nonlinear photomechanical shell model is developed to quantify polarized light induced structural dynamics and energy efficiency of these photomechanical films. Nonlinear material properties, light reflection and absorption are taken into consideration to predict bending for large deformation problems that are observed experimentally. The large deformation finite element shell model within the Finite Element Analysis Program (FEAP) is extended to accommodate photomechanical structural dynamics and energy efficiency calculations. Comparisons of the finite element calculations and laser induced free bending and blocked force light experiments show that the change concentration of crosslinked azobenzene mesogens (from 50% to 10%) increases the photomechanical bending efficiency by more than one order of magnitude. These quasi-static experiments and model comparisons are used to calculate theoretical limits on tranduction efficiency during large structural dynamic flapping motion.

8342-13, Session 3

A voltage sensing model of IPMC based on the underlying physical processes

D. Pugal, V. Palmre, K. J. Kim, Univ. of Nevada, Reno (United States)

The current paper presents a model of ionic polymer-metal composites (IPMC) to calculate induced voltage in response to an applied mechanical deformation. The model is based on the fundamental physical principles, namely the Poisson-Nernst-Planck system of equations and was implemented using the finite element (FE) method. In addition to the induced ionic migration, the model takes into account the effect of the electrode in generating the voltage due to deformation. The model considers different geometries and electrode configurations of IPMC. Namely, the induced voltage for various IPMC thicknesses and segmented/patterned electrodes was calculated. The measured voltage signal was compared to the model. Furthermore, it was studied how the voltage is induced on the different sections of patterned IPMCs and how the model can estimate it.

8342-14, Session 3

Ultrasonic performance of PVDF thin film sensors under thermal fatigue

V. T. Rathod, D. Roy Mahapatra, Indian Institute of Science (India); A. Jain, A. Gayathri, National Aserospace Labs. (India)

Ultrasonic strain sensing performance of large area PVDF thin films under thermal fatigue is investigated in this paper. Thin films are prepared using hot stretching. Piezoelectric-phase has been achieved which is confirmed by XRD studies. These sensors have potential applications in vehicle structural health monitoring including engine structures and other regions where thermal cycles can lead to fatigue degradation of the sensor performance itself. Large area thin film sensors are of interests from guided wave sensor design point of view, wherein various electrode patterns can be used to achieve multi-component sensing and wave mode filtering. The fabricated sensors are subjected to wide range of thermal loading conditions in the range of -80°C to 120°C using a DMA-TMA setup. This creates thermal fatigue in both the host structure as well as the sensors. The ultimate objective of such characterization is to develop sensor models to compensate thermal fatigue degradation of sensor performance in terms of piezoelectric coefficients, dielectric constants and elastic constants as functions of thermal loading cycles and ultrasonic wave frequencies. The fabricated sensors are bonded on plate strip specimen at one end and the ultrasonic guided waves are launched with a piezoeceramic wafer bonded on the other end. The exciter input voltages are varied to achieve varying strain levels. Range of parameters which show strong interactions among thermo-mechanical softening and nucleation of electrical depolarization sites are identified. The results have important application of these PVDF sensors for health monitoring under thermo-mechanical loading environment.

8342-15, Session 3

Development of conductive fibrous polymer membrane

J. Wang, H. Naguib, A. Bazylak, Univ. of Toronto (Canada)

Electrospun conductive polymers are promising material choices for a broad range of applications, such as electronics, sensors, actuators, biomedical applications, as well as the emerging energy applications including batteries, supercapacitors, fuel cells, and solar

cells. Electrospun conductive polymers have been studied, employing various material compositions and techniques, however the fabrication of highly conductive electrospun polymers is challenging. In this paper, we investigated two methodologies for the fabrication of electrospun conductive fibrous mat. First, we introduced conductive fillers, multiwall carbon nanotubes (MWCNT), into a polystyrene (PS) matrix. MWCNT concentrations were varied from 1 to 10%. Electrospinning conditions were tailored to produce fibers with minimal beads. Next, we investigated the effects of coating electrospun fibers with conductive polymers. Oxidant (FeCl3) fibers were spun in PS and then exposed to pyrrole monomer in a vacuum chamber. As a result polypyrrole (PPy) was coated on the fibers creating conductive pathways. In both methods the conductive fibers were characterized in terms of their morphologies, thermal stability and electrical conductivity.

8342-16, Session 4

Some new aspects of fracture mechanics of piezoelectrics

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Fracture of piezoelectrics has been under intensive investigation for more than 20 years. During that time, much theoretical as well as experimental work has been done. However, there are still aspects which have not been fully understood. Still, experimental data based on obviously similar boundary conditions scatter a lot, partly leading to contradictory conclusions. Also, a general fracture criterion covering arbitrary poling and loading conditions has not been found. In our work, we investigate some new aspects of piezoelectric fracture mechanics, which might lead to a better understanding of the subject and finally might contribute to close the above mentioned gaps in knowledge. One focus is on the electromechanical boundary conditions at crack faces. Thermodynamical as well as mechanical and dielectric equilibrium require the existence of both intrinsic charges and mechanical tractions at the crack faces. Simple approximations being nowadays available in literature are extended, in particular concerning arbitrary orientations of poling and electric field with respect to the crack plane. Therefore, semi-analytical calculations are connected to numerical FE simulations in order to solve the coupled multi-field problem of anisotropic solid and dielectric crack interior. Whereas crack face tractions impact the effective fracture toughness on a macroscopic scale, ferroelectric domain switching has a non-negligible influence on the mesoscopic level. First, small scale switching at the crack tip is investigated. In contrast to models published hitherto, full anisotropic piezoelectric field coupling is included. Second, large scale switching is investigated numerically based on the development of an ABAQUS user element.

8342-18, Session 4

Harmonic electro-optic modulation using relaxor ferroelectric PLZT ceramics

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Lead Lanthanum Zirconate Titanate (PLZT) ceramics are desirable for use in optical devices because of their good transparency from the visible to the near-infrared, and their high refractive index (n=2.5), which is advantageous in light wave guiding applications. The transmission of light through a PLZT ceramic film, having a relaxor ferroelectric composition of (9.5/65/35), exhibited a Fabry-Pérot interference pattern. Upon the application of an electric field, the transmitted irradiance was modulated at both the first and second harmonic frequencies to that of the applied field. Large changes were observed in the optical path difference within the material due to a combination of the electrostrictive and quadratic electro-optic effects. A theoretical model was developed to obtain harmonic expressions for the Fabry-Pérot transmitted irradiance, and it was successfully fitted to the experimental results. This work explores the interactions between the strain and the refractive index change in clamped and unclamped PLZT ceramics upon the application of an ac electric field.

8342-19, Session 5

Interdigitated electrode design for ferroelectric materials

D. M. Pisani, C. S. Lynch, Univ. of California, Los Angeles (United States)

No abstract available

8342-20, Session 5

Parametric study on the geometry and matrix properties impact on the performance of the AFCs

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Active fiber composites (AFCs) are comprised of long circular fibers in a polymer (usually a polyimide and epoxy). The fibers are made of a piezoelectric ceramic, lead zirconate titanate (PZT). The AFCs use interdigitated electrodes, which produce electric field lines parallel to the fiber direction. As a result, the AFC takes advantage of the high PZT's d33 constant. It is noted that, the d33 of the AFC is almost a third of the PZT's, mainly because of the mismatch in the dielectric properties between the polymer matrix and the ceramic fiber. Nonetheless, the AFCs are still of great interest because they have the potential to combine the flexibility and light weight of the polymer to the high piezoelectric performance of PZT. The objective of the current work is to develop a detailed FEM model to investigate the effects of AFC geometry and polymer properties on the overall performance in terms of mechanical displacement and electric potential. Several matrices (epoxy polymer and epoxy-based nanocomposites) are used in the model, and the results are analyzed to show the impact of each of the matrix property. For the AFC geometry, several parameters are varied to assess their impact on displacement and electric potential. Some of these parameters are related to the electrodes such as the electrode's fingers gap and their width. The other parameters are related to the composite itself such as fibers diameter, spacing between fibers and spacing between fibers and electrodes. This parametric study will lead to an optimized geometry and matrix that can be used for the manufacturing of AFCs with higher performance than what is currently available.

8342-21, Session 5

Sliding mode control design for hysteretic smart systems

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Ferroelectric and ferromagnetic materials are attractive for use in a wide range of applications due to their unique transduction capabilities. Taking full advantage of these capabilities requires a control design which accounts for the materials' inherent hysteretic behavior. A common approach is to partially cancel the hysteretic effects in the system by employing an approximate inversion algorithm in the control input, resulting in an almost linear system. We combine this method with a modified sliding mode control design to track a reference trajectory even in the presence of modeling and inversion errors. Modifications using model predictive control are used to reduce the chattering phenomenon associated with standard sliding mode control. Numerical simulations illustrate the effectiveness of the design.

8342-22, Session 5

In situ polarization of polymer films in microsensors

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Electret and polymer piezoelectric films have been previously integrated into Micro Electro Mechanical System (MEMS) acoustic sensors and energy harvesters. Common techniques employed in MEMS polymer integration include corona discharge and backlighted thyratron, followed by macro-scale assembly of the polymer into the micro device. In contrast, this paper reports a method for post-fabrication in-situ polarization of polymer films embedded within the MEMS device itself. The method utilizes microplasma discharges with self-aligned charging grids integrated within the device to charge fluoropolymer films in a fashion similar to the common corona discharge technique. This in-situ approach enables the integration of uncharged polymer films into MEMS and subsequent post-fabrication and post-packaging polarization, simultaneously enabling the formation of buried or encapsulated electrets as well as eliminating the need to restrict fabrication and packaging processes that might otherwise discharge pre-charged materials. Using the in situ approach, a microscale charging grid structure is fabricated and suspended a short distance above the polymer film. After fabrication of the charging grid, standard microfabrication steps are performed to build MEMS sensors. After completing the entire fabrication and packaging flow, the polarization process is performed. When energized by a high voltage, the sharp metal edges of the charging grid lead to high dielectric fields that ionize the air in the gap and force electric charge onto the polymer surface. This paper presents modeling and results for this in situ polarization process.

8342-23, Session 6

Lead-free piezoelectric thick films for transducer applications

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Demands for miniaturized devices integrated with microelectronics lead to great interests in the design and fabrication of film piezoelectric devices. Such devices often require high-performance piezoelectric films with thickness above 1 μm. In this study, two kinds of lead free piezoelectric thick films have been investigated. First, K0.5Na0.5NbO3 and Bi0.5Na0.5TiO3 thick films have been prepared by PVP-modified chemical solution deposition process, respectively. The effects of annealing temperature and PVP addition on the performances of the thick films were systematically investigated to improve crystallization and reduce the volatility of alkali ions. Secondly, Bi0.5Na0.5TiO3-Bi0.5Na0.5TiO3 and K0.5Na0.5NbO3-Bi0.5Na0.5TiO3 0-3 composite thick films have been prepared by a modified powder/sol-gel solution composite process. The influence of annealing temperature and weight ratio of the powder-to-solution on the structures and electrical properties of the composite thick films has been investigated. Applications of the thck films on high frequency ultrasonic transducers will be discussed.

8342-24, Session 6

Electrical properties and sensing ability of novel piezoelectric ceramics fibers with Pt core

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Piezoelectric ceramic fibers with metal core have been successfully fabricated by extruding powder-binder surround Pt core. The novel piezoelectric ceramics 0.55Pb(Fe0.06Ni0.27Nb0.67)O3-0.45Pb(Zr0.3Ti0.7)O3 (PFNN-PZT) were synthesized by normal sintering process. The sieving powders was mixed with organic binder, plasticizer and dispersant. After mixing and drying, the proper viscosity of clay-like mixture was formed. The green fibers were sintered at 1150-1250°C for 2 h. The microstructure, piezoelectric, ferroelectric, and dielectric properties were investigated. XRD data revealed that all samples show a pure pervoskite structure with pseudo-cubic phase. The grain size and density became lager with increasing the sintering temperature. The piezoelectric coefficient (d31),the relative dielectric constant (er) and the remanent polarization (Pr) show peak values of -240 pC/N, 3160, and 5.3 uC/cm2, respectively.

Piezoelectric ceramic fibers with Pt core is a new type piezoelectric device, each fiber can be used as sensor or actuator. In order to study the sensing performance, the polarized fiber was pasted on the surface of a cantilever beam. The effects of direction on the electric charge of the fiber sensor are tested. The results show that the fiber with high sensitivity for the vibration of the cantilever beam.

8342-25, Session 6

Overcoming hysteresis in multilayered piezoceramic actuators used in adaptive optics

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Piezoceramic actuators are of increasing interest within the field adaptive optics through their ability for macro and nano positioning. However a major drawback for their use is the inherent, non linear hysteresis that is present. This will reduce the accuracy in the positioning. Methods have been research to overcome the hysteresis but they often involve complex additions to the actuators and its positioning system. This paper discusses two methods to overcome the hysteresis in a more simplified approach. The first method is using direct capacitance measurements which correlate with the extension of the actuators providing a hysteresis of 5%. The second method involves measuring the frequency at a specific impedance phase, providing a hysteresis of between 1 to 2%. The raw hysteresis of the piezoceramic actuators is 20% therefore both methods provide a significant method to reduce the hysteresis during extension sensing. The ability to overcome the hysteresis to this level has allowed the advancement in adaptive optics and the development of a deformable mirror for use within the land based astronomy; correcting the wavefronts through the telescope mirror and for use within high powered intracavity laser systems. Also discussed will be the architecture of the multilayered piezoceramic used in the laser based application along with some of the issues that arose during the extension sensing and how these issues were resolved.

8342-26, Session 6

A general framework for numerical solutions to rate-dependent plasticity problems of piezo-composites

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Recent developments in smart material technology have resulted in multifunctional materials like Piezoelectric Fiber Reinforced Composites (PFRC). The multi-functionality provided by PFRC include load-bearing, actuation, sensing, health monitoring, energy harvesting etc.The known models for PFRC materials use linear piezoelectric constitutive equations, based on simple elastic micro-mechanical Voigt models. In these models, the nonlinear electro-mechanical couplings, hysteresis effects and inelastic properties of constituents are neglected. When the maximum strain(s) and strain rate(s) are reasonably small, then the material behavior is considered essentially elastic and linear.When used in dynamic applications like flapping wings in Micro Aerial Vehicles (MAVs), the PFRC

are subjected to dynamic conditions at high mechanical and electrical strain rates. MAV wings are also highly susceptible to winds and impact loading due to atmospheric particles etc. All the above conditions could potentially induce residual plastic strains in PFRC materials. Hence, in reality, plastic deformation could occur and constructing an elasto-plastic model for PFRC is of significance.In this work, a continuum model is formulated to describe the electro-elasto-plastic behavior of PFRC. An algorithm for rate-dependent elasto-plasticity based on multiplicative Lee decomposition of deformation gradient is developed. To enable dimensional reduction for computational efficiency, the developed algorithm is coupled with the Variational Asymptotic Method (VAM). An initial trial elastic stress is calculated and is used to obtain trial stretch and rotation tensor and the Cauchy-Green deformation tensor. Using a small strain subroutine, the stress integration is performed to obtain backstress and plastic strain increment. The developed algorithm is used to demonstrate the growth of plastic deformation in a cantileverunder dynamic electro-mechanical loading conditions. Overall this work provides a general framework to describe the rate-dependent electro-elasto-plastic constitutive behavior of new generation of PFRC materials.

8342-27, Session 6

Effect of cross-sectional nonlinearities on actuation characteristics of smart composite beams

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Piezocomposite materials are increasingly being explored for use in aerospace structures for various applications like morphing, active flow control, structural health monitoring and active vibration control as they offer superior properties (as compared to piezoceramics) such as enhanced actuation authority, higher flexibility, reduced density, better fatigue life and tailorability of electro-mechanical properties. Design of thin-walled aerospace structures incorporating such piezocomposite materials, for any of the above-mentioned applications, demands an efficient electro-mechanical model in order to predict their actuation/sensing characteristics accurately and the current work is motivated by this need. As a representative of thin-walled aerospace structures incorporating piezocomposite materials, a thin strip-like smart composite beam of rectangular cross-section is considered as it favors analytical treatment yielding closed-form solution for the beam constitutive law.

Most aerospace structures, including the piezocomposite ones considered in this work, are thin-walled and/or slender. Hence, their geometrical features are at multiple length scales. For example, the ratio of longitudinal dimension to lateral dimension of spars and stringers is large rendering beam models not only applicable but also preferable due to their computational efficiency, though not all such beam models are sufficiently accurate. By virtue of their multiple length scales, three-dimensional (3-D) models of most aerospace structures can be dimensionally reduced to equivalent one-dimensional (1-D) or two-dimensional (2-D) models, as in the case of beams or plates/shells, respectively. For thin strip-like beams, such a dimensional reduction from 3-D to 1-D can progress either in a single step or in two steps: first from 3-D to 2-D and then to 1-D. In this work, an attempt is made to dimensionally reduce one such 3-D electro-mechanical model using a two-step process to a 1-D electro-mechanical model, which is not only efficient but also highly accurate because of the employment of the Variational Asymptotic Method (VAM) as the derivation tool. In the second of the two-step process, starting with asymptotically-correct zeroth-order electro-mechanical strain energy per unit area of a composite plate, employing geometrically nonlinear beam kinematics (which relate the generalized plate and beam strain measures) and allowing for the most general 3-D cross-sectional warping field, VAM splits the 2-D plate problem into a 1-D through-width problem and a 1-D through-length problem. The resulting electro-mechanical beam constitutive law, which relates 1-D generalized forces with 1-D generalized beam strain measures, is linear in the zeroth-order approximation but nonlinear in the first-order approximation. This nonlinearity is rooted in the fact that the class of beams (strip-like) under consideration possesses very low torsional as well as thickness-wise bending stiffnesses compared to width-wise bending stiffness.

The developed model allows analysis of strip-like smart beams with arbitrary stacking sequence and loading. Using this completely nonlinear 1-D electro-mechanical constitutive law as input, the 1-D static actuation problem (required for morphing, for example) is solved employing geometrically nonlinear beam theory in order to predict the actuation characteristics in terms of 1-D deflections and rotations for the specified actuation input. Numerical results are presented and the effect of the cross-sectional nonlinearities on the actuation behavior is demonstrated. Parametric studies are carried out by varying stacking sequence, cross-sectional aspect ratio (beam width to thickness) as well as beam aspect ratio (beam length to width) to further explore the significance of cross-sectional nonlinearities in actuation of smart beams.

8342-28, Session 7

Structural health monitoring damage detection for remending multifunctional fiber composites

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Non-destructive evaluation (NDE) methods for structural health monitoring (SHM) of composite aerial structures (airplane wings, filament wound pressure vessels) are investigated for alerting a human maintainer and/or activating a self-healing system. Damage detection is the guiding metric for the maintainer. For self-healing activation, damage detection is coupled to a remending system. Low-velocity impact damage with energy levels between 5-15 ft-lb is of special concern as matrix cracking and other critical damage invisible to the surface of the structure often results. This damage may be repairable if the structure's matrix is made from remendable material. This study presents progress of the structural remendable polymer, "Mendomer" (Young's modulus E>2GPa), and results with commercially available remendable ionomeric material as multifunctional material solutions in healable composite matrix. Mendomer is capable of healing cleaved surfaces while recovering significant initial strength (80%) after repeated fracture and healing cycles. It is combined with healing material (<10% volume fraction) and used as the matrix in conventionally fabricated fiber-composites for matrix cracking, delamination, and general damage mitigation. Both resistive and inductive heating are locally applied for remending the polymer matrix. Mendomer synthesis and scalable fabrication are also discussed. Toward creating an autonomous self-healing system, passive SHM methods are compared for Mendomer self-healing system integration. This study also discusses overall system metrics such as added weight, power requirements, accuracy, reliability, cost, and maintainability for ready platform integration.

8342-29, Session 7

An experimental study of the self-healing behavior of ionomeric systems under ballistic impact tests

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The development of self repairing materials has an important scientific and technological implications, particularly in relation to cost-effective approaches toward damage management of structures.

This research work deals with the investigation of the self healing behavior after ballistic damage of ethylene-methacrylic acid ionomers

and theirs blends with epoxidized natural rubber (ENR).

Different kind of tests were carried out to characterize the materials object of study, in particular mechanical and thermal properties were measured by tensile test, Differential Scanning Calorimetry (DSC) and Dynamic Mechanical Thermal Analysis (DMTA).

The self healing capability has been studied by ballistic puncture tests; different conditions were assessed by varying sample thickness (0.5 - 5 mm), bullet impact velocity (200 - 5000 m/s) and bullet diameter (1 - 9 mm).

At low and medium impact speed (less than 1000 m/s), pure sodium and zinc based ionomers present similar self repair capacity but, interestingly, while EMNa/ENR blends also exhibit complete repairing just after the ballistic tests at any blend composition, EMZn/ENR blends do not. Hypervelocity impact tests, instead, showed that complete healing didn't occur at these speeds for all tested materials.

After all impact tests, the healing efficiency was evaluated by applying a pressure gradient. Hole closure was tested both by following vacuum decay and by checking for possible flow of a fluid droplet placed at the damage zone with the applied pressure difference. A morphology analysis of the impact zones was made observing all samples by optical stereo-microscope and scanning electron microscope both in the bullet entrance and exit sides.

8342-31, Session 7

Mechanical properties of continuously reinforced MWCNT polymer composites in compression

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Recent studies show that continuously reinforced CNT composite can have extraordinary mechanical properties. It was observed that the continuous CNT polymer composites exhibit both significant reinforcement and large damping capability in compressive loadings, which typically remain compromised. The damping property might result from buckling behavior of the CNT composites. Here, this paper is to study the buckling response of MWCNT within a polymer matrix by using analytical modeling including Timoshenko and shell buckling models, and experiments. Also, a finite element model is developed and used to investigate the effect of aspect ratios (L/D) of MWCNT on buckling behavior of the CNT polymer composites. This study provides us with insight to better understand the structure-property relation for such continuous CNT polymer composites.

8342-64, Session 7

Nanoparticle superlattice for blast-induced shock-wave management

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In this work, we seek to create an elastomeric composite material capable of blast-induced shock-wave management. While traditional segmented thermoplastic elastomers offer a useful starting point, control over crystallite size and morphology is limited. The blending approach affords exquisite control of particle size, density, and morphology by decoupling the hard and soft block syntheses. However, the hard/soft interface is typically weak for simple blends. Polymer-grafted nanoparticles allow tuning of the interface to overcome this issue. Here we develop a nanoparticle superlattice consisting of a bulk material with homogeneously dispersed embedded nanoparticles. Such a composite with appropriately sized particles and lattice spacing can manage shock-wave energy via dissipation and resonant trapping. The nanoparticle superlattice involves different particle types, sizes, densities, and spacing. These various parameters dictate the frequency of the shock-wave absorbed and therefore can allow for a single frequency or a range of frequencies to be targeted. The properties of the resultant nanoparticle superlattice are characterized using gel permeation chromatography to determine the molecular weight and the polydispersity index, nuclear magnetic resonance spectroscopy, infrared spectroscopy, and thermal gravimetric analysis to confirm the polymer composition, purity, and polymer percentage, transmission electron microscopy to characterize the nanoparticle spacing, and small angle x-ray scattering is used to determine the order of the sample and the resulting lattice parameters from the diffraction pattern. The work described here is part of an ongoing effort to develop and verify rules and tools for creating elastomeric composite materials with optimally designed compositions and characteristics for blast-induced shock-wave management.

8342-72, Session 7

Toughening mechanisms of thermoplastic particulate polycarbonate composites

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Toughness of a polymer is a key material property for energy absorbing capability for various engineering applications. Significant effort has been made to improve toughness of a polymer and hence increase the energy absorbing capability; typically rigid-particles in thermoplastics and rubbery modifiers in a brittle polymer matrix. The focus of this study is to investigate toughness of a thermoplastic polymer composite. A material of interest is a micron-size thermoplastic particle reinforced polycarbonate (PC) composite material, which is fabricated via a solution mixing method. The mechanical properties of the composites are characterized in tensile testing. Substantial improvement in toughness was observed for the micro-composites in this study. The toughening mechanisms are identified and quantitatively evaluated by a combined experimental and analytical modeling.

8342-85, Session 7

Intelligent energy dissipation capability of MWCNTs based nanofluid

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A nanofluid with effective energy dissipation capability is developed with functionalized multi-walled carbon nanotubes (MWCNTs) and a nonwetting high surface tension liquid. Both CF4 plasma treating and fluorosilane grafting methods were performed to modify the properties of tube inner walls. By adjusting the plasma treating pressure, time and the chain length of the grafted fluorosilane, the functionalized MWCNTs based nanofluids could achieve different energy dissipation capabilities. From the XPS, TGA and TEM test results, it is found that the tube inner surface treating rate mainly determines this energy dissipation capability. According to the molecular dynamics (MD) simulations research, the experimentally founded energy dissipation capability of this nanofluid is validated. Furthermore, it is found that if the MWCNTs have positive charges, the energy dissipation capability is strengthened while this capability of the MWCNTs with negative charges is weakened.

8342-12, Poster Session

Towards auxetic nanofibres

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This paper reports on progress towards the development of molecular-level fibres displaying auxetic (negative Poisson's ratio) behaviour - in other words, fibres which expand widthwise when stretched due to structural features at the molecular- or nano- scale.

To date, auxetic polymeric fibres have been produced using a melt extrusion process. The fibres have been used to demonstrate significant benefits in composites applications (e.g. enhanced fibre pullout

resistance, and reduced thermal distortion and residual stresses). They have also recently been deployed in textile structures, leading to potential in personal protective equipment, blast fabrics and apparel.

To fully realise the potential of auxetic fibres, however, it is necessary to reduce the diameter of the fibres and also to increase the strength and/or stiffness of the fibres. This will ultimately be achieved through the development of auxetic fibres based on molecular-scale structures and deformation mechanisms. A number of molecular-level auxetic materials exist, and others have been proposed. Of the latter, early attempts at designing molecular-level auxetics included molecular honeycomb structures which mimicked the structure of macroscale honeycombs known to be auxetic. More recently, liquid crystalline polymers have appeared the most promising route to date towards the development of the first synthetic auxetic molecular polymer.

In this paper, crystalline cellulose has been modelled using molecular mechanics methods. Recent experimental reports have demonstrated auxetic behaviour in some forms of cellulose. Molecular mechanics simulations have now been performed and found to reproduce the structure and auxetic character of auxetic cellulose. These models have then been used in uniaxial loading simulations to determine the predominant deformation mechanisms responsibe for the auxetic effect. From these simulations, it has been possible to develop simple analytical models to explain the auxetic effect, which it is hoped will lead to the design and synthesis of new fibre-forming auxetic molecular-level polymers.

8342-67, Poster Session

A study of characteristics of cellulose based nano composite

C. Yang, Andong National Univ. (Korea, Republic of); J. Kim, Inha Univ. (Korea, Republic of)

Cellulose has been investigated as a promising green material. Piezoelectricity is the embedded properties of this material. This property enables to react for outer force to be used as sensor and in reverse, electric current is converted to the force. Cellulose solution is deposited layer by layer using spin coating and electrospinning. Electrospinning method could generate nano-scaled fibers by overcoming the shear force between the solution and spinneret. Intensified electric voltage between spinneret and earthed target may expel the solution from the spinneret as a form of thin fiber. The first layer is deposited on the glass slide by spin coating and then electro-spinned cellulose fiber is collected on the 1st cellulose layer. After that cellulose is spin-coated again on the 2nd cellulose layer. Therefore, 3-layer of cellulose is mechanically bonded to make cellulose based nano composite. Sandwiched layer of electro-spinned cellulose may produce enhanced mechanical and electrical properties because of the nano-scaled electro-spinned cellulose layer. Mechanical tests are executed to observe the strength of cellulose composite. Strength of cellulose composite may depend on the properties of sandwiched layer such as thickness of fiber and that of layer. A narrow fiber may provide more surface area to contact between layers and helps adhesion of composite. Strength of cellulose composite is compared by changing thickness of sandwiched layer. Scanning electron microscope is investigated to observe the formation of layers and cross section of composite. Electrical properties are improved as the uni-direction of fiber enhances piezoelectricity. A prepared cellulose composite specimen is pulled to provide enhanced electrical properties. After pulling, gold electrode on both sides of the cellulose composite is deposited using thermal evaporator. Electrical properties such as capacitance are measured as a function of temperature to assess the dielectric constant of this composite. Converse and direct piezoelectric effects are measured. Induced in-plane displacements of the composite are measured by varying electric field. The induced electric-charge is measured when the composite is pulled with constant speed. The calculated piezoelectric constant may provide the key to be used as an actuator or sensor for this cellulose composite.

8342-68, Poster Session

Investigation of filler geometry and local debonding stress effects on mechanical properties of glass short fiber reinforced polycarbonate composites

W. Zhao, H. Kim, J. Suhr, Univ. of Delaware (United States)

Thermoplastic polymers are often reinforced by adding glass short fibers to improve Young's modulus and tensile strength of the polymers. However there often remains compromised, showing a decrease in impact strength. It is well-reported that toughness of a polymer is directly related to impact strength, which is an important property in many engineering applications where impact energy absorption and protection are important. Here, the focus of this study is to investigate glass short fiber geometry and the corresponding local debonding stress effects on toughness of the particulate polycarbonate composite materials. Glass short fiber reinforced polycarbonate composites are fabricated with three different aspect ratios of the fiber via a solution mixing technique. Tensile testing is performed for the glass fiber reinforced composites. The test results with emphasis on toughness are compared for the composites over pure polycarbonate. Also local debonding stresses vicinity of each glass fiber with different aspect ratios in composite are estimated by combining modeling and experiments. A FEM model is developed to determine local debonding stress at the interface between the fiber and matrix. The local debonding stress is found to considerably affect the toughness of the composites. An optimum aspect ratio of glass short fiber for enhancement in toughness is suggested for glass short fiber polycarbonate composite materials.

8342-69, Poster Session

Temperature tuning of band-structure of 1D periodic elastic composites

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In this paper we show that the band-structure of a periodic elastic composite, in addition to being dependent upon the micro-constituents and their microarchitecture, may also be tuned by changing the temperature. The essential idea is to fabricate a periodic composite with constituent materials which have temperature dependent elastic properties. As temperature is changed, such a composite is expected to exhibit a band-structure which changes with the temperature dependent properties of its micro-constituents. For our purpose, we use Polyurea and Steel to make a 1D periodic composite. Ultrasonic measurements are done on the sample from 100 kHz to 3 MHz under changing temperature and the changes in the first four pass-bands are studied. It is observed that the change in the band-structure is significant when the temperature is changed from -50 ˚C to 50 ˚C. Experimental results are compared with the theoretical calculations and it is shown that good agreement exists for the observed band-structure.

8342-70, Poster Session

Novel shape memory polyurethane containing silicone

C. Zhou, D. Li, D. Zhang, Y. Liu, J. Leng, Harbin Institute of Technology (China)

Shape memory polymers are ideal potential materials for the fabrication of special aerospace apparatus such as space deployable devices. However, conventional polyurethane (PU) exhibits poor thermal stability, water resistance, which limits their application in aerospace fields. A new kind of thermoplastic polyurethane containing silicone was investigated in this study. A series of polyurethanes with shape memory performance were synthesized by solution-polymerization, with

different molecular weights of hydroxyl- terminated polydimethylsiloxane (PDMS) and Polyethylene Glycol (PEG) as the soft segments and with 4, 4′-diphenylmethane diisocyanate (MDI) and 1, 4-butanediol (BDO) as the hard segments. The chemical compositions, structures, bulk and surface properties were investigated by using infrared surface quantitative analysis technique (FTIR-ATR), surface contact angle, stress-strain analysis, and dynamic mechanical thermal analysis (DMA). It was shown that the contact angle increased swiftly with raising PDMS content, indicating that water resistance ability improved with increasing PDMS content. The memory performance was increased as the molecular weight of soft segment. Physical cross linking was improved as hydrogen bond strengthen and further enhance polymer mechanical properties. The shape recovery rate of SMPU was greater than 95% and the shape recovery speed was in the range of 15-30 s.

8342-73, Poster Session

Fabrication of grape-like structures with micro capsule covering metal powder, and application to novel porous metal

S. Asano, T. Makuta, G. Murasawa, Yamagata Univ. (Japan)

We used a new method to fabricate salami-type porous metal from glass microcapsules and liquid metal. Each pore of its salami-like structure behaves as a micro-bell. This metal, which is more than 20% lighter than bulk material, also shows a unique characteristic: high-frequency oscillation is greatly attenuated when propagated in its medium. This method offers great potential for size, shape, and conformation control, with changed attenuation characteristics of its salami-like pore structure achieved merely by changing the grape-like structure obtained from previous process.

In present study, we fabricated some kinds of grape-like structures with microcapsules covering the whole surface of the metal powder. Salami-type porous metal was fabricated by subsequent mixing of the grape-like structures and liquid metal. Then, mechanical behaviors are measured for fabricated ones.

8342-74, Poster Session

Viscoelastic response of nanofiller enhanced carbon fiber epoxy composites

J. A. Varischetti, Univ. of Nevada, Reno (United States); J. Jang, J. Suhr, Univ. of Delaware (United States)

With a growing demands placed on the functionality and use of composite materials coupled with a growing interest in the use of nano scale fillers there exists a need to better understand the effects of nano scale fillers when used in conjunction with traditional carbon fiber epoxy composites. Of particular importance for improving the performance of carbon fiber epoxy composites is damping capacity, as composites having a high strength to weight ratio, are consequently poor at vibration attenuation, which can lead to premature wear and unwanted nose in composite structures. This study investigates the viscoelastic response of carbon nanofiber (CNF) reinforced carbon fiber epoxy composites. The viscoelastic response of CNF enhanced epoxy composites were characterized using Dynamic Mechanical Analysis (DMA) at wide ranges of temperatures and frequencies. For this study CNF enhanced resin was impregnated into conventional carbon fiber laminate composite materials; which were then tested using dynamic cyclic testing. It was observed that there exists the strong strain dependent behavior in the mechanical response, attributed to the random orientation of the CNF filler.

8342-75, Poster Session

Effects of aging on the shape memory behavior of highly nickel rich NiTi alloys

I. Kaya, H. E. Karaca, B. Basaran, Univ. of Kentucky (United States)

NiTi alloys are the most commonly used shape memory alloys and they have been widely employed in biomedical, electrical and mechanical applications. The Ni55Ti45 (at%) shape memory alloy shows many unique properties such as good corrosion resistance, smooth surface finish and high toughness. It should be noted that their properties are highly sensitive to the heat treatments. This study investigates the effects of aging on the phase transformation behavior and mechanical properties of Ni55Ti45 alloys. DSC, X-ray diffraction, hardness and compression tests were carried out to investigate the effect of aging on the transformation behavior and microstructure. It has been found that Ni55Ti45 shows multiple step transformations with 1-3% transformation strain and low irrecoverable strain under stress levels as high as 1000 MPa.

8342-76, Poster Session

Piezo actuator shape design for optimized ultrasonic radiation in phased array applications

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This contribution deals with the influence of specific shape design of piezo disc actuators used for Lamb wave excitation with respect to structural health monitoring applications. Piezo disc actuators, bonded onto isotropic material theoretically show a circular directivity pattern. Especially in the case of structural health monitoring applications it is important to generate sufficient powerful lamb waves to cover long distances, especially in the case of high damping materials. So for structural health monitoring actuators it is advantageous to focus the generated energy to the angle of interest. Beam forming is a method to create a directivity pattern with a powerful narrow main lobe and suppressed side lobes by using an array of piezo discs. By adjusting the phase of the signals that drive the single actuators of the array, the direction of the main lobe can be adjusted. The disadvantage of forming arrays of disc actuators is that the main lobe is generated on both sides of the array and so unwanted excitation in the 180° direction is produced. To find an optimal shape of a single piezo disc actuator for array application with just one main lobe investigations have been carried out. The manufacturing of the arbitrary shapes was done by micro machining. Calculations have been done to estimate the directivity pattern. Furthermore, simulations have been done to optimize the directivity pattern for the use of shaped piezo disc actuators in a phased array. Practical experiments have been done by bonding the actuators onto steel sheets, exciting them with different signals and scanning the directivity pattern with a laser scanning vibrometer.

8342-77, Poster Session

Analysis of functionally graded piezoelectric plates in actuator mode

R. G. Reid, R. Paskaramoorthy, Univ. of the Witwatersrand (South Africa)

Functionally graded piezoelectric plates have been extensively studied using two-dimensional theories. Many of these analysis techniques are extensions to approaches used for fibre-reinforced plastic (FRP) laminates. The effects of through-thickness strains are consequently considered since they can be significant in FRPs. Functionally graded piezoelectric materials (FGPMs) are usually made from ceramics, however, and so their through-thickness moduli are of the same order

as their in-plane moduli. Errors introduced by neglecting the effects of through-thickness strains are consequently far smaller than for FRPs. When the piezoelectric material is operating in actuator mode therefore, classical lamination theory (CLT) can provide useful estimates of the deflection and stresses in thin to moderately thick plates. Since CLT does not accommodate material properties that progressively change, it is consequently usual to discretize each layer of FGM into a large number of sub-layers and then use a constant set of material properties appropriate to each sub-layer. It is preferable, however, to use a method that directly considers variation in material properties. This paper presents such an approach, formulated as an extension to classical lamination theory. The true through-thickness variation in material properties and loading is approximated by polynomial series of sufficiently high order that accurate results are ensured. The resulting mathematical problem can be explicitly formulated irrespective of the actual variation in material properties and loading. Results obtained from the present method are compared against exact three-dimensional approaches to demonstrate the convenience and accuracy of the method.

8342-78, Poster Session

Strain gradient elasticity solution for functionally graded thick-walled cylinders

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In this paper, strain gradient elasticity formulation for analysis of thick-walled FG (Functionally Graded) cylinders is presented. The material properties are assumed to obey a power law in the radial direction. The governing differential equation is derived as fourth order ODE. A power series solution for stresses and displacements in thick-walled FG cylinders subjected to internal and external pressures is obtained. Some numerical examples are solved to study the effect of the characteristic length parameter and FG power index on the stress distribution in the thick-walled FG cylinders. It is shown that the characteristic length parameter has a considerable effect on the stress distribution of FG micro cylinders. Also, increasing material length parameter leads to decrease of the maximum radial and tangential stresses. Furthermore, it is shown that the FG power index has a significant effect on the maximum radial and tangential stresses.

8342-80, Poster Session

Mechanical vibration induced electrospinning of polyvinylidene difluoride

K. S. Moon, S. Kassegne, K. Morsi, A. Sepehri, San Diego State Univ. (United States)

Polyvinylidene difluoride (PVDF) is a polymer that is widely studied due to excellent mechanical properties, chemical stability and ferroelectricity. PVDF is a piezoelectric polymer with a low-cost, high flexibility and biocompatibility that is suitable for various energy conversion applications between the electrical and mechanical forms of energy. One of the novel techniques to create a PVDF fiber thin film is electrospinning. In electrospinning, charged droplets are dispersed from the tip of the Taylor Cone and are delivered to the target. If the liquid consists of a polymer melt or a polymer in solution and the concentration of that polymer is sufficiently high to cause molecular chain entanglement, a fiber, rather than a droplet, is drawn from the tip of the Taylor cone.

In the present work, the above technique has been applied to develop electrospun thin-film based on PVDF with the use of high electric field and a high-frequency mechanical vibratory motion as an electrospinning setup. The high-frequency vibratory motion is to create effective fluid viscous forces to achieve a localized fluid spreading and thinning behavior of extremely small polymer solution droplets or thin fibers. The effect of the mechanical vibration on the fiber formation on the target surface is studied. It is also demonstrated that a continuous and uniform thickness layer can be formed due to enhanced wetting and subsequent drying of isolated polymer droplets on the substrate. Deposition temperature can be controlled to optimize the wetting and drying process.

8342-81, Poster Session

Characterization of friction joints subjected to high levels of random vibration

O. de Santos, P. MacNeal, Jet Propulsion Lab. (United States)

When designing optical devices, the alignment of every element is integral to the proper functionality of the device. If any of these elements is secured by means of a friction joint, it is important to understand the limitations of the joint when vibrations (mainly during launch) occur; a phenomenon called “stick-slip” may happen and permanently displace joints relying on friction and cause optical misalignments. There is little to no data documenting the characteristics of the “stick-slip” phenomenon on friction joints under random vibratory motion.

The test program was designed with the aim of gathering data that would broaden the understanding of the “stick-slip” phenomenon and among other things provide sufficient information to quantify the static coefficients of friction of several single-bolt friction joint material pairings. This paper describes the test program in detail including test sample description, test procedures, and vibration test results of multiple test samples. The aforementioned material pairs used in the experiment were aluminum-aluminum, aluminum-dicronite coated aluminum, and aluminum-plasmadize coated aluminum.

Levels of vibration for each set of twelve material pairings were gradually increased until all samples experienced substantial displacement. Data was collected on 1) acceleration in all three axes, 2) relative static displacement between vibration runs utilizing photogrammetry techniques, and 3) surface galling and contaminant generation. This data was used to estimate the values of static friction during random vibratory motion when “stick-slip” occurs and compare these to static friction coefficients measured before and after vibration testing.

8342-82, Poster Session

Applications of multifunctional polymer-matrix composites in hybrid heat sinks

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Designers of electronic devices and telecommunications equipment have developed a variety of cutting-edge designs to boost the performance and portability of their products. One emerging technique is the use of a three-dimensional (3D) chip architecture, which vertically integrates a stack of chips, to increase the number of transistors on integrated circuits. Although the performances of system components are improved by integrating a very large System on a Chip (SoC) in multiple tiers, this also dramatically reduces the average distance between system components. As a result, these latest chips generate excessive amount of heat, and raise the temperature to an unacceptable level, thus shortening their lifetime. Heat sink designs which are optimized are one approach to minimizing the temperature rise. Traditionally, thermally-enhanced Kapton films would be sandwiched between the heat sinks and the chips, providing the required electrical insulation. Nevertheless, despite the thermal enhancement improvements to these films, which tripled the thermal conductivity (k) of the material, the value of k is only 0.37 W/mK. Such low thermally-conductive layers significantly restrict the dissipation and management of heat in electronic assemblies. Therefore, the drive for improved cooling efficiency requires the optimization not only the heat sink, but also the interface materials.

The main objective of this research is to develop novel polymer-matrix composite thermally conductive films that satisfy thermal, electrical, and mechanical requirements. These films can be attached to the bottom faces of the heat sinks, resulting in a hybrid heat sink structure, to satisfy

the electrical insulation requirements. A series of parametric studies were conducted to elucidate the effects of matrix materials, filler materials, and composite morphologies on the thermal, electrical, and mechanical properties of the thin film. The heat dissipation performance of the hybrid heat sinks were experimentally simulated by measuring the temperature distribution of the hybrid heat sinks attached to a 10 W square-faced (i.e., 10 cm by 10 cm) heater. Experimental simulation showed that the maximum temperatures on the heater were reduced by about 10°C when the thermally conductive polymer-matrix composite films were used to replace the Kapton film. It is believed that these thermally conductive and electrically insulative films would serve as a partial solution to enhance the cooling of future SoCs, thus allowing chip designers to achieve higher CMOS performance and efficiency trends in the future.

8342-83, Poster Session

Challenges of the electromechanical characterization of structural supercapacitors

C. Ciocanel, D. LaMaster, C. Browder, Northern Arizona Univ. (United States)

Development of multifunctional materials has gained significant momentum in the recent years. However, there are many challenges associated with the assessment of the properties of these materials. This paper focuses on the challenges associated with the electromechanical characterization of structural composite supercapacitors, both in and ex-situ. Discrepancies between capacitance values determined with two measurement methods are discussed and solutions for robust capacitance measurements are proposed. Furthermore, the effect of in-situ characterization on both electrical and mechanical properties is analyzed.

8342-84, Poster Session

Electrical characterization of multilayered structures for electro-bonded laminates

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This work reports on the experimental validation of multilayer dielectrics as suitable candidates of electro-bonded laminates EBL1,2. The EBL are structures able to switch, on demand and reversibly, their bending or torsional stiffness between a compliant state and a stiff state through a combination of electrostatic forces and friction. Further to the application of a voltage signal, the change in bending stiffness is expected to be proportional to the square of the number of layers constituting the EBL. While the change in bending stiffness is a pure geometrical consequence due to the onset of the physical bonding between the layers, the shear strength of the EBL is depending on the electrical properties, i.e., dielectric strength and relative permittivity, of its constitutive layers. The goal is that of obtaining values of shear strength comparable to those of an epoxy resin, i.e., 10 - 15 [MPa]. In recent work3 we suggested the use of multilayered structures having, theoretically, enhanced dielectric and insulating properties as constitutive components of EBL. In this work this hypothesis is validated and assessed on two particular multilayered structures through low frequency and high voltage electrical measurements. The results obtained will serve as a basis of their future optimization for a chosen working frequency.

Acknowledgements

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8342-32, Session 8

Design of a deployable structure with shape memory polymers

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Auxetic (negative Poisson's ratio) configurations have been used recently to build prototypes of deployable structures using classical shape memory alloys (Nickel-Titanium-Copper). Chiral configurations, featuring three or more inter-connected spiral-wound hubs, exploit efficient tensile-rotational mechanisms. These structures offer high deployability ratios in structural elements with load-bearing characteristics. Shape memory polymers have the potential to replace conventional shape memory alloys and other stored-energy actuators, and have the attractive properties of low mass, high actuation strain, easy fabrication and tunable thermal properties. In this work we discuss how shape memory polymers (SMP) integrated into a chiral core could offer enhanced deployable characteristics and increase the efficiency of the auxetic deformations in these unusual cellular structures. We consider the spiral-wound fundamental component needed for SMP n-chiral prototypes and present test results showing actuation motion of expanding SMP deployable structures. The angle of attachment of struts to hubs can be varied in order to tune the mechanical stiffness and compressibility of the deployed structure. The balance between axial loading in radial-connected struts and flexural loading in tangentially-connected struts can also be matched to the material properties and tailored to the application. Applications likely to benefit from these structures include lightweight elements for structural engineering applications, deployable structures for space applications and implantable medical devices.

8342-33, Session 8

Fabrication of sub-micron unidirectional patterns on shape memory polymer substrates

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Previously, we demonstrated the self-assembly fabrication of well-aligned unidirectional wrinkle patterns using pre-programmed shape memory polymer (SMP) as the substrate in an organic-inorganic bi-layer structure. In this study, the aforementioned corrugated-surface samples are used in two ways as the templates to create patterns whose wavelength is further reduced to hundreds of nanometers on SMP substrates. On one hand, they serve as the master to make a replica of a triple-shape SMP during a hot-pressing process. Unlike conventional SMPs, a triple-shape SMP is capable of recovering from one temporary shape to anther before returning to the permanent in sequence upon heating. In our case, it is programmed in such a way that it expands when the wavy surface features are transferred from the master, as the first transition temperature is reached. When temperature is further increased to the second transition point, it shrinks to return to the permanent shape resulting in the wavelength reduction of the initial wavy structure. On the other hand, the samples are employed as the mold of nanopatterning. Microdroplets containing nanoparticles are sandwiched between the mold and an SMP substrate. Through the evaporation of water and a local dewetting process, nanoparticles are deposited on the substrate as equal-spacing lines. At elevated temperatures, the SMP substrate shrinks to recover the permanent shape, further reducing the spacing of nanoparticle. The present study is expected to offer an effective path of creating sub-micron patterns with the potential of bottom-up nanodevices.

8342-34, Session 8

Shape memory performances and thermomechanical properties of shape memory cyanate composites

F. Xie, L. Huang, Y. Liu, J. Leng, Harbin Institute of Technology (China)

Shape memory cyanate composites are a new kind of smart materials, which have huge development potential and a promising future. A series of shape memory cyanate composites were prepared by cyanate ester, varying content of modifiers and some reinforcing fillers. The microstructure, thermal property, mechanical property and shape memory property of the shape memory cyanate composites were investigated by Fourier Transform Infrared spectroscopy (FTIR), Differential Scanning Calorimetry (DSC), Thermal Gravimetric Analysis (TGA), Dynamic Mechanical Analysis (DMA) and tensile test. The shape memory cyanate composites we prepared showed excellent mechanical properties, high glass transition temperature and heat resistance. The glass transition temperature can be adjusted from 156.9°C to 259.6°C, which is identical to pure shape memory cyanate polymer. The initial temperature of thermal decomposition came up to 300°C, which is enough high for the application in aerospace fields. The effects upon the cross-linking density, the mechanical property of fillers and modifiers were also investigated in the work. With the increasing modifier, the cross-linking density decreased, and then resulted in the decrease of tensile strength, but the fracture elongation increased. The shape memory composites we prepared show a good shape memory effect, as the shape recovery time is less than 100s and the shape recovery rate reaches 95%.

8342-35, Session 9

Analysis of the shape-recovery performance of thermally-activated shape-memory polymer composite with microstructural heterogeneities

M. Nishikawa, M. Hojo, Kyoto Univ. (Japan)

Thermally-activated shape-memory polymers (SMPs) are being investigated for practical use as deployable space structures, such as large antennas and long booms, employing the unique thermomechanical properties of these polymers around their glass transition temperature. The shape-fixity properties that the special multifunctional polymers exhibit can be utilized to fold up the structure so as to maximize the carrying capacity in rockets, while their shape-recovery properties facilitate their deployment in orbit. As SMPs are polymeric material, they do not have sufficient strength and stiffness when it is used as a structural material. In order to improve their strength and stiffness, the reinforcement with fillers including fibers or particles has been investigated in recent years. Such reinforcement increases the stiffness of SMPs, but it also decreases their shape recoverability. Our previous study, focusing on the microstructural effect in the SMP composite reinforced with carbon fibers, revealed that the degradation of shape recoverability is caused by the irrecoverable strain around the fiber ends and the degradation is closely related to the fiber volume content. Therefore the microstrutural design at the filler/matrix level is required to pursuit the better performance of SMP composite. In the background, we attempted to model the shape-recovery performance of the thermally-activated shape-memory polymer composites with microstructural heterogeneities in in-plane direction and in thickness direction. Using the model, we discussed how the gradient of filler content in the composite affects the shape-recovery properties of the whole composite.

8342-36, Session 9

Tailoring the time-dependent recovery of shape memory polymers

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On application of heat, thermally activated shape memory polymers (SMPs) are able to revert to a primary shape from a secondary shape, induced by mechanical deformation. In certain biomedical applications, it is desirable to induce shape recovery at controlled rates under quasi-isothermal conditions (body temperature), requiring knowledge of the time dependent response of SMPs.

In the present work, the time dependence of isothermal shape recovery has been investigated for a set of shape memory polyurethanes (SMPUs), in which the molecular architecture has been varied systematically. The viscoelastic and structural properties have been characterized using dynamic mechanical analysis (DMA) and isothermal shape memory tests carried out using a universal testing system (UTS) with optimized temperature control. The relationship between the viscoelastic properties of the various SMPUs, their time-dependent shape memory behavior and their molecular architecture is then discussed in terms of a simple 1-D model incorporating continuous relaxation spectra, whose detailed form may be identified with specific features of the polymer network and hence manipulated by modifying the basic formulation.

A key finding is the close correlation between the evolution of the loss factor, tan , with temperature during DMA scans at fixed frequency, the distribution of segmental mobility within the polymer network and the isothermal shape recovery rate. It is demonstrated that this knowledge may be exploited in the design and thermo-mechanical processing of SMPs, where predictable and reproducible shape recovery rates are required.

8342-37, Session 9

A model for intrinsic activation of shape memory polymers via a microvascular network

Y. Li, N. C. Goulbourne, Univ. of Michigan (United States)

No abstract available

8342-38, Session 9

Qualitative separation of the phase transition temperature of solvent responsive shape-memory polymer by Flory-Huggins theory

J. Yin, Harbin Univ. of Science and Technology (China)

In this study we analyzed the phase and state transitions of shape-memory polymers (SMPs) and solvent mixtures using the Flory-Huggins (FH) theory by extension of Vrentas and the Couchman-Karasz theory for glass transition, as well as Clausius-Clapeyron relation for melting transition. Using scaling relations of model parameters, we have obtained a theoretical prediction of phase and state diagrams of the transition temperature and solvent responsive shape recovery behavior of SMPs. The decrease in transition temperature is identified as the driving force for the shape-memory effect (SME) of SMPs in response to a solvent. Consequently, the thermodynamics of the polymer solution and the relaxation theory were used to characterize the dependencies of shape recovery time on the FH parameter and the ratio of the molar volume of solute to solvent. With the estimated model parameters, we constructed the state diagram for SMP, which is a powerful tool for design and analysis of phase transition temperatures and solvent responsive shape recovery behavior.

8342-30, Session 10

Electro-active spandex reinforced shape memory composites incorporating carbon nanotubes

J. Sun, Y. Xu, Y. Liu, J. Leng, Harbin Institute of Technology (China)

In this presented paper, spandex fibers with high elasticity and high recovery ratio were added into shape memory epoxy resin, and the mechanical property as well as recovery ratio and speed of the shape memory polymers composites (SMPCs) were improved obviously compared with pure shape memory resin. Young's modulus increases by 28.2%, tensile stress by 49.7% and fracture strain by 16.4% in samples with 20vol% spandex, while recover speed by 36s for samples with 40vol% spandex. Then graphitized multi-walled carbon nanotubes (GMWNTs) were mixed into the spandex reinforced SMPCs to make it electro-active. It was found that surface-modified (by acid treatment) GMWNTs incorporated very well with epoxy resin, and dispersion was achieved by high-energy sonication at a proper temperature atmosphere. Scanning Electron Microscope (SEM) results showed the particulate additives were dispersed homogeneously within SMPCs served as conductive paths. The electrical conductivity of the composites investigated by Four-point Probe Method increased as the surface-modified GMWTs increased (an order of 10-4 S cm-1 was obtained in samples with 4.5wt.% modified-GMWNTs content). For the mechanical property of SMPCs with 4.5wt.% modified-GWMNTs, its Young's modulus increase by 300% and the tensile stress by 26% compared with those of pure spandex reinforced SMPCs. However the SMPCs' fracture strain decreased when containing surface-modified GWMNTs.

8342-39, Session 10

The relationship between constituent properties and bending actuation of shape memory composites

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Shape memory composites (SMCs) based on shape memory alloys (SMAs) and shape memory polymers (SMPs), show great promise in adaptive structures due to their ability to combine strong actuation force of SMAs with the large deformation of SMPs. In order to optimize their actuation properties, sensitivity studies must be conducted to determine the most impactful parameters in determining the ultimate behavior of the SMC. The present study focuses on thermal and mechanical characterization of SMCs composed of Nickel-Titanium SMA and a styrene based SMP in order to elucidate the critical material properties for a functioning SMC. Here, the SMA wires have been trained with a one-way shape memory effect (SME) and integrated on the surface of the SMP. A morphing system was obtained by introducing SMA wires on the SMP system in the volume fraction range of 0.5% to 1.2%. It is clear that the proper balance of activation forces and modulus between the SMP and SMA is an important feature to consider when developing a SMC. Also important is a proper pairing of glass transition temperature for the SMP with the phase transition temperatures for the SMA. In addition, the current study has shown that during the heating process of the SMC, the thermal expansion of the SMP appears to overcome the actuation forces of the SMA wires, showing that the thermal expansion is also a critical variable for the composite performance. Based on these results, both the SMA and the SMP constituent parameters of temperatures, elastic modulus, actuation force, and thermal expansion are considered with regards to future tailoring the SMC performance.

8342-40, Session 10

Conductivity of graphene oxide thin films on a shape memory polymer (SMP) substrate during SMP programming and recovery

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In the present study, we investigate the conductivity of graphene oxide (GO) thin films deposited on shape memory polymer (SMP) substrates during SMP programming and recovery. The samples of GO thin films on SMP were fabricated using the layer-by-layer deposition technique. Graphite oxide was synthesized from graphite using the modified Hummers method. A mixture of graphite oxide in distilled water was sonicated using an ultrasonic cleaning bath to exfoliate individual GO platelets. A positively charged solution was obtained by addition of poly(styrene sulfonate) (PSS) to the GO solution, whereas a solution of poly(diallyldiamine chloride) (PDDA) was used as the negatively charged solution. SMP substrates were fabricated using a mixture of EPON resin 826 and Jeffamine D-230. The conductivity of these GO thin films were measured using a four-point probe during SMP programming for various strains, and during the recovery process. This research will provide information for designing graphene-based strain sensors.

8342-41, Session 10

Experimental and analysis of shape memory polymer composite tube

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As a typical smart material, shape memory polymers (SMPs) have the capability of variable stiffness to external stimuli, such as hear, electricity, magnetic and solvent, et al. In this research, a shape memory polymer composite (SMPC) tube composed of multi-layered filament wound structures is investigated. Significant changes in axial elastic modulus could be achieved through regulating the temperature. The SMPC tube possesses the flexibility under high temperature condition and the rigidity under low temperature condition. Based on the classical laminated-plate theory, the analysis results are deemed to possess satisfying accuracy with the experiment results in the axial elastic modulus prediction. In addition, the axial elastic modulus ratio is discussed under different material and geometry parameters of the SMPC tube. The presented analysis provides meaningful guidance to assist design and manufacture of SMPC tube in morphing skin applications.

8342-42, Session 10

Analyses the local buckling of double films bonded to fiber reinforced shape memory polymer

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In order to enhance the stiffness and improve the recovery force of SMP, we bonded a film of a stiff material (e.g., a metal) on a substrate. Specifically, the film is bonded to both surface of a compliant substrate, which was made of fiber reinforced shape memory polymer composite. When subject to finite flexure deformation, due to the effects of microbuckling and the shift in the neutral-strain surface, the fiber-reinforced SMP composites laminate can achieve much larger compressive strains than traditional hard-resin composite.

In this paper, we model the substrate as a layer of elastic solid. Besides, the theory of von Karman elastic nonlinear plate is employed to models the film. According to the minimal energy principle, the key parameters' analysis expressions in the flexural deformation process was calculated and the strain energy expression of shape-memory composite

thermodynamics system was further developed. Additional, the local post-buckling mechanics of unidirectional fiber-reinforced shape-memory polymer laminate was further discussed.

At last, we conducted experiments to testify the correction of the key parameters of shape-memory polymer composite material laminate under flexural deformation and the value of the experiment proved that the theoretical prediction is correct.

8342-43, Session 10

Significantly improving electromagnetic performance of nanopaper and its shape-memory nanocomposite by aligned carbon nanotubes

H. Lu, Harbin Institute of Technology (China)

A new nanopaper that exhibits exciting electrical and electromagnetic performance is fabricated by incorporating magnetically aligned carbon nanotube (CNT) arrays into carbon nanofibers (CNFs). Electromagnetic CNTs were blended with, and aligned into the nanopaper using a magnetic field, to significantly improve the electrical and electromagnetic performance of nanopapers and their enabled shape-memory polymer (SMP) nanocomposite. The morphology and structure of the aligned CNT arrays in nanopaper were characterized with scanning electronic microscopy (SEM). A continuous and compact network observed from the microscopic images indicated that the nanopaper could have highly conductive properties. Furthermore, the electromagnetic interference (EMI) shielding efficiency of the SMP nanocomposites with different weight content of aligned CNT arrays was characterized. Finally, the aligned CNT arrays in nanopapers were employed to achieve the electrical actuation and accelerate the recovery speed of SMP nanocomposites.

8342-46, Session 11

The effect of axial demagnetization on the predicted voltage output of a MSMA power harvester

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Magnetic shape memory alloys (MSMAs) are a class of materials that exhibit large, recoverable inelastic strain. MSMAs are useful for energy harvesting applications because of the change in magnetization they exhibit when loaded magneto-mechanically. This change in magnetization can be detected and converted into electrical power by a pick-up coil surrounding the material during cyclic mechanical loading.

This paper compares experimental results and model predictions on power harvesting of magnetic shape memory alloys (MSMAs). The theoretical predictions are made using a refined thermodynamic based constitutive model, developed initially by Kiefer and Lagoudas (2006, 2009), and improved by Waldauer et al. (2011). In an attempt to better predict the observed experimental response of the material the axial demagnetization field is included in the simulation. Simulated results are compared with those generated using the original Kiefer and Lagoudas model.

8342-47, Session 11

Magneto-thermo-mechanical characterization of NiMn based metamagnetic shape memory alloys under high fields

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Magnetic shape memory alloys have attracted significant attention as magnetic actuators due to their high frequency response and high actuation strains. NiMn based metamagnetic shape memory alloys represents magnetic field induced phase transformation between ferromagnetic and weakly (or non) magnetic phases. In these alloys, Zeeman energy can be increased with magnetic field, thus metamagnetic shape memory alloys provides orientation independence and higher actuation stress levels than NiMnGa alloys.

In this study, the results of NiMn based metamagnetic shape memory alloys such as NiMnCoGa with almost perfect superelastic behavior in polycrystalline form and high temperature phase transformation (above 100 oC), NiMnCoIn and NiMnSn alloys will be presented including shape memory effect under constant stress and magnetic field (up to 9 Tesla), isothermal stress cycling under magnetic field and isothermal stress generation with magnetic field.

8342-48, Session 11

Ultra low-power computing with multiferroic nanomagnets

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We have theoretically shown that multiferroic nanomagnets (consisting of a piezoelectric and a magnetostrictive layer) could be used to perform computing while consuming ~100 kT/bit (Appl. Phys. Lett. 97,173105, 2010). In contrast, today's transistors consume several 100,000 kT/bit. The next question was whether such ultra-low power logic devices could switch at competitive speeds. We therefore solved the LLG equations and showed that such multiferroic nanomagnets could switch at clock rates of ~1GHz, while dissipating ~ few 100 kT of energy/bit and can act as both memory (Appl. Phys. Lett. 99, 063108, 2011) and logic elements (Nanotechnology, 22, 155201, 2011, arXiv:1108.5758v1).

In this work we will present:

1.Theoretical study of stress induced magnetization dynamics in multiferroic nanomagnets.

2.Experimental fabrication and of such devices using e-beam lithography to create ~ 100 nm diameter elliptical nanostructures.

3.Simulation of a NAND gate with fan-out to evaluate the use multiferroic nanomagnets as an ultra-low power paradigm for traditional computing.

4.Demonstrating that dipole coupling between such multiferroic nanomagnets could also be elicited to perform higher order image processing applications such as image reconstruction and pattern recognition.

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8342-86, Session 11

Mechanisms of stiffening effect in magneto-rheological elastomers

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A polymer-matrix filled with magnetic particles forms an active composite. When an external magnetic field is applied the particles can be aligned into chain-like structures, such anisotropic composite is called a magneto-rheological elastomer (MRE). The stiffness of an MRE increases in a magnetic field, such stiffening effect exists in both shear and tensile moduli. However, the usual models fail to explain both phenomenon simultaneously. In this work, two different approaches are used to investigate the mechanisms of stiffening in MRE: a dipolar interaction model and a micromechanics model with continuum field theory. It is found that the microstructure of filler chains is key to the stiffening under a magnetic field parallel to the particle alignments: an

MRE with straight chains has an increase in the shear modulus but a reduction in the tensile modulus; in the contrast, an MRE with wavy chains can induce stiffening in both cases. In addition, the chain-chain magnetic interaction and the local non-uniform deformation are shown to be insignificant. It illustrates that the filler concentration plays an important role on the magnitude of stiffening effect, as observed in experiments.

8342-49, Session 12

Analytic and computational multi-scale micromechanics piezoresistive models for fuzzy fiber composite material

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The fuzzy fiber material system of interest herein is an engineering material that has a glass fiber core, with dense carbon nanotube "forest" emanating radially from the fiber surface along the length of the fiber. The interest in the fuzzy fiber material stems from its multifunctional nanocomposite interphase region which can provide enhanced load transfer and damage resistance in addition to providing electromechanical coupling in the form of piezoresistivity. The later functionality of the interphase is of particular interest as it pertains to the structural health monitoring (SHM) application envisioned for the fuzzy fibers in advanced hybrid composites for hypersonic aerospace vehicles. In the present work, the focus is on structural composites with an integrated structural health monitoring capability due to the inclusion of fuzzy fibers. While there is ample experimental evidence demonstrating the piezoresistive response of nanocomposites, the mechanisms governing piezoresistivity in nanocomposites are unclear, meaning there is little guidance for how to tune parameters to make better (higher gage factor) nanocomposite strain sensors. Here we seek to evaluate one of proposed mechanisms behind the piezoresistivity of nanocomposite material which is the inherent piezoresistivity of the carbon nanotubes. Both analytic and computational multiscale modeling approaches are employed herein to assess the magnitude of inherent piezoresistivity required to generate experimentally observed gage factors for piezoresistive nanocomposites.

8342-50, Session 12

Investigation of aligned carbon nanotube architectures to understand the actuation mechanism

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As a result of their extraordinary properties like low density, high Young's modulus, excellent electrical and thermal conductivity (etc.) carbon nanotubes (CNTs) reunion the world's research in the common effort to understand and to control this material within an application.

Besides already meeting requirements of lightweight construction, the ability of CNT-based structures to strain in the presence of free-movable ions and an electrical field, can help to reach bio-inspired structural adaptability.

Recent publications of a divergent CNT actuation behavior cause a science discussion about the driving mechanism, if it is either an electrostatic or a quantum-mechanical effect or a combination of both.

This paper focuses on testing aligned CNT-architectures in order to investigate the behavior of single CNTs along their axis.

In a first approach the actuation of aligned arrays of multi walled carbon nanotubes (MWCNTs-forest, -carpet) along the orientation axis of the single CNTs is detected optically. The influence of different heights and different ionic liquids is investigated.

In a second approach CNT-structures of randomly oriented CNTs as well as single CNTs of defined chirality are analysed electrochemically via Raman spectroscopy.

The tested materials in combination with the used experimental set-ups promise a more detailed understanding of the electrochemical processes at the surface of the single tubes and their resulting active behavior

8342-51, Session 12

Enhanced multifunctional properties of nanocomposites using MWCNTs

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New polymer-based nanocomposites have been pursued in recent years due to the novel properties of carbon nanotubes. Due to their superior thermal, mechanical and electrical properties, carbon nanotubes are being used as additives to various structural materials, resulting in multifunctional properties at low weight ratio.

In this paper, the mechanical and electrical properties of nanocomposites using multi-walled carbon nanotubes (MWCNTs) are studied. The weight ratio of MWCNTs varies from 0.01% to 5%. The mechanical properties measured are the Young's modulus, ultimate tensile strength, and fracture toughness. Tension, compression and three point bending tests are conducted to study and validate the improvement in mechanical properties. A digital image correlation system is used to accurately characterize the material response under both uniaxial and flexural loading. Electrical conductivity can be significantly improved using MWCNTs. The electrical conductivity of nanocomposites with different weight ratio is measured following ASTM standard D991. Finally, the MWCNTs are combined with commercial carbon fiber reinforced polymer matrix composites to develop high performance multifunctional composites with improved interlaminar elastic properties and electrical conductivity.

8342-52, Session 13

Effects of copper addition and annealing temperature on transition temperature of Ni-Ti shape memory alloys

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Shape memory alloy (SMA) wires are capable of providing contractile strain (~4%) mimicking the functionality of muscle fibers. They are quite promising in the field of embedded actuators due to their high power density, large stroke and low profile. The focus of our research was to address the two main drawbacks associated with these actuators, namely, transition temperature and manufacturing cost. Lowering the transition temperature allows the reduction in overall power consumption which is currently quite high for commercially available SMA's. Further, lower transition temperature may provide higher cyclic frequency due to less build-up of residual heat in the embedded structures. An alloy with composition of 55.5 wt% Ni - 44.5 wt% Ti was used as the base composition. Copper was added to the alloy in a controlled manner during processing. The addition of copper was found to reduce the transition temperature and thermal hysteresis. The samples were melted using an RF induction furnace in an inert argon atmosphere to prevent the formation of oxides and nitrides. The effect of annealing temperature on the transition temperature was also analyzed. Annealing temperatures of 700°C, 800°C, and 900°C were tested with a dwell time of 600 seconds followed by water quenching. All the synthesized samples were characterized for transition temperature, contraction strain, power consumption and cooling time. The method presented in this work provides a low cost technique for tailoring the transition temperature of nickel titanium based shape memory alloy actuators.

8342-53, Session 13

Stress-induced tuning of ultrasonic additive manufacturing Al-NiTi composites

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This paper deals with the development of active metal-matrix composites manufactured by Ultrasonic Additive Manufacturing (UAM), an emerging manufacturing process that allows the embedding of materials into metals through ultrasonic consolidation. In the UAM process, successive layers of metal tapes are ultrasonically bonded together at low temperatures, below 195°C, to form a metal matrix. Being a low-temperature process, UAM offers unprecedented opportunities to create parts both with embedded thermally sensitive materials, such as polymers, shape memory alloys, and other smart materials, as well as arbitrarily shaped internal features. In this study UAM is used to create composites with aluminum matrices and embedded NiTi elements. The incorporation of NiTi allows for unique composite properties such as the ability to tailor the overall composite coefficient of thermal expansion and tune the dynamic stiffness of the composites thereby shifting their natural frequencies. Both of these effects are due to blocking stresses developed by the prestrained NiTi elements embedded within the Al matrix. Since the embedded NiTi elements are constrained by the Al matrix, thermally induced transformation from detwinned martensite to austenite will be inhibited, instead producing a blocking force proportional to temperature. These effects will be observed and modeled by combining strain matching algorithms with thermomechanical constitutive models.

8342-54, Session 13

An innovative approach to achieve self centering and ductility of cement mortar beams through randomly distributed pseudo-elastic shape memory alloy fibers

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Fibers can play a major role in post cracking behavior of concrete members which are the elements connect the crack and distribute the stress across the crack. Addition of fibers in mortar can improve toughness of the members and energy dissipation through yielding. In general, fiber reinforcement undergoes plastic deformation with in a low strain level itself and especially steel fibers cannot regain their shape beyond yielding. So, self centering ability of the fibers is a desired characteristic in addition to ductility of the reinforced cement concrete undergo cyclic loading conditions (caused by earthquakes, for example). Further loading on this cracked member results in debonding of fibers leading to enormous performance deterioration.

An alternative reinforcement material such as shape memory alloy (SMA) could offer a scope for self-centering, thus improving performance especially after a severe loading has occurred. This is substantiated in controlled study conducted previously by the authors. In this study, the load-deformation characteristics of SMA fiber reinforced cement mortar beams under cyclic loading were investigated to assess the self centering mechanism. This study involves experiments on a beam structure and related analysis for the prediction of self-centering. Volume fraction of NiTi (SMA) fibers used in this study is varied from 0% to 0.5% with an increment of 0.25%. Cement mortar prism of size 40mmx40mmx160mm were tested by three point loading and were evaluated with respect to its selfcentering in the case of deflection, while it is subjected to loading and unloading. Then it has compared with the case of same volume fraction of steel fibers also.

It is found that NiTi fibers dominate over steel fibers in the case of selfcentering, energy dissipation case and so it is highly competent in the case of ductility. It may be crucial in bringing back the functionality of a structure and prevention of permanent secondary deformations that may lead to catastrophic failure in some structures. Also an attempt has been made to find the minimum dosage of fiber by reducing fiber length so that more the availability of fibers to stitch the crack. Since hook part act as an anchorage and will take care of proper bonding. NiTi Fibers of diameter 0.5mm and length 40mm were used in preliminary study and then conducted a further study based on the reduction in length of fiber to 28mm for the sake of improving the availability fibers at crack with the same volume fraction. Apart from the energy dissipation through its ductility, it is shown in this study that shape memory alloy reinforced cement mortar has very good self-centering properties.

8342-55, Session 13

Shape memory behavior of high strength NiTiHfPd alloys

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NiTiHfPd shape memory alloys are newly developed qua-ternary functional materials that recover shape against high stress levels (1000 MPa) and can show perfect superelastic behavior under extremely high stress levels of 2000 MPa at elevated temperatures in contrast to low strength conventional NiTi alloys. High strength NiTiHfPd alloys can be used in aerospace, automotive industry as actuators in morphing structures and also in bio-medical industry as high strength stents. In this study, we will show that various aging temperatures and time are very effective in manipulating transformation temperatures, strain, hysteresis and strength. It will also be revealed that NiTiHfPd can generate several times higher work output and can absorb relatively larger energy than other NiTi-based shape memory alloys.

8342-56, Session 14

Phenomenological modeling of induced transformation anisotropy in shape memory alloy actuators

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The shape memory alloy (SMA) research community continues to address the development and validation of SMA constitutive models for the enhancement of finite element packages, enabling design engineers to more effectively develop applications based on these unique materials. This work presents new extensions to a widely accepted three-dimensional constitutive model based on the developments of Lagoudas and co-workers that more accurately captures the highly anisotropic transformation strain generation and recovery observed in actuator components after common material processing and training methods have been applied. A constant back stress term inspired by the classical theory of plasticity with anisotropic hardening is introduced into the model to capture the desired effects. The model is implemented into a commercial finite element code using a return-mapping algorithm to solve the constitutive equations at each material point. The implemented model has been used to perform a 3-D analysis of an SMA torque tube actuator subjected to different loading schemes. Simple cases are first considered, wherein pure tensile and pure torsional loading are applied and the calibration of the constant back stress tensor requires the determination of a single non-zero component. A more advanced case considers the actuator response under combined tension/torsion loading, showing that the substantial multi-axial anisotropy developed during processing and training can be captured using the proposed model. Numerical results include correlations between the finite element predictions and available experimental measurements of SMAs torque tube actuators, illustrating the accuracy of the present model and its implementation.

8342-57, Session 14

Homogenized energy model for antagonistic shape memory alloy actuators

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Shape memory alloys (SMA) are novel materials used in a wide variety of applications. They possess a number of advantages, including high energy density, large strain recovery, and bio-compatibility. The often cited disadvantage is their limited bandwidth. The use of antagonistic SMA actuators increases potential bandwidth, while also providing greater range of motion, especially when used as bending actuators. However, the hysteretic, thermo-mechanical behavior of SMA is further complicated by the introduction of an antagonistic actuator. In this paper, we develop the homogenized energy model (HEM) for antagonistic SMA actuators. The simulated model is optimized to fit experimental data obtained from antagonistic SMA wires coupled to a spring element. Various cases are presented that illustrate the effects of pre-strain in the SMA wires and actuation frequency on the system response. The HEM accurately and efficiently quantifies the stress-strain and resistance-strain behavior of the system. The model is suitable for design optimization, model-based control algorithms, and mapping algorithms that utilize the SMA resistance to predict strain.

8342-58, Session 14

A closed-form solution for superelastic shape memory alloy beams subjected to bending

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A macroscopic phenomenological framework is used for developing a closed-form solution for analyzing the pure bending of shape memory alloy (SMA) beams. In order to study the effect of tension-compression asymmetry on the bending response, two different transformation functions are considered; a J2-based solution with symmetric tension-compression response, and a J2-I1-based solution capable of modeling the tension-compression asymmetry. The constitutive equations are reduced to an appropriate form for studying the pseudoelastic bending response of SMAs, and closed-form expressions are obtained for the stress and martensitic volume fraction distributions in the cross section. These expressions are used for calculating the bending moment-curvature analytically. Both circular and rectangular cross sections are considered and several case studies are presented for analyzing the accuracy of the presented method and also the effect of considering the tension-compression asymmetry on the bending response of SMAs.

8342-59, Session 14

Evolution of phase transformation and reorientation during stress arrest in shape memory alloys

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Stress arrest of loading or unloading during pseudoelastic phase transformations in shape memory alloys has shown to exhibit creep-like phenomenon even at strain rates that can be considered quasi-static and devoid of any thermal effects. This phenomenon termed as pseudo-creep is manifested as positive (negative) accumulation in strain during loading (unloading) when arrested at constant stress. Pseudo-creep is also found to occur during reorientation loading, where thermomechanical coupling is absent. In this paper, we report results of extensive studies conducted on polycrystal Ni-Ti wires for stress arrest of loading and unloading at normalized strain rates ranging from 4.25E-7 (virtually isothermal conditions) to 4.25E-5 in conjunction with a video multi-extensometry technique developed in our laboratory to measure spatially non-uniform deformations in the sample and have recorded evolution in phase transformations or reorientation in three consecutive segments of the wire (constituting the total gauge length for video multi-extensometry) during stress arrest.

8342-60, Session 14

Effect of applied stresses on retained martensite accumulation in NiTi shape memory alloys

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The shape memory and pseudoelastic behaviors of Shape Memory Alloys have been investigated for a wide variety of cyclic applications. In most applications, to obtain repeatable behavior the alloy is trained, which leads to the accumulation of residual strain as the cyclic response stabilizes. To understand the training process and to accurately capture the cyclic behavior it is important to understand the evolution of this residual strain. Specifically, the residual strain is typically a combination of inelastic strains such as transformation induced plastic strain, retained martensite and/or creep strain (in the case of HTSMAs). The acquired Two Way Shape Memory Effect (TWSME), as consequence of the training is also considered in the total residual strain.

The present effort aims to determine the quantity of retained martensite accumulation in particular as a function of upper pseudoelastic plateau stress (controlled by test temperature) and maximum applied stress. To quantify the retained martensite accumulated during cyclic loading, pseudoelastic nickel-titanium wires were utilized. Specimens were trained at different temperature above the austenitic finish temperature and to different applied maximum stress levels. The total residual strain was decomposed into the contributing, plastic strain, retained martensite and TWSME strain. To quantify the retained martensite, the trained SMA specimens were heated to 200 and 300C, and the strain recovered during the heating was recorded for each test case. Additionally, the effect of the flash heating on the TWSME as well as the cyclic stabilization was also investigated. The trend in the evolution of retained martensite as a function of the upper plateau stress as well as the maximum applied stress is presented.

8342-61, Session 15

Development of thermoplastic coated multifunctional transmission elements

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We report results on the development of innovative solutions for the cost-effective manufacturing of smart structural elements for power, light or current transmission that are embedded in a thermoplastic elastomeric material, which protects the transmission elements from their environment and also provide traction capabilities. Such robust multifunctional system is planned to act as a mechanical power transmission element, such as an elevator cable or hoisting belt, but also as a functional element for strain and temperature monitoring, as well as power transmission, during use or during maintenance periods. Steel cords, steel coated fiber optic sensors as well as polymer coated electrical wires are thus embedded side by side in a thermoplastic elastomer flat belt with a continuous process. To ensure adequate mechanical stress transfer, a fast-curing coupling method using a UV-curable epoxy primer will be presented for the cords and sensor integration. Finite element analysis was used to evaluate the internal stresses developed within the system and helped the pull-out test results interpretation for stress and energy release rate. Traditional surface treatments and silane coupling agent were tested for comparison

and were outperformed by the proposed UV-curable primer in processing time, adhesion and durability. Finally, strain and temperature measurements using the embedded fiber optics will be presented, using a distributed sensing method. The practical application of this multifunctional transmission element will be discussed in light of these results.

8342-62, Session 15

Noise and vibration mitigation in sandwich composite structures

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As demands rise for high performance composite materials, there is a great interest for multi-functional materials. Sandwich composites act as multifunctional materials by boasting superior bending stiffness at a much lower weight compared to metals. Therefore, this study focuses on sandwich composite structures with both high noise mitigation and passive structural dampening. Specifically, it is sought to understand how the vibrational responses of carbon-fiber face sheet sandwich composite beams are affected by the core's thickness, as well as its intrinsic properties. A combination of experimental and analytical methods was used to characterize the sound and vibrational properties of these sandwich beams. Coincidence frequencies were identified in the wave number domain, and from the frequency response functions the structural damping loss factor was determined using the half-power bandwidth method. Several key conclusions were reached; first is that acoustic performance can be improved by reducing flexural stiffness or the core's shear modulus, depending upon the applications frequency range. It was also determined that high structural damping corresponds with low wave number amplitudes. Thus as wave number amplitudes are proportional to noise level radiation, improved structural damping results in a reduction in noise level radiation.

8342-63, Session 15

Study on a new concept of multistable lattice structure

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A new concept of multi-stable lattice structure is proposed. A cell of lattice is assembled by four rectangular bi-stable composite laminates and each cell possesses three stable configurations. When numbers of cells are assembled together, the whole structure will be multi-stable. Under appropriate actuation, this multi-stable structure can transform between stable configurations and then achieves large deformations, but no energy is needed to maintain the large deformation. The advantage of this multi-stable structure makes it a brilliant prospect in the design and realize of light-weight morphing structures.

The commercial finite element code ABAQUS is chosen to simulate and analysis the multi-stable lattice structure. The finite element model of multi-lattice structure is built by a two-step method, and the stable configurations of lattice structure are predicted. The snap-through processes between stable configurations under external load is analysised. Different from the studies on the snap-through actuation of bi-stable composite laminates based on smart material, a new method of actuation is put forward with the help of finite element simulation. This new actuation method snaps the bi-stable composite laminate by raising the temperature of local resign of the laminate, the rise of temperature will reduce the level of internal thermal stress in the local region of laminate and destroy the global equilibrium, then the bi-stable composite laminate will snap to the other stable configuration. Experiments are carried out to test and verify this new actuation method, the results show that the effect of this new actuation method is the same as it is simulated by ABAQUS and is valid.

8342-65, Session 15

Conductivity and EMI shielding properties of electrospinning PANi/PEO/MWCNT fibrous membrane and its composite

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In this paper, Polyaniline-based fibrous membranes were fabricated with multi-walled carbon nanotubes and polyethylene oxide (PEO) by the electrospinning method with different MWCNT loading rate. And then PANi/PEO/MWCNT fibrous membranes reinforced epoxy based nanocomposite was then fabricated. The morphology and electrical properties of PANi/PEO/MWCNT fibrous membrane was characterized by scanning electron microscope (SEM) and investigated by four-point probe measurement. The EMI shielding performances of the composite was measured by vector network analyzer. The results showed that the conductivity of nano fibrous membrane increased with MWCNT loading increasing. The SEM images indicated that the CNTs well-oriented carbon nanotubes inside of the polyaniline fibers. The PANi/PEO/MWCNT fibrous membrane reinforced epoxy composite showed good EMI shielding performance.

8342-66, Session 15

Enhancement of impact-induced mechanoluminescence for structure health monitoring using swift heavy ion irradiation

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Mechanoluminescence (ML) refers to the light emission induced by mechanical actions on a solid such as compressing, stretching, bending, cleaving, impact. ML materials have recently attracted great attention due to their potential applications as a non-contacting imaging sensor for detecting cracks and measuring stress distributions in engineering structures, which is difficult to realize by conventional methods such as strain gauge. ML material with the best performance SrAl2O4:Eu2+ (SAOE) produces strong ML emission even under small mechanical stress. However, the ML performance of SAOE deteriorates rapidly under humid environment due to its hydrolysis, which hinders its applications especially in outdoor environments, e.g. structure health monitoring for bridges, buildings and tunnels. Thus ML materials with water resistance such as CaSrAl2Si2O8:Eu2+ have been developed, but the brightness of which is still much lower than SAOE. Thus it is highly desired to improve the ML intensity of these ML materials.

In this study, we introduce a novel method to improve the impact-induced ML in ML materials with swift heavy ion (SHI) irradiation. The impact-induced ML intensity of CaSrAl2Si2O8:Eu2+ was dramatically enhanced by about one order of magnitude using SHI irradiation. Furthemore, it was found that higher electronic stopping power and higher irradiation dose were more effective for improving the impact-induced ML. It is considered that the trap density suitable for the impact-induced ML was increased by the SHI irradiation, resulting in the impact-induced ML enhancement. The underlying mechanism was discussed, which is of great importance for developing new ML materials for structure health monitoring.

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8343-01, Session 1

Design and experimental validation of conformal load-bearing antenna structures

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1. Introduction

The newly designed fighter aircrafts of the 5th generation have not any external blade antenna installed in the skin of fuselage and wing structure designed in USA, China and Russia. That means numerous blade antennas needed for communication, navigation and electronic combat mission are embedded into the skin of aircraft structures. These antennas have also some of functions provided by skin structures that carries aerodynamic loads without structural discontinuity. These embedded antenna structure system is called Conformal Load-bearing Antenna Structure(CLAS) having various advantages. Structural efficiency is one of these advantages, which is especially valuable when there need to spare larger space for equipments in the aircraft.

Paul J. Callus[1] described the development history of various kinds of embedded antenna structure systems. Jim Tuss[2] defined the definition of CLAS and sorted the level of CLAS by the technology level when it is installed into an aircraft. S3TD, MUSTRAP, and LOBSTAR were developed as the CLAS level technology which means load bearing embedded antenna structures. To apply CLAS into the aircraft as a stealth technology, level CLAS technology seems required at least. By the result of academic research survey, it seems that array antenna or advanced level of electronic warfare antenna in CLAS are installed into stealth aircrafts and needed some of maintenance.

This study introduces the design technology of a newly attempted CLAS for a multi band antenna. Composite materials are used for load bearing structure and antenna is embedded into the CLAS system as one layered structure.

2. Material Selection

The material selections of each layer in CLAS are done for improving antenna performances for obtaining a targeted frequency band.

The electro-magnetic performance of antenna are required for several parameters such as gain, polarization, radiation pattern, and Voltage Standing Wave Ratio(VSWR) for C-band frequency ranges. The antenna is made of radiating element embedded in a composite material in configuration of patch type with slots. The composite material is chosen by its dielectric constants, density, tensile strengths, and elastic modulus to consider antenna performances and load-bearing capacity. Pocan DP T7140 LDS is selected as a composite material.

Although composite material can carry applied loads, the principal load is transferred by the carbon fiber reinforced polymer(CFRP) composites. The CFRP of CLAS is called by housing due to its functions for supporting CLAS system. The 24-plies of housing has stacking sequence of [(45/0/-45/90)4]s with quasi-isotropic characteristics. The face-sheet material is chosen as GFRP because it permit the transmitting and receiving the radio frequency signal. The face sheet also carries some portion of in-planar shear and tension load as well as housing does.

The main purpose of honeycomb core is to secure enough space between radiating element and housing for obtaining some of good performances on the electromagnetic antenna. In addition, the honeycomb core carries some portion of shear loads and has good transmissibility on the electro-magnetic wave.

3. Validation of CLAS Design

To validate the antenna performance of CLAS, several tests are needed, for example, electromagnetic test, static strength test(tensile and shear load test), impact resistance test, and fatigue test. Test results are evaluated to check a view of correlation, i.e. gains, polarization characteristics, VSWR, and return loss, respectively.

8343-02, Session 1

Status of shape memory polymers for aerospace applications

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Shape memory polymers (SMPs), polymer based shape memory composites (SMCs), and shape memory hybrids (SMHs) have attracted great interest in recent years for application in reconfigurable structures (for instance morphing aircraft, micro air vehicles, deployable space structures, and adaptive engines). However, before such applications can be attempted, the mechanical behavior of the SMPs must be thoroughly understood. This presentation represents an assessment of the state-of-the-art of SMPs, SMCs, and SMHs intended for aerospace applications. In particular, two questions will be evaluated. What are the current needs (both structural and actuation) as they pertain to the polymer based smart materials? And are these needs currently being met by the multifunctional materials community? Specific needs/requirements will be identified such as range of glass transition temperature, recovery time, strain energy and heat energy needed for activation, and resistance to environmental degradation. The available resins and material systems in the literature will be compared to each other as to their current ability (and apparent future potential) to meet the identified requirements.

8343-03, Session 1

Thermal and mechanical modeling of a conceptual shape memory alloy rotary actuator for aerospace applications

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Shape Memory Alloy (SMA) torque tubes have been proposed to provide thermally induced rotary actuation in aerospace applications. However, relatively long heating times limit the use of SMA actuators such as tubes, beams, and wires to low frequency applications. This low actuation frequency is not ideal for aerospace applications, which require faster deployment times than those generally achieved by SMA actuators. In order to determine trends and lower actuation times, three fully coupled thermomechanical analysis studies are conducted: one assessing heating performance, one assessing cooling performance, and one considering the power needed to simply maintain actuation. For each study, the computational analysis examines designs that include a heater array, thermally conductive layers to promote conduction between structural components, an SMA torque tube, and a housing structure. The studies utilize an accurate constitutive model implemented in a finite element framework to compute the time for a loaded thermally cycled SMA torque tube to actuate to a predetermined rotation. The studies consider various heater geometries and powers, ambient conditions, and thermal conductances. A parametric study employing an orthogonal array over a 256-dimensional design space is used to find trends related to heating actuation time for each design. The analysis for each study considers the solution to a transient thermomechanically coupled problem and includes the effect of latent heat of transformation. The studies demonstrate that the thermal conductance, ambient conditions, and power supplied to heaters have the greatest influence on the actuation time, while the heater geometries have minimal influence, and the conditions that are best for a rapid reverse transformation are not ideal for forward transformation. Thus, the overall actuation frequency can be increased by utilizing the trends discovered in this study.

8343-04, Session 1

Modeling fluid structure interaction of a shape memory alloy actuated morphing aerostructure

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The development of efficient and accurate analysis techniques for aerostructures incorporating shape memory alloys (SMAs) continues to garner attention. These active materials have a high actuation energy density, making them an ideal replacement for conventional actuation mechanisms in morphing structures. However, these components are often exposed to the same highly variable environments experienced by the assembly into which they are incorporated. Historically, modeling of structures entailed conservative approximations for boundary conditions. These approximations were formulated to simplify the problem and reduce computational cost. However, the inherent sensitivity of SMA transformation behavior to local changes in stress and temperature suggests that accuracy of predicting SMA thermomechanical response could be improved by allowing loading conditions to vary with the structure's environment. This is motivating design engineers to consider modeling fluid-structure interaction for prescribing dynamic, solution-dependent boundary conditions. This work presents an analytical study of a particular morphing aerostructure with embedded SMA ribbons and demonstrates the effective use of fluid-structure interaction modeling. A cosimulation analysis determines the surface deflections of the considered aerostructure using the Abaqus Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) processors. The global FEA solver utilizes a robust user-defined material subroutine which contains an accurate three-dimensional SMA constitutive model. Variations in the fluid environment are computed using the CFD solver, and fluid pressure and heat flux are translated into surface distributed loads and local temperature gradients. Results are validated with data from representative flow tests conducted on a prototype of the aerostructure.

8343-05, Session 2

A lightweight thermal energy recovery system based on shape memory alloys: a DOE ARPA-E initiative

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Automobiles consume nearly 13 million barrels of oil daily in the U.S. Nearly 50% of the fuel's energy is expelled as waste heat in the exhaust and coolant streams. This paper provides an overview of a recently completed US DOE ARPA-E contract to develop an SMA (shape memory alloy) based lightweight thermal energy recovery system.

In this project we developed a shape memory alloy (SMA) heat engine producing over 1 W/g of SMA, which is a significant advancement over the state of the art in solid-state thermal energy recovery systems (e.g. a 10 times improvement over thermoelectrics). SMA heat engines convert thermal energy directly into mechanical work. The alloy functions as a solid-state energy conversion element by recovering strain on the order of 4% through a reversible thermal phase transformation. Another plus is that SMAs can recover low-grade waste heat (T<= 150C), over 90% of industrial waste heat falling under this category. Indeed, SMA only requires low grade heat sources for high power output, including even those in residences and those occurring naturally in the environment.

Our heat engine design improves on past designs through better understanding of material behavior, using system and material models, utilizing recent and continuing improvements in narrow hysteresis SMA, and designing an innovative energy conversion element that improves convective heat transfer to increase operating frequency. A rotary thermal engine was developed based on heating SMA looped around pulleys. Thermal contraction of the SMA creates torque from which power may be extracted by a generator.

8343-06, Session 2

Hybrid energy harvesting/transmission system for embedded devices

A. Hehr, G. Park, K. M. Farinholt, Los Alamos National Lab. (United States)

In most energy harvesting applications the need for a reliable long-term energy supply is essential in powering embedded sensing and control electronics. The goal of many harvesters is to extract energy from the ambient environment to power hardware; however in some applications there may be conditions in which the harvester's performance cannot meet all of the demands of the embedded electronics. One method for addressing this shortfall is to supplement harvested power through the transmission of wireless energy, a concept that has successfully been demonstrated by the authors in previous studies. In this paper we present our findings on the use of a single electromagnetic coil to harvest kinetic energy in a solenoid configuration, as well as background and directed wireless energy in the 2.4 and 5.8 GHz radio frequency (RF) bands commonly used in WiFi and cellular phone applications. The motivation for this study is to develop a compact energy harvester / receiver that conserves physical volume, while providing multi-modal energy harvesting capabilities. As with most hybrid systems there are performance trade-offs that must be considered when capturing energy from different physical sources. As part of this paper, many of the issues related to power transmission, physical design, and potential applications are addressed for this device.

8343-07, Session 2

Mechanical energy harvesting utilizing phase transition in 32 mode relaxor-ferroelectric PIN-PMN-PT single crystals

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This work presents experimental evidence that under relatively low amplitude cyclic drive stress (~5 MPa), large open circuit electric field or large short circuit polarization change associated with ferroelectric rhombohedral to ferroelectric orthorhombic phase transition in domain engineered relaxor-ferroelectric single crystals can be captured. This paper demonstrates this phenomena in mechanically confined ternary PIN-PMN-PT single crystals poised at the rhombohedral side of the morphotropic phase boundary. Experimental electric field-stress results, methods of mechanical confinement and drive, and a broadband high efficiency mechanical energy harvester design are presented. Mechanical energy harvesters that operate on low amplitude stress vibrations as a design rule will benefit from this development.

8343-08, Session 2

Large-scale modular solid-state energy harvester for geomatics applications

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Geomatics, being is the discipline of gathering, storing, processing, and delivering spatially referenced information on vast scales relies on suites of various sensors and imaging devices such as meteorological sensors, seismographs, high-resolution cameras, and LiDAR's. These devices may be stationed for prolonged periods of time in remote and poorly accessible areas and are required to operate continuously over prolonged periods of time. In other cases, sensing and imaging equipment may be mounted on land, sea, or airborne platforms and expected to operate for many hours on its own power. Providing power to this equipment constitutes a technological challenge.

Solar and wind generators are often utilized, but each have their own limitations. Solar panels need sun and wind turbines can only work outdoors and because of their moving blades tend to require maintenance. Current submission describes the development of a solid-state piezoelectric energy harvester that is large enough to power a typical suite of Geomatics sensing and/or imaging equipment and can be deployed at sea, on sea ice, on the ground, and on air, sea, and land vehicle platforms.

The harvester in the current study employs modules comprising of piezoelectric transducers embedded in rigid printed circuit boards (PCB's) and put in a pre-buckled state via the application of compressive force. The pre-buckling of the PCB's drastically reduces their natural (resonance) frequency, making them in effect much more compliant without adding mass. The pre-buckled and hence compliant PCB's undergo elastic vibration due to disturbing inputs from the environment such as wind or wave action or the highly vibratory environment inside ground, sea, or airborne vehicles. The resulting mechanical deformation of the piezoelectric components is transduced into electrical charge and conditioned into usable DC power by the power collection electronics.

Each module comprises of a PCB with embedded transducers and houses its own power collection electronics. In addition, it possesses an especially designed housing that applies a tunable compressive force, allowing the user to adjust the natural frequency of the PCB. The power collection electronics on each PCB module are designed so that they can be "daisy-chained" with one module designated the "master" module into which the payload equipment is plugged. The mechanical housings incorporate mechanical means of interconnecting any number of power generation modules. The resulting system is modular, scalable, mechanically and electrically robust, and has no moving parts thus requiring virtually no maintenance. It can be deployed at any location where there exists a source of kinetic energy, which includes the vast majority of natural and man-made environments.

While small-scale piezoelectric energy harvesters are the topic of ongoing research, current work results in a number of important innovations. The highly broadband nature of disturbances resulting from wind or wave action requires harvesters that can operate in broadband environments and the pre-buckling method of lowering the harvesters' natural frequency addresses this requirement for the first time. In addition, the modular nature of the harvester allows the powering of many different types of equipment, both as primary and secondary (reserve) power source.

8343-09, Session 2

Evaluation of energy harvesting conditioning circuits

J. Cruce, G. Park, K. M. Farinholt, Los Alamos National Lab. (United States)

In the practical implementation of an energy harvesting system, signal conditioning electronics play an important role in defining the overall efficiency of these power systems. There are currently a number of commercially available energy harvesting circuits designed to condition the output of piezoelectric-based electromechanical transducers. In this paper we present a comparison study of several of these commercially available circuits, using a selection of transducer designs to evaluate performance as a function of input energy level and frequency content. This evaluation considers conditioning circuits that range from simple rectification designs to others that incorporate logic-based integrated circuits designed to optimize energy throughput. Custom circuit designs are also considered as part of this study, including synchronization circuits, as well as pre-charged switching circuits designed for electrostatic energy harvesters. The overall performance of each circuit is compared based on excitation amplitude and frequency, as well as the load characteristics of the storage mechanism used to collect the output energy of each conditioning circuit.

8343-10, Session 3

Wireless system for structural health monitoring based on Lamb waves

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For comprehensive fatigue tests and surveillance of large scale structures, a structural health monitoring system based on lamb waves in kHz range was realized and tested. The system is based on a wireless sensor network and focuses especially on low power measurement, signal processing and communication. Thereby we met the challenge of synchronizing the wireless connected sensor nodes with sufficient accuracy.

The sensor nodes were realized by compact, sensor near signal processing structures containing components for analog preprocessing of acoustic signals, their digitization, algorithms for data reduction and network communication. The core component is a digital microprocessor ARM Cortex-M3 von STMicroelectronics, which performs the basic algorithms necessary for data acquisition synchronization and filtering. As a first application, the system was installed on a cfrp structure.

8343-11, Session 3

Embedded sensor node deployment to monitor telescope drive system components

S. G. Taylor, C. J. Stull, J. Wren, E. Y. Raby, C. R. Farrar, Los Alamos National Lab. (United States)

This paper presents the deployment of an embedded active sensing platform for real-time condition monitoring of telescopes in the RAPid Telescopes for Optical Response (RAPTOR) observatory network. The RAPTOR network consists of several ground-based autonomous astronomical observatories primarily designed to search for astrophysical transients such as gamma-ray bursts. In order to capture astrophysical transients of interest, the telescopes must remain in peak operating condition to move swiftly from one potential transient to the next throughout the night. However, certain components of these telescopes have until recently been maintained in an ad hoc manner, often being permitted to run to failure, resulting in the inability to drive the telescope. In a recent study, a damage classifier was developed using the statistical pattern recognition paradigm of structural health monitoring (SHM) to identify the onset of damage in critical telescope drive components. In this work, that damage classifier is implemented on a prototype embedded active sensing platform, which is deployed to the telescope structure in order to detect the onset of telescope drive component damage and alert system administrators prior to system failure. The process of porting the PC-based damage classifier to the embedded sensor node is discussed, and the performance of the sensor node is validated using specimens of both healthy and damaged drive system components.

8343-12, Session 3

Laser excitation and noncontact sensing ultrasonic propagation imaging system for surface crack evaluation

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E. Flynn, Los Alamos National Lab. (United States)

Cracks are one of the most frequent types of damages occurring in different engineering structures and a reliable non-destructive evaluation technique is essential to detect any possible damage at the initiation phase. Small real fatigue closed surface cracks at the initiation phase are difficult to be detected through visual inspection. Ultrasound has been widely used but the conventional contact ultrasonic inspection techniques are not suitable for mass and couplant sensitive structures and are relatively slow. This paper presents a fully non-contact hybrid laser ultrasonic generation/air-coupled detection technique combined with wavelet-transformed ultrasonic propagation movie (WUPM) and ultrasonic frequency tomography (UFT) algorithms to extract defect-sensitive features aimed at performing a thorough diagnosis of damage. Optimization enables improved performance efficiency of air-coupled transducers (ACTs) to be used as receivers for non-contact hybrid laser ultrasonic propagation imaging (UPI) system as shown from the experimental results in this study. The surface crack evaluation results are analyzed on the basis of ease for damage visualization, accuracy of crack size estimation and sensitivity (SNR). The hybrid system was sensitive enough to detect real fatigue closed surface crack with size detection accuracy as high as 96%. The study also showed that the relation of scanning interval (density) with respect to crack width affects the performance of damage visualization as well as the accuracy of damage size estimation.

8343-13, Session 3

Development of state-of-the-art optical sensors for the monitoring of deep sea umbilicals and flexible pipelines

P. Bettini, S. Bertoli, G. Sala, Politecnico di Milano (Italy); R. Gaspari, G. Pozzati, Prysmian Group (Italy)

In the search for new deposits petrochemical extraction Companies are searching in challenging environments as deep sea-beds. At the same time, especially following the Gulf of Mexico disaster, there is a justified concern about the assessment of the installed asset condition.

The Politecnico di Milano, Department of Aerospace Engineering, and Prysmian Group R&D Department are currently carrying over a joint research project aiming to the development of new methods for the testing and evaluation of health status and conditions to be applied in the field of deep sub-sea umbilical normally employed for the petrochemical hydrocarbon extraction.

The monitoring methods and the measurement system under joint development will enable Prysmian to validate vs. full scale measurement the design analytical tools currently utilized to analyze the developed elements versus the operational scenarios for which any particular umbilical is currently designed.

Additionally, together with the Politecnico di Milano, Prysmian will develop a real-time measurement system to be utilized, during operational lifetime, for the asset management of the produced sub-sea umbilicals.

New techniques for the embedment of point and distributed optical strain and temperature sensors are developed. The know-how and experience of the Politecnico di Milano in discrete point stress measurement has been merged with the experience of Prysmian in distributed measurement methods so that a dual solution will be available.

Full scale samples will be sensorized and tested vs. design scenarios to correlate and compare the theoretical strain distribution obtained by the analytical tools vs. the measurement data.

8343-14, Session 3

Evaluation of strain-based deformation shape estimation algorithms for control and monitoring applications

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Methods are investigated for real-time deformation shape prediction of lightweight unmanned flying aerospace structures, for the purposes of Structural Health Monitoring (SHM) and condition assessment. Two methods are introduced in this study. The deformation prediction algorithm for the first method is based on the classical beam theory and uses high-resolution fiber-optic sensors to obtain strain data from a representative aerospace structure (e.g., flying wing) in order to predict the associated real-time deflection shape. The second method under investigation uses only few strain sensors and depends on the modal properties of the structure to estimate its deformation shape. Both methods are based on the use of fiber-optic sensors such as optical Fiber Bragg Gratings (FBG) which are known for their accuracy and light weight. In this study, the two methods are examined and compared through computational models involving Finite-Element Analysis (FEA). Furthermore, sensitivity analyses are performed on each method to investigate the effects of external factors such as noise pollution and material properties on the performance of the algorithms. This work analyzes the numerous complications and difficulties that might potentially arise from combining the state-of-the-art advancements in sensing technology, deformation shape prediction, and structural health monitoring, to achieve a robust way of monitoring ultra lightweight flying wings or next-generation commercial airplanes.

8343-15, Session 4

Design of 4 DOF ER haptic master for medical application

J. Oh, H. Cho, S. Choi, Inha Univ. (Korea, Republic of)

In this work, ER haptic master for minimally invasive surgery (MIS) have been proposed and analyzed. Using a controllable ER fluid, the masters can generate a reflection force with the 4-DOF motion and feature simple mechanism and continuous force control. The proposed master consists of two actuators : ER brake featuring spherical joint for 3-DOF rotational motion (X, Y and Z axes) and ER brake for 1-DOF translational motion. After analyzing the dynamic motion by integrating the mechanical and physical properties of the actuators, torque model of the proposed haptic master is derived. In order to generate a objective force, haptic master is designed and optimized based on the torque modeling. Then, with determined parameters, the reflection force of the proposed device is calculated as a function of applied field of voltage. For realization of master-slave MIS system, a encoder is integrated with the ER spherical joint to establish the MIS master system. In this work, slave and organ of patient is modeled in virtual space. In order to embody a human organ into virtual space, a volumetric deformable object is mathematically formulated by a shape retaining chain linked (S-chain) model. Accordingly the haptic architecture is established by incorporating the virtual slave with the master device in which the reflection force and desired position originated from the object of the virtual slave and operator of the master, respectively, are transferred to each other. In order to achieve the desired force trajectories, a sliding mode controller (SMC) is designed and implemented. The sliding mode controller which is known robust to uncertainties can compensate the adverse effect of the hysteretic behaviors of ER fluid. It has been demonstrated that the effective tracking control performance for the desired motion of reflection force is well presented in the time domain and their tracking errors are evaluated.

8343-16, Session 4

Miniature image guided three-axes scanning and positioning system

D. Avirovik, S. Priya, Virginia Polytechnic Institute and State Univ. (United States); D. Dave, The Univ. of Texas at Arlington (United States)

We have developed a high precision three-axes scanning and positioning system that has the possibility of being integrated into a Multifunctional Image Guided Surgical (MIGS) Platform. Our system provides the opportunity for conducting intricate procedures remotely on a patient lying in the operation room. The stage integrates three main components: an optical coherence tomography (OCT) probe, laser scalpel and suction cup. The device is image guided using the OCT probe and it is able to pin point any location requiring a laser scalpel incision. Due to the scanning capabilities, a high quality three-dimensional image of the tissue topography is obtained which allows the surgeon to make a confident decision of the location where laser scalpel will be used to make an incision.

The requirements for this stage in MIGS application are to provide scanning area of 400mm^2, resolution of less than 10 microns and velocities between 10 - 40 mm/s. In order to develop a miniaturized stage, a concept design was first created using NX Unigraphics. Once all of the necessary specifications were obtained, the stage was manufactured by using rapid prototyping techniques. The final design integrates cost-effective stepper motors, threaded rod drive train and a stepper motor controller. The EZ4axis stepper motor controller was capable of obtaining 1/8th micro-step resolution control over the motors which satisfies the initial stage requirements. In this paper, experimental results are presented on the physical characteristics of stage that show its promise for developing automated surgical tools and system.

8343-17, Session 4

Study of a smart polymer medical device, product development obstacles, and innovative solutions

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The concept is simple, within the pump a pH responsive polymer actuator swells in volume under electrically controlled stimulus. As the actuator swells it presses against a drug reservoir, as the reservoir collapses the drug is metered out to the patient. From concept to finished product, engineering this smart system entailed integration across multiple fields of science and engineering. Materials science, nanotechnology, polymer chemistry, organic chemistry, electrochemistry, molecular engineering, electrical engineering, and mechanical engineering all played a part in solutions to multiple technical hurdles. Some of these hurdles where overcome by tried and true materials and component engineering, others where resolved by some very creative out of the box thinking and tinkering. This paper, hopefully, will serve to encourage others to venture into unfamiliar territory as we did, in order to overcome technical obstacles and successfully develop a low cost smart medical device that can truly change a patient's life.

8343-18, Session 5

Design of shape memory alloy pipe couplers: modeling and experiments

M. Tabesh, J. G. Boyd, D. C. Lagoudas, Texas A&M Univ. (United States)

Shape memory alloy (SMA) pipe couplers use the shape memory effect to apply a contact pressure on the surface of the pipes to be coupled. Compared to currently available couplers, SMA couplers permit simplified installation procedures and a more temperature resistant metal-to-metal seal. In the current research, a SMA pipe coupler is designed, fabricated and tested in an experimental set-up. The thermally induced contact pressure depends on several factors such as the dimensions and properties of the coupler-pipe system. Analytical equations are derived using a thin-wall and thick-wall approximation for the behavior of the coupler during installation. In the thin-wall approximation, the variation of stress/strain over the thickness of the coupler/pipe is ignored, while the thick-wall approximation can capture the radial and circumferential stress/strain profiles and it takes into account a non-uniform martensitic distribution through the thickness. The developed equations are used to determine the optimal configuration of the pipe-coupler system. Additionally, an experimental set-up is prepared to examine the functionality of the coupler and two alloy systems are considered: NiTiNb and 52.7Ni-Ti (at%). The experiments allow for the measurement of coupling pressure through the use of strain gages mounted on an internally installed elastic ring. A finite element model of the set-up is also developed. The model, which assumes 2D plane stress, includes the implementation of a constitutive model capable of capturing the behavior of shape memory alloys. The outcomes of the finite element analysis as well as the analytical thin-wall and thick-wall equations are compared with the contact pressure obtained from the experimental results.

8343-19, Session 5

Design of a smart material electro-hydraulic actuator with improved frequency bandwidth

J. P. Larson, M. J. Dapino, The Ohio State Univ. (United States)

Smart material electro-hydraulic actuators utilize fluid rectification by one-way valves to collect the small, high-frequency, high-force motions of smart materials such as piezoelectrics and magnetostrictives into useful motions of a hydraulic cylinder. These actuators have potential to replace centralized hydraulic pumps and lines with lightweight, compact, power-by-wire systems. This paper presents the design and testing of an improved actuator system. A limitation on the performance of smart material pumps has been the frequency of operation. The actuator performance should increase with the operation frequency of the smart material driver; however, the typical pumping frequency for peak actuator performance has been limited to the several hundred hertz, while smart material drivers can operate in the kilohertz range. This limitation is due to fluid effects (inertia and resistance) as well as losses in the check valves used to rectify the fluid flow. To increase the bandwidth of operation, a lumped-parameter model was developed and validated based on experimental study of an actuator capable of a 15 W power output. The critical parameters for pump performance are identified and their effect on pump performance assessed. The geometry of the manifold passages connecting the smart material pump to the output hydraulic cylinder were found to be critical for determining the operating bandwidth of the system. Additionally, Computational Fluid Dynamic (CFD) analysis was used to evaluate the design of the actuator check valves. The validated model was then used to optimize the actuator design for improved performance at high pumping frequencies.

8343-20, Session 5

Piezoelectrically-induced ultrasonic lubrication by way of Poisson effect

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Friction exists at the interface between two objects as they slide relative to each other. It has been shown that ultrasonic vibrations superimposed on the macroscopic sliding velocity between two surfaces creates friction reduction. This phenomenon is often referred to as ultrasonic lubrication, which is of significant fundamental and technological interest for vehicle applications. By modulating the effective friction coefficient

with a piezoelectric transducer operated at ultrasonic frequency, friction-adaptive components can perform in optimal manner over a wide range of conditions.

Instead of longitudinal vibrations, this paper focuses on the lateral contractions and expansions of an object in and around the half wavelength node region. This lateral motion is due to the Poisson effect (ratio of lateral strain to longitudinal strain) present in all materials. We experimentally and numerically investigate how ultrasonic vibration changes the effective dynamic friction coefficient under various load conditions. A high frequency vibration (20 kHz and 8.5 microns amplitude) generated by an ultrasonic welder is transmitted into a horn. A block slides against the horn underneath it at various velocities. A series of tests are conducted with different starting points (middle of the horn, and 1 inch left or right to the middle), different combination of materials and surface finish (aluminum and stainless steel), and different normal loads up to several hundred pounds.

Finite element analysis results show that the first axial mode vibration is the dominating motion of the horn which causes the Poisson effect. The experimental results show that the effective friction coefficient is reduced by an average of 68.5% for an aluminum horn and stainless steel block. For an aluminum horn and stainless steel block, 85.7% friction reduction is achieved.

8343-21, Session 5

Adaptronic tools for superfinishing of cylinder bores

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Today in the production of internal combustion engines it is possible to make pistons as well as cylinders, for all practical purposes, perfectly round.

The negative consequences of the subsequent assembly processes and operation of the engine is that the cylinders and pistons are deformed, resulting in a loss of power and an increase in fuel consumption.

This problem can be solved by using an adaptronic tool, which can machine the cylinder to a predetermined non-round geometry, which will deform to the required geometry during assembly and operation of the engine.

The article describes the actuatory effect of the tool in conjunction with its measuring and controlling algorithms.

The adaptronic tool consists out the basic tool body and three axially-staggered floating cutter groups, these cutter groups consist out of guides, actuators and honing stones. The selective expansion of the tool is realised by 3 piezoelectric multilayer-actuators deployed in a series - parallel arrangement.

It is also possible to superimpose actuator expansion on the conventional expansion. A process matrix is created during the processing of the required and actual contour data in a technology module.

This is then transferred over an interface to the machine controller where it is finally processed and the setting values for the piezoelectric actuators are derived, after which an amplifier generates the appropriate actuator voltages. A slip ring system on the driveshaft is used to transfer the electricity to the actuators in the machining head.

The functioning of the adaptronic form-honing tool and process were demonstrated with numerous experiments. The tool provides the required degrees of freedom to generate a contour that correspond to the inverse compound contour of assembled and operational engines.

8343-22, Session 6

Damage detection in wind turbine gearboxes using outlier analysis

I. Antoniadou, G. Manson, W. J. Staszewski, K. Worden, The Univ. of Sheffield (United Kingdom)

The proportion of worldwide installed wind power in power systems increases over the years as a result of the steadily growing interest in renewable energy sources. Still, the advantages offered by the use of wind power are overshadowed by the high operational and maintenance costs, resulting in the low competitiveness of wind power in the energy market. In order to reduce the costs of corrective maintenance, the application of condition monitoring to gearboxes becomes highly important, since gearboxes are among the wind turbine components with the most frequent failure observations. While condition monitoring of gearboxes in general is common practice, with various methods having been developed over the last few decades, wind turbine gearbox condition monitoring faces two major challenges: the detection of intermittent faults and the detection of faults under the transient load conditions prevailing in wind turbine systems. Classical time and frequency domain methods fail to detect intermittent faults and faults under variable load conditions, due to the temporary effect that these faults have on vibration signals.

This paper uses the statistical discipline of outlier analysis for the damage detection of gearbox tooth faults. A simplified two-degree-of-freedom gearbox model, considering non-linear backlash, time-periodic mesh stiffness and static transmission error, simulates the vibration signals to be analysed. Local stiffness reduction is used for the simulation of tooth faults and statistical processes determine the existence of intermittencies. The lowest level of fault detection, the threshold value, is considered and Mahalanobis squared distance is calculated for the novelty detection problem.

8343-23, Session 6

Ultrasonic underwater transmission of composite turbine blade structural health

A. J. Heckman, J. L. Rovey, K. Chandrashekhara, S. E. Watkins, Missouri Univ. of Science and Technology (United States)

A data transmission approach is investigated for monitoring applications of hydrokinetic turbine blades. In-service monitoring is critical due to the difficult environment for blade inspection and the cost of inspection downtime. Composite blade designs have advantages that include long life in marine environments and great control over mechanical properties. Additionally, composite blades provide a medium for embedding sensors into the blades for in-situ health monitoring. One of the challenges with in-situ health monitoring is transmission of sensor signals from the remote rotating reference frame of the blade to the system monitoring station. In the presented work, a novel system for relaying in-situ blade health measurements is described and demonstrated. Specifically, an ultrasonic communication system is used to transmit sensor data underwater from the rotating frame of the blade to a fixed relay station. Data are then broadcast via radio waves to a remote monitoring station. A microcontroller receives the initial strain measurement signal and transmits the data underwater using an ultrasonic transmitter. An ultrasonic receiver connected to another microcontroller acquires the signal, which is then broad cast to a remote monitoring station. Experimental design, development, and analysis of the ultrasonic underwater communication system for composite turbine blade structural health data transmission are described. Power requirements for the system are of paramount importance and are used to assess viability and possible modes of operation. The system is demonstrated by taking strain data from a composite blade, transmitting it through the water, and then sending results to a remote laptop computer for analysis.

8343-24, Session 6

Full-scale fatigue tests of CX-100 wind turbine blades. Part I: Testing

K. M. Farinholt, Los Alamos National Lab. (United States); S. G. Taylor, Los Alamos National Lab. (United States) and University of California, San Diego (United States); G. Park, C. M. Ammerman, Los Alamos National Lab. (United States)

This paper overviews experimental methods for several structural health monitoring (SHM) methods applied to two 9-meter CX-100 wind turbine blades that underwent fatigue loading at the National Renewable Energy Laboratory's (NREL) National Wind Technology Center (NWTC). The first blade was a pristine blade, which was manufactured to standard specifications for the CX-100 design. The second blade was manufactured for the University of Massachusetts, Lowell with intentional simulated defects (primarily waviness and wrinkles) within the fabric layup. Each blade was instrumented with piezoelectric transducers, accelerometers, acoustic emission sensors, and foil strain gauges. The blades underwent harmonic excitation at their first natural frequency using the Universal Resonant Excitation (UREX) system at NREL. Blades were initially excited at 25% of their design load, and then with steadily increasing loads until each blade ultimately reached failure. Data from the sensors were collected between and during fatigue loading sessions. The data were measured over multi-scale frequency ranges using a variety of acquisition equipment, including off-the-shelf systems and specially designed hardware developed by Los Alamos National Laboratory. The hardware systems were evaluated for their aptness in data collection for effective application of SHM methods to the blades. The results of this assessment will inform the selection of acquisition hardware and sensor types to be deployed on a CX-100 flight test to be conducted in collaboration with Sandia National Laboratory at the U.S. Department of Agriculture's (USDA) Conservation and Production Research Laboratory (CPRL) in Bushland, Texas.

8343-25, Session 6

Full-scale fatigue tests of CX-100 wind turbine blades. Part II: Analysis

S. G. Taylor, Los Alamos National Lab. (United States) and University of California, San Diego (United States); H. Jeong, J. K. Jang, K. M. Farinholt, G. Park, Los Alamos National Lab. (United States); M. D. Todd, Univ. of California, San Diego (United States); C. M. Ammerman, Los Alamos National Lab. (United States)

This paper presents the analysis results of several structural health monitoring (SHM) methods applied to two 9-meter CX-100 wind turbine blades that underwent fatigue loading at the National Renewable Energy Laboratory's (NREL) National Wind Technology Center (NWTC). The first blade was a pristine blade, manufactured to standard CX-100 design specifications. The second blade was manufactured for the University of Massachusetts, Lowell with intentional simulated defects within the fabric layup. Each blade was instrumented with a variety of sensors on its surface. The blades underwent harmonic excitation at their first natural frequency with steadily increasing loading until ultimately reaching failure. Data from the sensors were collected between and during fatigue loading sessions. The data were measured at multi-scale frequency ranges using a variety of data acquisition equipment, including off-the-shelf systems and prototype data acquisition hardware. The data were analyzed to identify fatigue damage initiation and to assess damage progression. High- and low-frequency response functions, time series-based methods, and wave propagation methods were applied to assess the condition of the turbine blade. The analysis methods implemented were evaluated in conjunction with hardware-specific performance for their efficacy in enabling the assessment of damage progression in the blade. The results of this assessment will inform the selection of specific data to be collected and analysis methods to be implemented for a CX-100 flight test to be conducted in collaboration with Sandia National Laboratory at the U.S. Department of Agriculture's (USDA) Conservation and Production Research Laboratory (CPRL) in Bushland, Texas.

8343-26, Poster Session

A 4-DOF haptic master device for minimally invasive surgery

P. Nguyen, J. Oh, S. Choi, Inha Univ. (Korea, Republic of)

This paper introduces a novel 4-DOF haptic master device for minimally invasive surgery featuring magneto-rheological (MR) fluid. It consists of three rotational and one translational motion. The rotational motions are constituted by two friction-free MR (FFMR) brake plus one MR brake. For translational motion, a mechanism with the aid of linear stepping motor is adopted. The FFMR brake used in the system possesses a salient advantage that its range of braking torque varies from negative to positive values. Therefore, the device is expected to be able sense in a wide environment from very soft tissues to bones. In this paper, overall of the design of the device is presented from idea, modeling, optimal design, manufacturing to control of the device. Moreover, experimental investigation is undertaken to validate the effectiveness of the device.

8343-27, Poster Session

A fractional calculus for nonlinear energy sink used in vibration absorption system

B. Fang, S. Li, T. Yang, W. Huang, Harbin Institute of Technology (China)

The phenomenon of energy pumping, in which vibratory energy is transferred irreversibly within a nonlinear, multi-degree-of-freedom system with the goal of reducing the transient response of the primary substructure, has recently been investigated analytically and through numerical simulations. The dynamics of single degree of freedom linear subsystem with attached nonlinear energy sink is investigated. The response of a linear oscillator attached to nonlinear energy sink with relatively small mass under external forcing in a vicinity of main resonance is studied analytically and numerically. It is possible that targeted energy could transfer from linear oscillators to the nonlinear energy sink in this system. Analytical model is verified numerically and a fairly good correspondence is observed. Fractional calculus offers a powerful tool to describe the dynamic behavior of real vibration absorption. A version of the fractional derivative models is presented and investigated in this paper for analyzing vibration absorption behavior of nonlinear energy sink. It is shown that the fractional-order system is in a stronger position than the traditional nonlinear energy sink coupled to the linear oscillator.

8343-28, Poster Session

Charging SiO2 and CYTOP electret film by air purifier for MEMS-based energy harvesting systems

A. Saad, Hochschule Furtwangen Univ. (Germany)

This paper reports a new type of charging electrets is presented. Low cost equipment is used for charging .Extremely large potentials with very good long term stability have been achieved.

Charging of electrets is essential for MEMS based capacitive vibration energy harvester [1]. CYTOP [2] and SiO2 [3] are widely used electrets in miniaturized energy harvesters. SiO2 electrets have good charge storage stability and can work in harsh environment. Electrets are typically charged by corona charging [2].

A new charging technique for SiO2 and CYTOP electrets with an

ionization set-up which is based on low cost components used in so-called AIR PURIFIER is presented.

Samples were either oxidized with thickness between 0.5 µm and 1.5 µm or spin coated with 7.1- 11.0 µm CYTOP. The charging was done using OEM components used Air Ionizer Apparatus. Where Air Ionizer Apparatus can generate ions very effectively (up to 2.1 trillion Ions/cm3 at 2.9 cm from emitter [4]).. The achieved electret potential (up to -1000 V) will be discussed in respect to experimental (e.g. time to potential) and technological (e.g. thickness) parameters.

In comparison to corona charging , the presented technique provides a low cost principle to charge a whole 4”-wafer with acceptable uniformity whereas corona charging can charge only small chips at once (size 10×20 mm2 [5]) and achieved potential and long term stability is better for the new charging type. Additionally, further investigation of Ionic- Hair dryer Technique of charging electrets will be presented [6].

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8344-01, Session 1

Optical sensing techniques for military applications

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Engineers and scientists at the Army's Aviation and Missile Research, Development, & Engineering Center (AMRDEC) are currently investigating methods to implement smaller, lighter, and cheaper weaponry by exploring the insertion of optical sensors and components into Army platforms. Specific areas of interest include chemical sensing, target imaging, and electro-optic (EO) countermeasures. Optical sensors utilizing techniques such as Terahertz (THz) reflectometry, Raman spectroscopy, Surface Enhanced Raman Spectroscopy (SERS), and microstructured (Photonic-crystal) optical fiber technology, can significantly increase the quality control of rocket engine manufacturing and reduce the maintenance and operating cost of missiles by nondestructively detecting the off-gassing of the stabilizer, MNA (to predict propellant degradation). The chemical sensors can also be used for the detection of toxic industrial chemicals and explosive devices. Other military applications for advanced optical sensors/devices include the potential of replacing the spatially coherent laser source presently used as a counter-measure to EO Sensors. The currently fielded lasing technology contains only a single wavelength, therefore, increasing the possibility to be readily defeated (e.g., adding a band rejection filter in front of an EO sensor). By replacing the single wavelength laser with a high power, spatially coherent broadband source, the counter-measure cannot be easily defeated due to its response over all wavelengths of the EO sensors. Experiments and conceptual demonstrations have been conducted with regard to the implementation and utilization of optical sensors for military applications. The current and ongoing efforts being undertaken by Army researchers are discussed in this paper. Critical technical challenges for the various technologies, and the authors' approach for overcoming the technical barriers are also presented. Finally, future efforts to implement advanced optical sensing technology are presented.

8344-02, Session 2

Nanostructured materials for multifunctional applications under NSF-CREST research at Norfolk State University

A. K. Pradhan, Norfolk State Univ. (United States)

We will report our research progress in the field of core-shell as well as aligned nanostructures proposed under NSF-CREST center for nano and bio-inspired materials and devices (CNBMD). We will report on the fabrication and characterization of condensed and mesoporous silica as well as hydogel coated CoFe2O4, FeCo and Fe2O3 alloy magnetic nanocomposites for biomedical applications. We will also describe the growth and growth kinetics of aligned semiconductor nanostructures as well as metal doped semiconductors for metatronic as well as other device applications will be discussed. In addition, we will illustrate other center activities on neural probes and biosensors.

8344-03, Session 2

Development and Investigation of flexible polymer neural probe for chronic neural recording

C. S. Smith, K. D. Song, H. Yoon, Norfolk State Univ. (United States); T. Zeng, L. D. Sanford, W. Kim, Eastern Virginia Medical School (United States)

Neural recording through microelectrodes requires biocompatibility and long term chronic usage. With a potential for various applications and effort to improve the performance of neural recording probes, consideration is taken to the tissue and cellular effects in these device designs. The degeneration of neurons due to brain tissue motion is an issue along with brain tissue inflammation in the insertion of the probes. To account for motion and irritation the material structure of the probes must be improved upon. This research presents the fabrication of neural probes on the microscale utilizing flexible polymers. Polyimide neural probes have been considered possibly to reduce degradation in their variability caused by brain motion. The microfabrication of the polyimide neural probe has an increased flexibility while accounting for biocompatibility and the needs for chronic use. Through microfabrication processes a needle probe is produced and tested for neural recording.

8344-04, Session 2

Carbon nanocones: mechanical and vibrational properties

F. Scarpa, Univ. of Bristol (United Kingdom); J. Narojczyk, Institute of Molecular Physics (Poland); K. W. Wojciechowski, Polish Academy of Sciences (Poland)

Carbon nanocones are nanostructures occurring on the surface of natural graphite, or manufactured by plasma torching hydrocarbon assemblies. Some initial molecular dynamics simulations have shown metastable capabilities in nanocone structures subjected to compressive loading. In this work we describe the overall mechanical properties of nanocones and nanohorns using an high fidelity atomistic-continuum approach. We also highlight the peculiar vibrational spectroscopy of these nanostructures, with fundamental mdoes swicthing from beam-like to curved-shell ones, with different spectra peaks depending on the geometry of the nanostructure. The peculiar vibrational spectroscopy can be used to design NEMS structures with different wave beaming characteristics.

8344-05, Session 3

Microwave graphene syntheses and graphene-based sensors/actuators

I. Oh, KAIST (Korea, Republic of)

Graphene, a single layer assembly of carbon atoms densely packed into a benzene ring structure, have unique properties, thus making it a potential material for various applications. In this study, microwave-based eco-friendly techniques for graphene syntheses from various precursors like graphite, carbon nanotubes, and carbon fibers will be introduced. Microwave radiation as external energy source was used to produce strong expansion of the graphite worm in the thickness direction. Also, a facile one-pot synthesis of metal decorated graphene is newly developed and the graphene nanosheets decorated with metallic nanoparticles

were applied to make various chemical sensors and actuators. The graphene nanoparticles and sheets were applied to develop high-sensitive biomolecule sensors and artificial muscles. Also, four different graphene-based actuators will be demonstrated including GO-CNT bilayer, G-Nafion, ferromagnetic shape memory polymer and transparent ionic polymer actuators.

8344-06, Session 4

Graphene-based nanocomposite smart material

I. Kang, Pukyong National Univ. (Korea, Republic of)

To address the need for new composite smart materials, this paper presents graphene based nano composite processing and its characteristics to develop a smart material having piezoresistivity for sensing. Among several possible smart nanoscale materials, graphene has aroused the most interest in the research community because of its remarkable electrical, mechanical and other physical properties. While graphene has been reported impressive material properties in nanoscale, the properties of the bulk composite materials are not enough to be studied an engineering material in macro scale. Therefore fabrication of a nano hybrid material and its material characterization to develop a novel smart material for sensors is studied to realize the applications of graphene. In this study, 1, 3 and 5 wt% graphene/epoxy composites were fabricated and their resistivity was measured. The electrical conductivity was obtained from 3 wt%.

8344-07, Session 4

Magnetic and optical properties of CoFe2O4/ZnO core-shell nanocomposites for biomedical applications

A. K. Pradhan, K. Zhang, Norfolk State Univ. (United States)

In this work, the magnetic and optical properties of CoFe2O4/ZnO core-shell nanostructures are presented. Spinal CoFe2O4 nanoparticles were prepared via a modified precipitation process. The ZnO shell layer used to coat CoFe2O4 nanoparticles were fabricated by sol gel technique. The crystal structures and morphologies of these nanocomposites were analyzed by x-ray diffraction and transmission electron microscopy. The magnetic properties, such as blocking temperature, magnetization, were measured by the superconducting quantum interference device (SQUID) magnetometer. The optical properties affected by magnetic core were carried out by ultraviolet-visible spectroscopy.

8344-08, Session 4

Carbon nanotube based composite fibers for strain sensing, signal processing, and computing

H. Vardhan, D. Roy Mahapatra, Indian Institute of Science (India)

Carbon nanotube dispersed in polymer matrix has been aligned in the form of fibers and interconnects and cured electrically and by UV light. Conductivity and effective semiconductor tunneling against reverse to forward bias field has been designed to have differentiable current-voltage response of each of the fiber/channel. The current-voltage response is a function of the strain applied to the fibers along axial direction. Biaxial and shear strains are correlated by differentiating` signals from the aligned fibers/channels. Using a small doping of magnetic nanoparticles in these composite fibers, magneto-resistance properties are realized which are strong enough to use the resulting magnetostriction as a state variable for signal processing and computing. Various basic analog signal processing tasks such as addition, convolution and filtering etc. are performed. These preliminary study shows promising application of the concept in combined analog-digital computation in carbon nanotube based fibers. Various dynamic effects such as relaxation, electric field dependent nonlinearities and hysteresis on the output signals are studied using experimental data and analytical model.

8344-09, Session 5

Al-doped ZnO aligned nanorod arrays for opto-electronic and sensor applications

A. K. Pradhan, Norfolk State Univ. (United States)

We report the growth of vertically aligned Al:ZnO nanorod arrays synthesized by the hydrothermal technique at considerably low temperature on a sputtered Al:ZnO seed layer. The morphology demonstrates that the nanorod arrays maintain remarkable alignment along the c-axis over a large area. The investigation of the optical properties of the seed layers as well as the nanorod arrays show varied band gaps. The optoelectronic properties of nanorod arrays on Al:ZnO/p-Si seed layer with SiO2 have been illustrated. The photocurrent is significantly reduced in nanorod arrays on AZO/SiO2/p-Si heterojunction due to multiple scattering phenomena associated with the nanorod arrays. The optical properties of the AZO film with and without the AZO nanorod arrays were investigated. Also the effects of an intermediate layer in the AZO/P-Si heterojunction structure with and without the AZO nanorod array present were explored. All the various intermediate layers displayed photovoltaic effect behavior, especially with the AZO/SiO2/P-Si heterojunction structure which exhibited ideal diode behavior. The optoelectronic properties of nanorod arrays on AZO/P-Si seed layer with SiO2 have been illustrated. The photocurrent is significantly reduced in nanorod arrays on AZO/SiO2/P-Si heterojunction due to multiple scattering phenomena associated with the nanorod arrays. The results have tremendous impact for sensor fabrication, including glucose sensor.

8344-10, Session 5

Acetone vapor sensor made with cellulose-TiO2/MWCNTs hybrid nanocomposite

Y. Chen, H. Jung, J. Kim, Inha Univ. (Korea, Republic of)

This paper reports the cellulose-TiO2/MWCNTs (CTM) hybrid nanocomposite as an acetone vapor sensor operated at room temperature. TiO2/MWCNTs nanocomposite is successfully synthesized by hydrothermal method and characterized by transmittance electron microscopy, X-ray diffractometry. Cellulose solution was blended with TiO2/MWCNTs nanocomposite to form CTM hybrid nanocomposite. Finally, comb shaped electrodes are patterned on CTM surface by lift-off process. The chemical vapor is provided using a bubble system. The gas sensitivity of the hybrid film during exposure of the gas is investigated by measuring the electrical resistance between electrodes using a LCR meter. This vapor sensor shows a quick response time with reliability. The CTM hybrid nanocomposite vapor sensor has good stability throughout the sensing test. The vapor sensing mechanism of this hybrid nanocomposite is also discussed in this paper.

8344-11, Session 5

Design of nanostructured-based glucose biosensors

F. Williams, A. Komirisetty, Norfolk State Univ. (United States)

One of the most successful biosensors has been the glucose sensor. Its technology has progressed to allow patients to monitor their blood glucose in the comfort of their homes. Much research is being focused on the use of nanostructures (nanowires, nanotubes, nanoparticles, etc.) to provide for miniaturization and improved performance of these devices. This paper presents the design of glucose sensors that will be

integrated with advanced nano-materials, bio-coatings and electronics to create novel devices that are highly sensitive, inexpensive, accurate, and reliable. In the work presented, a glucose biosensor and its fabrication process flow have been designed. The device is based on electrochemical sensing using a working electrode with bio-functionalized zinc oxide (ZnO) nano-rods. Among all metal oxide nanostructures, ZnO nano-materials play a significant role as a sensing element in biosensors due to their properties such as high isoelectric point (IEP), fast electron transfer, non-toxicity, biocompatibility, and chemical stability which are very crucial parameters to achieve high sensitivity. Amperometric enzyme electrodes based on glucose oxidase (GOx) are used due to their stability and high selectivity to glucose. The device also consists of silicon dioxide, silicon nitride, and aluminum oxide layers as well as platinum working and counter electrodes and a silver/silver chloride reference electrode. Currently, the biosensors are being fabricated using the process flow developed. Once completed, the sensors will be bio-functionalized and tested to characterize their performance, including their sensitivity and stability.

8344-12, Session 5

Integrated linear Fresnel spectrometer chip

Y. Park, National Institute of Aerospace (United States); S. H. Choi, G. C. King, NASA Langley Research Ctr. (United States); H. Yoon, Norfolk State Univ. (United States); U. Lee, Gachon Univ. Gil Medical Ctr. (Korea, Republic of)

A tiny motionless optical spectrometer chip was fabricated using a linear gradient-gap Fresnel grating which was mounted perpendicularly to the sensor array surface. Unlike the common spectrometers which are based on Fraunhoffer diffraction with a regular periodic line grating, the new linear gradient Fresnel spectrometer chip can be miniaturized much smaller into Fresnel regime beyond the limit of conventional spectrometers. Also, the new Fresnel spectrometer system has a new data collection algorithm since it is proportional to the energy scale (hc/λ), while the conventional spectrometers are proportional to the wavelength scale (λ). We discuss the unique physical properties and optical performance test results of the new linear Fresnel spectrometer chip.

8344-13, Session 5

Smart healthcare textile sensor system for unhindered-pervasive health monitoring

P. Rai, P. S. Kumar, S. Oh, H. Kwon, G. N. Mathur, M. P. Agarwal, V. K. Varadan, Univ. of Arkansas (United States)

No abstract available

8344-62, Session 5

The Zigbee wireless electrocardiogram measurement system design with an algorithm removing motion artifact by using adaptive filter and moving weighted factor

H. Kwon, S. Oh, V. K. Varadan, Univ. of Arkansas (United States)

The method of diagnosing irregularities of cardiac by investigating heart signal is usually used as one of the method to check cardiac disorder. The traditional method to detect the electrocardiogram(EKG) is that patients need to visit a hospital and lie down a room called by cardiac signal detection room with attaching many kinds of electrodes, which are small sensors to detect EKG signal by using connection method called as Lead I,II, and III. In addition, even a little movement of patient makes a severe effect to measure clear EKG signal. In these days, as the necessity about early detection of disorders is rising on the fore, many people are briskly researching a new concept escaping from the traditional method checking ECG signal in hospital. The research is based on the two kinds of concept. The first is the wireless technology which can provide convenience and simpleness, and the second is motion artifact remove algorithm which can detect clear EKG signal from measurement subject. This paper suggests a wireless technology called by Zigbee and a motion artifact algorithm. The motion artifact created by measurement subject's movement or even respiration action influences to distort EKG signal, and the frequency distribution is around from 0.2Hz to even 30Hz. The frequencies are duplicated in actual EKG signal frequency, so it is impossible to remove the artifact by using low-pass filter or high-pass filter without any distortion of EKG signal. The suggested motion artifact algorithm in this paper has two kinds of main areas to extract EKG signal from measured original signal. The first part is to extract motion signal from measured signal, and the second part is to extract clear EKG by using extracted motion signal and measured original signal. The paper suggests a moving weighted factor, peak to peak detection, interpolation in order to extract motion signal, and the paper is used an adaptive filter in order to detect EKG signal by using extracted motion signal and measured original signal.

8344-14, Session 6

Printed hybrid systems

J. Mäkinen, K. Keränen, T. Alajoki, M. Koponen, A. Kemppainen, K. Rönkä, R. Korhonen, VTT Technical Research Ctr. of Finland (Finland)

This paper presents research activities carried out at VTT, the Technical Research Centre of Finland, in the field of hybrid integration of optics, electronics and mechanics. Main focus area in our research is the manufacturing of electronic modules and product structures with printed electronics, film-over-molding and polymer sheet lamination technologies and the goal is in the next generation of smart systems utilizing monolithic polymer packages. The combination of manufacturing technologies such as roll-to-roll -printing, injection molding and traditional component assembly is called Printed Hybrid Systems (PHS).

Several demonstrator structures have been made, which show the potential of polymer packaging technology. One demonstrator example is a laminated structure with embedded LED chips. Element thickness is only 0.3mm and the flexible stack of foils can be bent in one direction. The combination of printed flexible circuit boards and injection molding has also been demonstrated with several functional modules. The demonstrators illustrate the potential of origami electronics, which can be cut and folded to 3D shapes. It shows that several manufacturing process steps can be eliminated by Printed Hybrid Systems technology. The main benefits of this combination are small size, ruggedness and conformality. The devices are ideally suited for medical applications as the sensitive electronic components are well protected inside the plastic and the structures can be cleaned easily due to the fact that they have no joints or seams that can accumulate dirt or bacteria.

8344-15, Session 6

Synthesis and characterization of thermoelectric ink for renewable energy applications

J. Lee, Univ. of Arkansas (United States); H. J. Kim, NASA Langley Research Ctr. (United States); S. Oh, Univ. of Arkansas (United States); S. H. Choi, NASA Langley Research Ctr. (United States); V. K. Varadan, Univ. of Arkansas (United States)

Printing technology can enable continuous and high-speed fabrication of thermoelectric devices on both flexible and rigid substrates. The printing process, patterns, substrates and inks need to be investigated and optimized for the fabrication of these printable thermoelectric devices. Ink design in terms of physical properties like wettability and viscosity,

choice of binder and filler materials is a critical part in the fabrication of printable thermoelectric devices, especially printable p-type materials and n-type materials to make p-n junctions. In this study, thermoelectric inks are formulated and thermoelectric generators are designed and implemented with these inks through a printing process. Ball-milled and sonificated p- and n-type Bi2Te3 are used as the nanoparticle fillers for n-type and p-type inks. These fillers are suspended in polymer/solvent solutions to provide suitable fluidic characteristics for the printing process.

8344-16, Session 7

Cellulose-gold nanowire composite for electronic applications

J. Kim, B. Lim, S. Park, Chosun Univ. (Korea, Republic of)

By modification of cellulose itself, nano-sized electrical inner paths can be formed by chemical bonding of metallic or semiconducting nanowires to cellulose fibrils during regenerated process. Already our earlier result of the chemical bonding between carbon nanotubes and the regenerated cellulose has been reported as a novel electronic material for potential paper transistor material. In this paper, we study the cellulose-gold nanowire composite for electronic application due to its huge potential for paper transistor and other applications such as biosensors and strain sensors due to its electrical response sensitivity. The detailed material properties of cellulose-gold nanowire composite will be shown and its potential for electrical applications will be demonstrated.

8344-17, Session 7

Titanium dioxide-cellulose hybrid nanocomposite based condoctometric glucose biosensor

M. Maniruzzaman, S. K. Mahadeva, H. Jung, J. Kim, Inha Univ. (Korea, Republic of)

This paper investigates the feasibility of conductometric glucose biosensor based on glucose oxidase (GOx) immobilized TiO2-cellulose hybrid nanocomposite (TCHN). TiO2 nanoparticles were blended with cellulose solution prepared by dissolving cotton pulp with lithium chloride/N,N-dimethylacetamide solvent to fabricate TiO2-cellulose hybrid nanocomposite. The enzyme (GOx) was immobilized into this hybrid material by physical adsorption method. The successful immobilization of GOx into TiO2-cellulose hybrid nanocomposite via covalent bonding between TiO2 and GOx was confirmed by X-ray photoelectron analysis. The linear response of our propose glucose biosensor is obtained in the range of 1-10mM with correlation coefficient of 0.93. Our study demonstrates TiO2-cellulose hybrid material as a potential candidate for an inexpensive, flexible and disposable glucose biosensor.

8344-18, Session 7

The development of ternary alloy thin film plasmonic and magneto-optical sensors

J. R. Skuza, National Institute of Aerospace (United States); S. H. Choi, NASA Langley Research Ctr. (United States)

Materials have been heavily sought after and researched in recent years for sensor applications in various smart structures. Sensors that incorporate active elements, i.e. ones that can be controlled by some external agent (such as a modulated magnetic field), show a distinct advantage in sensitivity over ones with passive elements. An example of an active sensor is a plasmonic sensor that incorporates a ferromagnetic material into the structure, thus intertwining the plasmonic and magneto-optical (MO) properties of the system. Fabrication of these sensors has typically been via multilayered structures with segregated noble metal / ferromagnetic heterostructures. However, the plasmonic and MO properties of these multilayered structures are dependent on the interfaces within the heterostructure. It is theorized that combining this multilayered noble metal / ferromagnetic structure into a single layer will improve the overall performance of the sensor. Certain ternary alloys under specific growth conditions exhibit a ferromagnetic phase with plasmonic properties. The MO and plasmonic properties of these single-layered ternary alloys will be discussed within the context of MO and plasmonic sensors.

Materials have been heavily sought after and researched in recent years for applications in various smart structures, such as sensors. Sensors that incorporate active elements show a distinct advantage over sensors with passive elements. This is most notably seen in plasmonic sensors where the incorporation of a ferromagnetic material into the structure intertwines the plasmonic and magneto-optical (MO) properties of the system. MO and plasmonic properties of single-layered ternary alloys that exhibit a ferromagnetic phase will be discussed within the context of MO and plasmonic sensors.

8344-19, Session 7

Effects of iron sources on the structural and electrochemical properties of LiFePO4/C composites for lithium ion batteries

G. Wang, L. Chen, G. N. Mathur, V. K. Varadan, Univ. of Arkansas (United States)

Lithium iron phosphate LiFePO4 is one of the most promising cathode materials for lithium-ion batteries due to its advantages of lower cost and environmental compatibility as compared to other lithium cathode materials, especially for power batteries to electric vehicles (EV). It is found that the electrochemical properties of lithium iron phosphate are dependent on the synthesizing method and the reaction conditions. In the present paper, ferrous and ferric iron precursors were used to synthesize LiFePO4/C by aqueous sol-gel method and solid-state reaction technique, using ethylene glycol or sucrose as chelating agent and carbon source. The phase structure, particles morphology and carbon content of LiFePO4/C products were characterized by XRD, SEM and elemental analysis, respectively. Electrochemical impedance spectroscopy and cyclic voltammetry were applied to study the reaction kinetics of the LiFePO4/C cathode materials. The results show that different particles morphology and electrochemical properties of LiFePO4/C were obtained using different iron sources.

8344-20, Session 8

Wirelessly powered airship with 3rd gen energy sources for the future transportation systems

K. Lee, Turner-Fairbank Highway Research Ctr. (United States)

The speed of technology development, life style, and economic size are rapidly changing the environments of the current transportation system. Because the rate of increase of vehicles on the road is faster than that of infrastructure capacity increase, traffic density becomes higher and more fatalities and injuries happen. A new concept of the transportation system is urgently required to prepare for the future. And the creation of 3rd generation energy sources is the most powerful way to meet the future of the USA.

The airship has four major functional units: power harvesting, electric propulsion, flight stability control, and electric hoist for cargo and or people elevators. The power will be collected by highly efficient solar photo-voltaic (PV) or solar thermoelectric (TE) for daytime and microwave power for nighttime. This speech will introduce the new NANO materials that generate highly efficient solar photo-voltaic and the new inventions, regarding the latest rectenna technology. Airship structure design, electric propulsion, and flight control system will be also covered.

8344-21, Session 9

Probabilistic analysis and design considerations of LINA-type QCA Devices

S. C. Lee, L. R. Hook IV, The Univ. of Oklahoma (United States)

It is known that due to the many random factors, from thermal fluctuations to wave interference, computational perfection in nanoelectronic circuitry will be difficult to achieve. Defects and faults arise from instability and noise processes which lead to unreliable results. A probabilistic computational model is needed to reduce such errors and to achieve more reliable computation. Recently, Hook and Lee proposed a new quantum-dot cellular automata (QCA) nanoelectronics circuit design method using lattice structured 2-D 2-dot QCA cells. It is shown that this method not only can implement any combinational and sequential logic design but also offers periodicity and symmetry characteristics that are widely found in naturally occurring and self-assembled materials (molecules, crystals, etc.) for fabrication.

The purpose of this paper is to stochastically analyze LINA-type QCA circuit behaviors in a noisy environment. In this analysis, circuit signals become random variables. Circuit component functions are characterized by probabilistic circuit component models. And for any given set of input signal probabilities, the probabilistic signal at any interior part and the outputs of the circuit can be calculated using the arithmetic expressions. Illustrative examples of this analysis method are presented and verified by simulation. In addition, techniques to reduce the random noise effects to the reliability of 2-D 2-dot QCA circuits operated in an inevitable noisy environment are also presented. Finally, computational algorithms will be presented which analyze the LINA circuit probabilities based on nearest neighbor and transfer matrix methods resulting in formulas which must be considered in the design of any implementable LINA-type QCA device. These concepts are extended to improve the reliability of communication and logic structures.

8344-22, Session 9

Electronic current transport in CNT-FETs for operation in ballistic region

A. Srivastava, Y. Xu, Louisiana State Univ. (United States); A. K. Sharma, C. Mayberry, Air Force Research Lab. (United States)

Carbon nanotubes have exhibited excellent molecular adsorption properties and their dimensions are comparable to typical bio-molecules such as the DNA. Carbon nanotube field effect transistors (CNT-FETs) and integrated circuits are being explored for electrical sensing of bio-materials and gases. The adsorbed molecules by the carbon nanotube and the CNT-FET result in a change of the CNT conductance and electronic properties of the CNT-FET which can be easily monitored. It thus becomes very important to better understand electronic transport and model its behavior in relation to bio- and chemical sensing. Recently Srivastava et al. [1] have developed compacts analytical models for current transport in CNT-FETs compatible with EDA tools for analysis and design of CNT-FET based integrated circuits. The current transport model is limited to application in non-ballistic region. Since applications requiring a large number of bio-sensing using CNT-FETs are in 2-20 nm range, the current transport model of CNT-FETs has been suitably modified for operation in the ballistic region for use in integrated circuit design and sensing applications.

In the present work, the surface potentials in a CNT-FET have been coupled with the current transport equations to obtain compact electronic current transport models for operation in the ballistic region. A p-type CNT-FET is considered for the analysis which can be easily applied in n-type CNT-FETs. The present work is also compared with other electronic transport models and experimental measurements. A close agreement establishes the validity of our electronic transport model of the transistor operation in the ballistic region. It is also shown that two subbands in the valance band of CNT are sufficient for computation of current in CNT-FETs. The present current transport model characterizing CNT-FET in the ballistic region is simple and compatible with EDA tools for bio-sensing chip design.

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8344-23, Session 9

Designing quantum-dot cellular automata logic devices in 3-dimensional space

J. F. Herrera, S. C. Lee, The Univ. of Oklahoma (United States)

Quantum-dot cellular automata (QCA) is a promising new paradigm in the field of nanotechnology. This new paradigm has the potential to allow for fast and low-power computation that would be well beyond what current CMOS technologies are capable of. Several possible physical implementations have been proposed and verified for use with QCA. The four-dot rectangular cell has traditionally been used as the basis for QCA circuit designs. However, two-dot designs, that are perhaps better suited, have also been suggested. In addition, QCA designs have generally been two-dimensional (2-D) which leaves a yet unexplored third dimension to be exploited. 3-dimensional (3-D) QCA could potentially allow for a more optimal, efficient and simple design. This paper proposes three-dimensional (3-D) designs of an inverter, a majority gate, an AND gate, and an OR gate for both four-dot and two-dot architectures.

8344-24, Session 9

Surface topography dependent plasmonic characteristics

G. C. King, NASA Langley Research Ctr. (United States); H. Kim, Y. Park, National Institute of Aerospace (United States); K. D. Song, Norfolk State Univ. (United States); S. H. Choi, NASA Langley Research Ctr. (United States)

Understanding of the physics of plasmonic behavior within quantum-confined domains is a key interest of this study. To realize and observe the plasmonic behavior experimentally, a series of arrayed nanometer-sized aperture configurations was fabricated in thin silver films on a quartz substrate using a focused ion beam (FIB) instrument. Each aperture has nano-scale symmetrical features built around it. Various surface topographic features built around each aperture cause the plasmon to undergo a topography-dependent momentum change which is uniquely represented by artificially created electromagnetic dipole radiation. The study also exploits the surface plasmon polariton (SPP) phenomenon to permit phase changing capability and controlled variation in intensity and spectral response of the transmitted light. Any changes in transmitted light between the apertures built on the plain surface and the surface with topographical features are measured to identify the electromagnetic dipole radiation by loss. By injecting a varying electrical field in the array, a quantum constraint is imposed on the surface plasmon (SP) that can vary the characteristics of the transmitted light. The near field scanning optical microscope (NSOM) and a spectrometer were used to analyze laser light of several wavelengths, both with and without an applied electrical field.

8344-25, Session 10

Music close to one’s heart! Heart rate variability with music: diagnostic with e-bra and smart phone

S. Hegde, National Institute of Mental Health and Neuro Sciences (India); P. S. Kumar, P. Rai, G. N. Mathur, V. K. Varadan, Univ. of Arkansas (United States)

Music is a powerful elicitor of emotions. Emotions evoked by music,

through autonomic correlates have been shown to cause significant modulation of parameters like heart rate and blood pressure. Consequently, Heart Rate Variability (HRV) analysis can be a powerful tool to explore evidence based therapeutic functions of music and conduct empirical studies on effect of musical emotion on heart function. However, there are two limitations with current studies. Firstly, HRV is often recorded while the subject is in sitting position and music is actively processed during the experimental condition. However, in reality, music listening behaviour has transformed completely with the introduction of ultra portable music players which are used by people on the move. Secondly, they have produced variable results to different emotions evoked via music, owing to variability in the methodology and the nature of music chosen. Therefore, a pragmatic understanding of HRV correlates of musical emotion in individuals listening to specifically chosen music whilst carrying out day to day routine activities is needed. In the present study, we aim to study HRV in 10 musically untrained women using an e-bra with nano-sensors to record heart rate in real time. The e-bra developed previously, has several salient features that make it conducive for this study- fully integrated garment, dry electrodes for easy use and unrestricted mobility. The study considers two experimental conditions:- First, HRV will be recorded when there is no music in the background and second, when music chosen by the subject is playing in the background. In both the conditions HRV will be recorded while the subject is carrying out similar daily routine task (walking, jogging, light physical work and gardening etc). This study would be the first of its kind on the effects of music and its HRV correlates in real time using e-bra.

8344-26, Session 10

Wireless power using magnetic resonance coupling for neural sensing applications

K. D. Song, H. Yoon, D. L. Geddis, Norfolk State Univ. (United States); K. Lee, Federal Highway Administration (United States); J. Kim, Inha Univ. (Korea, Republic of); S. H. Choi, NASA Langley Research Ctr. (United States)

In this presentation, we will discuss about the performance or suitability of wireless power transmission module using magnetic resonance coupling, specifically designed for neural sensing systems and in-vivo animal models. This research presents simple experimental set-ups and circuit models of magnetic resonance coupling modules for this application. Several technical issues that are involved in positioning and sizing of source/receiver coils will be discussed in comparison with conventional inductive coupling devices. Furthermore, potential thermalization of tissue while wireless power transmission will also be addressed.

8344-27, Session 10

Wireless structural sensor made with frequency selective surface antenna

S. Jang, J. Kim, Inha Univ. (Korea, Republic of)

Nowadays, various types of wireless sensor have been developed by advance of wireless communication technology and information technology. This paper reports a wireless structural sensor made with frequency selective surface (FSS) antenna. FSS based wireless sensor can be made on a flexible substrate so at to reduce the coast and increase the sensing range. When microwaves are applied to the FSS antenna, the microwave reflection and transmission characteristics of the FSS are changed by geometrical shape and lumped impedance change of the FSS antenna. The reflection and transmission characteristics will be investigated in terms of FSS size, unit distance and external mechanical strain. This remote sensor can detect structural damage and strain.

8344-28, Session 10

Wireless brain-machine interface using EEG and EOG: brain wave classification and robot control

S. Oh, P. S. Kumar, H. Kwon, V. K. Varadan, Univ. of Arkansas (United States)

A brain-machine interface (BMI) links a user's brain activity directly to an external device. It enables a person to control devices using only thought. Hence, it has gained significant interest in the design of assistive devices and systems for people with disabilities. In addition, BMI has also been proposed to replace humans with robots in the performance of dangerous tasks like explosives handling/diffusing, hazardous materials handling, fire fighting etc. There are mainly two types of BMI based on the measurement method of brain activity; invasive and non-invasive. In the invasive BMI, electrodes are implanted directly into the appropriate region of the brain using neurosurgery techniques. Invasive BMI can provide pristine signals but it is expensive and surgery may lead to undesirable side effects. Recent advances in non-invasive BMI have opened the possibility of generating robust control signals from noisy brain activity signals like EEG and EOG. A practical implementation of a non-invasive BMI such as robot control requires: acquisition of brain signals with a robust wearable unit, noise filtering and signal processing, identification and extraction of relevant brain wave features and finally, an algorithm to determine control signals based on the wave features. In this work, we developed a wireless brain-machine interface with a small platform and established a BMI that can be used to control the movement of a robot by using the extracted features of the EEG and EOG signals. The system records and classifies EEG as alpha, beta, delta, and theta waves. The classified brain waves are then used to define the level of attention. The acceleration and deceleration or stopping of the robot is controlled based on the attention level of the wearer. In addition, the left and right movements of eye ball control the direction of the robot.

8344-29, Session 10

A film-type haptic actuator for mobile devices

D. Kim, Inha Univ. (Korea, Republic of); S. Kim, Korea Univ. of Technology and Education (Korea, Republic of); J. Kim, Inha Univ. (Korea, Republic of)

Over time, a wide variety of haptic actuators have been designed and implemented for mobile devices. This paper addresses a film type electro-static actuator using an air gap structure composed of an active film and patterned polydimethylsiloxane (PDMS) columns. A cellulose acetate (CA) film charged with an electric potential can generate vibration under the AC voltage input. Its performance is evaluated depending on various actuation conditions. It is found that the induced displacement of the actuator is proportional to the level of biased electric potential. The CA electro-static actuator has a great potential to generate a wide variety of tactile sensations.

8344-54, Poster Session

Analysis of micro bending test for polycrystalline materials by modified strain gradient theory

B. Jung, H. Park, Pohang Univ. of Science and Technology (Korea, Republic of)

Recent experiments with non-uniform plastic deformation have shown the size effects in micro/nano scale. But the classical continuum plasticity can't predict these size effects in micro/nano scale, since the constitutive equation of the classical mechanics doesn't include the internal length as a parameter for the deformation.

The mechanism based strain gradient (MSG) plasticity is one of the methods to analyze non-uniform deformation behavior in micro/nano scale. The MSG plasticity is the multi-scale analysis connecting the micro-scale notion of the statistically stored dislocations (SSDs) and the geometrically necessary dislocation (GNDs) to meso-scale deformation using the strain gradient.

In this paper, modified strain gradient theory is proposed based on the nonhomogeneity of polycrystalline metallic materials and free surface effect. When the grains of crystalline metals deform, overlaps and voids appear at the grain boundary. These overlaps and voids can be corrected by the GNDs. By taking into account the nonhomogeneity of polycrystalline materials, the density of the GNDs due to the deformation is calculated. Consideration of the GNDs on the grain boundary and free surface effect give a relationship between the size effect and the flow stress. This relationship can explain the size effects in micro/nano scale. Using the proposed model, analysis of the effect of both specimen size and grain size under the micro bending test of polycrystalline materials is carried out.

8344-55, Poster Session

Synthesis and characterization of lithium ion batteries

A. K. Pradhan, K. Zhang, M. Arslan, Norfolk State Univ. (United States)

Layered lithiated transition metal oxides have been investigated as a cathode materials for lithium ion batteries due to the following advantages, such as high output voltage of 3.6 V, high energy density larger than 450Wh/dm3, low self-discharge rate less than 10%, no memory effect resulting in long cycle lives for more than 1000 times charging and discharging, free maintenance and no environmental pollution. In this study, the LiNiO2 particles and LiV3O8 nanorods were successfully synthesized by sol-gel wet chemical methods. Annealing heat treatment influence the crystallinity of the final product, which may be consequently affected their electrochemical performance.

8344-56, Poster Session

Remarkable evolution of electrical conductivity in Al:ZnO films

H. Dondapati, A. K. Pradhan, K. Zhang, Norfolk State Univ. (United States)

Transparent conductive Al-doped ZnO (AZO) films were fabricated on glass substrates by RF magnetron sputtering technique with varying substrate temperatures. The electrical and optical properties of the films were strongly affected by the substrate temperature. AZO films deposited at 400 oC showed the optimum electrical and optical properties. Highly oriented AZO films in the (0002) direction were observed in specimens as increasing of the substrate temperature. It was found that the band gap increased from 3.60 eV to 3.76 eV as the substrate temperature increases from 300 to 400 °C. As the substrate temperature increases, the electrical resistance decreases, reaching a minimum value, in the order of 1.2 X 10-3 Ω-cm for films deposited at 450 oC. The as-grown AZO films have an average transmittance of above 85% at the visible region. Analysis of X-ray photoelectron spectra indicated that AZO films deposited at elevated temperatures contained large amount of Al content due to Zn deficiency, however we have also investigated the decrement in bandgap from 3.76 eV to 3.72 eV as the substrate temperature increased from 450 to 500 o C. These results demonstrated the possibility to improve the conversion efficiency of CIGS solar cells with AZO films as transparent conductive oxide layers.

8344-57, Poster Session

The investigation of Molybdenum (Mo) thin films properties as a function of reduced deposition thickness

O. Bamiduro, H. Dondapati, A. K. Pradhan, Norfolk State Univ. (United States)

Ex-situ characterizations were employed to investigate the physical, chemical and mechanical properties of Molybdenum (Mo) thin films deposited on Soda-Lime Glass (SLG) substrates via Radio frequency (r.f.) magnetron sputtering technique. The effects of varying the deposition time (960s, 1200s, 1440s and 1680s) with post thermal treatment influenced chemical states, structural, morphological, optical, electrical and mechanical behavior of the Mo thin films. There was a sharp contrast in the surface morphology as the annealing temperature increased. Consequently, the incremental change in the surface roughness induced a decrease in electrical and the reflective properties. The X-ray photoelectron spectroscopy data revealed the traces of oxygen in the Mo lattice sites as the films undergo thermal treatment.

8344-58, Poster Session

Ultrasound contrast agent fabricated from microbubbles containing instant adhesives, and its ultrasound imaging ability

T. Makuta, Y. Tamakawa, Yamagata Univ. (Japan)

The ultrasonic diagnostics is widely used in a medical setting because it is safe, low-cost and real-time diagnostic technology. Non-invasive surgery techniques and drug delivery system with acoustic characteristics of ultrasound contrast agent (USCA) have been studied intensively in recent years. Many USCA are offered commercially and its structure is microbubble coated by surfactant or lipid bilayer, that is, hollow microsphere. Aqueous solution including USCA is prepared by shaking the mixture of the low solubility gas, saline and bubble stabilizer like surfactant and lipid. USCA collapses easily under the blood circulating and the ultrasound irradiating because it is just a stabilized bubble without solid-shell by surface adsorption of surfactant or lipid.

We developed the new fabrication method of the hollow microsphere with polymer shell, which can be fabricated just blowing vapor of commonly-used instant adhesive into water as microbubbles. The main ingredient of instant adhesive is generally cyanoacrylate monomer, which is polymerized within seconds in the presence of water. Therefore, the cyanoacrylate vapor contained inside microbubble initiates polymerization on the gas-liquid interface soon after microbubbles are generated in water. Consequently, hollow microspheres coated by cyanoacrylate thin film are generated. We also investigated the ultrasound imaging ability of the capsules in the flow channel and the results indicated the capsules enhanced the acoustic signal especially in the harmonic contrast imaging.

8344-59, Poster Session

Synthesis and characterization of lithium ion batteries

M. Arslan, K. Zhang, A. K. Pradhan, Norfolk State Univ. (United States)

Layered lithiated transition metal oxides have been extensively developed and investigated as a cathode materials for lithium ion batteries due to the following advantages, such as high output voltage of 3.6 V, high energy density larger than 450Wh/dm3, low self-discharge rate less than 10%, no memory effect resulting in long cycle lives for more than 1000 times charging and discharging, free maintenance and no environmental pollution. The cathode materials in lithium ion battery are generally in

the form of LiMO2 (M= Co, Ni, Mn, etc). Currently, lithium vanadium oxides also were studied. It is well known that the synthetic condition and methods are closely related to the electrochemical properties of lithium ion batteries. In this work, the wet chemical sol gel techniques have been used to synthesize LiNiO2 and LiV3O8. In this study, the LiNiO2 particles and LiV3O8 nanorods were successfully synthesized by sol-gel wet chemical methods. Annealing heat treatment influence the crystallinity of the final product, which may be consequently affected their electrochemical performance.

8344-60, Poster Session

The effects of Molybdenum (Mo) thin films properties as a function of reduced deposition thickness

O. Bamiduro, H. Dondapati, A. K. Pradhan, Norfolk State Univ. (United States)

No abstract available

8344-61, Poster Session

Remarkable evolution of electrical conductivity in Al:ZnO films

H. Dondapati, A. K. Pradhan, Norfolk State Univ. (United States)

Transparent conductive Al-doped ZnO (AZO) films were fabricated on glass substrates by RF magnetron sputtering technique with varying substrate temperatures. The electrical resistivity undergoes from a semiconductor to metal with increasing substrate temperatures. Similarly, the band gap increased from 3.60 eV to 3.76 eV as the substrate temperature increased. The remarkable evolution of electrical conductivity in Al:ZnO films were explained using density of states. These results are important for designing the conducting and transparent window layer of the solar cells and sensors.

8344-30, Session 11

New technologies for micropatterning functional nanocomposite polymers

A. Khosla, B. L. Gray, Simon Fraser Univ. (Canada)

We present a review of different micropatterning technologies for flexible elastomeric functional nanocomposites with a particular emphasis on mold material and processes for production of large size substrates. The functional polymers include electrically conducting and magnetic polymers developed at the Micro-instrumentation Laboratory at Simon Fraser University, Canada [1,2,3,4]. Previously we have reported hybrid microfabrication processeses for nanocomposite polymers micromolded against SU-8 photoepoxy masters [3]. However, SU-8 is limited to substrate sizes that are compatible with microelectronics processing, and de-molding problems are observed. Recently, we have developed new processes that address the problems faced with SU-8 molds. These new technologies for micropatterning nanocomposites involve new substrate materials, for example: Poly(methyl methacrylate) (PMMA) and Cyclic Olefin Copolymer (COC). A low cost PMMA microfabrication technology has been developed, which involves fabrication of micromold via either CO2 laser ablation [4] or deep UV. We have also explored screen printing technologies for printing of novel nanocomposite polymers on wide area fabrics/textiles for sensing applications.

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8344-31, Session 11

Effect of doping with rare earth elements (Er, Ho) on smart optical materials (ScN, AlN) in an applied electric field

H. Kim, Y. Park, National Institute of Aerospace (United States); G. C. King, S. H. Choi, NASA Langley Research Ctr. (United States)

The development of materials and fabrication technology for field-controlled spectrally active optics is essential for applications such as membrane optics, filters for LIDARs, windows for sensors, telescopes, spectroscopes, cameras and flat-panel displays. Rare earth dopants offer a large number of absorption and emission bands and can easily be incorporated into many high quality crystalline and amorphous hosts. In wide band-gap semiconductors like ScN and AlN, the existing deep levels can capture or emit the mobile charges and can be ionized with the loss or capture of the carriers. This is the basic concept of smart optic materials, and band gap shrinkage with dopants supports the possibility of this concept.

In the present work, semi-metallic materials (ScN, AlN) doped with rare earth elements (Er,Ho) were fabricated and tested in an applied electric field to characterize optical properties that are influenced by Zeeman or Stark effects. These effects can be verified using UV-Vis spectroscopy, Hall effect measurement and observation of the refractive index shift. The optical band gaps of ScN films with Er and ScN films with Ho were experimentally estimated to be about 2.33eV and 2.24eV (±0.2eV) respectively, smaller than that of undoped ScN (2.5±0.2eV). The red-shifted absorption onset is direct evidence for the decrease of band gap energy (Eg) and the broadening of valence band states attributable to the doping. A decrease in refractive index with applied field was observed as a smaller shift in absorption coefficient using a variable angle spectroscopic ellipsometer. In the presence of an electric field, mobile carriers are re-distributed within the space charge region (SCR) to produce this electro-refractive effect. The refractive index change is also affected by the density and location of deep levels within the SCR. In addition, the microstructure change was observed by TEM analysis. In the future, we will apply these field-controlled spectrally active material systems to applications of smart optics.

8344-32, Session 12

Rhombohedral epitaxy of cubic Si/Ge/SiGe quantum well structures on trigonal c-plane sapphire

S. T. Seaman, NASA Langley Research Ctr. (United States) and National Institute of Aerospace (United States); S. H. Choi, NASA Langley Research Ctr. (United States); H. J. Kim, Y. Park, National Institute of Aerospace (United States)

Using rhombohedral epitaxy, cubic crystals can be epitaxially grown on trigonal crystals in rhombohedral alignment. This allows for improved lattice-matching over traditional epitaxy resulting in reduced defects (e.g.

cracks and dislocations). This method however, is commonly hampered by the formation of 60 degree-rotated twin defects, preventing growth of single-crystalline layers. Using x-ray diffraction (XRD) wafer-mapping, the formation of twin defects can be monitored on the whole wafer-scale, allowing for growth conditions to be optimized. This allows for fabrication of single-crystal epitaxial layers of Si/Ge/SiGe on c-plane sapphire, as our group has previously demonstrated.

By growing thin, alternating layers (~40nm or less) of Si, Ge, and SixGe1-x with and electron-beam evaporator, quantum-well (QW) structures can be grown for semiconductor devices. The QWs induce particle confinement, virtually limiting charge carrier mobility from three dimensions of freedom down to two. In the application of photovoltaics, this allows for a more efficient path to the electrodes, and better overall efficiency. Due to mismatch in lattice constants, Si and Ge typically form defects when deposited on one another. However, the thin nature of the QWs allows for defect-free strain-balancing of layers with mismatched lattice constants. Growth conditions have been investigated to optimize the electron-hole transport in the strain-balanced QW structure. The results are presented here, showing improvement in charge carrier mobility with single crystal Si/Ge/SiGe QW structures on c-plane sapphire substrates over typical QW structures grown on conducting substrates.

8344-33, Session 12

Electromagnetic characterization of carbon nanotubes with defects and strain

B. Javvaji, D. Roy Mahapatra, Indian Institute of Science (India)

An atomistic simulation framework has been developed using molecular dynamic potential and continuum electromagnetic field approximation in a coupled manner. The method takes into account electromagnetic field interaction with electron or ion and the atomic nucleus depending on the material type and intensity of excitation. Electromagnetic radiation and scattering characteristics of nanostructures are simulated using the developed computational scheme. In particular, in this paper we obtain the equilibrium structure of carbon nanotube (CNT) at a given temperature and when subjected to tensile and torsional loadings leading to defect formation. Stone wall and other types of defects are formed under these conditions, which have been studied in detailed by the authors recently. The defect structure obtained in this way is now subjected to electromagnetic field using the developed computational scheme. Modification in the electromagnetic characteristics over a wide range of phonon and electromagnetic frequencies are simulated. The results are analyzed with possible potential applications in designing nanostructured antennae and electromagnetic transmission/ shielding using CNT-composite. Combinatorial effect by computational design to achieve broadband tenability in electromagnetic characteristics of such nano-structured composite is highlighted.

8344-34, Session 12

Hydrogen peroxide-sensitive membrane for optofluidic device manufacture

P. Bhagwat, Saint Louis Univ. (United States); C. Kim, Missouri Univ. of Science and Technology (United States); D. B. Henthorn, Saint Louis Univ. (United States)

In this work, the fabrication of a hydrogen peroxide-sensitive membrane and its integration in an optofluidic microdevice were studied. While hydrogen peroxide is an important analyte in biomedicine (monitored in studies of oxidative stress, for example), it is also a product of various enzymatic reactions. By integrating enzymatic and fluorescent elements, an optical detection method becomes possible for numerous metabolites, including glucose, sucrose, lactate, alcohol, creatinine, gluatamate, urate, cholesterol, etc. Europium tetracycline (EuTc), a complex that is known to show reversible, concentration-dependent fluorescence in the presence of hydrogen peroxide, was chosen as the reporter molecule in the sensing element. The EuTc fluorophore, when immobilized in a Nafion ionomer membrane, showed a reversible response to dynamically-changing hydrogen peroxide concentrations. Dissolution of EuTc in Nafion was rapid and spontaneous, and both pre-formed and liquid drop-cast formulations were used. In addition, destruction of fluorescence, which occurred in solution at high hydrogen peroxide concentrations, was prevented. Nafion was found to be an effective immobilization membrane that retained the EuTc fluorophore, allowed for sufficient transport of the hydrogen peroxide analyte molecule to maintain efficient device response, and stabilized the complex against degradation. These membranes were fabricated for use in fluidic microdevices. Measurements of fluorescent intensity were done using a reflection probe setup (405 nm excitation, 615 nm emission) while various analyte challenges were delivered.

8344-35, Session 12

Covalent functionalization of carbon nanotube in-situ grown on metal-silicon chip

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Abstract

We report on the successful chemical functionalization of carbon nanotubes (CNT) forests, as they are growing on a silicon chip with metal contact thin film as the buffer layer between the CNT forests and the substrate. The morphology of the CNT forests was maintained after the functionalization. Also, electrical properties of CNT forests were preserved while a high surface area of functional groups was demonstrated. Thus, we provide the foundation for an ideal miniaturized biosensor arrays that can be easily integrated with CMOS.

A silicon wafer with a 0.5 µm silicon oxide was used as the substrate. Using lithography, a pattern was created on a photo resist (PR) film on the substrate. Electron beam evaporation was employed to deposit thin films of metals and compounds (Ti 1nm/Mo 10 nm/Al2O3 5nm /Fe 1nm). Iron film is used as a catalyst to grow CNT forests. After e-beam evaporation, the photoresist is dissolved in an organic solvent (LOR and IPA) assisted by an ultrasonic bath, a process known as lift-off. The wafer is diced into chips and CNT forests are grown on the chips using thermal chemical vapor deposition (CVD) process. In this process, the catalyst (iron) is first annealed at 500 oC for 5 minutes. Later, in the presence of ethylene, hydrogen and nitrogen gases are added at 700 oC, and CNT forest grown by CVD. The process is carried out in a cold tube furnace system (Black Magic by Aixtron). The resistance between the tips of the CNT structures range from 100 - 200 Ω.

Our strategy to functionalize the CNT forest on chip is based on the well known 1,3 dipolar cycloaddition of azomethine ylides to C60 [1] and SWCNT [2] in solution. The azomethine was formed upon heating to 120 °C in dichlorobenzene from the imines formed in situ between glycine and benzaldehyde, and reacted with the CNT forest on chip. The procedure yielded the amine-modified CNT forest on chip after cleaning. The amine-modified CNT forest on chip was further functionalized by an amide coupling with O-(2-azidoethyl)-O-[2-(diglycolyl-amino)ethyl] heptaethylene glycol to introduce azide functionalities on the CNT forest on chip. The amide coupling was carried out using PyBOP [3] as coupling reagent under mild basic conditions (DIPEA in anhydrous DCM at r.t.) . The functionalized CNT forests on chip were analyzed using SEM with EDS.

The EDS data proving presence of what appears reasonably stoichiometric amounts of nitrogen is convincing evidence that we have successfully attached the azide group on the CNTs by the two-step reaction scheme described above. We cannot get quantitative data from EDS, however, the qualitative information from the spectra above clearly justify our conclusion that we have successfully achieved covalent functionalization of surface-grown CNTs on metal films as the contact metal layer. Importantly, as concluded from the EM data, this technique does not significantly affect the morphology of the CNT forests, but the structures are preserved and, hence, may be exploited, for example, as arrays of sensing surfaces.

Word count: 491

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8344-36, Session 12

Polymer degradation measurements using 3D SERS substrates decorated with gold nanoparticles

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Surface Enhanced Raman Spectroscopy (SERS) substrates enable drastically decreased Levels of Detection (LOD) for a broad range of analytes of interest to the DoD, First Responders and Forensic Scientists. EngeniusMicro reports on efforts create SERS substrates applicable for analysis of gas phase samples by the use of nanoparticle decorated 3D porous structures. A porous material such as ceramic is infiltrated with nanoparticles to provide high density along the internal channels of the material. This density provides an increased number of metallic plasmonic hot spots that bind to oppositely charged analytes as they are passed through the porous membranes. These robust structures facilitate the analysis of extremely low concentration vapor phase chemistries that are currently complex to sample using traditional Raman handling techniques. In addition existing handheld and benchtop test equipment can achieve improved fingerprint detection of a myriad of chemical species with no hardware changes and little change to existing on board look up libraries.

EngeniusMicro is working with several DoD and University partners to bring this technology to the marketplace as a viable COTS SERS product.

8344-37, Session 12

Preparation and characterization of nanocompsoites with carbon nanotubes and core-shell type polyanaline for the conductive colloidal ink

J. Lee, V. K. Varadan, Univ. of Arkansas (United States)

Printing method for electronics fabrication has attractive advantages such as low material consumption, high speed fabrication and low temperature process. The stable conductive ink is among the most important factors for the fabrication of high resolution electronic elements. Metal particles, conductive polymers and carbon materials are widely used as fillers in conductive inks. Among these fillers, carbon nanotubes (CNTs) are extremely attractive due to their superior electrical properties, extra high mechanical properties and excellent chemical stability. In this research, CNTs and core-shell type polyaniline nano-composites were synthesized and formulated into electrically conductive colloidal inks appropriate for printed electronics. Various surface treatment methods for CNTs were applied to make the stable nano-composites. The experimental conditions were optimized to achieve high conductivity and stability. Their structure and surface morphology of the nanocomposites were characterized by scanning electron microscopy (SEM) and transmission electron microscope (TEM). And four point probe automatic resistivity meter was used to observe the conductivities of the nanocomposites.

8344-38, Session 13

Porous CNTs/chitosan composite with lamellar structure prepared by ice-templating

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Chitosan possesses beneficial properties such as its biodegradability, biocompatibility, and adsorption of metallic ions, which make it attractive in various applications. In addition, besides excellent mechanical and electrical properties, carbon nanotubes have been reported to be biocompatible platforms for neuronal growth and differentiation. In this work, porous carbon nanotubes/chitosan (CNTs/CHI) composites have been prepared by unidirectional freezing CNTs and chitosan aqueous solution and subsequent freeze drying, which is named as ice-templating. Two macroscopic morphologies with high and low aspect ratio have been produced by immersion freezing and one-side contact freezing respectively. The influences of experimental factors such as freezing rate and concentration to the micro-structure of products have been investigated. The SEM characterization indicates that the produced CNTs/CHI composites are composed of a three dimensional network with lamellar structure and macropores in micron scale, and the products by two freezing style have different structural characters. The specific surface area of the produced porous CNTs/CHI composite is up to 30m2/g. The porous CNTs/CHI composite has a high porosity and good mechanical strength, which makes it having very good permeability and processability. It is anticipated that this composite has various application such as biological carrier, catalyst supports, adsorbents, or permeable membrane.

8344-39, Session 13

Paper-like ZnO-cellulose hybrid nanocomposite: fabrication and its applications

H. Ko, Inha Univ. (Korea, Republic of); J. Kim, Chosun Univ. (Korea, Republic of); J. Kim, Inha Univ. (Korea, Republic of)

This paper reports the fabrication of Paper-like ZnO-Cellulose hybrid nanocomposite by using a low temperature wet chemical process in an aqueous solution. ZnO layer based nano structure is grown by simple chemical reaction including the alkaline hydrolysis and utilizes wet state cellulose substrate. Reaction time of chemical process controls the thickness and particle density of ZnO layer. Structural data of the ZnO-Cellulose hybrid nanocomposite shows a crystal orientation limited growth mechanism of ZnO nano-rod. The growth is dependent on the reaction time of chemical process. This composite material can be applied to flexible electronics and electro-mechanical devices such as transistors and strain sensors.

8344-40, Session 13

Synthesis and characterization of functionalized magnetic nanoparticles

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Magnetic nanoparticles have been used in a wide array of industrial and biomedical applications due to their unique properties at the nanoscale. They are extensively used in magnetic resonance imaging (MRI), magnetic hyperthermia treatment, drug delivery, and in assays for biological separations. Furthermore, superparamagnetic nanoparticles are of large interest for in vivo applications. However, these unmodified nanoparticles aggregates and consequently lose their superparamagnetic behaviors, due to high surface to volume ratio and strong dipole to dipole interaction. So, there is a need for surface coating for the enhancement and effectiveness of magnetic nanoparticles to be used in various applications. In addition to providing increased

stability of the nanoparticles in different solvents or media, stabilizers such as surfactants, organic/inorganic molecules, polymer and co-polymers are employed as surface coatings, which yield magnetically responsive systems. In this work we present the synthesis and magnetic characteristics of Fe3O4 and CoFe2O4 nanoparticles coated with 3-aminopropyltriethoxy silane (APS), citric acid, oleic acid, and biodegradable polymers. The magnetic hysteresis were measured by a superconducting quantum interference device (SQUID) magnetometer with in-plane magnetic field. The uncoated and coated magnetic nanoparticles were characterized by using fourier transform infrared, UV-vis, X-ray diffraction, transmission electron microscopy, and thermo-gravimetric analysis.

8344-41, Session 13

Effectiveness of multiple pulses on flow index of electroporation

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Electroporation (EP) is the formation of reversible pores in cell membranes without rupturing the membrane using a high electric field. EP is an important technique for various biomedical applications, such as drug delivery, gene transfection and therapeutic treatments. A biomedical-Microelectromechanical System (bioMEMS) device was developed to investigate this phenomenon. This paper presents theoretical analysis and experimental results of EP using single and multiple pulses. The bioMEMS device contained integrated electrodes inside microchannels. Stained cells were introduced inside the microchannels and excitation pulses were applied through the integrated electrodes. Sequences of images were captured using an integrated-camera on an optical microscope in the bright-field mode. Stained pixel data in the sequences of images were extracted through image processing. EP were detected from the decrease of stained pixels with electric pulses of 5 V to 20 V. Flow Index of EP (FIEP) for various excitation parameters were computed from the normalized (wrt initial) stained pixel (NSP) data. Increased FIEP, indicating higher fluidic exchange through cell membranes, were observed with increased pulse energy. Multiple pulses increased FIEP when increased energy was delivered, but reduced FIEP when the same amount of energy was delivered. Mean FIEP using 20 V excitation for 1 pulse of 1 ms was 0.256, 10 pulses of 1 ms was 0.329 and 1 pulse of 10 ms was 0.422. These experimental results were in agreement with the corresponding theoretical analysis. Such analysis permits optimization of pulse parameters for EP-based drug delivery and other related applications.

8344-42, Session 14

Thermal effects of X-band microwaves on skin tissues

K. D. Song, H. Yoon, Norfolk State Univ. (United States); K. Lee, Turner-Fairbank Highway Research Ctr. (United States); J. Kim, Inha Univ. (Korea, Republic of); S. H. Choi, NASA Langley Research Ctr. (United States)

For various applications of microwave, it is important to understand how to achieve effective transmission of microwave frequencies. The loss mechanism while transmission often appears as thermal effects due to absorption of microwave by lossy medium such as human skin, muscles, and other organic parts including brain. Microwave absorption could affect brain tissue thermally because it is a lossy medium that generates thermal energy. In this paper, thermal effects of microwave in the range of 6 - 13 GHz are investigated through animal skins and compared with humans.

8344-43, Session 14

Microfluidics on compliant substrates: foldable and bendable devices and system packaging

B. L. Gray, Simon Fraser Univ. (Canada)

Flexible polymer devices and packaging schemes that can conform to the body or other surfaces are under increasing focus for wearable and implantable health monitors, drug delivery devices, and prosthetics. While dwarfed by research into other flexible microsystems and conventional microfluidics, research into flexible-substrate microfluidics is a natural “next step” for increasing flexible microsystems functionality, e.g., extending wearable health monitoring to biofluid analysis, sealing for microfluidic systems, or foldable systems. However, difficulties in implementing active devices and reliable packaging technologies have limited the success of microfluidics on flexible polymer substrates. While devices developed in materials such as silicon can be embedded in a polymer package containing microchannels and electronic routing accomplished by thin film metal, such solutions are not optimal: methods to embed the devices, which may be many in number, must be developed, and thin film metal lines on a polymer substrate may suffer from poor adhesion, development of microcracks, and electrical failure. This review paper discusses recent developments in mechanically flexible polymer microfluidic technologies based on free-standing polymer substrates and novel electronic and microfluidic interconnection schemes developed primarily at the Microinstrumentation Lab at Simon Fraser University. Hybrid technologies based on nanocomposite polymer materials and devices are discussed, along with demonstrations of devices and packaging materials and structures employing these technologies. We discuss the potential merits and drawbacks of these new technologies in the greater context of flexible-substrate microfluidic systems, and microfluidics in general.

8344-44, Session 14

Fabrication of IDT electrode onto cellulose electro-active paper by inkjet printing

S. Mun, H. Jung, J. Kim, Inha Univ. (Korea, Republic of)

This paper investigates a direct inkjet printing method for electrode patterning on a cellulose Electro-Active Paper (EAPap). Flexibility and transparency of the EAPap are advantageous for a versatile substrate in flexible printable electronics. To fabricate EAPap actuator, inter-digital transducer (IDT) electrodes are printed on the EAPap with drop-on-demand (DOD) inkjet printing method. Silver patterns are obtained from organometallic silver ink by jetting and heat treatment at 150°C in air. IDT patterns are made on both sides for an in-plane actuator with different comb width. The actuator performance of the in-plane EAPap will be evaluated by measuring its in-plane displacement.

8344-45, Session 14

Development of a phase modulation plasmon resonance image detection system based on time-stepped quadrature phase shifting method

S. Lee, T. Huang, National Taiwan Ocean Univ. (Taiwan)

In this research work, a phase modulation surface plasmon resonance (SPR) image detection system adapted time-stepped quadrature phase shifting method as the phase retrieving technique has been developed. There are many techniques used to retrieve the phase from the interference fringes, such as five steps phase shifting, rotating analyzer, etc. However, they need five fringes images or three rotating steps of the optical component for each phase retrieving if they are used to get the relationship of phase variation versus the time changes

in some experiment. Therefore, we chose the time-stepped quadrature phase shifting method to be the phase retrieving technique. Since time-stepped quadrature phase shifting method is originally developed for electronic speckle pattern interferometry (ESPI), we have modified the algorithm and verified it with the simulated data. The path-independent phase unwrapping method was utilized to reconstruct the sample's phase distribution on the testing area. A previous built-up system, OBMorph, has been modified to complete the phase modulation SPR image detection function and the time-stepped quadrature phase shifting technique. Some different concentration sodium chloride-water solution and Ethanol-water solution has been measured by the system. The experimental results showed the trend of the phase variation was coincident to the concentration change. Hence, the integrating the time-stepped quadrature phase shifting method into the phase modulation SPR image system can successfully obtain the phase changes while the sample varies as time. The required inference fringes images were much less than before and the optical component rotating time has reduced to one time in the system we developed.

8344-46, Session 15

Ultrasonic matrix array transducer made of PMN-PT single crystals for volumetric imaging

Y. Roh, S. Kim, H. Park, Kyungpook National Univ. (Korea, Republic of)

In comparison with two-dimensional imaging in ultrasonic medical diagnosis, volumetric images provide clinicians with more confidence in the diagnosis of disease and add knowledge of complex pathology. Matrix array transducers have been developed in this work, which can image cardiac structures in real-time and 3-D. The matrix array transducers have 4,096 (64*64) ultrasonic elements made of the piezoelectric single crystal, PMN-PT, within the area less than 1 inch square.

Two different structures of the matrix array have been developed: (1) assembly of eight 64*8 element modules, and (2) whole 64*64 elements on a PMN-PT single crystal plate. Both structures have been designed to have their center frequency at 3.5 MHz and fractional frequency bandwidth over 70%. Each element consists of an acoustic lens, two matching layers and a backing load. In order to reduce the level of cross-talk, minor kerfs have been installed between the major kerfs dividing the elements of the matrix array, which eventually quadruples the number of elements in the array. The arrays have been made by means of very fine crystal dicing and aligning technology, and sophisticated fabrication processes. The whole 64*64 element array structure has a special backing layer named conductive backing that has graphite electrodes inside to connect each PMN-PT element to electric wires while preserving acoustic damping properties. A multi-layer flexible printed circuit board has also been developed to wire the acoustic elements to external electronic circuits.

Detailed fabrication and characterization processes are described to compare the advantages and disadvantages of each array structure.

8344-47, Session 15

Determination of effective boundaries and material properties of SRR-rod and fishnet metamaterials

W. Wang, Univ. of Washington (United States) and National Cheng Kung Univ. (Taiwan); F. Hsieh, Univ. of Washington (United States)

Metamaterials (MMs) operated in quasi-optical or Terahertz (THz) frequency range have been attracting attention over the past several years due to their unique phenomena, such as the negative refractive index and strong resonance in THz range, lacking in naturally occurring media. In order to utilize these phenomena of MMs in applications for bio-chemical sensing, spectroscopy, bio-imaging, security and communications, the effective boundaries of MMs must be determined first, before the constitutive parameters and frequency-dependent material properties of MMs are characterized.

To meet this demand, we propose two optimization models to determine effective boundaries of split-ring-resonator (SRR)-based and fishnet MMs. The optimization models are defined based on the assumption of effective medium theory and characteristic of homogeneous media. The results are then compared with the traditional definition proposed by Kong.

To retrieve effective refractive indices, impedances, and material properties, such as electric permittivity ( ) and magnetic permeability (μ) of MMs, we propose a full extraction method allowing determination of properties over all frequencies of interest including the strong resonant band, where the results are unavailable by the well-known robust method proposed by Kong. The method based on the material continuity can retrieve missing results in the strong resonant band where the imaginary part of permittivity or permeability is negative. Finally, the refractive index, impedance, permittivity, and permeability of two slabs composed of SRR-based and fishnet MMs, respectively, are retrieved by the proposed method.

8344-48, Session 16

Nondestructive technology for the assessment of dental implant stability

A. Tabrizi, B. Berhanu, P. Rizzo, M. W. Ochs, Univ. of Pittsburgh (United States)

The robustness and reliability of two nondestructive evaluation methods to assess dental prostheses stability is presented. The study aims at addressing an increasing need in the biomedical area where robust, reliable, and non-invasive methods to assess the bone-interface of dental and orthopedic implants are increasingly demanded for clinical diagnosis and direct prognosis.

The methods are based on the electromechanical impedance method and on the propagation of solitary waves. Nobel Biocare® 4.3 x 13 mm implants were entrenched inside soup bones and beef rib bones that were immersed inside Normal Saline for 24 hours before test in order to avoid dehydration and simulating physiologic osmolarity of the corticocancellous bone and plasma. Afterwards the bones were immersed in a solution of nitric acid to allow material degradation, inversely simulating a bone-healing process. This process was monitored by bonding a Piezoceramic Transducer (PZT) to the abutment and measuring the electrical admittance of the PZT over time. On the other hand the bones calcium loss was calculated after immersing in acid by Atomic Absorption Spectroscopy over time for comparison. Moreover a novel transducer based on the generation and detection of highly nonlinear solitary waves was used to assess the stiffness of the abutment-implant bone.

In these experiments it was found that the PZT's conductance and some of the solitary waves parameters are sensitive to the degradation of the bones and was correlated to the bone calcium loss over time.

8344-49, Session 16

Capacitive micromachined ultrasonic matrix array transducer for volumetric imaging in real time

Y. Roh, S. Kim, Kyungpook National Univ. (Korea, Republic of); J. K. Song, K. I. Cho, Y. Kim, S. Lee, B. Kim, D. Kim, Samsung Advanced Institute of Technology (Korea, Republic of)

In comparison with two-dimensional imaging in ultrasonic medical diagnosis, volumetric images provide clinicians with more confidence in the diagnosis of disease and add knowledge of complex pathology. Capacitor Micromachined Ultrasonic Transducers (cMUT) matrix arrays have been developed in this work for the volumetric imaging in real-time. The matrix array has 8,192 (64*64) cMUT elements with integration of beam forming electronics within a foot print less than 1.2 inch square. Each cMUT element comprises 24 capacitive micro-cells in turn.

The cMUT has been designed to operate at the center frequency of 4.5 MHz and to have a fractional frequency bandwidth over 100%. Each cMUT element is flip-chip bonded to application specific integrated circuits (ASIC) chips for digital and analog processing of the ultrasonic signals. The cMUT and ASIC modules are bonded to a printed circuit boards (PCB) that are connected to a housing handle. Active surface of the cMUT array is protected by a polymeric layer that works as an acoustic matching layer as well, and the whole modules are encapsulated by an acoustic lens and a housing handle and nose.

Performance of the cMUT matrix array is characterized with a commercial pulse-echo measurement system, and is compared with that of a piezoceramic matrix array that has been developed by the present authors. The performance factors of particular consideration are the -6dB frequency bandwidth, electro-mechanical impedance and cross-talk level of the transducers. The comparison demonstrates the promising potential of the cMUT matrix array as a high level medical volumetric imaging probe.

8344-50, Session 16

Medical CT image reconstruction accuracy in the presence of metal objects using x-rays up to 1MeV with x-ray targets of Beryllium, Carbon, Aluminum, Copper, and Tungsten

J. E. Clayton, Varian Medical Systems, Inc. (United States)

Flat panels imagers based on amorphous silicon technology (a-Si) for digital radiography have been accepted by the medical community as having several advantages over film-based systems. Radiotherapy treatment planning systems employ computed tomographic (CT) data sets and projection images to delineate tumor targets and normal structures that are to be spared from radiation treatment. The accuracy of CT numbers are crucial for radiotherapy dose calculations. Conventional CT scanners operating at kilovoltage X-ray energies typically exhibit significant image reconstruction artifacts in the presence of metal implants in human body. Megavoltage X-ray energies have problems maintaining contrast sensitivity for the same dose as kV X-ray systems. We intend to demonstrate significant improvement in metal artifact reductions and electron density measurements using an amorphous silicon a-Si imager obtained with an X-ray source that can operate at energies up to 1 MeV. We will investigate the ability to maintain contrast sensitivity at this higher X-ray energy by using targets with lower atomic numbers and appropriate amounts of X-ray filtration than are typically used as X-ray production targets and filters.

8344-51, Session 16

Investigation of a coplanar strip dipole rectenna elements for microwave power transmission: simulation and experiment

S. Y. Yang, Inha Univ. (Korea, Republic of); K. D. Song, H. Yoon, Norfolk State Univ. (United States); J. Kim, Inha Univ. (Korea, Republic of)

The performance of dipole rectenna for microwave power transmission is very critical to the size and configuration of the dipole rectenna. Thus, it is important to verify the performance of dipole rectenna by comparing its performance in terms of simulation and experiment. This paper reports an experimental and computational investigation of coplanar strip (CPS) dipole rectenna for microwave power transmission. Rectenna consists of an antenna and a rectifier that involves a Schottky diode. CPS dipole antenna and rectenna are simulated using commercial software, so called Ansoft's HFSS and designer. CPS dipole antenna as well as rectenna is fabricated on a copper coated polyimide substrate using an etching process. The characteristics of CPS dipole antenna are tested by using a pulse analyzer and spectrum analyzer under a 1.2 W microwave power incidence. Also the performance of CPS dipole rectenna is tested. Comparison of the simulation results will be compared with the experiments. The verified simulation approach for the CPS dipole rectenna will bring an effective design approach of rectennas for microwave power transmission.

8344-52, Session 16

Predicting brain tissue deformation around an implantable electrode due to dynamic micromotion

M. Polanco, Old Dominion Univ. (United States); H. Yoon, Norfolk State Univ. (United States); K. Lee, Old Dominion Univ. (United States)

Brain cells located adjacent to an implantable electrode are susceptible to both insertion and mechanical damage due to micromotion as the tissue undergoes cyclic periods of pulsation and breathing. The brain cells inevitably interface with electrodes that are typically much lighter and stiffer in comparison. As a result, the brain's high sensitivity to deformation poses a great challenge in designing a neuron probe that is durable throughout time, as mechanical damage in the brain can reduce the usefulness of the electrode. A number of electrode design parameters need to be examined to determine how the brain's high susceptibility to deformation can be minimized, such as material properties and geometry. Objectively, a neuron probe may need to be designed such that it can conform to motion of the brain and electrical functionality is maintained during deformation. To better understand the design enhancements needed for the neuron probe, a series of dynamic simulations are conducted which represent the motion the brain is expected to undergo over time. This motion will, in turn, influence the motion of the neuron probe throughout time. Of interest is how the brain tissue deformation near the interface of the neuron probe will be affected by micromotion of the probe. The nonlinear transient explicit finite element code LS-DYNA is used to carry out the analyses. Analytical results show that shear and compressive deformation of brain tissue is dependent on both the displacement frequency at which the brain tissue moves over time, and on the coefficient of friction prescribed on the interface between the neuron probe and the brain.

8344-53, Session 16

Size dependence of the electrochemical properties of hematite particles and their applications in lithium ion batteries

L. Chen, G. Wang, G. N. Mathur, V. K. Varadan, Univ. of Arkansas (United States)

Hematite particles are a type of promising electrode active materials for lithium ion batteries due to their low cost and high specific capacity. However, the cycling performances of hematite particles are not as good as those of the conventional electrode active materials for lithium ion batteries. This paper reports our work on the study of the relationship between the electrochemical properties and the particle sizes, aiming to optimize the electrochemical properties of hematite particles for their applications in lithium ion batteries. Three types of hematite particles with diameters 44 μm, 5 μm, and 200 nm respectively were compared. Their crystalline structures were characterized by X-ray diffraction (XRD) and their particle morphologies were analyzed by scanning electron microscopy (SEM). Composite electrode materials were made from hematite particles with carbon black as the conducting material and PVDF as the binding material (hematite : carbon black : PVDF = 7 : 2 : 1). Prototype lithium ion batteries (CR2032 button cells) were assembled with the composite electrodes as cathodes and metal lithium as anodes. It was found that the lithium ion button cells with cathodes made from hematite nanoparticles exhibited much better charge/discharge behaviors than those with cathodes made from two other types of hematite particles. The relationship between the particle sizes and their electrochemical performances was analyzed, and the optimum size for their applications in lithium ion batteries was proposed.

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8345-01, Session 1

Laser based structural health monitoring for civil, mechanical, and aerospace systems

H. Sohn, KAIST (Korea, Republic of)

No abstract available

8345-02, Session 1

Magnetostrictive sensors for civil, mechanical, and aerospace systems

A. B. Flatau, Univ. of Maryland, College Park (United States)

No abstract available

8345-03, Session 2a

Stochastic subspace identification for operational modal analysis of arch bridge

C. Loh, M. Chen, National Taiwan Univ. (Taiwan); Y. Liu, Univ. de Costa Rica (Costa Rica)

In this paper both off-line and on-line recursive stochastic subspace identification (RSSI) algorithms are applied to tack the modal parameters of an arch bridge during operation. The basis of the present monitoring concept is the analysis of non-destructive measurements taken at regular time intervals to provide information about the current state of health situation in a structure. The approach includes two steps: First, a covariance-driven recursive stochastic subspace identification is applied to obtain a mathematical description of the system. Using state-space transformation, the time-varying physical meaningful system properties can be extracted. Thereby, Novelty analysis is applied. In the beginning, the system matrix and noise covariance are developed from the reference state are generated. Then the Kalman filter estimation was used to predict the responses for the vibration time history of all sensing nodes. The result of outliner analysis (Mahalanobis norm) for the arch bridge under operational condition is estimated. The effects of external environment (traffic loading) on the extract modal parameters and Novelty index are discussed. Comparison between the Covariance-driven RSSI and Data-driven RSSI on modal parameter identification as well as the computation time for on-line processing was also made in this study.

8345-04, Session 2a

Prediction of stress waves propagation in progressively loaded seven wire strands

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High tensile strength steel strands are widespread load carrying structural components in civil structures. Due to their critical role, several researchers have investigated nondestructive techniques to assess the presence of damage such as corrosion or the change in prestress level. (prestress loss). Ultrasonic guided waves are known to be an effective approach for defect detection in components with waveguide geometry like the strands. However, guided wave propagation (dispersion properties) in steel strands is fairly complex partially due to the strand helical geometry and the axial prestress. For instance, the strand axial stress generates a proportional radial stress between adjacent wires (interwire stress) that is responsible for inter-wire coupling effects.

While experimental and numerical investigations have attempted to study and predict wave propagation in axially loaded strands, the propagation phenomenon is not yet fully understood. The present paper intends to improve the knowledge of dispersion properties in progressively loaded seven wire strands accounting for helical geometry and inter-wire contact forces. Full three dimensional Finite Element simulations as well as Semi-Analytical Models will be used to predict the dispersion curves in strands as a function of the axial stress.

8345-05, Session 2a

Data-driven finite element model estimation of a distributed mass structural system using a scanning laser Doppler vibrometer

J. Kim, K. Kim, H. Sohn, KAIST (Korea, Republic of); J. P. Lynch, Univ. of Michigan (United States)

Data-driven subspace system identification techniques recently developed from the control theory provide a rich set of analytical tools for system identification of structural dynamics systems. Physical interpretation of black-box system identification models obtained from measurement data is direly needed to extract a physical description (i.e., discretized finite element model) of the target structural system. However, the physical interpretation of these black-box system identification models remains a major hurdle in their application to structural engineering problems such as structural health monitoring (SHM). In particular, little work has been done for continuous dynamic systems. In this study, a finite element model (i.e., the physical parameters such as mass, stiffness, and damping matrices) of a distributed mass structural system is estimated solely based on measured experimental data. An aluminum cantilever beam is excited by a series of Lead Zirconate Titanate (PZT) patches with known inputs and the corresponding displacement responses are scanned over the entire beam using a scanning laser Doppler vibrometer (LDV).

8345-06, Session 2a

Vibration-based residue prestress force measurement for eccentrically prestressed concrete beam

Z. Sun, J. Xu, Tongji Univ. (China)

The measurement of residue prestress force is one main issue for condition assessment of prestressed concrete beam bridge. This paper proposes a vibration based parameter estimation technique for this purpose. Under immeasurable spatial external excitations, beam velocity responses at multiple points are collected firstly. The prestress force of the beam is then identified based on the minimization of the least square difference between the measured response and the predicted response from a baseline numerical model. A set of experimental studies on prestressed concrete (PC) beams with variant length, subjected to variant prestress force with variant eccentricity, are tested to show the effect of prestress force and the effect of bending moment due to eccentricity on fundamental frequency of the beam. The results show that this vibration based method for prestress force identification is both theoretically possible and practically feasible.

8345-07, Session 2a

* Estimation of load redistribution on a cable-stayed bridge using a combination of sensing techniques

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The motivation of this work is the installation of a monitoring system on a new cable-stayed bridge spanning the Adige River 10 km north of the town of Trento. This is a statically indeterminate structure, having a composite steel-concrete deck of length 260 m overall, supported by 12 stay cables, 6 per deck side. These are full locked steel cables of diameters 116 mm and 128 mm, designed for operational loads varying from 5000 to 8000 kN. The structural redundancy suggests that plastic load redistribution among the cables can be expected in the long term. To monitor such load redistribution, the owner decided to install a monitoring system to measure cable stress; the precision specified was of the order of few MPa. However no cable release or any form of on-site calibration involving tension change was allowed. The solution found was a combination of built-on-site electromagnetic and fiber-optic elongation gauges, these appropriately distributed on both the cables and the anchorages. We discuss how the set of gauges allows tension and elongation measurement with the appropriate precision, and compare the initial monitoring results with the tension estimates made using a non-destructive vibration test.

8345-08, Session 2b

The use of exact Lamb waves modes for modeling the power and energy transduction of structurally-bonded piezoelectric wafer active sensors

B. Lin, V. Giurgiutiu, A. M. Kamal, Univ. of South Carolina (United States)

This paper presents a theoretical modeling and verification of power and energy transduction of structurally-bonded piezoelectric wafer active sensors (PWAS) for structural health monitoring (SHM). After a literature review of the state of the art, we developed a model of power and energy transduction between the PWAS and a structure containing multimodal ultrasonic guided waves. The use of exact Lamb waves modes for power modeling is an extension of our previously presented simplified model that considered axial and flexural waves with low frequency approximation. The model assumptions include: (a) straight-crested multimodal ultrasonic guided wave propagation; (b) ideal bonding (pin-force) connection between PWAS and structure; (c) ideal excitation source at the transmitter PWAS and fully-resistive external load at the receiver PWAS. Frequency response functions are developed for voltage, current, complex power, active power, etc. Multimodal ultrasonic guided wave, normal mode expansion, electromechanical energy transformation of PWAS and structure were considered. The parametric study of PWAS size and impedance match gives the PWAS design guideline for PWAS sensing and power harvesting applications.

8345-09, Session 2b

Ultrasonic monitoring of a pipe under operating conditions

C. Liu, J. Harley, N. A. O'Donoughue, Y. Ying, M. H. Altschul, J. H. Garrett, Jr., J. M. F. Moura, I. J. Oppenheim, L. Soibelman, Carnegie Mellon Univ. (United States)

Pipes carrying fluids under pressure are critical components in infrastructure and industry. We bond piezoelectric transducers to a pipe segment to excite and detect ultrasonic waves, and we intend to recognize changes in those signals when a scatterer is present. However, environmental and operational variations produce dramatic changes in those signals, and therefore a useful signal processing approach must distinguish change caused by a scatterer from change caused by ongoing variations.

We study pressurized pipe segments (10-in diameter) in a working hot-water supply system that experiences ongoing variations in pressure, temperature, and flow rate; the system is located in an environment that is noisy mechanically and electrically. We conduct pitch-catch tests, with duration of 10 ms, between transducers located roughly 16 diameters apart. We typically repeat the tests every minute over a test period ranging from 24 to 48 hrs, and we schedule two test periods per week. Our data collection effort began 1 July 2011.

Each test period yields a dataset containing between 1440 and 2880 records. We apply signal processing techniques to the records within a dataset to illustrate the ongoing variations, identify their source, and (in some cases) compensate for particular components of variation. We also study datasets over different test periods, spanning months, and evaluate the results for stationarity over time. We conduct tests in which we apply and remove a grease-coupled mass scatterer during a test period, and report our preliminary results to distinguish the change caused by the scatterer from change caused by ongoing variations.

8345-10, Session 2b

Finite element simulation of guided waves generated by laser pulses

J. Hong, W. Liu, Michigan State Univ. (United States)

Thermoelastic guided waves, induced by a laser pulse on a material surface, demonstrate advantages for nondestructive evaluation of structures due to the noncontact feature and effectiveness to generate broadband signals. Both symmetric and asymmetric Lamb waves can be generated by the local thermal expansion from the laser energy absorption. We consider the thermo-mechanical equation and solve the problems using the finite element method. The capability of the finite element method for the modeling of guided wave propagation induced by laser pulses is demonstrated, and the numerical results are compared with experimental results using unfocused and line-focused laser sources.

8345-11, Session 2b

Identification of subsurface damage in composite materials using laser vibrometry measurements and nonlinear vibration response characteristics

S. S. Underwood, D. E. Adams, Purdue Univ. (United States)

Composite materials are being used more frequently in commercial and military aircraft structures. However, a drawback to using composite materials for aircraft applications is that damage often occurs beneath the surface, making it difficult to inspect these aircraft using visual or line-of-sight techniques. A method for detecting subsurface damage in composite materials is investigated using laser vibrometry measurements and the nonlinear behavior indicative of subsurface damage in a composite as a means of detecting damage.

Several composite panels are obtained, which closely resemble the materials used in aircraft structures, and are damaged at known locations using controlled force levels. A scanning laser vibrometer is used to measure frequency response behavior on the panels as they are excited at multiple amplitudes of excitation. Various excitation techniques, including broadband excitation from a piezoelectric actuator and harmonic excitation from a rotating imbalance exciter, are compared.

Nonlinear behavior, resembling stiffness and damping nonlinearities, is identified in the vicinity of composite damage from the multi-amplitude frequency response data obtained using the laser vibrometer measurements. The localized nonlinear behavior identified through several nonlinear identification analysis techniques is then used to locate the subsurface damage in the composite panels. The results of these investigations suggest that identifying localized nonlinear behavior in the vicinity of composite material damage using a laser vibrometer as a noncontact measurement technique is a feasible method for detecting and locating subsurface damage in composite materials.

8345-12, Session 2b

Recent advancement on the NDE by means of highly nonlinear solitary waves

X. Ni, P. Rizzo, Univ. of Pittsburgh (United States)

In this paper, we propose the use of highly nonlinear solitary waves (HNSWs) for the nondestructive evaluation of aluminum lap-joints bonded by high-strength two ton epoxy. A HNSW transducer was used to generate and detect the propagation of incident and reflected HNSWs. The time of flight and amplitude ratio of the reflected HNSW were adopted to interpret the bonding condition of aluminum lap-joints. Two experiments are reported. In the first experiment we monitor the curing process of a two-ton epoxy at aluminum lap-joints. In the second experiment we detect different bonding condition of aluminum lap-joints such as good bonding, fair bonding (with undesired resin to hardener ratios), slide bonding, and no bonding, after the epoxy was fully cured. The results of experiments shows the proposed method is able to detect different bonding conditions of aluminum lap-joints. Finally, this paper shows the design of novel HNSW-based transducers. These transducers are designed to enable the nondestructive testing of structural components that are difficult to be reached.

8345-13, Session 3a

Substrate material property effects of a folded patch antenna for wireless strain sensing

X. Yi, R. Vyas, C. Cho, H. Lee, Y. Wang, R. T. Leon, M. M. Tentzeris, Georgia Institute of Technology (United States)

For application in structural health monitoring, a folded patch antenna has been previously designed as a batteryless and wireless sensor that measures strain in metallic structures. The patch antenna consists mainly of a piece of poly-tetra-fluoro-ethylene (PTFE) substrate sandwiched between two copper layers. When the antenna is under strain/deformation, its electromagnetic resonance frequency varies accordingly. Through a radiofrequency identification (RFID) chip mounted on the antenna, the resonance frequency variation due to strain is interrogated and recorded by a wireless reader. In this application, the material properties of the antenna components can have significant effects to the sensor performance. This paper investigates such effects which can be exploited for improving future sensor designs. In particular, both temperature variation and strain cause changes to the substrate dielectric constant. The change in dielectric constant affects the resonance frequency, which consequently affects strain reading. Temperature chamber testing is performed to characterize the temperature effect to the dielectric constant; tensile testing is performed to characterize the strain effect to the dielectric constant. The characterization results are utilized to significantly improve the analytical and modeling accuracy of the sensor.

8345-14, Session 3a

Success and pitfalls in wireless sensor network for SHM

J. Tao, M. Richardson, X. Yu, Case Western Reserve Univ. (United States)

This paper presents an evaluation of wireless sensor network for structural monitoring applications. A series of laboratory experiments were conducted by installing the wireless sensor nodes on a model building. The results were compared with traditional accelerometers. The results showed that the recorded acceleration time history by wireless sensors matches very well with those by traditional wired accelerometers. Success and pitfall of deploying the WSN on a four span bridge was described. It summarizes aspects of existing sensor nodes that need to be further improved.

8345-15, Session 3a

Network architecture design of an agile sensing system with sandwich wireless sensor nodes

S. Dorvash, X. Li, S. N. Pakzad, L. Cheng, Lehigh Univ. (United States)

Wireless sensor network (WSN) is recently emerged as a powerful tool in the structural health monitoring (SHM). Due to the limitations of wireless channel capacity and the heavy data traffic, the control on the network is usually not real time. On the other hand, many SHM applications require quick response when unexpected events, such as earthquake, happen. Realizing the need to have an agile monitoring system, an approach, called sandwich node, was proposed. Sandwich is a design of complex sensor node where two Imote2 nodes are connected with each other to enhance the capabilities of the sensing units. The extra channel and processing power, added into the nodes, enable agile responses of the sensing network, particularly in interrupting the network and altering the undergoing tasks for burst events. This paper presents the design of a testbed for examination of the performance of wireless sandwich nodes in a network. The designed elements of the network are the software architecture of remote and local nodes, and the triggering strategies for coordinating the sensing units. The performance of the designed network is evaluated through its implementation in a monitoring test in the laboratory. For both original Imote2 and the sandwich node, the response time and the energy cost are estimated. The results show that the sandwich node is an efficient solution to the collision issue and the latency in dense wireless sensor networks.

8345-16, Session 3a

* A radar-based sensor network for distributed bridge displacement measurements

J. A. Rice, Univ. of Florida (United States); C. Li, C. Gu, Texas Tech Univ. (United States)

The development of effective structural health monitoring (SHM) strategies is critical as aging infrastructure remains a national concern with widespread impact on the quality of our daily lives. Wireless smart sensor networks (WSSNs) are an attractive alternative to traditional SHM systems for their lower deployment cost and their ability to enable new methods of distributed data processing. While acceleration has been the primary measurement utilized in most WSSN SHM applications, practically and accurately capturing structural deflections has been proven much more challenging. Displacement sensors produce reliable low-frequency measurements but are often difficult to implement in long-term field deployments. Conventional technologies for measuring

deflection, both dynamic and static, are either too bulky or expensive to be integrated into WSSNs or lack sufficient accuracy. This paper presents the validation and characterization of a network of low-cost, wireless radar-based sensors for the enhancement of low-frequency vibration-based bridge monitoring and the measurement of static bridge deflections. Experimental results utilizing a laboratory-scale truss bridge are presented and the performance of the wireless radar sensors is compared to conventional vibration and displacement transducers. In addition, challenges associated with detection distance, interference rejection and signal processing are addressed.

8345-121, Session 3a

Percussive augmenter of rotary drills (PARoD)

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Increasingly, NASA exploration missions are including sampling tasks to acquire samples for in-situ analysis or for potential sample return to Earth. To address the requirements for samplers that could be operated at the conditions of the various bodies in the solar system a piezoelectric actuated percussive mechanism was developed that allows drilling by as low preload as 10N (significant for operation at low gravity), using a drill that can be as light as 400g, can be operated by an average power of 2-3W and drill rocks as hard as basalt. A key feature of this drilling mechanism, which is called the Ultrasonic/Sonic Driller/Corer (USDC), is the use of a free-mass to convert the ultrasonic vibrations generated by piezoelectric stack to sonic impacts on the bit. Recognition of the need to optimize the operation of the USDC and the ability to perform various functions led to the development of many configurations and sizes. Significant improvement of the penetration rate was achieved by augmenting the hammering action by rotation and use of a fluted bit to enhance the rock fracturing and providing effective cuttings removal. Generally, hammering is effective in fracturing the drilled medium while rotary of fluted bits removes cuttings. To take advantage of these two capabilities, a novel configuration of a percussive mechanism was developed that serves as an augmenter of commercial rotary drills. The developed augmenter was demonstrated to increase the drilling rate of rotation alone by 1.5 to over 10 times.

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8345-17, Session 3b

* Wireless signal networks for monitoring subsurface infrastructures

E. Ghazanfari, S. Yoon, S. Pamukcu, M. T. Suleiman, L. Cheng, Lehigh Univ. (United States)

Real time global subsurface monitoring can be achieved using the concept and application of the wireless signal networks. The wireless signal networks (WSN) use the signal strength variation of wireless sensor nodes in the host medium as the main indicator of an underground event that results in marked change of physical properties of the host medium. The concept is proved through laboratory and controlled field experiments. A comprehensives parametric study was conducted to calibrate signal attenuation with network and soil properties. Physical simulations conducted to verify the capability of the networked system to detect artificially induced geo-events demonstrated that calibrated electromagnetic signal strength variations can be used as indicators to detect and monitor physical changes in the subsurface. Monitoring of shallow subsurface infrastructures (pipelines, pavements and shallow foundations) are among the most feasible applications of wireless signal network for subsurface monitoring. A large scale experiment is conducted in a soil box using embedded wireless and conventional sensors on and in vicinity of embedded infrastructure. Appropriate low frequency experimental bands are tried to improve and extend the communication radius for the WSN system in the large scale experiment. This paper presents the results of the experiments conducted using the large soil box and the comparative data obtained from the WSN and auxiliary measurement systems. Theoretical model estimations are verified with experimental results.

8345-18, Session 3b

* Response time improvement using sandwich-node architecture in wireless sensor networks for structural health monitoring

Z. Wang, S. N. Pakzad, Lehigh Univ. (United States)

Recently, application of wireless sensor networks (WSNs) in structural health monitoring(SHM) has received a significant interest. Although various hardware platforms for wireless sensor networks have been developed, they use essentially the same architecture: sensing unit, signal processing, AD converter, microprocessor and wireless transceiver which are tightly coupled together to form a wireless sensor node. A challenge in use of this hardware architecture is the lack of capability of quick response to unexpected events, e.g. earthquake. To address this challenge and improve the response time of wireless sensors a new architecture, called sandwich, is proposed. A sandwich node is composed of a sensor board and two nodes connected together. Each node has a microprocessor and a wireless transceiver on it. The design is such that the first node is dedicated to manage the sensor board and to process the sensing data while the second one detects the emergency events and controls the first node. The proposed prototype has been implemented using Imote2 and its performance is evaluated. Also, performance comparison is made between WSNs based on sandwich node and the normal sensor node. The results show that the sandwich node achieves a significant improvement in terms of response time to emergency events.

8345-19, Session 3b

Long-term monitoring of a cable stayed bridge using a SCADA system

M. Torbol, M. Shinozuka, Univ. of California, Irvine (United States)

DuraMote is a wireless network of accelerometers. It is designed for supervisory control and data acquisition (SCADA) of pipe ruptures and leakages of water distribution systems. The pipe rupture and the leakage are detected by analyzing the acceleration data gathered from the accelerometers. The system has different components. The gophers contain the accelerometers and are located underground attached to the water pipe. The roocas are located just above ground, supply power to multiple gophers, retrieve data from them and transmit through Wi-Fi to a base station. The relays support the Wi-Fi network and insure the transmission of the data from the roocas to the base station. In this experiment, the system was used for long term monitoring of a 500 m cable stayed bridge. The purpose was to test the reliability, the robustness, the durability, and the efficiency of the system. The bridge size and its location were perfect for this experiment. The bridge was subjected to heavy rain, wind, and typhoon. 24 accelerometers, 13 gophers, 10 roocas, 5 relays, and 1 base station were installed on the structure. Acceleration data are continuously recorded. From the data the natural frequencies, the mode shapes, and other parameters are calculated. In this experiment for the first time a large DuraMote network was kept in place for long term monitoring. The experiment demonstrated the capabilities of the system. However, the system showed also

problems that did not show up in short term laboratory test. While fixing these problems, the DuraMote system was improved at both hardware and software level.

8345-20, Session 3b

* Heterogeneous wireless sensor networks for computational partitioning of a Markov parameter-based system identification method

J. Bergman, J. Kim, J. P. Lynch, Univ. of Michigan (United States)

Embedded computation in wireless sensor networks (WSN) can extract useful information from sensor data in a fast and efficient manner. Such computation is carried out by leveraging the computing resources on the individual wireless sensors to create a distributed computing network that can be used to extract information such as modal parameters. The computationally intensive nature of these algorithms makes it desirable to add additional computational abilities to existing wireless sensor units. However, adding increased computational resources to a wireless unit has an adverse effect on its power consumption. This is a significant problem where power is limited by the environment in which the unit is located. This leads to a trade-off between additional computational resources or better power consumption performance. By developing a hybrid network consisting of wireless units optimized for sensing interspersed with more powerful computationally focused units, it is now possible to build a network that is more efficient and flexible than a homogeneous WSN. For this project such a network was developed using Narada units as low power sensing units and the iMote2 as an ultra-efficient computational engine. In order to demonstrate the capabilities of such a configuration a network was created to extract structural modal parameters based on Markov parameters. The resulting network was then successfully tested in both the lab and field to prove the feasibility of this system. This paper details both the architecture of the network used as well as the results of the tests.

8345-21, Session 3b

Decentralized system identification on wireless smart sensor networks

S. Sim, Ulsan National Institute of Science and Technology (Korea, Republic of); B. F. Spencer, Jr., Univ. of Illinois at Urbana-Champaign (United States)

Wireless Smart Sensor Networks (WSSNs) facilitates a new paradigm to structural identification and monitoring for civil infrastructure. Conventional monitoring systems based on wired sensors and centralized data acquisition and processing have been known to be challenging and costly due to cabling and expensive equipment costs. The WSSN has been emerged to overcome such difficulties, making deployment of a dense array of sensors on large civil structures both feasible and economical. However, as opposed to wired sensor networks in which centralized data acquisition and processing is common practice, the WSSN requires decentralized algorithms due to the limitation associated with wireless communication; to date such algorithms are limited. This study presents decentralized system identification in the WSSN using two widely used approaches: Stochastic Subspace Identification (SSI) with Canonical Variate Algorithm (CVA) and Eigensystem Realization Algorithm (ERA) with Natural Excitation Technique (NExT).The decentralized system identification using SSI-CVA and ERA/NExT is implemented on MEMSIC's Imote2 sensor platform and experimentally verified on a 3D truss bridge model.

8345-22, Session 4a

External confinement and energy dissipation for seismic accelerated bridge construction

G. Chen, Missouri Univ. of Science and Technology (United States)

In this study, shape memory alloy (SMA) wires were weaved into carbon fiber reinforced polymer (CFRP) sheets to provide external confinement and energy dissipation to the segmental construction of concrete columns with unbonded post-tensioning tendons. SMA and CFRP can be effectively integrated to further improve the rapid construction of columns, the long-term maintenance and post-earthquake repair, and the safety of bridges in moderate-to-high seismic zones. This presentation will focus on two key issues: SMA-CFRP interface integrity and energy dissipation capacity. SE08 Nitinol wires of 0.006 inch in diameter with an etched surface were used in various tests. Static tests indicated that the load-displacement curves of all five specimens are fairly consistent. The yield and ultimate loads correspond to the minimum loading plateau stress at 3% strain and the ultimate tensile stress of the Nitinol SMA wires. There was no indication of pulling off the SMA wires from the CFRP sheet. The minimum embedment length was found less than two inches. Cyclic tests indicated that the hysteresis loops due to five cycles of displacement are very stable. The permanent displacement of the specimen is approximately 0.1 inch due likely to the flexibility of the CFRP sheet. In column applications, the level of permanent deformation of the CFRP-SMA system expects to be significantly reduced if not eliminated since CFRP sheets will be bonded to a RC column and will be subjected to tension as the column experiences lateral deformation. The Nitinol wires can be used to effectively dissipate earthquake energy consistently.

8345-23, Session 4a

Experimental validation of the finite element model analysis of a steel frame in simulated post-earthquake fire environments

Y. Huang, W. J. Bevans, Missouri Univ. of Science and Technology (United States); Z. Zhou, Dalian Univ. of Technology (China); H. Xiao, G. Chen, Missouri Univ. of Science and Technology (United States)

During or after an earthquake event, building systems often experience large strains due to shaking effects as observed during recent earthquakes, causing permanent inelastic deformation. In addition to the inelastic deformation induced by the earthquake effect, the post-earthquake fires associated with a short fuse of electrical systems and leakage of gas devices can further strain the already damaged structures during the earthquakes, potentially leading to a progressive collapse of buildings. Under these harsh environments, measurements on the involved building by various sensors can only provide limited structural health information. However, a finite element model, once validated with tests, can provide detailed behavior of the entire structure. In this paper, a temperature dependent nonlinear 3-D finite element model (FEM) of a one-story steel frame is set up in ABAQUS based on the cited material property of steel from EN 1993-1.2 and AISC manuals. The FEM is validated by testing the steel frame in simulated post-earthquake environments. Comparisons between the FEM analysis and the experimental results show that the FEM reasonably predicts the structural behavior of the steel frame in post-earthquake fire conditions. The validated FEM can continue providing critical structural conditions in harsh environments for fire fighters to use in their life-saving rescue missions.

8345-24, Session 4a

A novel landslide warning solution using single mode telecom fiber embedded in geo-textile

P. Kung, QPS Photronics Inc. (Canada)

This paper will discuss the application of a new distributed fiber optics sensing technology using interference where the fiber has been reinforced by a fiber glass coating which is then embedded in geo textiles and used as a solution for landslides warning. The fiber glass coating prevents moisture penetration and provides extra pulling strength. The geo-textile provides the added restraining force. The solution is therefore capable of measuring not only small earth movements but also provides added time delay to a pending crisis so that people can evacuate from danger. The method involves sending a continuous wave of modulated-frequency light through a coupler into a reference fiber, the other output of the coupler is connected to a sensing fiber. The laser source is modulated in frequency to provide a coherence gain function, as the fiber is subjected to changes in strain, the value of the coherence gain will change which is detected by an optical detector from the reflected signal. The sensing fiber is installed as a meandering pattern down the slope of the landslide region; each meander is supported on both ends by a pair of deeply anchored earth nails on the stable portion of the slope. As the earth moves, it produces strain on each meandering section and the strain can be quantified with clear location.

8345-25, Session 4b

Recent enhancements to and applications of the SmartBrick structural health monitoring platform

A. Gunasekaran, N. Patel, S. Sedigh, Missouri Univ. of Science and Technology (United States)

The SmartBrick network is an autonomous, wireless solution for structural health monitoring of civil infrastructures. The base station is currently in its third generation and has been laboratory- and field-tested in the United States and Italy. The sensor nodes are currently in the second generation and have undergone laboratory testing. In this paper, we present recent enhancements made to hardware and software of the SmartBrick platform. Salient improvements described include the development of a new base station with fully-integrated long-range GSM and short-range Zigbee communication. The major software improvements described in this paper include migrating to the Zigbee Pro stack, which was carried out in the interest of interoperability. To broaden the application of the platform to critical environments that require survivability and fault tolerance, we have striven to achieve compliance with military standards in the areas of hardware, software, and communication. We describe these efforts and present a survey of the military standards investigated. Also described is instrumentation of a three-span experimental bridge in Washington County, Missouri; with the Smartbrick platform. The sensors, whose output is conditioned and multiplexed; include strain gauges, thermocouples, push potentiometers, and three-axis inclinometers. Data is stored on site and reported over the cellular network. Redundant sensing and communication provide reliability and facilitate corroboration of the data collected. A web interface is used to issue remote configuration commands and to facilitate access to and visualization of the data collected.

8345-26, Session 4b

Wireless structural health monitoring of cable-stayed bridge using iMote2-platformed smart sensors

D. Ho, K. Nguyen, P. Lee, D. Hong, S. Lee, J. Kim, S. Shin, Pukyong National Univ. (Korea, Republic of); C. Yun, KAIST (Korea, Republic of); M. Shinozuka, Univ. of California, Irvine (United States)

In this study, wireless structural health monitoring (SHM) system of cable-stayed bridge is developed using Imote2-platformed smart sensors. In order to achieve the objective, the following approaches are proposed. Firstly, the sensor nodes are described on the design of hardware components and embedded software for acceleration and impedance-based SHM. Secondly, the performance of the Imote2-platformed sensor nodes integrated with solar-powered system is evaluated. In this approach, a solar-powered harvesting system is designed for the autonomous operation of acceleration-impedance sensor nodes. Finally, for validation, some parameters (e.g., supply voltage, charge status, temperature, acceleration, impedance signatures) of operating system are analyzed to examine the performance of the sensor nodes on a full-scale cable-stayed bridge under long-term monitoring condition.

8345-27, Session 4b

Efficient campaign-type structural health monitoring system using wireless smart sensors

J. Li, Univ. of Illinois at Urbana-Champaign (United States); T. Nagayama, The Univ. of Tokyo (United States); K. A. Mechitov, B. F. Spencer, Jr., Univ. of Illinois at Urbana-Champaign (United States)

Wireless Smart Sensor Networks (WSSNs) have attracted great attention in recent years in Structural Health Monitoring (SHM), by enabling better understanding of the dynamic behavior of large scale civil infrastructures through dense deployment of sensors. With a fraction of the deployment time and the cost compared with wired SHM systems, WSSNs serve as ideal systems for campaign-type monitoring such as short-term in service performance evaluation, post-disaster condition assessment and design optimization of long-term SHM system before permanent deployment, etc. Efficient data collection is generally needed in campaign monitoring due to limited operation time. A number of improvements have been made to the ISHMP (Illinois SHM Project) Toolsuite to facilitate efficient data collection for campaign monitoring. A post time synchronization scheme is proposed to reduce the latency of data collection while maintaining high accuracy of synchronization of collected data. The effectiveness is verified in a shaking table test. A multi-hop bulk data transfer approach using multiple RF channels is also proposed to achieve high data throughput. Campaign monitoring is carried out for the Government Bridge using dense array of sensors. The performance of the WSSN is evaluated and modal analysis is performed using collected data.

8345-28, Session 5a

A novel approach to detecting breathing cracks based on vibration-data

G. Yan, Univ. of Western Sydney (Australia)

To take best advantage of the character of bilinear systems, a system identification method for bilinear systems is developed using separated data from impulse or free-vibration responses of the system. This method transfers nonlinear system identification into linear system identification by dividing the global responses into different parts representing the corresponding stiffness regions according to the stiffness interface. In this way the modal parameters in each region can be identified respectively. Then the procedure for identifying the existence of breathing cracks in a beam and also quantifying the cracks is proposed by looking for the difference in the natural frequencies between regions. Through introducing the Hilbert Transform, the procedure is extended to identify the breathing crack in a piecewise-nonlinear system, a beam with large deflection. The proposed method and procedure have been demonstrated by numerical simulations.

8345-29, Session 5a

Comparative study of electromechanical impedance and Lamb wave techniques for fatigue crack detection and monitoring in metallic structures

S. I. Lim, Y. Liu, C. K. Soh, Nanyang Technological Univ. (Singapore)

Fatigue cracks often initiate at the weld toes of welded steel connections. Usually, these cracks cannot be identified by the naked eyes. Existing identification methods like dye-penetration test and alternating current potential drop (ACPD) may be useful for detecting fatigue cracks at the weld toes. To apply these non-destructive evaluation (NDE) techniques, the potential sites have to be accessible during inspection. Therefore, there is a need to explore other detection and monitoring techniques for fatigue cracks especially when their locations are inaccessible or cost of access is uneconomical.

Electro-mechanical Impedance (EMI) and Lamb wave techniques are two fast growing techniques in the Structural Health Monitoring (SHM) community. These techniques use piezoelectric ceramics (PZT) for actuation and sensing. Since the monitoring site is only needed to be accessed once for the instrumentation of the transducers, remote monitoring is made possible. The permanent locations of these transducers also translate to having consistent measurement for monitoring.

The main focus of this study is to conduct a comparative investigation on the effectiveness and efficiency of the EMI technique and the Lamb wave technique for successful fatigue crack identification and monitoring of welded steel connections using piezoelectric transducers. A laboratory-sized non-load carrying fillet weld specimen is used in this study. The specimen is subjected to cyclic tensile load and data for both techniques are acquired at stipulated intervals. It can be concluded that the EMI technique is sensitive to the crack initiation phase while the Lamb wave technique correlates well with the crack propagation phase.

8345-30, Session 5a

Spectral element method for modeling Lamb wave interaction with open and closed crack

H. Sun, L. Zhou, Nanjing Univ. of Aeronautics and Astronautics (China)

Lamb wave inspection is the most widely used damage detection technique based on ultrasonic waves. Lamb wave propagation in complex structures is very complicated due to multiple reflection and mode conversion at geometrical and material features. For effectively monitoring structural health, numerical simulation is employed to for extract damage features. Spectral element method, an effective and fast simulating method for Lamb wave propagation, is used to simulate Lamb wave interaction with open and closed crack. Firstly, dispersion relations are analyzed in a beam containing open (non-contact surface condition) and closed (fully contact one) crack. Secondly, based on dispersion relations obtained, formulations for damaged spectral element models, i.e. dynamic stiffness matrix, are derived for beams containing open and closed cracks, respectively. Dynamic stiffness matrix is used to conduct some numerical simulations to study differences in damage features, e.g., wave amplitude and arrival time for fundamental symmetric and anti-symmetric Lamb wave, between open and closed crack models. Also Lamb wave interaction with different crack lengths is investigated. In addition, differences in reflection and transmission features in different crack tips of the crack are also analyzed. Finally, damage features obtained are successfully used to guide an experiment for damage detection in an aluminium beam.

8345-31, Session 5a

* Impact localization on a cylindrical plate by near-field beamforming analysis

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Detecting the point of impact is of great importance in health monitoring of structural systems especially those used in aviation fields. One candidate for the impact localization method is the beamforming analysis proposed by McLaskey et al. [1] that requires only a small array of 4 to 8 sensors. This technique is considered to be more suitable than conventional time difference of arrival (TDOA) method because it is not influenced by noise and dispersion of waves generated by the impact event. This beamforming method with 4 sensors is extended here to a thin cylindrical plate geometry using guided Lamb waves. A difficulty involved is that this technique which assumes constant wave speed in all propagation directions does not work for a medium where wave speed is as a function of propagation direction such as anisotropic plates or cylindrical geometry. In order to overcome this problem, the beamforming analysis in conjunction with an optimization technique that introduces an objective function or error function is developed in this study. The optimization based on the experimentally obtained direction dependent Lamb wave speeds improves the accuracy of the beamforming analysis. The proposed technique is experimentally verified by comparing the predicted values with the exact points of impact on a cylindrical aluminum plate.

References:

1) G. C. McLaskey, S. D. Glaser and C. U. Grosse, “Beamforming array techniques for acoustic emission monitoring of large concrete structures”, Journal of Sound and Vibration, Vol. 329, pp. 2384-2394, 2010.

8345-32, Session 5b

* Nonlinear solitary wave-based inspection of plate structures using granular crystals

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We propose a diagnostic scheme based on nonlinear waves formed within granular crystals to inspect thin plate structures. We generate a highly nonlinear solitary wave by impacting one end of a 1-D granular crystal with a striker. The propagating solitary wave is transmitted from the granular crystal to a large, thin plate via direct mechanical contact. We study the structural response of the plate as a function of its geometry, material properties, and boundary conditions. In particular, the restitutional motion of the plate results in the formation of reflected solitary waves that travel back in the granular crystal. We measure the reflected waves using a piezoelectric discs embedded in one of the spherical particles composing the granular crystal. We analyze the attenuation and propagation speed of the reflected waves to characterize the thickness of the plate and the distance to the fixed plate boundary. Using classical impact theory, we derive an analytical relationship between the solitary waves’ response and the mechanical properties of the plate. We numerically model the coupling mechanism between the granular and continuum media using a combined Discrete Element/Finite Element simulation. We find that the experimental results are in excellent agreement with analytical and numerical predictions. Lastly, we perform preliminary experiments to show that granular crystals are capable of detecting hidden delaminations in carbon fiber reinforced composites. The findings in this study suggest that granular crystals can be used for the nondestructive evaluation of geometry, boundary conditions, and defects of plate structures without using any permanently mounted sensors or bulky scanning systems.

8345-33, Session 5b

Delineation of structural damage from piezo-fibre-based sensor degradation

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The next-generation design of structural components involves combining multiple functions. The goal of such Multi-functional structures (MFS) is to incorporate various tasks and functions such as structural, electrical and thermal features within a structural housing. The blending of multiple subsystems into a single material or structure reduces overall system mass and size while simultaneously increasing system performance and functionality. However, the performance and behaviour characteristics of the multi-functional structures can be affected by degradation of any of the sub-components such as sensor. This can be caused by sustained use as well as exposure to severe environmental conditions or damage resulting from external conditions such as loading abrasion, operator abuse or neglect. This paper investigates diagnostic techniques to distinguish sensor degradation from structural damage, with a focus on interdigital piezoelectric fibre transducers. With the increasing application of structural health monitoring (SHM) systems to manage the on-going integrity of safety-critical structures, it is important to improve the reliability of SHM systems by reducing erroneous information from sensors. This requires a new capability to delineate failures associated with sensors and the sensor network from actual damage in the structure being monitored. This is especially important when the deleterious structural changes in the sensor occurs without any discernible change in the structure being monitored In the present work, an assessment is carried out to quantify the degradation in the electric and electromechanical characteristics of polymer composite PZT sensors, under fatigue loading. Changes in the electrical properties of these sensors such as capacitance and inductance have been measured. The strain measurements of the sensor have also been compared to the theoretically calculated strain. The results show that the delineation of structural damage from sensor degradation is possible by monitoring the changes in the key electrical properties of the sensor components such as electrodes and PZT fibers.

8345-34, Session 5b

Experimental detection of debonding of piezotransducers with the segmented electrode

H. A. Ti noco Navarro, Univ. Autónoma de Manizales (Colombia); A. L. Serpa, Univ. Estadual de Campinas (Brazil)

The piezoelectric transducers (PZT) are bonded to smart structures by means of an intermediate adhesive layer, with the main objectives of applying methodologies of structural health monitoring, nondestructive evaluation, nondestructive inspection and structural control to the structures. However, the application of these methodologies depends on the health of the adhesive joint that couples mechanically the PZT with the smart structure. This research shows an experimental technique based on the segmentation of electrodes of a PZT patch in sheet form. One electrode is segmented in three equal parts (end left, middle, end right) to obtain three electrical signatures of a PZT. The electrical signatures (voltage) of the end electrodes are related to the middle electrode voltage. Three experiments were carried out in this study: two static cases and one dynamic case. For the static case, the left end (first case) and the right end (first case) were debonded. In the dynamic case, only one side was debonded. The results show that the voltage relations present linear behavior and the change in the slope of the voltage ratio allows to identify which electrode is debonded. This technique showed to be effective in the three studied cases of debonding and it could be used to identify debonding in real time.

8345-35, Session 5b

PWAS-based wireless acoustic emission sensor

H. Huang, The Univ. of Texas at Arlington (United States)

Acoustic Emission sensing usually requires specially design piezoelectric transducer and complicate signal preconditioning. Moreover, the large bandwidth of AE signal makes wireless AE acquisition and transmission using conventional wireless sensor nodes extremely difficult. This paper presents a wireless AE sensing system based on low cost low profile piezoelectric wafer active sensor (PWAS). The wireless AE sensor converts the analog AE sensor to a radio frequency signal using a passive mixer. In order to match the high impedance of the PWAS sensor to the input impedance of the mixer, a low power charge amplifier is implemented. The power consumption of the charge amplifier is in the milliwatt range, which is supplied by solar-cell based energy harvesting unit. The wireless AE sensor is characterized using pencil lead break experiment. The design, implementation, and characterization of the wireless AE sensing system will be discussed.

8345-36, Session 6a

* Finite element model updating of a steel pedestrian bridge with wireless and mobile sensors

D. Zhu, J. Guo, C. Cho, C. Fang, Y. Wang, K. Lee, Georgia Institute of Technology (United States)

Owing to the high complexity of civil structures, structural behavior predicted by finite element models built according to the design drawings is usually different from the behavior of an actual structure in the field. To improve the prediction accuracy, finite element model updating can be conducted base on sensor measurement from the actual structure. This paper describes the finite element model updating of a steel frame pedestrian bridge, based upon structural vibration data collected by wireless sensors and mobile sensors at high spatial resolutions. The mobile sensor is capable of maneuvering on ferromagnetic structures with motorized magnetic wheels, as well as attaching/detaching an accelerometer onto/from the measurement location. Static wireless sensors are also installed on the bridge to validate the mobile sensor measurement. The modal characteristics of the pedestrian bridge are then extracted from the measurement data. It is demonstrated that the mobile sensors are capable of providing similar high quality measurements as the wireless sensors. A finite element model of the bridge is first constructed according to the structural drawings, and then condensed using a substructure analysis technique. With this technique, the stiffness contribution of the concrete floor slabs is adequately described and meanwhile, the total number of DOFs (degrees of freedom) is significantly reduced. The finite element model is finally updated through an optimization procedure that minimizes the modal characteristics difference between the model and the field measurement.

8345-37, Session 6a

* Structural damage monitoring with piezo paint acoustic emission sensor

Y. Zhang, Univ. of Maryland, College Park (United States)

Piezo paint AE sensor offers a new approach for broadband AE signal sensing such as in applications of near-field fatigue-induced AE monitoring. Unlike signals from conventional narrowband AE sensors, near field AE monitoring using film piezo paint AE sensor yields pulse like signals that may be used for waveform based signal analysis. Waveform based signal analysis may provide comprehensive information about fatigue cracks. This piezo paint AE sensor passively monitors the stress wave in structures and offers a promising new approach to broadband

stress-wave sensing in the ultrasonic frequency range of interests with the following advantages: low-profile, flexible film that conforms to curved surface, broad-band sensor that has less signal distortion in the specified frequency range - essential to waveform based signal interpretation for damage detection such as the acoustic emission based crack size and localization method. Data collected from a number of lab tests provides useful data for characterizing the performance of the piezo paint AE sensor. This paper presents some recent experimental results for validating the performance of piezo paint AE sensor for fatigue crack and structural buckling monitoring and characterizing their signal features in both lab and field tests. Film-like AE sensor made of piezo paint is shown to be able to capture the AE signals emitting from fatigue crack development or plastic deformation.

8345-38, Session 6a

Enhancing piezoelectric properties of PVDF using zinc oxide nanoparticles

J. S. Dodds, F. J. Meyers, K. J. Loh, Univ. of California, Davis (United States)

Structural health monitoring (SHM) and damage detection technologies are crucial for monitoring sudden and progressive damage and for preventing catastrophic structural failure. Among the diverse suite of sensing technologies available, piezoelectric materials have been widely adopted for its use as sensors (e.g., acoustic emissions and dynamic strain sensing) and as actuators (e.g., propagating Lamb waves for active sensing). Traditionally, piezoceramics such as lead zirconate titantate (PZT) and piezopolymers such as poly(vinylidene fluoride) (PVDF) are used. PZTs offer high piezoelectricity but are mechanically brittle, and PVDF are conformable to complex structural surfaces but exhibit lower piezoelectricity. So as to achieve a combination of these desirable properties (i.e., high piezoelectricity and flexibility), piezoelectric zinc oxide (ZnO) nanoparticles can be inserted into piezopolymers during fabrication. The main objective of this research is the fabrication and characterization of a piezoelectric thin film that consists of ZnO nanoparticles embedded in a PVDF-trifluoroethylene (TrFE) matrix. First, various concentrations of ZnO are used in PVDF-TrFE for optimizing its piezoelectric performance. Second, film fabrication is performed by dispersing ZnO in a PVDF-TrFE and followed by spin coating the solutions onto a rigid substrate. Then, a high voltage amplifier is employed for applying a high electric field to each of the films (i.e., poling), while a mixed-signal oscilloscope and Sawyer-Tower circuit is used for measuring its response. Graphs of electric field compared to electric displacement can be obtained for determining the films' piezoelectricity and its dependence on ZnO concentrations. Finally, their strain sensing and actuation capabilities are demonstrated.

8345-39, Session 6a

* Development of a self-sensing, flexible, and multifunctional thin film sensor using P3HT and carbon nanotubes

D. Ryu, K. J. Loh, Univ. of California, Davis (United States)

In order to prevent catastrophic structural collapses and to facilitate timely maintenance and repair, high performance robust structural health monitoring (SHM) systems are required for detecting damage. To date, a variety of advanced sensor prototypes (e.g., piezoelectric materials, sensing skins, fiber optics, and wireless sensors) have been proposed and validated for SHM. However, these technologies still suffer from (1) high energy demand, (2) large form factors, and (3) durability issues. In a previous study a photosynthesis-inspired and photocurrent-based strain sensor for SHM has been proposed. The poly(3-hexylthiophene) (P3HT)-based nanocomposite sensor has been shown to generate photocurrent whose magnitude varies in tandem with applied strain. However, the sensing film is still limited in that the nanocomposite is brittle and can fail due to applied mechanical deformations. Therefore, in this study, a highly flexible photocurrent-based strain sensor and multifunctional nanocomposite will be designed and validated in the laboratory. First, the brittle indium tin oxide layer will be replaced with flexible conductive polymer- and nanomaterial-based electrodes. The optical performance of the electrodes will be characterized using ultraviolet-visible absorption spectroscopy. Second, tuning the photoactive layer with optimized amounts of P3HT and carbon nanotubes will enhance photocurrent generation and its strain sensing performance. The strain sensing properties of the self-sensing P3HT-based sensors will be evaluated by measuring photocurrent generated as a load frame strains each sample. The mechanical properties of the film will also be characterized to show that the films can sustain larger deformation and strain with the new polymeric electrode.

8345-40, Session 6a

Design and evaluation of a thermoelectrical energy harvesting system

G. Wu, X. Yu, Case Western Reserve Univ. (United States)

Power supply strategy is among the crucial components to reduce the instrument cost and to ensure the long term function of sensors. This paper describes the design of a thermoelectrical energy harvest system to be installed on the surface of pavements. The system will collect energy from the temperature difference between the pavement surface and the sub grade soil. The electronic circuit was designed to manage and store the energy produced by the thermal gradient across the pavement structure. Preliminary evaluation was conducted to assess the performance of energy harvesting strategy under emulated conditions.

8345-41, Session 6b

* Design and validation of high-precision wireless strain sensors for structural health monitoring of steel structures

H. Jo, Univ. of Illinois at Urbana-Champaign (United States); J. Park, KAIST (Korea, Republic of); B. F. Spencer, Jr., Univ. of Illinois at Urbana-Champaign (United States)

Despite various wireless smart sensor networks (WSSN) have been successfully implemented for full-scale structural health monitoring (SHM) applications, monitoring of low-level ambient strain, particularly, high-precision synchronized and high-throughput strain monitoring has not been readily available using wireless smart sensors (WSS). For effective measurements and processing of low-level ambient strain, usually, high signal amplification of hundreds or thousands times is required. However, such a high signal amplification can lead a significant offset, if the Wheatstone bridge is not accurately balanced, which would be consequently out of range of ADC inputs; ADC input range of battery-powered smart sensor is limited. In this paper, design and validation of high-precision strain sensor board for Imote2 WSS platform are presented. Balance of the Wheatstone bridge is controlled by digital potentiometers parallel connected to the bridge, and to automatically balance the bridge, software has been developed using ISHMP (Illinois Structural Health Monitoring Project) Services Toolsuite. In addition, the strain sensor board is designed for combined use with the existing accelerometer board (SHM-A) and data acquisition board (SHM-DAQ) previously developed under ISHMP, so that it can utilize the all capabilities of the SHM boards such as anti-aliasing filter, synchronized sensing, and user-selectable digital filter, and provide temperature correction, and accommodating with external analog sensors that requires signal amplifications up to 2500 times. The sensor board has been calibrated with lab-scale tests and experimentally validated through field testing on a cable-stayed bridge.

8345-42, Session 6b

Smart PZT-interfaces for hybrid SHM in cable-stayed bridge

K. D. Nguyen, P. Lee, J. Kim, Pukyong National Univ. (Korea, Republic of)

For the safety of cable-stayed bridges, it is very important to ensure the tensile forces of cables. The loss of cable force could significantly reduce load carrying capacity of the structure and even results in structural collapse. This study presents smart PZT-interfaces for hybrid structural health monitoring (SHM) in cable-stayed bridge. The following approaches are carried out to achieve the objective. Firstly, smart PZT-interfaces are designed to monitor the cable force by using impedance and vibration responses. Secondly, wireless sensor nodes are designed for vibration-based and impedance-based SHM. The sensor node is mounted on the high-performance Imote2 sensor platform to fulfill high operating speed, low power requirement and large storage memory. Finally, a system of smart PZT-interfaces and wireless sensor nodes is evaluated for its performance on a lab-scale cable-anchorage model.

8345-43, Session 6b

Preliminary study of low-cost GPS receivers for time synchronization of wireless sensors

R. E. Kim, Univ. of Illinois at Urbana-Champaign (United States); T. Nagayama, The Univ. of Tokyo (Japan); H. Jo, B. Spencer, Jr., Univ. of Illinois at Urbana-Champaign (United States)

Growing public concerns on the health of the aging civil infrastructures prospered structural health monitoring (SHM) using various sensors. Pinnacle technology on the wireless sensors enabled usage of wireless smart sensor network (WSSN) on the SHM and significantly lowered the entire cost of the network. Although researchers proposed methods to establish reliable WSSN, assuring accurate time synchronization of the wireless network and network communication are challenging features for implementing full scale monitoring of the structure. WSSN currently relies on CPU clock time for time synchronization. However, using PC clocks in particular is not reliable enough due to various effects on crystal tolerance such as calibration and/ or temperature effect. The effect results the network time drift of many mille-seconds. Also, reliable network communication is partially achieved by increasing number of sensors on the network or using strong antenna power. Usage of low-cost GPS receivers for time synchronizing the WSSN is proposed in this study to cure the problems. GPS is known to have satellite time synchronization every second and provide an accuracy of few nano-seconds. GPS time synchronized nodes also obsolete the need of communication within the network when collecting data from the environmentally challenging structures. This study provides a preliminary work on establishing WSSN time synchronized using low cost GPS receivers.

8345-44, Session 6b

* Passive, wireless conductivity sensors for reinforced concrete structures

J. Kim, P. Pasupathy, S. L. Wood, D. P. Neikirk, The Univ. of Texas at Austin (United States)

A passive, wireless and low-cost sensor has been developed at the University of Texas at Austin to monitor the conductivity of reinforced concrete members in civil infrastructure systems. By monitoring conductivity, the sensors provide information on the progress of chloride-induced corrosion of the embedded reinforcement in RC structures. The sensors would be attached to the reinforcement cages before placement of the concrete in new construction or in portions of rehabilitated structures and then the sensors will be interrogated as part of a routine inspection. A new sensor design, a non-contact conductivity sensor, has been developed to prevent damage during placement of the concrete; a metal shielding element is positioned on top of the sensor but is not connected to the circuit of sensor. The results of two experimental investigations are discussed in this paper. Firstly, conductivity sensors were submerged in liquids of increasing conductivity. Secondly, conductivity sensors were embedded in concrete cylinders and interrogated over a 40-week period. Analysis of the measured data demonstrated that the new designed conductivity sensors successfully detected conductivity variations in concrete.

8345-45, Session 6b

Experimental valitation of energy harvesting devices for civil engineering applications

H. Jung, I. Kim, J. Park, KAIST (Korea, Republic of)

In the field of structural health monitoring using wireless sensors, considerable research attention has been recently given to vibration-based energy harvesting devices for exploring their feasibility as a power source of a wireless sensor node. Most of the previous studies have focused on lab-scale tests under the ideal conditions. To clearly demonstrate the applicability of the energy harvesters, however, their performance should be thoroughly investigated in real situations. In this study, the effectiveness of several newly-developed energy harvesting devices (e.g., the electromagnetic energy harvester for stay cables and the rotational energy harvester for low-frequency excitation) are validated through a series of field tests on an in-service cable-stayed bridge. Also, the possibility whether the devices can be used as a power source of a wireless sensor node is examined.

8345-46, Session 7

Embedding passive wireless shear/ compression sensors in shoes for diabetic foot diagnostics

I. Mohammad, H. Huang, The Univ. of Texas at Arlington (United States)

A foot ulcer is the initiating factor in 85% of all diabetic amputations. Ulcer formation is believed to be contributed by both pressure and shear forces. However, no quantifiable parameters exist to predict the formation of a foot ulcer, primarily due to the lack of in-shoe sensors. An antenna sensor based on the principle of microstrip patch antenna is utilized to measure shear and loop antenna sensors will be employed for compression sensing. These two sensors will be integrated vertically and embedded in the insole of shoes for measuring plantar pressure/ compression distribution. The change in resonant frequencies of these antenna sensors will be monitored to measure shear/compression. This hypothesis is first validated using electromagnetic simulation. Subsequently, the antenna sensor's capability to detect crack orientation was experimentally validated. The principal of operation will be discussed first followed by detailed descriptions on the antenna design, simulation model, sensor fabrication, experimental setup, procedure and results. A novel sensor identification scheme that can wirelessly interrogate multiple sensors simultaneously without the need of batteries at the sensor nodes will also be discussed.

8345-47, Session 7

Mutual synchronization between structure and central pattern generator

J. Hongu, D. Iba, Kyoto Institute of Technology (Japan)

This paper discusses mutual synchronization between structures and Central Pattern Generators, which are installed in a new controller for

active mass dampers. The active mass dampers have been applied to structural vibration control of high-rise buildings, bridges and so on. In this case, the mass of the active mass damper must oscillate in an appropriate phase in relation to the control object, and generally, the damper has been designed by linear control theory as pole placement method, optimal control method, and all the rest. On the other hand, on walking of animate beings like mammals or insects, both side feet have appropriate phase relations; moreover, it is possible to keep moving on irregular ground. That is, algorithms for the walking would be embedded into the animate beings to control the complicated and redundant bodies with ease and robustness. In biological study, the Central Pattern Generators in bodies playing a significant role in the walking have been learned over the last few decades, and some studies said that some animate beings are able to control their feet by using the generators without their brains in the walking. Moreover, mathematical models of the pattern generators have been proposed, and some researchers have been studying to realize walking of biped-robots using the pattern generators embedded in a computer. In this study, the algorithm is installed into a controller for the active mass damper; furthermore, synchronization properties of the controller is discussed.

8345-48, Session 7

Simultaneous localization and mapping with consideration of robot system dynamics

R. Jaai, N. Chopra, B. Balachandran, Univ. of Maryland, College Park (United States); H. Karki, The Petroleum Institute (United Arab Emirates)

In the simultaneous localization and mapping (SLAM) problem, it is required for a robotic system to acquire the map of its environment while simultaneously localizing itself relative to this evolving map. In order to solve the SLAM problem, given observations of the environment and control inputs, the joint posterior probability of the robot pose and the map are estimated by using recursive filters such as the extended Kalman filter (EKF) and the particle filter. The implementation of these filters requires a motion model to describe the evolution of the robot pose with control inputs, and additionally, an observation model to describe the relations between the robot pose and measurements of the environment. In general, the motion model is derived from the kinematics of the robotic system, without taking the system dynamics into account. In this article, we investigate the performance and efficacy of standard SLAM algorithms when the dynamics of the robotic system is taken in account in the motion model and provide experimental results to illustrate the theoretical findings.

8345-154, Session 7

An in situ damage imaging algorithm for a distributed array of passive and active sensors

C. H. Wang, F. Rose, RMIT Univ. (Australia)

Accurate and continuously updated information of the location, size and severity of structural damage would provide a crucial input for real-time structural health monitoring (SHM) and safety prognostics. A synthetic time-reversal approach was first proposed in the SHM context by the authors (Wang, C.H, J.T. Rose, and F.K. Chang “A synthetic time-reversal imaging method for structural health monitoring,” Smart Materials & Structures, 13, 415-423, 2004). That approach is best suited to a distributed array of active sensors, such as piezoelectric actuators that can both transmit and receive. This paper extends the time-reversal imaging algorithm to enable the use of passive sensors, such as optical fibre sensors and strain gauges, for imaging structural damage. Since passive sensors are more amenable to multiplexing, this new approach will reduce the wiring requirement of structural health prognostics systems.

8345-116, Poster Session

A new control approach for the design and implementation of low frequency large band inertial platforms

F. Acernese, G. Giordano, Univ. degli Studi di Salerno (Italy); R. De Rosa, Univ. degli Studi di Napoli Federico II (Italy); S. Vilasi, R. Romano, F. Barone, Univ. degli Studi di Salerno (Italy)

Inertial platforms require a careful design not only of the mechanical attenuation stages but also of the control system, especially if a residual horizontal motion better than 10-15 m/sqrt(Hz) in the band 0.01 - 100 Hz is a requirement.

The latter is a limitation, for example, for the mechanical suspensions of interferometric detectors of gravitational waves, still based on accelerometers (inertial damping).

For this task, we introduced a new control philosophy, providing the control system with the instantaneous relative positions of the mechanical components.

In the paper we discuss the new control architecture and the tests on a state-of-the-art mechanical suspension.

8345-117, Poster Session

Long term seismic noise acquisition and analysis with tunable monolithic horizontal sensors at the INFN Gran Sasso Laboratory

F. Acernese, G. Giordano, S. Vilasi, R. Romano, Univ. degli Studi di Salerno (Italy); R. De Rosa, Univ. degli Studi di Napoli Federico II (Italy); F. Barone, Univ. degli Studi di Salerno (Italy)

In this paper we describe the scientific data recorded by the mechanical monolithic horizontal sensor prototypes located in the Gran Sasso Laboratory of the INFN. The mechanical monolithic sensors, developed at the University of Salerno, are placed, in thermally insulating enclosures, onto concrete slabs connected to the bedrock, and behind a sound-proofing wall. The main goal of this experiment is to characterize seismically the site in the frequency band 10^-4 - 30 Hz and to get all the necessary information to optimize the sensors.

8345-118, Poster Session

Mechanical monolithic tiltmeter for low frequency measurements

F. Acernese, G. Giordano, S. Vilasi, Univ. degli Studi di Salerno (Italy); R. De Rosa, Univ. degli Studi di Napoli Federico II (Italy); R. Romano, F. Barone, Univ. degli Studi di Salerno (Italy)

The paper describes the application of a monolithic folded pendulum (FP) as a tiltmeter for geophysical applications, developed at the University of Salerno. Both the theoretical model and the experimental results of a tunable mechanical monolithic FP tiltmeter prototype are presented and discussed. Some of the most important characteristics, like the possibility of tuning its resonance frequency to values as low as 70 mHz and its measured resolution better than 0.1 nrad at 100 mHz, are detailed. Among the scientific results, earth tilt tides have been already observed with a monolithic FP tiltmeter prototype.

8345-119, Poster Session

Low-frequency/high-sensitivity horizontal monolithic sensor

F. Acernese, G. Giordano, S. Vilasi, R. Romano, Univ. degli Studi di Salerno (Italy); R. De Rosa, Univ. degli Studi di Napoli Federico II (Italy); F. Barone, Univ. degli Studi di Salerno (Italy)

This paper describes a new mechanical implementation of a folded pendulum based inertial sensor, configurable as seismometer and as accelerometer.

The sensor is a compact, light, scalable, tunable (1500 in air) instrument, with immunity to environmental noises guaranteed by an integrated laser optical readout.

The measured sensitivity curve is in very good agreement with the theoretical one (10^-12 m/sqrt(Hz) in the band (0.1-10 Hz).

Typical applications are in the field of earthquake engineering, geophysics, and in all applications requiring large band-low frequency performances coupled with high sensitivities.

8345-120, Poster Session

State-of-the-art of IT-based high precision patch/implant system technology development for safety management of buildings/large structures in Korea

K. T. Park, C. Lee, B. Lee, Y. Yu, Korea Institute of Construction Technology (Korea, Republic of)

Damage of infrastructures, mainly caused by worldwide anomaly climate, global warming, and natural disasters etc., is a real issue nowadays. Adjusting to this situation, Korea has started a research that develops a high precision patch/implant system with a new IT, as a base, that can use as a necessity to the safety management of buildings/large structures.

The technologies which should be developed in this research are kind that measures and valuates the soundness and safety of a structure based on the value of an attached sensor. During this research period, patch form optical fiber sensor and capsule implant form wireless sensor etc. various sensor technologies, stress sensing and structure condition evaluation technologies, sensor high durability and low-power compact smart structure sensor network hardware technologies, high precision image processing based automatic crack extracting and radiation sensor applying technologies, combined management/control technologies about development systems, and practical use technologies for buildings/large structures of development systems will be developed effectively. By these results, we can acquire higher sensor system performance with a measurement scope (precision etc.) goal elevation of over 200% than conventional sensor system. We have the goal of achieving the safety management planning and commercializing of automatic and high technology buildings/large structures. If this research successfully develops, worldwide groundbreaking development of maintenance related main facilities is expected.

8345-122, Poster Session

A damage detection technique for reinforced concrete structures

A. Wu, J. N. Yang, Univ. of California, Irvine (United States); C. Loh, National Taiwan Univ. (Taiwan)

Civil engineering structures, such as reinforced concrete frames, exhibit nonlinear hysteretic behavior when subject to dynamic loads, such as earthquakes. The ability to detect damages in structures after a major earthquake will ensure their reliability and safety. Innovative analysis techniques for the damage detection of structures have been extensively studied recently. However, practical and effective damage identification techniques remain to be developed for nonlinear structures, in particular hysteretic reinforced concrete (RC) structures. In this paper, a smooth hysteretic model with stiffness and strength degradations and with the pinching effect is used to represent the dynamic characteristics of reinforced concrete (RC) frames. A system identification method capable of detecting damages in nonlinear structures, referred to as the adaptive quadratic sum-square error with unknown inputs(AQSSE-UI), is used to detect damages in hysteretic RC frames. The performance of the AQSSE-UI technique is also demonstrated by the experimental data.

A 1/3 scaled 2-story RC frame has been tested experimentally on the shake table at NCREE, Taiwan. This 2-story RC frame was subject to different levels of ground excitations back to back. The RC frame is firstly considered as a linear model with rotational springs, and the tracking of the degradation of the stiffness parameters is carried out using the AQSSE-UI technique. Then the same RC frame is considered as a nonlinear structure with plastic hinges following a smooth hysteretic model. Experimental results show that the AQSSE-UI technique is quite effective for the tracking of: (i) the stiffness degradation of linear structures, and (ii) the non-linear hysteretic parameters with stiffness and strength degradations.

8345-123, Poster Session

A sub-PolyMAX method for structural flexibility identification

J. Zhang, Southeast Univ. (China)

A novel Sub-PolyMAX method is proposed not only for structural modal parameters, but also for structural flexibility identification by processing impact test data in narrow frequency bands. The traditional PolyMAX method solves denominator polynomial coefficients by minimizes the least square errors of FRF estimates in the whole frequency range, but FRF peaks in different structural modes may have different levels of magnitudes, which leads that identified modal parameters in the modes with small FRF peaks are inaccurate. In contrast, the proposed Sub-PolyMAX method implements LS solvers in subspaces of the whole frequency range independently, thus the St-Id results from a narrow frequency band are not affected by FRF data in other frequency bands. Through performing structural identify in narrow frequency bands, not in the whole frequency space, the proposed method has the following merits: (1) It produces accurate modal parameters, even in the modes where FRF peaks are very small; (2) It significantly reduces computation cost by reducing the number of frequency lines and the model order; (3) It is able to accurately identify flexibility matrix from impact test data, from which structural deflection under any static loads can be predicted. Finally, numerical and laboratory examples are investigated to verify and illustrate the effectiveness of the proposed method.

8345-124, Poster Session

Assessment of mode-based damage detection methods to severely damaged steel building

H. HoThu, A. Mita, Keio Univ. (Japan)

After a large earthquake, evaluation of damage of structures is an important task for structural health assessment. The structural health monitoring has become a major research focus in the area of structural dynamics. The presence of damage or deterioration in a structure can be detected by the changes in the natural frequencies of the structure. Furthermore mode shape changes can be categorized as damage localization. Besides, many damage detection algorithms based on the modal properties of structure such as modal frequencies, mode shapes, curvature mode shapes and modal flexibilities have been studied for several decades. However, in most algorithms, identifying the precise location and magnitude of the damage is difficult. Using only modal

frequencies and their mode shapes changes to qualify damage seems very difficult to get the real damage in many previous studies. The purpose of this study is to evaluate assessment procedures to identify the location and magnitude of the real damage in four-story steel building by the shifts of natural frequencies and mode shapes. The proposed damage assessment method will be checked with simulation, five-story model experiments and full-scale test data. The excitations are represented by different intensity levels of the 1995 Hyogoken Nanbu Earthquake that are obtained in JR-Takatori Station, and the acceleration data of E-defense tests on full scale four-story steel building will be analyzed. This research desires to test the applicability of representation damage identification methods in order to give correlation between models and real building with only the changes in frequencies and mode shapes.

8345-125, Poster Session

Research of a real-time overload monitoring and response system of bridges and roads

Y. Yu, Y. Shi, X. Zhao, J. Ou, Dalian Univ. of Technology (China)

Due to the general overloading of vehicles, premature failure of bridges and roads are more and more obvious. Structural behaviors of engineering structures need real-time monitoring and diagnosis, timely detection of structural damage, evaluation of their safety, and necessary precautions, in order to prevent major accident such as the collapse of bridges and roads. But the existing monitoring system, which is very expensive, does not apply to the low budget structures. Therefore, a potable, low-cost, low-power structural monitoring system, which consists of electric resistance strain gauge, collection and execution unit, graph collection system and analysis software, is designed in this paper. The system can collect the critical data about the force of pavement to take the certain judge algorithm. The alarm will be given and the overburden data will be transmitted to IDC to make the further analysis when the pavement is overburden. At the same time, the plates of overweight vehicles can be collected and sent to the relevant departments. The system has the features of simple structure, easy realization, and low cost, which fills the application gaps in structural health monitoring of low-budget project.

8345-126, Poster Session

Homeostasis control of building environment using sensor agent robot

E. Nagahama, A. Mita, Keio Univ. (Japan)

We need new buildings that can fulfill urgent requirement on energy-efficiency and more flexible comfort. Currently smart houses are being studied, but they can't respond flexibly to unexpected events because their control systems are based on prescribed scenarios. That is our motivation to explore living things' high adaptability to environmental changes. Living things have survived thanks to four adaptive mechanisms, sensory adaptation, adaptation by learning, physiological adaptation, and evolutionary adaptation. The last two adaptation mechanisms give the living things an ability to conquer harsh events such as unseen viruses and drastic change of living environment. We call buildings that have the four adaptations described above "biofied building". A biofied building integrates sensor agent robots which interact with residents and gather information on the buildings and residents. The information includes emotion and unconscious human feelings. In this research, we are particularly interested in the homeostasis phenomenon as the third adaptation and propose a prototype model to control the building environment. In the homeostasis phenomenon, even if the environment changes, human is able to maintain a constant body temperature. We converted this human's temperature control mechanism in a spaces control algorithm. In this algorithm, a resident is in the control loop as both sensors and controllers. Sensor agent robot gathers his/her uncomfortable feelings and broadcasts them to the whole living spaces. Broadcast signals make devices start operations based on some characteristics of its receptors. By computer simulation, we ensured that this model is simple and robust.

8345-127, Poster Session

Design and concept of fiber-optical and I2C hybrid sensor bus system for telecommunication satellites

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In this paper the concept and design of a Hybrid Sensor Bus (HSB) for telecommunication satellites is presented. The HSB development in the frame of an ESA-ARTES project has been started in 2011 and will be tested as flight demonstrator onboard the German Heinrich Hertz Communication satellite (H2Sat) in 2016 before it becomes a final product.

In state of the art European telecommunication platforms hundreds of sensors are necessary for satellite control and monitoring. The sensors are wired point-to-point (p2p) to the satellite management unit (SMU) which results in a high mass impact but preliminary increases AIT effort and thereby the overall satellite costs.

Sensor bus architectures reduce AIT cost by reduction of wiring effort, reduction in required test time and by providing a flexible sensor topology. The HSB system includes several plug-and-play modules including a controller module (HCM), a fiber optical interrogator module (FIM) and an I²C electrical interrogator module (IIM). The HSB system provides advanced performance which includes programmable and sensor specific alarm functions, averaging of dedicated sensors hence resulting in a reduction of SMU processor load. The combination of electric I²C sensors for punctual resolved measurements and FBG fiber-optic sensing for e.g. thermal mapping of panels by embedding sensor fibers in the satellite structures results in a very flexible system ["Fiber Optic Sensing for Telecommunication satellites", ICSO Conference 2008].

In this paper we present the design of the HSB system taking into account requirements from European platform manufacturer OHB System, Thales Alenia Space, Astrium Satellites. A detailed analysis of environmental conditions and sensor requirements in the satellite for a lifetime of 15 years is included. A detailed simulation according to the thermal management inside the HSB and according to the degeneration of electronic components due to cosmic radiation in the geostationary orbit is also included. The HSB design ensures to come to a product which can be implemented by platform manufacturers as replacement of standard p2p systems to build up a more flexible, in cost reduced sensor system.

8345-128, Poster Session

Music recommendation system for biofied building considering multiple residents

T. Ito, A. Mita, Keio Univ. (Japan)

Building environment control system has been explored by learning from adaptive bio-systems. Some researches present adaptive music recommendation system, which uses bio-inspired algorithm to utilize user preference learning and user behavior, but they do not cover multiple users yet. Previous research mentioned that broadcasting multiple residents' feeling to all devices is a key for realizing biofied building control based on homeostasis nature. In this paper, we present music recommendation system based on two user's music preference and behavior. This research has two objectives. First objective is to build the system which is able to recommend music matching to two user's work. Second objective is to verify that this music recommendation system contributes to two user's collaborative work. There are three steps in this system. Firstly, the system acquires whether the music matches to their work or not by sensing user behavior showing in their foot. Secondly, if

the behavior is more active than the normal behavior and the music does not matches to the user, the system recommends user preferred music using Markov decision process to calm down the user's mood. If the behavior is more passive than the normal behavior and the music does not matches to the user, the system recommends user preferred music using Markov decision process to uplift the user's mood. If the music matches to user's work, the system recommends user preferred music to keep user's mood. Thirdly, the system gets feedback data for user preference learning.

8345-129, Poster Session

Distributed measurement of impact strain and pressure in clay by use of embedded fiber-optic sensors

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This paper presents the efficacy of measuring spatial and temporal distribution of dynamic strains and pressure generated internally in a bed of clay in response to an applied impact load at the surface using FBG (Fiber Bragg-Grating) and BOTDR (Brillouin Optical Time Domain Reflectometry) based distributed fiber optic sensor arrays. Fast distributed sensing is realized at 1.20 KHz sampling rate and spatial resolution smaller than 1 cm. In the experiments, the FBG proved more accurate and sensitive than BOTDR for dynamic sensing.

Impact stress measurements were acquired by tactile pressure sensors. The FBG sensor response are compared to impact pressure distribution recorded by embedded tactile sensors. The new system is anticipated to serve as the next generation of distributed sensing in geological media as it is capable of acquiring internal vibration strain and pressure accurately and simultaneously.

8345-130, Poster Session

Distributed multifunctional sensor network for composite structural state sensing

X. P. Qing, L. Gao, Commercial Aircraft Corp. of China, Ltd. (China)

Advanced fiber reinforced composite materials are becoming the main structural materials of next generation of civil aircraft because of their high strength and stiffness to weight ratios, and strong designability. In order to take full advantages of composite materials, there is a need to develop an embeddable multifunctional sensing system to allow a structure to "feel" and "think" its structural state. In this paper, the concept of multifunctional sensor network integrated with a structure, similar to the human nervous system, has been developed. Different types of network sensors are permanently integrated within a composite structure to sense structural strain, temperature, moisture, aerodynamic pressure; monitor external impact on the structure; and detect structural damages. Utilizing this revolutionary concept, future composite structures can be designed and manufactured to provide multiple modes of information, so that the structures have the capabilities for intelligent sensing, environmental adaptation and multi-functionality. The challenges for building such a structural state sensing system and some solutions to address the challenges are also discussed in the paper.

8345-131, Poster Session

A statistical approach of fatigue crack detection for a structural hotspot

P. Jin, L. Zhou, Nanjing Univ. of Aeronautics and Astronautics (China)

This work focus on an unsupervised, data driven statistical approach to detect and monitor fatigue crack growth in lug joint samples using surface mounted piezoelectric sensors. Early and faithful detection of fatigue cracks in a lug joint can guide in taking preventive measures, thus avoiding any possible fatal structural failure. The lug joint samples used in this paper are prepared from an aluminum alloy plate with 6 mm thickness and are instrumented with a surface mounted piezoelectric sensor network. Experiments are conducted on three lug joints under constant fatigue loading. The fatigue loading was stopped every 1000 cycles after any small cracks was spotted, and the piezoelectric signals corresponding to 11 narrow-band actuations (from 200kHz to 300kHz, interval: 10kHz) were acquired at every fatigue-loading-stopped cycle. The on-line damage state at any given fatigue cycle is estimated using a damage index approach as the dynamical properties of a structure change with the initiation of a new crack or the growth of an existing crack. Using the measurements performed on an intact lug joint as baseline, damage indices are evaluated from the frequency response of the lug joint with an unknown damage state. As the damage indices are evaluated, a Bayesian analysis is committed and a statistical metric is evaluated to identify damage state (say crack length).

8345-132, Poster Session

Genetic mechanism for designing new generation of buildings from data obtained by sensor argent robots

C. Ono, Keio Univ. (Japan)

Current smart buildings are designed based on prescribed scenarios so that they cannot deal with unexpected events. Moreover, they do not evolve by themselves. "Biofied building" is the concept that we aim to make living spaces safer and more comfortable by embedding autonomous mechanisms in the living spaces. The key technologies for biofication are sensor networks to acquire information and data-processing technologies for effective utilization of information. As a first step towards the realization of "Biofied building", a system for acquisition and storing information must be developed. In this research, we will propose a mechanism to convey the data for next generation's buildings. First, we suggest a database inspired by genetics. It's necessary to encourage active evolution of building design. Secondly, we discuss functions of mutation evolution. In the genetics, people are affected by mutation evolution. Thus, it's necessary for conveying the data for next generation. Next, we suggest the method of using information of parent generation. And we discuss the method of environmental setting for existing. Finally, we use sensor agent robot to collect most data, as they can follow residents and acquire data at any point. By using collected data and data mining, we analyze the important data for conveying for r next generation's buildings by using genetic mechanisms. As a result, the buildings adapts to changes of the environment and human's behavior.

8345-133, Poster Session

Frequency response analysis of multi-degree-of-freedom system with harmonically varying damping

S. Hirohata, D. Iba, Kyoto Institute of Technology (Japan)

This paper analyzes effects of harmonically varying damping on a multi-degree-of freedom system. Recent research has demonstrated a new application of variable damping considering a single-degree-of-freedom system. In the study, the variable damping coefficient was harmonically varied. As a result of this operation, the response contains new components that have modulated frequencies different from the input frequency. By varying the damping coefficient at a suitable frequency, one can generate new vibrations that contain arbitrary frequencies, amplitude, and phases. Additionally, the previous study applied the

concept of harmonically varying damping to achieve response control of a single-degree-of-freedom structure subjected to a primary sinusoidal base excitation. A variable damper was used in conjunction with a secondary sinusoidal base excitation to reduce response due to the primary base excitation. If the primary sinusoidal base excitation contains the natural frequency of the system, resonance is induced. However, another resonance can be generated by the modulated component caused by the variable damping device and the secondary base excitation. The additional resonance is adjusted to be out of phase with the primary response, resulting in effective control of the structure. An expression for the variable damping controller has been developed, and control performance has been verified by numerical simulation. However, no such study considering a multi-degree-of-freedom system has yet been conducted. For this reason, this study presents the effect of the harmonically varying damping on the multi-degree-of-freedom system. Especially, the influence on a structure with a dynamic absorber who has a variable damper is discussed.

8345-135, Poster Session

Optimal sensor placement based on substructure sensitivity

S. Zhou, Y. Bao, H. Li, Harbin Institute of Technology (China)

Optimal sensor placement is key issues of structures health monitoring (SHM). In study of sensor placement, the main achievement focus on optimal criterions of sensor locations based on modal test, while optimal criterions of sensor locations based on damage identification, optimal method of sensor locations and optimal sensor number should be investigated further.

In this study, a novel optimal sensor placement strategy based on substructure sensitivity is proposed. Optimal sensor placement based on sensitivity analysis is an alternation method to consider damage identification. The basic idea of the proposed methodology is that influence range of different damage parameters is different.

First, damage sensitivities in every element based on modal parameters are calculated. Then the elements that are sensitive to damage are selected. According to the detection of damage sensitivity in these elements, minimums number can be found by sensitivity. At last, the elements that are not selected are considered as not sensitive to modal parameters and would be placed the strain sensors.

Numerical simulation of a three-dimensional truss structure is implemented to evaluate the minimum sensor number of different damage parameters according to the above methods. Moreover, damage location can be detected under single-damage situation and the element with most severe damage can be identified in multi-damage case using the proposed sensor placement.

8345-136, Poster Session

Development of the damage assessment methodology for ceiling elements

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In resent years, many ceiling elements were damaged and dropping down to floor after earthquakes in Japan. On March 11 2011, a number of people are injured and killed by the dropping ceiling elements due to the 2011 off the pacific coast of Tohoku Earthquake. The damaged ceiling element is quite dangerous, because the weight of the ceiling element is usually heavy. After earthquakes, the monitoring for ceiling elements with and without damages is needed. However, the damage assessment of the ceiling elements is quite few.

This paper presents the basic concept of a damage assessment methodology for ceiling elements. The proposed system consists of the smart sensor and the inspection robot. In this proposed scheme, the distributed smart sensors firstly measure the strain of the ceiling element to detect the damage occurrence. Next, the robot inspects the damage location and captures the photographic image of the damage condition. The smart sensors have the microcontroller, sensors, TCP/IP device to send the measuring data to PC.

The inspection robot has the wireless camera and microprocessor. The wireless camera can send the data to the place about 30m away from the camera. The microprocessor can connect to the sensors. At first, the proposed system is demonstrated by experiments of a full-scale suspended ceiling utilizing shaking table facilities. Next, the inspection robot applied the inspection for the ceiling of the real structure damaged by the 2011 off the pacific coast of Tohoku Earthquake.

8345-137, Poster Session

Research on sensing ability of the FBG strain sensor encapsulated by asphalt

T. Zhao, X. Zhao, Y. Cui, Y. Wang, j. chen, Dalian Univ. of Technology (China)

In recent years, such early damage phenomena of asphalt pavement as rutting, cracking and so on usually appear shortly after it was open to traffic. In view of this, the strain monitoring of asphalt pavement as one of feasible measures to diagnose the pavement disease has been well applied for the quality evaluation based on the analysis of the monitoring data, which can provide reliable guidance for the maintenance and improved design of pavement. As a result of its special superiority in Health Monitoring, FBG sensors are adopted to monitor the strain of asphalt pavement. However, traditional FBG sensors can not reflect real strain of asphalt pavement due to its large -modulus and large-size. Based on the above, a new type of FBG sensor packaged by asphalt used for the strain monitoring of asphalt pavement was researched.

In this paper, test and research of the sensing ability of the FBG strain sensor encapsulated by asphalt is carried out. Firstly, the design idea of FBG strain sensors encapsulated by asphalt was described in detail, the design principle and production process of FBG strain sensors encapsulated by asphalt was discussed emphatically.This kind of sensor is equipped with pure Fiber Bragg Grating and the Fiber Bragg Grating with the consolidation of the micro-spring. Pure Fiber Bragg Grating sensor can accurately measure the average strain within the range of small strain, the Fiber Bragg Grating with the consolidation of the micro-spring can implement low precision testing for the average strain within the range of large strain, full-scale and multi-level precision strain monitoring can be completed Pure Fiber Bragg Grating and Fiber Bragg Grating with the consolidation of the micro-spring. Secondly, the calibration experiment of FBG strain sensors was carried out to measure such sensing properties as linearity, repeatability and sensitivity,The test method is mainly that the FBG strain sensor encapsulated by asphalt is embedded in ordinary concrete specimens and asphalt concrete specimens to respectively test their operability and application performance, and obtain the sensing parameters. This can be applied to the actual.

We obtained the sensing parameters of the FBG strain sensor encapsulated by asphalt after the experimental analysis, The testing results also show that the proposed sensor features good sensing property,the sensing ability can completely meet the need of the actual project. while its application in asphalt pavement, however, needs further study.

8345-138, Poster Session

Large substructure identification using substructure isolation method

J. Hou, Dalian Univ. of Technology (China)

Structural Health Monitoring (SHM) has been a hot researched field in civil engineering, in which damage identification is an important

procedure on maintaining structural integrity and safety. For large and complex structures it is usually not easy to identify them globally and accurately due to their complex boundary conditions, nonlinear components, etc. Therefore, substructuring methods are popular, which can only focus on local small substructure instead of the complex entire structure, and thus only needs a few sensors correspondingly placed on the substructure. However, because of the coupled interface force, many of the current substructure methods usually belong to time domain method and are often limited to the small substructure.

In this paper Substructure Isolation Method (SIM) is used for large substructure identification. The isolation method firstly utilizes the measured responses to construct the responses of the isolated substructure, which is a virtual and independent structure with the same system parameters as the real substructure. Then, the substructure identification is carried out equivalently via the isolated substructure and flexibly by some of the existing identification methods which aim originally at the large structure. Therefore, the performance of the SIM offers the possibility that the large substructure can be identified. A numerical bridge model is used to verify the proposed method, which preforms efficiently and accurately.

8345-139, Poster Session

A new deformation monitoring method for flexible variable camber wings (FVCW) based on FBG Sensors

P. Li, J. Leng, Harbin Institute of Technology (China)

In this research, an indirect method is presented to monitor the deformation of the flexible variable camber wings(FVCW) using FBG sensors.

Firstly, the vertical displacement and deflection angle of the FVCW are deduced by strain detection of the local deformation based on the von-Karman strain-displacement relationships.

Secondly, a theoretical finite element model of the FVCW with pneumatic artificial muscles is developed. The theoretical calculations and analysis optimize the localization of the fiber grating sensor networks in the FVCW. The experimental setup to measure the change of strain for the wing's sheet is designed. Two groups of FBG sensors are bonded on the upper /lower side of the sheet respectively to measure the deflection on the some certain points.

Finally, the experiment results of direct measurement show good agreement with this theory deduction. In comparison with the numerical results, the average error of the experimental results under different air pressure is lower than 2%. The presented theoretical and experimental techniques have a great impact on the safe deployment and effective operation of FVCW.

8345-140, Poster Session

Damage identification using substructural virtual distortion method

Q. Zhang, Dalian Nationalities Univ. (China)

Virtual Distortion Method (VDM) is a fast structural reanalysis method, in which virtual distortions regard to damaged elements are introduced to simulate structural modifications or damages. However for large and complex structure, VDM is difficult to perform due to that they require many distortions to be considered.

This paper proposes the virtual distortions of the substructure other than the element are used in the damage identification. Such that the required number of virtual distortions depends on the substructure other than the elements, and then the number of virtual distortions is reduced, which improves the computational efficiency. In addition, under a certain load action, the structural response may be expressed by a few of main eigenvectors, and thus it only needs to compute the virtual distortions which are relative with these main eigenvectors. This further reduces the necessary distortions.

In this paper, first it derives the relation among the eigenvectors of the substructure, virtual distortions, actual distortions, and the substructure damage extent; then the main eigenvectors are chosen by the relativity analysis between the structural responses and the substructure eigenvectors. In this way, given damage extents, the corresponding virtual distortions can be obtained by solving a linear equation. Therefore the estimated response of the damaged structure can be obtained quickly via the intact structure response and the virtual distortions. The damage are optimized and identified by simply minimizing the least square distance between the measured response and the estimated response. A numerical frame model is used to verify the proposed idea.

8345-141, Poster Session

Performance evaluation of reinforced concrete slab using a load test with continuous AE monitoring

M. Di Benedetti, Z. Karim, A. De Luca, T. Shokri, A. Nanni, Univ. of Miami (United States)

Load testing is a consolidated evaluation technique part of the structural assessment protocol for serviceability and safety of constructed reinforced concrete (RC) facilities. Different load application procedures as proposed by ACI 318 and 437 documents (i.e., 24-hour load test method (24h LT) and cyclic load test method (CLT)) were investigated and acoustic emission (AE) monitoring was implemented during the field tests of one-way RC slabs in a building used for residential. The 24h LT and the CLT prescribe specific acceptance criteria: maximum and residual deflections for the former, while, for the latter, deviation from linearity and permanency ratio have to be considered. This research aimed at developing a complementary procedure to evaluate the performance of the RC slabs using continuous AE monitoring. AE signals were acquired throughout the duration of the various load tests providing the opportunity to verify in-situ an acceptance criterion already satisfactorily employed in laboratory tests. Such criterion is based on the ratio of peak cumulative signal strengths recorded during the reload hold versus the initial load hold of the same load-set. The results of this research project indicate that the proposed AE-based method has untapped potential.

8345-142, Poster Session

Study of the compact fiber optic photoacoustic ultrasonic transducer

N. Wu, Y. Tian, X. Zou, X. Wang, Univ. of Massachusetts Lowell (United States)

Recently, many studies have been exerted on developing ultrasonic transducers that can feature high frequencies for better resolutions and compact sizes for the limit space nondestructive testing applications. Conventional ultrasonic transducers, which are made by piezoelectric materials, suffer from issues such as low frequencies and bulky sizes due to the difficulty of dicing piezoelectric materials into smaller pieces. On the other hand, generating ultrasonic signals by photoacoustic principle is a promising way to generate a high frequency ultrasonic pulse. Optical fiber is a very compact material that can carry the light energy. By combining the photoacoustic principle and the optical fiber together, a novel ultrasonic transducer that features a high frequency and a compact size could be achieved. In this paper, an ultrasonic transducer using gold nanoparticles as the photoacoustic generation material is described. Gold nanoparticles are deposited on the end surface of an optical fiber acting as the ultrasonic generator. A cavity and a diaphragm are fabricated in the center of the fiber using as the ultrasonic receiver. A phase array technique is applied to the transducer to steer the direction of the acoustic beam. Simulation results demonstrated that the photoacoustic ultrasonic transducer is feasible.

8345-143, Poster Session

New federal regulations about the safety management of railroad bridge in U.S.: opportunities and challenges for railroad bridge monitoring

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New federal regulations now mandate North American railroad bridge owners to closely assess the structural capacity of their bridges. Consequently, railroad companies are currently looking into implementing new monitoring systems in specific bridges to help them complying with this new rule. The first part of this article describes new federal regulations mandating the adoption of bridge management systems by railroad owners, and the possibilities that are arising as a consequence for railroad bridge monitoring. Specifically, this new rule comes from Federal Railroad Administration (FRA), Department of Transportation (DOT), and it falls under the 49 Code of Federal Regulations (CFR), Parts 213 and 237. This final rule specifically requires railroad track owners to know the safe capacity of their bridges and to additionally conduct special inspections if either weather or other exceptional conditions deem them necessary to ensure safe railroad bridge operations. This new federal rule became effective for all Class I carriers starting on March 14, 2011; Class II carriers from September 11, 2011, and all the rest (primarily, Class III carriers) from September 11, 2012. The second part of this paper will cover past and current studies about the viability of bridge monitoring, and actual monitoring experiences for railroad bridges. Thirdly, lessons learned from these monitoring examples, as well as recommendations for future applications, are suggested at the end of this paper, including wireless monitoring strategies for railroad bridges, such as: campaign sensing inspections (periodic monitoring); bridge replacement observations (short term monitoring); and permanent bridge instrumentation (long term monitoring).

8345-144, Poster Session

Sensorless position estimation for piezoelectric actuators at different temperature

M. N. Islam, R. J. Seethaler, The Univ. of British Columbia (Canada)

Piezoelectric actuators are used for highly dynamic small displacement actuation applications. For accurate motion, position sensors have been used in feedback control schemes, since an accurate model suitable for sensorless control is difficult to synthesize. Some of the difficulty arises from the highly nonlinear hysteresis behavior of soft piezoelectric materials. Another problem, that is difficult to capture, is the behavior under varying temperature. However, for some applications, such as fuel injectors, feedback sensors are prohibitively expensive and consequently the actuation accuracy is less than desired. In this paper, a model suitable for sensorless control of piezo stack actuators is presented that is able to capture the actuator behavior under varying operating temperatures. It is shown that piezoelectric model parameters such as capacitance, electromechanical coupling coefficient etc. are functions of temperature. To apply such a model to a real time control application, a measurement of temperature is required. Therefore, it is also shown that temperature can be extracted from the nonlinear relationship of capacitance with temperature and position. Hence, using a novel real-time capacitance measurement, we can first identify the stack temperature and then the remaining parameters of the constitutive piezoelectric model. In the final section of this paper we show how to apply our model for piezo stack actuators to a simple sensorless position sensing scheme.

8345-145, Poster Session

Computer-vision based crack detection and analysis

P. Prasanna, K. J. Dana, N. Gucunski, B. Basily, Rutgers, The State Univ. of New Jersey (United States)

Cracks on a bridge deck should be ideally detected at an early stage in order to prevent further damage. To ensure safety, it is necessary to inspect the quality of concrete decks at regular intervals. Conventional methods usually include manual inspection of concrete surfaces to determine defects. Though very effective, these methods are time-inefficient. This paper presents the use of computer-vision techniques in detection and analysis of cracks on a bridge deck. High quality images of concrete surfaces are captured and subsequently analyzed to build an automated crack classification system. After feature extraction using the training set images, statistical inference algorithms are employed to identify cracks, followed by the calculation of dimensions of the cracks and the percentage cracked sub-region.

In addition to testing and comparison of various classification algorithms, the use of a panoramic camera is demonstrated for the purpose of context localization. Also, large scale image stitching is incorporated to generate a coherent spatial mosaic from the individual digital surface images. The generated mosaic is annotated with the crack classification results. This method is a more cost effective solution in the long run as it helps reduce the manual effort involved. The results demonstrate the feasibility of the proposed crack observation and classification system.

8345-146, Poster Session

Determining corrosion intensity in prestressed concrete with acoustic emission

J. Mangual, M. K. ElBatanouny, W. Velez, P. Ziehl, F. Matta, Univ. of South Carolina (United States); M. Gonzalez, MISTRAS Group, Inc. (United States)

Presence of corrosion in embedded prestressing strands has a destructive influence on both strands and concrete. Thus, an accelerated corrosion test was conducted in order to determine the corrosion rate of prestressing strands embedded in concrete using acoustic emission (AE) technique. Four concrete blocks of 4.5 in. (114 mm) squared area and 8 in. (203 mm) long were tested. A ½ in. (13 mm) diameter 7-wire low relaxation prestressing strand was embedded in the center of each specimen. The specimens were partially immersed in NaCl solution with concentration of 3% and they were electrically connected to a power supply and a copper plate forming a galvanic cell. Each specimen was instrumented with AE sensors to record data continuously. Corrosion was detected using half-cell potential measurements and AE sensing while the rate of corrosion was measured using linear polarization resistance (LPR) test. The data form half-cell potential and AE were correlated to determine the onset of corrosion, while the LPR results were used to find a relation between the corrosion rate and AE data. At the end, the sectional mass loss was calculated using Faraday's law and the strands were extracted from the specimens, cleaned and weighed to quantify the experimental mass loss. AE intensity analysis was performed and related to the sectional mass loss results. AE source triangulation technique was used to locate corroded areas.

8345-147, Poster Session

Failure study of SnO2 room temperature gas sensors fabricated on nanospike substrates

H. Ren, P. Wang, H. Huo, M. Shen, H. Sun, M. Ruths, Univ. of Massachusetts Lowell (United States)

SnO2 thin film room-temperature gas sensors have been fabricated on silicon nanospike surfaces made by femtosecond pulsed laser irradiation.

A silane monolayer with low surface energy was deposited on the surface of the sensors using 1H,1H,2H,2H-perfluorooctyltrichlorosilane, in order to generate a self-cleaning behavior on the sensor surface like lotus leaves. Failure studies were performed with water droplet impact and local static strain tests. The sensitivity of the gas sensor remains at a constant level after several thousand cycles of water washing. Based on the sensing results, applied static strain in the range of 0 to 0.12 does not affect the sensor performance. These results indicate that such gas sensors can work properly in the open air, exposed to moisture and heavy particulates and in circumstances with local static stain.

8345-148, Poster Session

Miniature control surface actuation device for precision guided mortar munitions

D. Avirovik, S. Priya, Virginia Polytechnic Institute and State Univ. (United States)

This paper reports a novel control surface actuation device for precision guided mortar munitions. The device was designed to fit in a small volume and operate with minimal power. The actuation device uses microfiber composites (MFC) piezoelectric actuators which are integrated inside a shell and are responsible for morphing fins of gun-fired munitions. The device allows complete control over the entire missile allowing yaw, pitch and roll rotations. Analytical, finite element (FE) and experimental model of the MFC driven actuation device were developed in order to verify the capability of the system to meet the following requirements: 3 degrees stroke, 5Nm torque, 10ms rise time, low power drive electronics and ability to withstand 50KG acceleration. The analytical approach creates a dynamical and static model of the actuator, predicting the force output as well as the deflection characteristics, i.e. stroke and torque. The FE model of the structure provides a more elaborate analysis of the whole mechanism, validating the analytical model and also simulating the mechanism to withstand 50KG acceleration. Two separate analyses were conducted using the FE approach. The first analysis was static, which calculated the deflection and torque output by the actuation device and the second was transient analysis which calculated the rise time of the actuator as well as the ability to withstand high acceleration impact. Finally, a prototype of the mechanism including a driving circuit was constructed and tested to validate the analytical and FE approach. A systematic modeling description will be provided in this paper to demonstrate the capability of the actuation surface.

8345-149, Poster Session

Damage assessment of small-scale wind turbine blade using piezoelectric sensors

M. Rim, S. Kim, I. Lee, KAIST (Korea, Republic of)

Conventionally the operation should be stopped and experts are needed to assess the condition of structures. This causes time, human and economic wastes, and some new kinds of systems are needed to improve these problems. Monitoring the health of structures at real-time is possible through structural health monitoring (SHM) systems which also make it possible to detect the suddenly occurred damage. Therefore SHM systems are being focused recently in many application fields such as aircraft, aerospace, civil structures and so on. Piezoelectric materials are widely used for sensors of SHM system to assess damage of structures.

Piezoelectric materials have particular characteristics such as the piezoelectric effect which is that piezoelectric materials generate an electric charge to applied mechanical stress. When the structure is deformed, the impedance of the structure is changed and as a result, the impedance of the piezoelectric sensor which is installed at the structure is also changed. Therefore it is possible to monitor the structural health by measuring the impedance of the sensors. This is concept of impedance-based method.

In this paper, the small scale wind turbine blade which includes several artificial debondings was manufactured and was used for health monitoring. Polymer type piezoelectric material, PVDF was used for sensor to monitor the condition and to detect the artificial debondings of specimen. Impedance-based method using piezoelectric sensors was applied for this real-time SHM system.

8345-150, Poster Session

Modal parameter extraction of highway bridge by FEM simulation of operational loading conditions

P. O. Mensah-Bonsu, S. Jang, Univ. of Connecticut (United States)

The finite element method (FEM) updating technique combined with modal analysis has been used as a means of damage detection. The success of its use on aircraft and other vibratory mechanical structures has led to its adoption for civil structures for continuous monitoring, damage identification and lifespan prediction. Its application to structural health monitoring (SHM) of civil structures, however, comes with limitations since unlike mechanical structures civil structures are often monitored under ambient excitation. The mode shapes extracted under ambient conditions require a means of normalization that assumes low amplitude white noise as the input excitation. However, mode shapes acquired this way show a wide variation which has limited its use for small damage detection. In the past, techniques to overcome this limitation have focused on modal parameter extraction using mass variation of the field structure. In this paper,a new technique of normalization is carried out by simulating operational traffic loading on a 3D finite element model of the bridge.Thus, normalization of the mode shape is carried out on the FEM model using a Bayesian mass variation under probable traffic loading. The robustness of this promising method is tested on a skewed in-service highway bridge.

8345-151, Poster Session

Decision support system for integrating remote sensing in bridge condition assessment and preservation

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Since the National Bridge Inventory (NBI) was first conducted, structural health monitoring (SHM) of U.S. bridge infrastructure has consisted largely of time and labor-intensive surveys with subjective results. In-situ and embedded sensors, while more reliable and accurate, can be costly and in many cases infeasible for SHM because they require installation in hard-to-reach places or during construction. Remote sensing (RS) technologies such as radar, electro-optical and infrared imaging and laser scanning may offer an innovative, cost-effective method of monitoring the dynamic conditions of U.S. bridges in real-time. While some RS techniques may be costly for state agencies to deploy on their own, RS imagery is available through government agencies or commercial vendors for moderate or no cost. How can disparate RS datasets be integrated with one another and with inventory data in a way that is meaningful to bridge asset management decision makers? The author(s) discuss the development and functionality of the Bridge Condition Decision Support System (DSS), a web-based asset management tool for bridge managers and inspectors. The DSS seamlessly merges bridge metrics from RS data with NBI inventory data allowing decision makers to compare up-to-date bridge condition metrics from multiple inputs as a time series. It enables analysis of RS and inventory data available through user-friendly web services which can also leverage virtually unlimited server-side data processing. Using open-source software, the authors developed a scalable, spatially-aware bridge condition database with a fast, flexible server application programming interface (API) and a cross-browser compatible web mapping application written in Javascript.

8345-152, Poster Session

A study on Q-factor of CCBG sensors by coupled mode theory

S. Wu, T. Wei, J. Huang, H. Xiao, J. Fan, Missouri Univ. of Science and Technology (United States)

The innovative coaxial cable Bragg grating (CCBG) sensor can achieve the attractive attributes of high resolution, remote operation and multiplexing capability as their fiber optical counterpart. Since it is built in an elastic coaxial cable, it also has the unique advantages of large strain capability and robustness to survive harsh conditions, suitable for structural health monitoring. The Q-factor of the resonances in CCBG, which determines the sensitivity of the interrogated signal and hence the resolution in strain measurements, is studied in this paper by coupled mode theory (CMT). In CCBG, the TEM mode is the dominant propagation mode, so coupling only occurs between the forward and backward TEM waves. Both the reflection and transmission spectra can be obtained by solving the CMT equations. The Q-factor of the resonances is then calculated using the values of the resonant frequency and the corresponding 3 dB bandwidth. The relationships between the Q-factor and the geometry/material parameters, such as the number of discontinuities, grating period, dielectric properties of the materials in the coaxial cable and the discontinuity regions, etc., are investigated quantitatively, and closed-from expressions are obtained to approximately describe these relationships. Design guidelines are then developed based on the established device physics, to facilitate the sensor design and fabrication targeting at a high Q-factor for improved sensitivity and accuracy of the CCBG sensor.

8345-153, Poster Session

Comparison of passive and active mass dampers for control of floor vibrations

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Active vibration control (AVC) is a relatively new technology for the mitigation of annoying human-induced vibrations in floors. However, recent technological developments have demonstrated its great potential application in this field. Despite this, when a floor is found to have problematic floor vibrations after construction the unfamiliar technology of AVC is usually avoided in favour of more common techniques, such as Tuned Mass Dampers (TMDs) which have a proven track record of successful application, particularly for footbridges and staircases.

This study aims to investigate the advantages and disadvantages that AVC has, when compared with TMDs, for the application of mitigating pedestrian-induced floor vibrations in offices. Simulations are performed using the results from a finite element model of a typical office layout that has a high vibration response level. The vibration problems on this floor are then alleviated through the use of both AVC and then TMDs and the results of each mitigation configuration compared.

The results of this study will enable a more informed decision to be made by building owners and structural engineers regarding suitable technologies for reducing floor vibrations.

8345-155, Poster Session

A novel kind of fiber optic sensor based on BOTDA for steel corrosion

X. Zhao, X. Kong, P. Gong, X. Lv, J. Ou, Dalian Univ. of Technology (China)

Reinforced concrete is widely used in every civil engineering field now. Steel corrosion is the key factor leads to deterioration of reinforced concrete structures which has caused severe damage and great economic loss every year in the world. The monitoring of steel corrosion is a essential way to research and solve the problem of steel corrosion which is a hot point in the civil engineering field. Lots of research on steel corrosion monitoring has been carried out, but common methods reported are based on electrochemical method, whose durability and stability are the obstacles to long time span corrosion health monitoring. Comparing with traditional monitoring technique, fiber optic sensing technique has many outstanding advantages, such as high precision, good stability, durability, electromagnetic interference immunity, etc. Based on the above, a novel kind of fiber optic sensor based on BOTDA for steel corrosion was researched.

In this paper, a novel kind of fiber optic corrosion sensor was proposed and tested. Firstly, the design of the fiber optic corrosion sensor was described in which the design principle and production process of the sensor was explained emphatically. And then the fiber optic corrosion sensor encapsulated by cement mortar was embedded into concrete specimens to monitor expansion strain caused by steel corrosion in electrochemical accelerating corrosion system. Experiment results show that the design of the sensor which has high survival ratio is realizable and corrosion expansion strain distributed along the monitored steel can be measured consecutively. We also obtained the sensing parameters of the fiber optic corrosion sensor encapsulated by cement mortar after the experimental analysis and reached the development rule of the corrosion expansion strain which adheres to the form of Boltzmann Fit curve. Lastly, we obtained the relationship between corrosion expansion strain and corrosion expansion force by elasticity formulas. The performance of sensor can completely meet the need of the actual project which is featured with low cost and expansion strain monitoring ability. In conclusion, the fiber optic corrosion sensor can be used for corrosion monitoring and evaluation of durability of concrete structures, which has a significant contribution to the research of steel corrosion and durability of concrete structures.

8345-156, Poster Session

Fiber optics sensors simplify the problem of monitoring bridge deflection and provide a comprehensive solution for weight in motion, traffic monitoring, and analysis

P. Kung, QPS Photronics Inc. (Canada)

This paper will discuss the use of Vibrofiber to monitor the deflecting of the bridge under adverse conditions: excess load, strong wind , earth quake etc. The fringes in these cavity sensor have features like peaks and valleys which are sensitive to temperature and strain. When the bridge becomes over loaded, we might want to locate the cause of the overload. A simple Sagnac FBG interferometer has been invented to provide such diagnostics. A pair of these long fiber with such cavity sensors can be installed on the under side of the target bridge segment between by two columns. The concern is to monitor the deflection between the supports together with any distortion of the bridge deck. Each of the long fiber segment has a pair of Vibrofiber sensors ,one to measure the deflection as a result of the excess strain, another to measure temperature and provide compensation for the deflection data An array of Vibrofiber sensors with different center wavelengths will support the typical multi-segment bridge structure. The interrogation unit is a tunable laser hoping to different ITU grids. A separate DFB laser will run a grating based Sagnac interferometer, measuring weight in motion, identifying the speed and the make of vehicle in traffic and provide deflection diagnostics. Overloaded trucks and speeding vehicles can be captured and tagged for corrective actions.

8345-157, Poster Session

Quantitative comparison of Lamb wave interaction with high- and low-cycle fatigue cracks measured using laser Doppler vibrometry

C. T. Owens, E. D. Swenson, Air Force Institute of Technology (United States)

The primary objective of this paper will be to experimentally characterize and quantify significant differences in Lamb wave interaction with high- and low-cycle fatigue cracks in aluminum plates. Quantitative measures will be used to clearly identify if and how wave interaction/propagation behaviors change between the two crack types.

Test specimens are 3.175 mm thick 6061-T6 aluminum plates cut into a “dogbone” shape. Overall dimensions are 610 mm x 305 mm, with a test section of 305 mm x 254 mm. A stress concentrator (hole/notch) is placed in the center of each specimen in order to facilitate fatigue crack growth. Specimens are mounted in a set of mild steel grips and cyclically loaded in a 500 kN Material Test Systems uniaxial fatigue test machine in order to propagate fatigue cracks. Small (6.35 mm diameter x 0.254 mm thick) PZT transducer(s) are adhesively bonded to each plate and used to induce Lamb waves. Test waveforms consist of 5-1/2 cycle sine wave bursts with excitation frequencies between 100 and 600 kHz, modulated with a Hamming window.

1D and 3D Lamb wave measurements are made using both Polytec PSV-400-3D-M and UHF-120 SLDV systems. Both systems are designed for full-field vibration measurements and consist of laser/interferometer sensor head(s), data acquisition systems, data management software and computers, etc. The 3D system makes surface velocity measurements resolved into both in-plane (X-Y) and out-of-plane (Z) components, while the UHF system makes only out-of-plane (Z) displacement measurements, but at frequencies up to 1.2 GHz.

Experimental data is expected to reveal small but quantifiable differences in reflected/diffracted Lamb wave energy between high- and low-cycle fatigue cracks (due primarily to the different sized plastic zones around each crack type). Transmission and reflection coefficients at various locations surrounding the damage sites on each test article are expected to clearly show these differences.

8345-158, Poster Session

Damage detection capability of electromechanical impedance technique under varying static load

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Periodical monitoring and maintenance of structures, to ensure their serviceability and safety is essential. Early detection of degradation such as cracks is desirable to reduce cost of maintenance and to mitigate potential hazards. These concerns have subsequently triggered research and development in the area of structural health monitoring (SHM). The advent of smart material, such as the piezo-impedance transducer provides an excellent alternative to conventional non-destructive evaluation (NDE) technique for SHM applications.

The electromechanical impedance (EMI) technique, which emerged a decade ago, employs piezo-impedance transducers (normally PZT patches) to dynamically actuate the host structure and simultaneously sense its responses. Any damage occurring in the structure will alter its structural response, which in turn be reflected from the electrical signatures measured by the piezo-impedance transducer. Previous studies found that the EMI technique is very efficient in detecting and characterizing damage, even in its incipient stage. However, most of the studies were carried out on structure free of stress, which is deemed impractical. It is well-known that the signatures measured from the EMI technique is susceptible to static loading. This research paper intends to investigate the damage detection ability of the EMI technique when applied on structure under varying static load. Experimental tests were conducted on specimen under varying loads with different level of damages.

8345-159, Poster Session

Real-time vision-based modal parameters estimation at 10000 fps

H. Yang, I. Ishii, T. Takaki, Hiroshima Univ. (Japan)

In this study, we introduce a real-time vision-based modal parameters estimation system at 10000-fps as a real-time non-contact full-filed dynamics measurement technique. High-speed vision is used for determining the multi-point displacements of vibrating object. The vibration series images are captured at 10000-fps sampling speed, and simultaneously processed by using the field programmable gate array (FPGA) hardware. Stochastic subspace identification (SSI) is one of popular and effective output-only time domain modal parameters estimation algorithms, which are necessary for large-scale structures under ambient or operational conditions. SSI algorithm is used in off-line modal analysis applications, limited by the time-consume calculation of singular value decomposition. In order to realize real-time modal parameters estimation, we employ a fast output-only modal parameters estimation algorithm (SSI-CPAST), combining SSI with constrained projection approximation subspace tracker (CPAST). By improving and implementing SSI-CPAST algorithm on a real-time 10000-fps vision platform, the modal parameters of vibrating object are simultaneously estimated. Our simultaneous 10000-fps modal parameters estimation system can real-time and long-term measure the displacements of 100 measurement points, and simultaneously estimate the modal parameters of vibrating object. Therefore, it can effectively track the dynamics of time-varying system in real time. To demonstrate the performance of our real-time vision-based modal parameters estimation system, the resonant frequencies and modal shapes for cylinder cantilevers with different artificial damages and mass sudden change, excited by human finger tapping, were estimated in real time. Experimental results show that our system can measure the high frequency vibration displacement at 10000-fps, and simultaneously estimate the resonant frequencies and modal shapes quite accurately.

8345-160, Poster Session

Seismic performance of RC shear wall structure with novel shape memory alloy dampers in coupling beams

C. Mao, China Earthquake Administration (China); J. Dong, Tongji Univ. (China); H. Li, Harbin Institute of Technology (China); J. Ou, Dalian Univ. of Technology (China)

Shear wall system is widely adopted in high rise buildings because of its high lateral stiffness in resisting earthquakes. According to the concept of ductility seismic design, coupling beams in shear wall structure are required to yield prior to the damage of wall limb. However, damage in coupling beams results in repair cost post earthquake and even in some cases it is difficult to repair the coupling beams if the damage is severe. In order to solve this problem, a novel passive damper was proposed in this study. The coupling beams connecting wall limbs are cut off in the middle and the dampers are installed between the ends of the two half coupling beams. Then the relative flexural deformation of the wall limbs is transferred to the ends of coupling beams and then to the SMA dampers. After earthquakes the deformation of the dampers can recover automatically because of the pseudoelasticity of austenite SMA material. In order to verify the validity of the proposed dampers, seismic responses of a 12-story coupled shear wall with such passive SMA dampers in coupling beams was investigated. The additional stiffness and yielding deformation of the dampers and their ratios to the lateral stiffness and

yielding displacements of the wall limbs are key design parameters and were addressed. Analytical results indicate that the displacement responses of the shear wall structure with such dampers are reduced remarkably. The deformation of the structure is concentrated in the dampers and the damage of coupling beams is avoided.

8345-161, Poster Session

Fully integrated dynamic and static tactile sensing system for manipulators

N. Wettels, Somatis Technologies (United States); B. Pletner, IPTRADE Inc. (United States)

The importance of tactile information for hand functionality is obvious in clinical cases where patients suffering peripheral nerve damage to their hands are able to initiate, but not maintain stable grasp due to lack of sensory feedback from cutaneous sensors. Neurophysiologists have determined that rapid reflexive adjustment of grip is essential for handling objects and depends on tactile feedback via the spinal cord. Object grasping by robotic hands in unstructured environments demands a sensor that is durable, compliant, and responsive to various force conditions. In order for a tactile sensor to be useful for grasp control in unstructured environments, it should have the following properties: tri-axial force sensing (two shear plus one normal component), compliant surface for grip, wide dynamic range (depending on application), insensitivity to environmental conditions, ability to withstand abuse, good sensing behavior (e.g. low hysteresis, high repeatability), and finally slip and incipient slip detection.

This is particularly important in tasks such as bomb disposal and surgery that require precisely calibrated grip forces in order to apply a precise amount of force to the payload. It is furthermore of utmost importance that the grip force is adjusted dynamically in response to the dynamic operating environment. This requires the sensing system to have both static and broadband components in order to accurately relate dynamic slip and incipient slip conditions to the grip force controller.

Current research proposes realizing the above features in a novel sensing system comprising of an innovative elastomeric optical force sensor with embedded piezoelectric vibration sensors. As an object contacts the surface of the optical sensor, it alters the path of light to a distributed set of phototransistors, safely housed within the protective core. Information about the contacted object such as center of pressure and force vectors can be extracted from the information in the changing patterns of light. In this study, an embedded LED was utilized to produce a constant light source throughout a layer of silicon rubber which covered a plastic mandrel containing a set of sensitive phototransistors.

While the optical sensor resolves the grip pressure statically and quasi-statically, piezoelectric sensors embedded within the optical sensor's electronics pick up the high frequency content of the contact force between the gripper and the payload. Incipient slip is detected by a combination of static and quasi-static changes in the pressure distribution along the gripper surface and dynamic changes in the frequency signature of the contact force. As a result, sensor information includes both slip directionality and speed, leading to high-precision grip adjustment that is sufficient to avoid payload drop but does not overcompensate and potentially damage the payload.

Robotic grippers by necessity often work in hostile environments where humans cannot or would not operate. Hence tactile sensing systems need to be fully integrated into a scalable, modular, and mechanically robust package that can be adapted to many different types of grippers and manipulators. The proposed elastomeric optical sensor with embedded piezoelectric components yields precisely such a sensing system.

8345-163, Poster Session

Global stability analysis of side torsion for thin-walled aqueduct

X. Bai, North China Univ. of Water Conservancy and Electric Power (China)

Aqueduct is the key building of The South-to-North Water-Transfer Project in China. As its wall is very thin, the stability of prestressed aqueduct structure has become prominent and the global side torsion stability of the aqueduct should be analyzed.

In this paper, the cross-sectional geometry of a typical U-shaped thin-walled aqueduct was shown and its geometric properties were calculated. Then the Galerkin method and Rayleigh-Ritz method were used to establish equilibrium equation of the U-shaped prestressed aqueduct in the side torsion stability analysis. Finally the critical moment (critical load) of U-shaped thin-walled aqueduct with side torsion buckling was obtained.

Four factors weree discussed in this paper which would influence the side torsion buckling of the whole aqueduct, namely, the aqueduct span, wall thickness, the flange width, and the ratio of height to width.

Results show that the calculated side torsion stability results by Galerkin method and by the Rayleigh-Ritz method are very close. The value by Galerkin method is slightly smaller than that of the Rayleigh-Ritz method. The results by Rayleigh-Ritz method are more close to reality. For the U-shaped aqueduct, its side torsion buckling stress is much greater than the design value of compressive strength of concrete in the common section size and span. This shows that in common conditions, the global side torsion buckling of the aqueduct can not occur. Among the four factors, the most influential factor affecting the critical stress of side torsion buckling is the aqueduct span.

8345-164, Poster Session

Hybrid SHM of cable-anchorage system in cable-stayed bridge using smart sensors and interfaces

P. Lee, K. D. Nguyen, J. Kim, Pukyong National Univ. (Korea, Republic of)

Cable force is an important parameter of cable-stayed bridge since the loss of cable force could significantly reduce load carrying capacity of the bridge. This study presents hybrid structural health monitoring (SHM) of cable-anchorage system in cable-stayed bridge using smart sensors and interfaces. The following approaches are carried out to achieve the objective. Firstly, wireless sensor nodes are designed for vibration-based and impedance-based SHM. The sensor node is mounted on the high-performance Imote2 sensor platform to fulfill high operating speed, low power requirement and large storage memory. Secondly, interfaces are designed to monitor the cable force by using impedance and vibration responses. Finally, the performance of the proposed system is experimentally evaluated on a lab-scale cable-anchorage system.

8345-165, Poster Session

Wireless vibration-based SHM of caisson-type breakwater under foundation damage

S. Y. Lee, K. Nguyen, J. Kim, Pukyong National Univ. (Korea, Republic of); J. Yi, Korea Ocean Research & Development Institute (Korea, Republic of)

This paper presents wireless vibration-based SHM of caisson-type breakwater. To achieve the objective, the following approaches are implementaed. Firstly, wireless vibration-based SHM method for caisson-type breakwater which is use vibration features include power spectral density and mode shape is proposed. Secondly, dynamic behaviors of

caisson structure is analyzed. Thirdly, the proposed method is evaluated by numerical and experimental tests on lab-scaled caisson structure. Loss of foundation due to scouring is considered as damage of caisson structure. Finally, applicability of the proposed method is examined by field tests on existing real-scaled caisson-type breakwater.

8345-166, Poster Session

Full-scale laboratory validation of a wireless MEMS-based technology for damage assessment of concrete structures

D. Zonta, Univ. degli Studi di Trento (Italy); D. Trapani, Univ degli Studi di Trento (Canada)

The evaluation of seismic damage is today almost exclusively based on visual inspection, as building owners are generally reluctant to install permanent sensing systems, due to their high installation, management and maintenance costs. To overcome this limitation, the EU-funded MEMSCON project aims to produce small size sensing nodes for measurement of strain and acceleration, integrating Micro-Electro-Mechanical Systems (MEMS) based sensors and Radio Frequency Identification (RFID) tags in a single package that will be attached to reinforced concrete buildings. To reduce the impact of installation and management, data will be transmitted to a remote base station using a wireless interface. During the project, sensor prototypes were produced by assembling pre-existing components and by developing ex-novo miniature devices with ultra-low power consumption and sensing performance beyond that offered by sensors available on the market. The paper outlines the device operating principles, production scheme and working at both unit and network levels. It also reports on validation campaigns conducted in the laboratory to assess system performance. Accelerometer sensors were tested on a reduced scale metal frame mounted on a shaking table, back to back with reference devices, while strain sensors were embedded in both reduced and full-scale reinforced concrete specimens undergoing increasing deformation cycles up to extensive damage and collapse. The paper assesses the economical sustainability and performance of the sensors developed for the project and discusses their applicability to long-term seismic monitoring.

8345-167, Poster Session

A study on real time monitoring for railroad bogie using energy harvesting

J. Kim, Korea Railroad Research Institute (Korea, Republic of)

This study was intended to identify the applicability of energy harvesting technologies which is regarded the new and renewable energy for monitoring the intelligent railroad bogie. Thus, this study was researched for using wireless sensor monitoring system with the energy harvester in the railroad bogie. The vibration during train operation was measured on the train bogie, and the temperature change during train operation was measured on the axle bearing. we research the characteristic of environmental energy of railroad vehicle during the normal operation for the energy harvester, and we also research and calculate the expected generate energy by the energy harvester in the lab. scale test and simulation.

8345-168, Poster Session

Mechanical design of a langmuir probe for a QuadSat PnP satellite

J. Klepper, J. Kuker, C. Del Barga, A. N. Zagrai, A. M. Jorgensen, New Mexico Institute of Mining and Technology (United States)

In recent years, there is an increasing interest in utilizing small, efficient, plug-and-play (PnP) designs for components of satellite systems. This contribution describes a mechanical design of a sensor package to be placed aboard an AC Microtec QuadSat PnP Satellite. A sensor package includes a Langmuir probe for the in-orbit measurement of plasma properties. By measuring the potential between the electrode in the plasma and the electrode outside the plasma, a function can be developed between the voltage potential and the current flowing back out of the plasma. The paper details mechanical design, fabrication, and system integration of a low cost, low mass Langmuir Probe on aboard of a QuadSat PnP Satellite. The satellite is scheduled to fly on a Polar Satellite Launch Vehicle (PSLV) rocket in the fourth quarter of 2011. The mission life of the satellite, governing the sensor package design, is anticipated to be one month. Details of the sensor package mechanical design are provided and sensor validation procedures are discussed.

8345-169, Poster Session

Electromechanical impedance-based health diagnosis for tendon and anchorage zone in a nuclear containment structure

J. Min, H. Shim, C. Yun, KAIST (Korea, Republic of)

For a nuclear containment structure, the structural health monitoring is essential because of its high potential risk and grave social impact. In particular, the tendon and anchorage zone are to be monitored because they are under high tensile or compressive stress. In this paper, a method to monitor the tendon force and the condition of the anchorage zone is presented by using the impedance-based health diagnosis system. First, numerical simulations were conducted for cases with various loose tensile forces on the tendon as well as damages on the bearing plate and concrete structure. Then, experimental studies were carried out on a scaled model of the anchorage system. The relationship between the loose tensile force and the impedance-based damage index was analyzed by a regression analysis. When a structure gets damaged, the damage index increases so that the status of damage can be identified. The results of the numerical and experimental studies indicate a big potential of the proposed impedance-based method for monitoring the tendon and anchorage system.

8345-171, Poster Session

Inductively coupled corrosion potential sensor for steel reinforced concrete with time domain gating interrogation

D. J. Thomson, K. Perveen, G. E. Bridges, S. Bhadra, Univ. of Manitoba (Canada)

Corrosion is a major problem for civil infrastructure and is one of the leading factors in infrastructure deterioration. Techniques such as half-cell potential can be used to periodically monitor corrosion, but can be difficult to reliably interpret. Wired systems have large installation cost and long-term reliability issues due to wire corrosion. In this paper an embedded inductively coupled coil sensor able to monitor the corrosion potential of reinforcement steel in concrete is presented. The sensor is based on a coil resonator whose resonant frequency changes due to the corrosion potential being applied across a parallel varactor diode. The corrosion potential can be monitored externally using an inductively coupled coil. An accelerated corrosion test shows that it can measure corrosion potentials with a resolution of less than 10 mV. This sensor will detect corrosion at the initiation stage before observable corrosion has taken place. Detection of corrosion at the initiation stage will allow effective intervention to mimimize the impact of corrosion. The sensor has an open hoop design to allow the unimpeded diffusion of reactants from above and below the sensor. In addition a simple potable interrogation system based on time domain gating of signals is presented that has achieved 20 kHz resonant frequency resolution for 3 MHz resonant frequencies. The wireless sensor is passive and simple in design, making it an inexpensive, battery less option for long-term monitoring of the corrosion potential of reinforcing steel.

8345-172, Poster Session

A novel large strain sensor using SrAl2O4:Eu2+ / rubber composite

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The sensing of large strain is integral to many engineering applications such as structure health monitoring, biomechanics (e.g. advanced prosthetics), haptic interface, etc. Several methods, such as interferometric strain gauge, digital image correction and differential digital image tracking have been developed in order to measure large strains. However such techniques are expensive, complicated and cumbersome.

We previously reported that SrAl2O4: Eu2+ (SAOE) can emit strong Mechanoluminescence (ML) proportional to the strain/stress applied on the subject. The ML can quantitatively convert to the strain/stress distribution of a stainless steel plate and this technique has shown promise as a simple, inexpensive strain sensor. Up to now, the SAOE powder was mixed with an epoxy resin to prepare a SAOE film sensor. However, this film can only measure strain reliably up to a few percent, due to the brittleness of the used epoxy resin.

Aiming at measurement of large strain, the SAOE powder was mixed with a rubber binder to prepare a flexible sensor. Tensile and compression test were carried out to study the characteristics of SAOE rubber sensor. It was found that the ML intensity increased with the increase of the strain until more than 13% strains. When the tensile or compression speed was increased, the ML also was enhanced steadily. Furthermore, we found for the same amount of strain, the ML intensity induced by tensile load is stronger than that of compressive load induced. The different responsive ML intensity between the tension and compression maybe come from the anisotropy of the elasticity modulus of the rubber.

8345-173, Poster Session

Bayesian updating methodology for real time maintenance schedule optimization

C. Sbarufatti, A. Manes, M. Giglio, Politecnico di Milano (Italy)

Fatigue design of aircrafts is strictly connected to their maintenance. Especially for helicopters, the presence of high frequency load cycles as well as low frequency manoeuvres, which provoke higher amplitude loads, makes fatigue crack propagation not only a safety issue, but also an economic aspect to be carefully optimized while setting the time inspection intervals. Nowadays, aircraft end-users are trying to establish the “on condition” maintenance, or the possibility to schedule new time intervals according to the actual structural state, given the structural condition of the machine is known with certain reliability. Two characters are needed: from one hand a reliable diagnostic unit, from the other hand a dynamic prognostic unit. The former should be able to get real time knowledge about the structural condition, highlighting damage presence, making then inference over damage type, position and extent. The latter, based upon the output from the previous one, should determine the propagation curve, statistically defining a distribution of residual useful life, to be dynamically updated according to real time measures. The work herein reported is about the definition of a Bayesian updating methodology able to statistically correlate the uncertainties of the diagnostic unit to those of the prognostic one. The method should serve as a valid tool to determine in real time whether a certain machine does need or not to stop for maintenance, obviously given the safety parameter suggested by regulations has been set.

8345-174, Poster Session

Dispersion and curing monitoring of carbon nanotube modified epoxy systems

A. S. Paipetis, G. Gkikas, S. A. Grammatikos, N. Barkoula, Univ. of Ioannina (Greece)

The remarkable mechanical and electrical properties exhibited by carbon nanotubes (CNTs) have encouraged efforts to develop mass production techniques. As a result, CNTs are becoming increasingly available, and more attention from both the academic world and industry has focused on the applications of CNTs in bulk quantities. These opportunities include the use of CNTs as conductive filler in insulating polymer matrices and as reinforcement in structural materials. The use of composites made from an insulating matrix and highly conductive fillers is becoming more and more important due to their ability to electromagnetically shield and prevent electrostatic charging of electronic devices. In recent years, different models have been proposed to explain the formation of the conductive filler network. Moreover, intrinsic difficulties and unresolved issues related to the incorporation of carbon nanotubes as conductive fillers in an epoxy matrix and the interpretation of the processing behavior have not yet been resolved. In this sense, a further challenge is becoming more and more important in composite processing: cure monitoring and optimization. This paper considers the potential for real-time control of cure cycle and dispersion of a modified epoxy resin system commonly utilized in aerospace composite parts. It shows how cure cycle and dispersion control may become possible through real-time in-situ acquisition of dielectric signal from the curing resin, analysis of its main components and identification of the significant features.

8345-175, Poster Session

Comprehensive property retrieval and measurement of concrete spalling using machine vision for post-earthquake safety assessments

S. German, I. Brilakis, R. DesRoches, Georgia Institute of Technology (United States)

Current procedures in post-earthquake safety and structural assessment are performed by a skilled triage team of structural engineers/certified inspectors. These procedures, in particular the physical measurement of the damage properties, are time-consuming and qualitative in nature. Spalling has been accepted as an important indicator of significant damage to structural elements during an earthquake, and thus provides a sound springboard for a model in machine vision automated assessment procedures as is proposed in this research. Thus, a novel method that automatically detects regions of spalling on reinforced concrete columns and measures their properties in image data is the specific focus of this work. According to this method, the region of spalling is first isolated by way of a local entropy-based thresholding algorithm. Following this, the properties of the spalled region are depicted by way of classification of the extent of spalling on the column. The region of spalling is sorted into one of three categories by way of a novel global entropy-based adaptive thresholding algorithm in conjunction with well-established image processing methods in template matching and morphological operations. These three categories are specified as the following: (1) No spalling; (2) Spalling of cover concrete; and (3) Spalling of the core concrete (exposing reinforcement). In addition, the extent of the spalling along the length of the column is quantified. The method was tested on a database of damaged RC column images collected after the 2010 Haiti Earthquake, and comparison of the results with manual measurements indicate the validity of the method.

8345-176, Poster Session

Effects of surface electric field on SnO2 room temperature gas sensors fabricated on nanospike substrates

H. Ren, P. Wang, H. Huo, M. Shen, M. Ruths, H. Sun, Univ. of Massachusetts Lowell (United States)

SnO2 thin film room-temperature gas sensors have been fabricated on silicon nanospike surfaces prepared by femtosecond pulsed laser irradiation. The surface morphologies of the as-fabricated silicon nanospikes and SnO2 thin film gas sensors indicate that the surface roughness increased significantly after the SnO2 layer was deposited. The surface morphology of the silicon nanospikes was studied with atomic force microscopy (AFM) and the surface electric field distribution with electric force microscopy (EFM). By comparing AFM morphology and EFM images, we observed that the aspect ratio of the nanostructures in the EFM image was larger than that in the AFM image, which indicates that the nanospikes on the silicon surface can induce an enhanced electric field around their sharp features. The electric field around the tips dramatically increases when there is current flowing through the SnO2 layer. The enhanced electric field and increased surface area on the nanospike structures are the main factors providing the high sensitivity of these room temperature gas sensors.

8345-177, Poster Session

Ultrasonic gas accumulation detection and evaluation in nuclear cooling pipes

L. Yu, B. Lin, Y. Shin, J. J. Wang, Z. Tian, Univ. of South Carolina (United States)

The presented technique is a nondestructive reflectometry technique, which is based on the radar principle. This reflectometry method will utilize a relatively low energy ultrasonic pulse in order to transmit the pulse down a waveguide, and any impedance discontinuity generates a reflection that one can detect; the impedance discontinuity can be located and characterized from the reflected signal. In this application, the pipeline filled with cooling fluid corresponds to the waveguide, and the gas accumulation causes the impedance discontinuity. Like other reflectometry techniques, the amplitude of the reflected waveform can be used to measure the discontinuity, while the time delay of the reflected wave can be used to locate it. Particularly, the phase difference between the measured reflected signal and the reference signal will be related to the quantity of impedance discontinuity, which reflects the volume of gas accumulation in the pipes. The gas accumulation detector, piezoelectric wafer sensors, will be used to generate and/or receive propagating guided wave in the pipe structures. Due to the multiple mode and dispersive natures of guided wave, the analysis of guided wave detection is complicated. We will use cross time-frequency analysis to relate the wave signatures directly with the size of gas accumulation in the fluid. Cross timefre quency analysis is capable of preserving the time- and frequency- varying phase difference while traditional time-frequency distribution cannot. Simple controlled proof-of-concept small scale tests have been conducted to evaluate the efficiency of the presented ultrasonic detection method.

8345-178, Poster Session

Miniature fiber optic temperature sensor for concrete structural health monitoring

X. Zou, A. Chao, N. Wu, Y. Tian, T. Yu, X. Wang, Univ. of Massachusetts Lowell (United States)

This paper presents a miniature fiber optic temperature sensor and its application in concrete structural health monitoring. The temperature sensor is based on Fabry-Perot (FP) principle. The endface of the fiber was wet etched. A piece of borosilicate glass was thermally deposited into the cavity on the etched endface to form an FP cavity. Temperature calibration experiments were performed. A sensor with 30 μm microcavity length was demonstrated to have a sensitivity of 0.006 nm/ and linearity coefficient of 0.99. During the early-age of concreting, the sensor was embedded in the concrete structure to monitor the temperature change caused by the exothermic chemical reaction between the cement and water. The dramatically increased temperature inside the structure was directly related to its future structural health. During the concrete hydration experiment, the measured peak temperature of concrete specimens was 59.7 12.5 hour after concrete casting.

8345-179, Poster Session

Magnetic nanoparticle enhanced actuation strategy for mixing, separation, and detection of biomolecules in a microfluidic lab-on-a-chip system

A. Munir, H. S. Zhou, Worcester Polytechnic Institute (United States)

Magnetic nanoparticle (MNP) tagged with biomolecules in a microfluidic system can be efficiently used in various applications such as mixing, pre-concentration, separation and detection. These systems can be realized for bio-defense, drug delivery, and pharmaceutical development. In this work magnetically actuated biosystems consisting of microfluidic channel and superparamagnetic nanoparticles will be designed and developed. The combination of magnetic field with microfluidics will allow simplifying the complexity of the system compared to the existing devices. Both theoretical finite element models together with proof of concept experimentation will demonstrate that biomolecules can be easily manipulated within the microchannel by tagging them with magnetic nanoparticles. Presence of MNPs together with time-dependent magnetic actuation will also help in efficiently mixing the samples, which often is limited by diffusion in microchannels. This work will also emphasize the importance of considering magnetic nanoparticles interactions for a complete design of magnetic nanoparticle-based Lab-on-a-chip system where all the laboratory unit operations can be easily integrated. The strategy demonstrated in this work will not only be easy to implement but also allows for versatile biochip design rules and provides a simple approach to integrate external elements for enhancing mixing, separation and detection of biomolecules. The vast applications of this novel concept studied in this work demonstrate its potential to be applied to other kinds of on-chip immunoassays in future. We think that the possibility of integrating magnetism with microfluidic-based bioassay on a disposable chip is a very promising and versatile approach for point-of care diagnostics especially in resource-limited settings.

8345-181, Poster Session

Experimental and theoretical characterization of non-bending ionic polymer transducer sensing

B. Kocer, U. Zangrilli, L. M. Weiland, Univ. of Pittsburgh (United States)

Ionic Polymer Transducers (IPTs) have both actuation and sensing capabilities. However, the electromechanical response of an IPT as a sensor is quite different from the actuator response. IPT sensors are not limited to bending, i.e., they also produce current for axial and shear deformations. Thus existing bending models cannot explain IPT sensing, no less provide a roadmap toward enhancing sensitivity. In this study, the objective is to experimentally define non-bending IPT sensing characteristics and compare the empirical results with predictions derived from a model based on the streaming potential hypothesis. An in-house displacement control rig will be employed to establish empirical results. A finite element approach will be employed in the companion

model development. The IPTs considered will employ Nafion as the ionic polymer layer, while the electrode will also include high surface area RuO2 metallic powder and deposited per the Direct Assembly Process.

8345-182, Poster Session

Swell-based in-situ oxide removal methods for PDMS-copper particle composite corrosion sensing elements

P. A. Huang, J. W. King, Univ. of Arkansas (United States)

Recently, a micro-corrosion sensor technology utilizing PDMS (polydimethylsiloxane) and micro/nano-metal particles, as the sensing element, was proposed and currently under-development. One of the key challenges encountered is the removal of the native oxides inherently existing on the metal particles. Numerous techniques were experimented to counter this problem, with swell-based protocols being identified as the most promising solution. Swelling of the composite allows the enhanced diffusion of oxide etchants into and etched oxide out of the material matrix. Two different swell-based methods, utilizing liquid-based liquid solvents and supercritical CO2 emersions, will be presented here. In terms of compatibility, common microfabrication solvents were used to evaluate the former, while supercritical CO2 is often used in the release of stiction sensitive microstructures. Both methods are classified as low temperature techniques (less than 100 degrees Celcius). Also in both cases, the oxide etching performance is dependent on the amount of dilation of the material and the mixing compatibility between the swelling agent and the etchant (such as acetic acid and hexafluoroacetylacetone, respectively for copper oxides). Commonly, the composite exhibits a swelling ratio of 10-20%, exhibiting more sensitive to the percentage content of the metal particles albeit well below those reported in literature for pure cross-linked PDMS. The swelling time-constant is found to be on the order of minutes while oxide removal for cubed coupons with 6.35mm on each side is on the order of hours.

8345-183, Poster Session

Computation assisted design of flow sensing pillar

J. Tao, X. Yu, Case Western Reserve Univ. (United States)

This paper describes the computation assisted design of a micro-pillar transduction element for flow sensing. The sensing component of the pillar element is a piezoelectric fiber deposited with different types of electrodes. The electric field distribution with different electrodes design is modeled from which the mode of polarization is determined. Computational simulations were conducted on the electro-mechanical coupling to determine the effects of electricity production on the vibration performance. Computational fluid dynamics simulations were also conducted to study to the influence of design array arrangement (spacing, pattern) on the original flow field.

8345-49, Session 8a

Numerical and experimental demonstration of MEMS strain sensor

H. Saboonchi, D. Ozevin, Univ. of Illinois at Chicago (United States)

Silicon has piezoresistive property that allows designing strain sensor with higher gauge factor compared to conventional metal foil gauges. The sensing element can be micro-scale using MEMS, which minimizes the effect of strain gradient on measurement at stress concentration regions such as crack tips. The challenge of MEMS based strain sensor design is to decouple the sensing element from substrate for true strain measurement and to compensate the temperature effect on the piezoresistive coefficients of silicon. In this paper, a family of MEMS strain sensors with different geometric designs is introduced. Each strain sensor is made of single crystal silicon and manufactured using deposition/ etching/oxidation steps on a n- doped silicon wafer in (100) plane. The geometries include sensing element connected to the free heads of U shape substrate, a set of two or more sensing elements in an array in order to capture strain gradients and two directional sensors. The response function and the gauge factor of the strain sensors are identified using multi-physics models that combine structural and electrical behaviors of sensors mounted on a strained structure. The relationship between surface strain and strain at microstructure is identified numerically in order to include the relationship in the response function calculation. The sensors are tested on a compact tension specimen and their behaviors are compared with conventional miniature metal foil gauges and numerical calculations.

8345-50, Session 8a

Measurement of longitudinal strain and estimation of peel stress in adhesive-bonded single-lap joint of CFRP material using embedded FBG sensor

X. Ning, H. Murayama, K. Kageyama, K. Uzawa, D. Wada, The Univ. of Tokyo (Japan)

In this research, longitudinal strain and peel stress in adhesive-bonded single-lap joint of carbon fiber reinforced plastics (CFRP) were measured and estimated by embedded fiber Bragg grating (FBG) sensors. Two unidirectional CFRP substrates were bonded by epoxy to form a single-lap configuration. The distributed strain measurement system is used. It is based on optical frequency domain reflectometry (OFDR), which can provide measurement at an arbitrary position along FBG sensors with the high spatial resolution. The longitudinal strain was measured based on Bragg grating effect and the peel stress was estimated based on birefringence effect. Special manufacturing procedure was developed to secure the FBG sensor. A portion of the FBG sensor was embedded into the adhesive layer and another portion was bonded on prepregs along the fiber direction. Photomicrograph of cross-section of specimen was taken to prove the sensor was embedded into proper position after the curing. The residual strain was monitored during curing and also bonding process. Tensile tests were carried out and longitudinal strain and peel stress of the bondline are measured and estimated along the embedded FBG sensor. Numerical simulation will also be implemented to evaluate the measurement precision. The influence of embedded FBG sensor on the strength of host material will be also evaluated by additional tests of the specimen without embedded sensor.

8345-51, Session 8a

Wireless interrogation of patch antenna for strain measurement

X. Xu, H. Huang, The Univ. of Texas at Arlington (United States)

This paper presents a new wireless interrogation technique for the strain measurement using the patch antenna. The structure under monitoring forms the ground plane of the antenna sensor array. Strain experienced by the patch antenna sensor causes the resonant frequency of the antenna sensor to shift. Therefore, by monitoring the resonant frequency of the antenna sensor, the strain can be measured. The antenna sensor can be interrogated wirelessly based on the principle of antenna backscattering. In this paper, we present a wireless antenna interrogation scheme that has a much higher resolution, which enables us to detect small frequency changes.

The application of the patch antenna for strain measurement was evaluated by bonding the patch antenna to an aluminum cantilever beam and applying loads at the free end of the beam. The resonant frequency was measured at different loads. The patch antenna can be wireless interrogated using a mono-static radar system and a single impedance-

switching circuit that modulates the backscattered signal. Detailed experiment setup, data processing algorithm and measurement results will be presented.

8345-52, Session 8b

Self-healing sandwich composite structures

D. Fugon, C. Chen, K. J. Peters, North Carolina State Univ. (United States)

We present recent advances in the development of self-healing sandwich composite structures. Achieving self-healing in these laminated material systems represents a different challenge than that typically addressed in self-healing materials due to the large-scale region that must be repaired. We specifically address the self-repair of sandwich composites after a low-velocity impact occurs on one of the facesheets. The resulting damage is in the form of penetration of the facesheet, debonding of the facesheet from the foam core and significant crushing of the foam core. These three damage mechanisms result in a large volume that must be filled with a resin-hardener system to reconnect the facesheet and foam core for the transmission of loads. We present a vascular delivery system for the resin and hardener components that is fabricated at the core-facesheet interface. The channel size is optimized based on the post-impact resin-hardener delivery and mixing conditions. Self-healing is achieved without the need for external stimuli such as heat. The successful repair of a significant portion of the strength of the laminates (scaled by the laminate weight) are demonstrated through four-point bending and edgewise compression testing.

A modified vascular delivery system is then demonstrated that is integrated directly into the facesheet material (during fabrication) and therefore reduces the weight penalty of introducing the vascular network. For this modified system, optical fiber sensors are introduced into the same layer to identify the key benchmarks in the photopolymerization process of the self-healing resin-hardener system. For the previous system the predicted self-healing efficiency could be estimated for a particular geometry based on the statistical output of the four-point bending and edgewise compression testing. This predicted efficiency is also dependent upon the expected impact loading, which may not be known with great certainty. By including the optical sensors into the self-healing system a much better estimate of the self-healing efficiency is obtained for a specific laminate.

8345-53, Session 8b

A bio-inspired acoustic source locator

J. Tao, X. Yu, J. Berrilla, Case Western Reserve Univ. (United States)

Accurately locating acoustic source is important for wildlife for the purpose of locating prey, predators and engaging in social behaviors. Directional sensitivity in ears can be achieved by sensing the interaural amplitude, time differences and spectral composition of the signals. This paper describes a unique sensing strategy for acoustic source that is inspired from aquatics. The sensing mechanism is a based on densely spaced sensor pillar array features directional sensitivity. By directional coding of these pillars the source of the acoustic signal can be accurately estimated. Acoustic locator based on this principle can be fabricated to be very small, which is a major advantage that enables various potential applications.

8345-54, Session 8b

Fly-ear inspired directional acoustic sensors

H. Liu, M. Yu, Univ. of Maryland, College Park (United States)

Animal hearing organs are governed by a fundamental size constraint; the smaller the organ size, the smaller the available directional cues for directional hearing. However, with an auditory organ separation of only 520 μm, it is remarkable that the parasitic fly Ormia ochracea can achieve a human-like localization precision. The key to this fly's phenomenal directional hearing ability is believed to be due to the mechanical coupling between its two eardrums, which amplifies the minute directional cues in the acoustic stimulus to a level the fly can easily resolve. In this article, a simplified mechanics model is used to further show that the fly ear possesses a unique dual-optimality characteristic, namely, it has maximum directional sensitivity and minimum nonlinearity at its working frequency. Inspired by the fly ear, a directional acoustic sensor consisting of two circular clamped diaphragms and a coupling bridge is proposed and micro-fabricated. The sensor's frequency response and directional cues for various frequencies and incident angles will be shown along with the simulation results. This work provides a framework for the development of fly-ear inspired directional microphones that can be useful in many areas.

8345-55, Session 9a

Probabilistic characterization of wind turbine demand envelopes for operational structural integrity assessment

A. Velazquez Hernandez, R. A. Swartz, Michigan Technological Univ. (United States)

Wind energy is an increasingly important component of this nation's renewable energy portfolio, however safe and economical wind turbine operation is a critical need to ensure continued adoption. Safe operation of wind turbine structures requires not only information regarding their condition, but their operational environment. Given the difficulty inherent in structural health monitoring (SHM) processes for wind turbines (damage detection, location, and characterization) some uncertainty in conditional assessment is expected. Furthermore, given the stochastic nature of the loading on turbine structures, a probabilistic framework is appropriate to characterize their risk of failure at a given time. Such information will be invaluable to turbine controllers, allowing them to operate the structures within acceptable risk profiles. This study explores characterization of the turbine loading and response envelopes for critical failure modes of the turbine blade structures. A framework is presented to develop an analytical estimation of the loading environment (including loading effects) based on the dynamic behavior of the blades influenced by behaviors including along and across-wind aero-elastic effects, wind shear gradient, tower shadow effects, and centrifugal stiffening effects. The proposed methods are based on modal decomposition of the blades and require frequent updates to the estimated modal properties to account for the time-varying nature of the turbine and its environment. The estimated demand statistics are compared to a code-based resistance curve to determine a probabilistic estimate of the risk of blade failure given the loading environment.

8345-56, Session 9a

Localization and quantitative depth estimation of defects in wind turbine blades using infrared thermography

A. Manohar, J. D. Tippmann, F. Lanza di Scalea, Univ. of California, San Diego (United States)

Localization and quantitative estimation of the defect depth are critical problems in Nondestructive Evaluation of wind turbine blades using Infrared Thermography. Infrared Thermography is an attractive technique in inspecting wind turbine blades because of its wide-area inspection capabilities. Wind turbine blades are mainly built using composites and they are very susceptible to damages like delaminations and skin-core disbonds that occur due to stresses caused by wind loads. In most cases, the damage is not visible to the naked eye and hence Nondestructive Evaluation plays an important role in early identification of defects to prevent catastrophic losses. In this study Multivariate Outlier

Analysis is used for localizing the defects and a 3D heat conduction model is developed and employed to quantify the defect depth. Proof-of-concept results are established on a stainless steel sample with six flat bottom holes at different depths and other relevant results are presented on a 9m CX-100 wind turbine blade. The blade was designed at the Sandia National Laboratory and known defects were incorporated during the manufacturing phase. The experimental results that are obtained and the theoretical model validate the proposed research study.

8345-57, Session 9a

Deflection calculation of a composite wind turbine blade using finite difference method from measured strain

I. Kwon, K. Choi, Y. Huh, D. Yoon, Korea Research Institute of Standards and Science (Korea, Republic of)

The tip deflections of wind turbine blades should be monitored in real time to prevent catastrophic failures of wind turbine power plants caused by blade tower hitting. In this presentation, a prediction method of wind turbine blade tip deflection was proposed using a finite difference method based on arbitrary beam bending and moment theory using measured strains. The blade strains were measured using fiber optic Bragg grating sensors. In order to confirm this method, a 100 kW composite wind turbine blade was manufactured with epoxy molded fiber optic Bragg grating (FBG) sensors installed in the shear web of the blade: a number of these sensors, the normal FBG probes, were fabricated to only measure strains and the other sensors, the temperature compensated FBG probes, were prepared to also measure strain and temperature. Because the output signals of FBG sensors are dependent on strains as well as temperatures, the sensor output signals should be compensated by temperatures to obtain the accurate strains. These FBG sensors were attached on the lower and upper parts of the web at one meter intervals throughout the entire length of the blade. To evaluate the measurement accuracy of the FBG sensors, conventional electrical strain gauges were also bonded onto the surface of the web beside each FBG sensor. By performing the static load test of the blade, the tip deflection of the blade was well predicted within the averaged error of 2.25%.

8345-58, Session 9a

Wind turbine inspection tests at UCSD

J. D. Tippmann, A. Manohar, F. Lanza di Scalea, Univ. of California, San Diego (United States)

The wind industry is rapidly growing to help meet the increasing world energy demands as well as the need for clean and renewable energy sources. With the goal to explore new technologies and innovations which could help potentially improve the efficiency and effectiveness of wind energy, the NDE/SHM laboratory at UCSD acquired a unique wind turbine blade that will be used for performing several research projects related to wind turbine blade technology and non-destructive inspection techniques. The blade was built using the CX-100 design developed by TPI Composites, Inc. and Sandia National Laboratory (SNL). The 9-m blade was constructed with several embedded defects that represent the most common manufacturing defects typically found, such as out-of-plane waviness, composite delamination, and adhesive disbond. The defects were embedded during the manufacturing process by using similar methods developed by both TPI and SNL for simulating actual defect characteristics. Though the blade is small in comparison to the average utility sized blade of 40 meters, the blade features similar materials and manufacturing methods, allowing for several inspections techniques to be studied on a representative platform. The inspection techniques include advanced infrared thermography and other guided wave techniques. The blade is also being used for studying the structural dynamic behavior as part of an effort to study the potential for vibration suppression in the blade using composite piezoelectric transducers.

8345-59, Session 9b

* Ultra-fast nano-oscillators based on carbon nanoscrolls for nano-scale energy harvesting and storage

Z. Zhang, T. Li, Univ. of Maryland, College Park (United States)

Significant research progress on graphene in past several years has enabled the exploration of carbon nanoscrolls (CNSs), a one-dimensional carbon nanomaterial that is distinct from carbon nanotubes (CNTs). A CNS is formed by rolling up a monolayer graphene into a spiral multilayer nanostructure, whose core size is highly tunable by relative sliding between adjacent layers. In other words, a CNS is topologically open, fundamentally distinct from a tubular CNT, which is topologically closed (e.g., whose core size can only be changed slightly by stretching the carbon-carbon (C-C) bonds). The open and highly tunable structure of CNSs, combining with the exceptional mechanical and electronic properties inherited from the basal graphene, has inspired an array of novel nano-device applications, such as hydrogen storage medium, water and ion channels, radially breathing nano-oscillators and translational nano-actuators.

In this paper, we demonstrate ultrafast CNS-based axial nano-oscillators that operate at frequencies from 10s GHz to more than 100 GHz, using molecular dynamic (MD) simulations. Initiated by a single-walled carbon nanotube (CNT), a monolayer graphene can continuously scroll into a CNS with the CNT housed inside. The CNT inside the CNS can oscillate along axial direction at a natural frequency of 10s gigahertz (GHz). The unique topological structure of the CNS-based nano-oscillator offers a viable pathway to fabricating ultrafast axial nano-oscillators, addressing a significant challenge that still remains for the previously proposed MWCNT-based axial nano-oscillator.

We further propose an effective strategy to reduce the dissipation of the CNS-based nano-oscillator by covalently bridging the carbon layers in the CNS. Our results show that the interlayer bridging bonds in the CNS can effectively suppress the self-oscillation of the CNS, leading to a significant improvement in the sustainability of the CNS-based nano-oscillators. We further demonstrate that, such a CNS-based nano-oscillator can be excited and driven by an external AC electric field, and oscillate at more than 100 GHz, which exemplifies the promising potential to leverage CNS-based nano-oscillators for energy transduction, harnessing and storage (e.g., from electric to mechanical) at nano-scale.

8345-60, Session 9b

Smart photonic coating as a new visualization technique of strain deformation of metal plates

H. Fudouzi, T. Sawada, National Institute for Materials Science (Japan); Y. Tanaka, I. Ario, Hiroshima Univ. (Japan); T. Hyakutake, I. Nishizaki, Public Works Research Institute (Japan)

The authors proposed a new rubber material with reversible tunable color by elastic deformation “Photonic rubber sheet” (Langmuir, 22, 1365, 2006). This tunable photonic crystal material have a potential applications for strain imaging. Thus we also demonstrated structural color change caused by strain of plastic deformation (Adv. Powder Technol. 20, 502, 2009) as follow. The polyvinyl chroride (PVC) sheet was covered with a thin layer of arrayed colloidal particles indicating structural color with tunability by elongation of the sheet. The arrayed colloidal particles were fabricated by self-assembly over 100 cm^2 area. The colloidal particles array with cubic close packed, ccp, was in filled with poly (dimethylsiloxane), PDMS, elastomer. The ccp (111) planes of colloidal crystal film diffracts light of selective wavelengths; structural color. The principle of the new method based on the change of structural color of the plastic sheets. As the sheet was stretched by mechanical stress at 100 degree C in the horizontal direction, it reduced in size in the vertical direction. In consequence, the distance of ccp (111) planes decreased and the reflected wavelength of light shifted to shorter wavelengths. In

this conference, we will present a new method to visualize local strain distribution in deformed aluminium sheets. Furthermore, we will also demonstrate a new mechanism strain gauge by measuring Bragg's diffraction peak. This novel colloidal crystal film has a potential to be applied for engineering field such as "Photomechanics technology".

8345-61, Session 9b

Wireless sensor array based on DNA decorated single-walled carbon nanotubes for gas monitoring

Y. Liu, Y. Zhang, M. R. Dokmeci, M. Wang, Northeastern Univ. (United States)

There is growing interest in making sensors, optoelectronic and electronic devices with nanomaterials. Carbon nanotubes (CNTs) are unique materials due to their excellent electrical, mechanical and thermal properties, and also have good chemical stability. Single-walled carbon nanotubes (SWNTs) are formed by one atomic layer and have an extended π-bonding configuration. The conductivity of SWNTs is susceptible to trace amount of molecules or ions attached on to their surfaces. CNTs have exceptionally high sensitivity and fast response and were utilized in numerous chemical and biological sensing applications for environmental monitoring. One of the present problems with SWNT sensors is their nonselective response to many analytes. In order to reduce the undesirable response of SWNTs to interference analytes, a wireless sensor array with six channels were developed to measure the resistances of six SWNT sensors simultaneously during exposure to gases. Ultrathin films of SWNTs were assembled onto the microelectrodes by a low temperature, low cost Dielectrophoretic (DEP) assembly process. ssDNA of different sequences were used to functionalize the nanotubes and improved their response to the gas vapors dramatically. The responses of DNA decorated SWNTs and bare SWNTs to toxic organics were measured simultaneously. The development of this wireless sensor array enables real time gas monitoring with various functionalized SWNTs from a distance.

8345-62, Session 9b

* Strain gradient monitoring using a Ba0.67Sr0.33TiO3 flexoelectric sensor

W. Huang, F. Yuan, X. Jiang, North Carolina State Univ. (United States)

Developing sensors for in-situ monitoring of the onset and growth of cracks in the early stage, is of growing interest and important for structural health monitoring (SHM). The strain gradient sensor (SGS) based on flexoelectric effect offers a unique approach for monitoring near the severe strain gradient fastener areas. In this paper, a Ba0.67Sr0.33TiO3 (BST) flexoelectric sensor is studied, for the first time, for strain gradient monitoring. Specifically, a BST SGS is designed by considering the measured properties, prototyped and laminated into a circular hole to monitor the strain gradient generated under different load conditions. The measured transverse flexoelectric coefficient μ12 of BST is about 8.5 μC/m for BST cantilevers with thickness of 30 μm. Initial FEM analysis of a plate with a hole was conducted and the results agreed with the analytical prediction which suggests a sinusoidal distribution of strain gradient. The calculated strain gradient increases sharply at the vicinity of hole as it is inversely proportional to the cube of the radical distance between the interested point to the center of hole. This finding guides BST SGS design for practical engineering applications. Flexoelectric SGS prototyping and tests are planned, and more results will be presented in the full paper. The strain gradient sensing technology reported in this paper can be applied in a broad range of structural health monitoring.

8345-63, Session 10a

Manufacturing of flexible strain sensors using conductive polymeric materials and direct writing technology for monitoring of structures

J. Choi, M. Vatani, K. Lee, G. Yun, The Univ. of Akron (United States)

In this paper, a new flexible strain sensor is manufactured with conductive polymeric materials in the form of printed circuits and demonstrated for applications in structural health monitoring. Flexible sensors with high durability are advantageous to long-term monitoring of civil infrastructure with complex geometries. Low-cost sensors will not only allow dense deployment of sensing nodes to large-scale structures but also enable intelligent inspection of structural health in combinations with smart sensing technology. To manufacture flexible strain sensors, direct writing of conductive polymeric materials on a flexible substrate is used. Direct writing is a promising technology to directly create patterns on a substrate using various materials. In this work, micro-dispensing system with the resolution of 100 μm is developed, and several conductive polymers and nanoparticles are used. In the proposed sensor, strains of host materials under mechanical loadings are measured through change of conductivity (resistance) of the patched sensors with printed bridge circuits. In order to demonstrate viable performance of the proposed sensor, static and dynamic tests of a beam structure are conducted. Potentials of the proposed new sensor are well demonstrated in this paper.

8345-64, Session 10a

Magnetic flux leakage based steel cable NDE operated on a cable climbing robot

S. Park, J. Kim, C. Lee, Sungkyunkwan Univ. (Korea, Republic of); J. Lee, Sejong Univ. (Korea, Republic of); S. Park, KPM (Korea, Republic of)

The steel cables in long span bridges such as cable stayed bridges and suspension bridges are critical members which suspend dead load due to the main girders and bridge floor slabs. Damage at cable members can occur in the form of cross-sectional loss caused by corrosion, wear and fracture, and it can lead to structural failure due to concentrated stress of the cable. Therefore, the MFL (Magnetic Flux Leakage) inspection system -based online nondestructive evaluation (NDE) for steel cables is proposed in this study so that the cross-sectional loss of the cables can be detected easily. Furthermore, a wheel-based cable climbing robotic system which can climb up and down the cylindrical cables is incorporated for application of the proposed NDE system to even inaccessible locations. While the robot moves along the cable, the proposed NDE system measures the magnetic flux density to detect the cross-sectional loss of the steel cable. To verify the feasibility of the proposed approach, a steel cable bunch specimen which has several types of damages were fabricated, and it was scanned by the climbing robotic inspection system. To interpret the condition of the wire rope, LMA (Loss of Metallic Cross Section Area) and LF (Local Fault) signals were used to evaluate the location of the flaws, the level of damage. Finally, the results were compared with the information of actual inflicted damages to confirm the accuracy and effectiveness of the proposed cable monitoring system.

8345-65, Session 10a

Structural behavior of concrete box bridge using embedded FBG sensors

W. Chung, Kyung Hee Univ. (Korea, Republic of); D. Kang, Korea Railroad Research Institute (Korea, Republic of)

This study investigates the application of fiber Bragg grating (FBG)-based sensing systems to precast concrete box bridges. A full-scale precast concrete box girder was fabricated and tested in order to identify its dynamic and static performance. Multiplexed FBG strain sensors were embedded along the length of steel rebar and a strain-induced wavelength shift was measured. The experimental program involved the measurement of the nonlinear static behavior until failure. The measured values from the FBG-based sensors are compared with the results using electric signal-based sensors. The results show that the FBG sensing system is promising and can improve the efficiency of structural monitoring for bridges.

8345-66, Session 10a

Hybrid structural health monitoring using wireless multi-scale sensors

S. Jang, S. Dahal, G. K. Contreras, J. Fitch, J. Karamavros, R. Bansal, Univ. of Connecticut (United States)

With the rapid development of electrical circuits, wireless smart sensor networks have shown significant potential for replacing existing wired SHM systems due to their cost effectiveness and versatility. In this project, a new high-accuracy displacement sensor system has been developed combining a high resolution analog displacement sensor and wireless microprocessor platform. The wireless sensor is calibrated in the laboratory to get the high precision displacement data from analog sensor. The developed multi-scale sensing system is evaluated in a laboratory bridge structure to check its performance. Finally, the developed wireless multiscale sensing system will be deployed on in-service highway bridge for SHM.

8345-67, Session 10a

Application of three dimensional electromechanical impedance model for damage assessment of plate

V. G. M. Annamdas, Birla Institute of Technology and Science, Pilani (India) and Nanyang Technological Univ. (Singapore); Y. Yang, Nanyang Technological Univ. (Singapore); S. Park, Sungkyunkwan Univ. (Korea, Republic of)

Cost-effective and reliable damage detection models are crucial for successful monitoring of any ancient or modern age engineering structure. Lead Zirconate Titanate (PZT) based electromechanical impedance (EMI) method is emerging as a promising alternate for conventional structural health monitoring (SHM) of various engineering structures. The PZT patches are usually surface bonded and then excited in the presence of electric field to a desired frequency spectrum. The excitations result in prediction of unique frequency dependent electromechanical (EM) admittance signature. Any change in the signature during the monitoring period indicates dis-integrity/ damage in the host structure. However, apart from locating damages, the increase in severity of damages has to be predicted on time to avoid collapse of the entire structure. This paper presents such a model which had effectively predicted the severity of damages along two principle directions of the structure. This was achieved by experimental damage study on plates and subsequent verification by semi numerical 3D model. Statistical root mean square deviation (RMSD) index was used for evaluating the damages made on plates. Additionally, a new frequency proximity index (FPI) was introduced to measure the effectiveness of the model. RMSD measures the changes in height of peaks of signature and FPI scales the frequency spectrum of signature. Thus results of RMSD index and FPI are used as complementary to each other to study damage propagation in a structure.

8345-68, Session 10b

Robust vision-based crack thickness quantification for condition assessment of structures

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Visual inspection of structures is a highly qualitative method. If a region is inaccessible, binoculars must be used to detect and characterize defects. Although several non-destructive evaluation methods have been proposed for inspection purposes, they are nonadaptive and cannot quantify crack thickness reliably. A contact-less remote-sensing crack detection and quantification methodology based on 3D scene reconstruction (computer vision), image processing, and pattern recognition concepts is introduced. The proposed approach utilizes depth perception to detect cracks and quantify their thickness, thereby giving a robotic inspection system the ability to analyze images captured from any distance and using any focal length or resolution. This unique adaptive feature is especially useful for incorporating mobile systems, such as unmanned aerial vehicles (UAV), into structural inspection methods since it would allow inaccessible regions to be properly inspected for cracks. Guidelines are presented for optimizing the acquisition and processing of images, thereby enhancing the quality and reliability of the damage detection approach and allowing the capture of even the slightest cracks which are routinely encountered in realistic field applications where the camera-object distance and image contrast are not controllable.

8345-69, Session 10b

An interferometric radar for displacement measurement and its application in civil engineering structures

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Measuring static and dynamic displacement of in-service civil engineering structures is an important issue for the purpose of design validation, performance monitoring, or safety assessment. In most applications, especially for large-scale structures, it is not feasible to provide a stationary platform at the location where its displacements need to be measured. Furthermore, when displacements at a large number of locations are desired, measuring them using the conventional method can be prohibitively expensive, if not impossible.

Recent progress in radar techniques and systems has led to the development of a microwave interferometer, potentially suitable for non-contact displacement monitoring of civil engineering structures. This paper describes a new interferometric radar system, named IBIS-S, which is possible to measure the static or dynamic displacement at multiple points of structures simultaneously with high accuracy.

In this paper, the technical characteristics and specification of the radar system is described. Subsequently, the actual displacement sensitivity of the equipment is illustrated using two laboratory tests including harmonic motion and random motion upon a shake table. Finally the application of the radar system to the measurement of ambient vibration response on a cable-stayed bridge is presented and discussed. Results show that the new system is an accurate and effective method to measure displacements of multiple targets of structures. It should be noted that the current system can only measure the vibration of the target position along the sensor's line of sight. Hence, proper caution should be taken when designing the sensor posture and prior knowledge of the direction of motion is necessary.

8345-70, Session 10b

Partially stripped fiber optic sensor packages applied to large infrastructures

K. S. Kim, Hongik Univ. (Korea, Republic of)

For monitoring of large infrastructures, optical fiber sensors are very convenient. The fiber sensor packages are very small and do not disturb the structural properties. They also have several merits such as electro-magnetic immunity, long signal transmission, good accuracy and multiplicity of one sensor line. Strain measurement technologies with fiber optic sensors have been investigated as a part of smart structure. In this paper, we investigated the partially stripped fiber optic sensor package application to the monitoring of large infrastructures. In order to make good and durable package, minimum attachment using fixture, fixation of partially stripped sensor fiber with epoxy to prevent slip are applied. Prestrain using movable nuts also applied to the sensor packages. To reduce the polarization which causes peak split of FBG, prevention from shear strains by separation and protection for sensor part from base materials applied. The fiber optic sensor packages showed good durability and long term stability for continuous monitoring of the infrastructures as well as good response to the structural behaviors during construction.

8345-71, Session 10b

Ultra low-power corrosion-enabled sensor node

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Sensing systems play a lead role in the structural health monitoring (SHM) paradigm by performing actuation, data acquisition, and communication in order to enable the implementation of a health monitoring strategy. In many applications power provision is limited by the use of a battery as their power capacity often fails to exceed the intended long-term sensing requirements of the host structure. Energy harvesting has emerged as a potential powering solution to provide autonomous functionality to sensing systems.

Galvanic corrosion as a form of energy harvesting has proved to be a viable source for operating simple low-power sensing and computing platforms for marine structures. The power characteristics of the energy harvester define a unique design problem for the sensor node power electronics, as the output voltage and current are extremely limited. This initiative considers the design of a sensor node that makes use of high-efficiency switching converters and low-power microprocessors to reduce the power demands on the energy harvester. In addition, the power electronics features a low duty-cycle control circuit to isolate the energy harvester from the sensing electronics for more efficient operation. A sensing proof of concept is conducted by means of temperature measurement.

8345-72, Session 10b

Piezoelectric impedance based strength and elastic modulus gain monitoring in concrete

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This paper presented an experimental study on piezoelectric impedance based cubic compressive strength, axial compressive strength and elastic modulus gain monitoring for concrete during curing process. The low cost piezoceramic (PZT) patch was attached at the concrete specimen. The electro-mechanical impedance (EMI) spectra of surface bonded PZT patch were then collected using an impedance analyzer by sweeping the frequency. The statistical index RMSD is then adopted to quantify the variation of EMI spectra during the curing process of concrete. In this paper, three sets of experimental tests are performed on the concrete with PZT patches. Then, finite element analysis is carried out to verify the validity of the experimental results. The experimental and numerical results demonstrate the EMI technique is a practical and reliable nondestructive test method for monitoring the strength and elastic modulus during the process of concrete.

8345-73, Session 11a

Application of higher order SVD to vibration-based system identification and damage detection

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Singular value decomposition (SVD) is a powerful linear algebra tool. The application of SVD includes computing the pseudoinverse, matrix approximation, and determining the rank, range and null subspace of a matrix. It is widely used in many different signal processing methods, such principal component analysis (PCA), singular spectrum analysis (SSA), frequency domain decomposition (FDD), subspace identification and stochastic subspace identification method (SI and SSI). In each case, the data is arranged appropriately in matrix form and SVD is used to extract the feature of the data set. However, an increasing number of signal processing problems involve more than two indices, such as time, time delay, 3-Direction measurement and spatial information. It is more appropriate to describe the data set in the tensor form. Therefore, development of multi-linear singular value decomposition technique is necessary to decompose the data set and extract the data feature. Recently, higher order singular value decomposition (HOSVD) was developed to this purpose. It can decompose the data tensor with any orders to several orthogonal bases uniquely. In this study, discussion on the application of higher order singular value decomposition to process the vibration signal measured from sensor network. 3 modes data arrays are arranged and higher order singular value decomposition is used to process the data set. The spectral and spatial information can be derived simultaneously from this approach. The proposed algorithm is used to process the shaking table test data of the 6-story steel frame as well as the earthquake-induce ground motion of strong motion array. Features contained in the vibration data are extracted by the proposed method. Damage detection can also be investigated from the test data of the frame structure through using HOSVD.

8345-74, Session 11a

Vision-based 6-DOF displacement measurement of structures with a planar marker

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The estimation of translational and rotational displacement of large structures is usually considered as major indicators for structural safety. Recently, several vision-based measurement methods have been developed. Most vision-based systems, however, estimate displacements in 1-D or 2-D space. There are 6-DOF measurement methods using combination of lasers and cameras. But, the system is complex to install and not easy to maintain. To mitigate this problem, this paper proposes a simple 6-DOF displacement measurement system using only one camera and a planar marker. Using the square shaped planar marker, whose world geometry is known a priori, the 6-DOF relation between the marker and the camera can be calculated. The camera that has telescopic lens captures a marker image and detects corners of the marker. Using homography transformation, 6-DOF relative pose information to the structure is estimated. In order to verify the feasibility of the proposed system, various simulations and experimental tests are performed. The system for experiments consists of a CCD camera with a built-in 37x zoom lens and Atom CPU embedded board for maker image processing. The square marker is installed about 20 meters distance away from the camera, and the displacement estimation is compared with the ground truth. The results show the applicability of the proposed 6-D measurement system to real structures.

8345-75, Session 11a

Numerical modeling of guided waves in pipe-like structures

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Ultrasonic guided waves have been utilized for accurate diagnosis of structural integrities for thin structural components. In this research, wave propagation excited by surface-mounted instruments such as PZT and MFC transducer rings in an infinite isotropic hollow cylinder is investigated. A mathematical model of the wave propagation system is studied both analytically and numerically. Detail derivation of the characteristic equation of the system is conducted, and the development of waves is simulated by the Finite element method (FEM). Compared with the analytical results, the accuracy of the numerical modeling is verified.

8345-76, Session 11a

ViSP (visually servoed paired structured light system) for measuring structural displacement

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To inspect structural conditions, structural displacement is needed to be estimated at any time. Therefore, conventional sensors such as accelerometers, GPS, and LDV (Laser Doppler Vibrometer) have been widely used. However, aforementioned sensors have one of drawbacks that it indirectly measure the displacement, difficult to install or maintain, highly sensitive to environmental changes, or require high cost. Therefore, our previous study proposed a vision-based approach which is composed of a paired structured light (SL) system. The proposed system composed of two sides facing each other, each with a camera, a screen, and one or two lasers controlled by a 2-DOF manipulator. In this system, the relative translational and rotational displacement each in three axes between two sides can be estimated from positions of the laser beams projected on the screens and the rotation angles of the manipulators. To validate the performance of the system, the various experimental tests in a real structure were performed. The estimated results were compared to the results from another type of vision-based monitoring system and it show that the presented system has potential of estimating the response of the real civil structures.

8345-77, Session 11a

Computer vision based structural health monitoring of civil infrastructure systems: review and example applications

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Computer vision and image processing based techniques have found many applications in several areas such as surveillance, remote sensing and medical imaging. Yet, implementations of these technologies to Structural Health Monitoring (SHM) of Civil Infrastructure Systems (CIS) are still very limited and need further investigation. Such applications may include, but are not limited to, vision based fault and damage detection, correlation of traffic data with structural response and non-contact measurements. Several image processing and pattern recognition techniques should be integrated for successful applications. In this paper, a review of different approaches for vision based SHM of CIS is presented. Theoretical discussions are followed by different real life examples where strengths and limitations of different methods are presented in a comparative fashion.

8345-78, Session 11b

Deep drilling and sampling via the wireline auto-gopher driven by piezoelectric percussive actuator and EM rotary motors

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The ability to penetrate and perform sample acquisition at depth of meters is critical for the NASA in-situ exploration missions to bodies in the solar system, including missions to Mars and Europa. To address this need a rotary-hammering drilling and coring device, called Auto-Gopher, is being developed that employs a piezoelectric actuated percussive mechanism for breaking formations whereas an electric motor generates rotation that removes the cuttings. The penetration rate is optimized by simultaneously activating the percussive and rotary motions of the Auto-Gopher. The percussive mechanism is based on the Ultrasonic/Sonic Drill/Corer (USDC) mechanism that driven by piezoelectric stack that was demonstrated to require low axial preload. This sampler is a wireline mechanism that is incorporated with an inchworm mechanism that allows thru cyclic coring and core removal to reach great depths in subsurfaces. The developed corer/sampler is intended to establish the capability to penetrate the subsurface of Mars beyond the oxidized and sterilized zone and acquire pristine samples. The Auto-Gopher represents a lesson learned from the development of the Ultrasonic/Sonic Gopher drill that is percussive only and was demonstrated in Antarctica in 2005 to penetrated about 2 meters deep ice. A field demonstration of the Auto-Gopher is planned to reach as deep as 3 to 5 meters in gypsum subsurface.

8345-79, Session 11b

Single piezo-actuator rotary-hammering (SPaRH) drill

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The search for present or past life in the Universe is one of the most important objectives of NASA's exploration missions. Drills as subsurface sampler of rocks, ice and permafrost is an essential tool for astrobiology studies on other planets. Increasingly, it is recognized that drilling via a combination of rotation and hammering offers an efficient and effective rapid penetration mechanism with the capability to use the rotation as an intrinsic method for removal of cuttings from the borehole while benefiting from the impact and shear forces for fracturing the penetrated medium. The conventional drills that use a single actuator are based on a complex mechanism with many parts and their use in future mission involve greater risk of failure and may require lubrication that can introduce contamination. In this paper, a compact drill is developed that uses a single piezoelectric actuator to produce hammering and rotation of the bit. A horn with asymmetric groves was design to impart a longitudinal (hammering) and transverse force (rotation) to a keyed free mass. The drill requires low axial pre-load since the hammering impacts fractures the rock under the bit kerf and rotates the bit to remove the powdered cuttings while augmenting the rock fracture via shear forces. The vibrations 'fluidize' the powdered cuttings inside the flutes around the bit reducing the friction with the auger surface. This action reduces the consumed power and the heating of the drilled medium helping to preserve the pristine content of the produced samples. The drill consists of an actuator that simultaneously impacts and rotates the bit by applying force and torque via a single piezoelectric stack actuator without the need for a gearbox or lever mechanism. This reduces the development/fabrication cost and complexity. The drill mechanism will be described and the test results will be reported and discussed.

8345-80, Session 11b

Miniaturization of planar horn motors

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There is a great need for compact, efficient motors for driving various mechanisms including robots or mobility platforms. A study is currently underway to develop a new type of piezoelectric actuators with significantly more strength, lightness, capabilities, and efficiency. The actuators/motors utilize piezoelectric actuated horns which have a very high power density and high electromechanical conversion efficiency. The horns are fabricated using our recently developed novel pre-stress flexures that make them thermally stable and increases their coupling efficiency. Its monolithic design that pre-stresses the piezoelectric stack eliminates the use of stress bolt. This design allows embedding our solid-state motors and actuators in any structure and the only macroscopically moving parts are the rotor or the linear translator. The developed actuator uses a stack/horn actuation and has a Barth motor configuration, which potentially generates very large torque and speeds that do not require gearing. A finite element modeling and design tools were investigated to determine the requirements and operation parameters and the results were used to fabricate a motor. This new design offers a highly promising actuation mechanism that can potentially be miniaturized and integrated into systems and structures that involve actuation. It can be configured in many shapes to operate as multi-degrees of freedom and multi-dimensional motors/actuators including unidirectional, bidirectional, 2D and 3D. We will present our experimental measurements from a bench top design and our results from our efforts to miniaturize the design using 2x2x2 mm piezoelectric stacks in thin plates that are the order of 3 x 3 cm will be reported.

8345-81, Session 11b

High temperature piezoelectric drill

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Future NASA missions will require a variety of new technologies in order to enable operation at the extreme conditions that will be encountered at planned future exploration sites in the Solar System. Venus is one of the planets that are targeted for a mission in the NASA Decadal study of potential new Frontier missions and it is considered a planet with a hostile environment where the average temperature is 460oC and its ambient pressure is about 90 atm. Since the existing actuation technology cannot maintain functionality under the harsh conditions of Venus, it is a challenge to perform sampling and other tasks that require the use of moving parts. Specifically, the currently available electromagnetic actuators are limited in their ability to produce sufficiently high stroke, torque, or force. In contrast, advances in developing electro-mechanical materials (such as piezoelectric and electrostrictive) have enabled potential actuation capabilities that can be used to support such missions. In this reported study we developed a piezoelectric actuated drill that operates at the temperature range up to 500°C and the mechanism is based on the Ultrasonic/Sonic Drill/Corer (USDC) configuration. The detailed results of our study will be presented in this paper.

8345-82, Session 11b

Sensor applications for structural diagnostics and prognostics in aerospace systems

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There are emerging sensor technologies that will be deployed in future rotorcraft or retrofitted to existing rotorcraft and aircraft for structural diagnostics and prognostics. The vehicle health management system is likely to contain heterogeneous sensor arrays. The structural state awareness may be diagnosed and given a prognosis based on information data available from a dissimilar sensor (heterogeneous) system. This paper reviews the state-of-the-art commercial off the shelf (COTS) and emerging sensor technologies for monitoring the structural health of aircraft and rotorcraft components. This paper presents results from different sensor systems and combinations thereof, tested on simulated airframe joints and the respective sensor signals, and then correlated with crack detection and propagation. The information fusion system used to extract information from the heterogeneous sensor arrays is also presented.

Sensor Review

For successful implementation of an onboard structural integrity monitoring system, real time damage detection is important for damage tolerance implementation. While this effort focuses on fatigue damages in airframe joints, the proposed system architecture can be implemented for damage monitoring of rotor and other airframe components. The diagnostic methods using the sensor signals should reliably detect the size and types of damage for rotorcraft components, down to 0.015-0.040” crack depth or less in metallic dynamic PSE (principal structural elements). The minimal requirements for detection are higher for airframe structures because of the built-in redundancy in the structure. For example, in some of the areas, such as in the Main Gear Box attachments or the tail pylon bushing and bolted joints, it is necessary to provide local damage detection coverage, while in the bulkhead skin region, frame station global sensor deployment strategies are needed for wider structural coverage. This paper reviews different types of COTS and emerging damage monitoring sensor technologies that can be used in the global and local damage detection modes. The sensor review is not intended to be an exhaustive list but provided only as a reference. This work reviews different types of physical sensing elements, which are (1) magnetostrictive sensors (2) piezoelectric sensors (both piezo wafer and active fiber composite sensors) (3) Fiber optic Bragg grating sensors (4) Meandering Winding Magnetometer (MWM) eddy current sensors (5) Comparative Vacuum Monitoring Sensors (6) Alternating Current Potential Drop and (7) Carbon Nanotube Sensors, and (8) graphene-based sensors.

Sensor Array Technologies

In order to increase the robustness of the diagnostics and prognostics capability of the deployed structural integrity monitoring architecture, optimal number, type and placement of observers is important. The sensor architecture needs to combine at least two types of sensing elements. In this case, the strategy is to be able to monitor the component using a combination of global damage sensor network and local crack monitoring system. Global Damage Monitoring Sensor (GDMS) networks are defined by detection and localization of damage with strategically deployed transducers network. Local Crack Monitoring Sensor networks (LCMS) are placed in close proximity to known crack/damage hotspot locations and are used for quantification of crack size and tracking crack propagation rates. For the GDMS, the transducers are either in passive monitoring or active interrogation mode and interacting with each other. The self sensing capabilities of these sensing elements detect acoustic signals that emanate from the underlying fiber breakage, crack propagation or impact. The sensor arrays may operate on demand schedule when the transducers can be used to excite the structure sequentially and the rest of the sensors used to sense. The signatures thus obtained can be used to map the structure and compared with historical data to find out any changes caused by damages in the structure.

8345-83, Session 12a

Vibration analysis of a smart helicopter blade with piezoelectric actuated trailing edge flaps

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Vibratory loads in helicopters arise from a variety of sources such as the rotor system, the tail rotor, the engine, and the transmission and lead to

fatigue damage of structural components, human discomfort, difficulty in reading instruments and reduced effectiveness of weapon systems. Therefore, the closely linked problems of vibration prediction and vibration reduction in helicopters have received considerable attention. The concept of using trailing-edge flaps for helicopter vibration control is not entirely new. However, since the 1990's, the advancement of smart materials opens a new domain of active trailing-edge flap systems driven by smart material actuators. The emergence of these compact, lightweight, high bandwidth, and low power requirement actuators has revived the interest in active trailing-edge flap rotors. In this study, effects of plain trailing edge flaps on the vibration characteristics of a hingeless rotor blade is investigated via finite element method. The blade features flap-lag-torsion coupling and has plain trailing edge flaps that are actively controlled by bender type piezoelectric actuators. Both the strain and the kinetic energy expressions for the problem are derived analytically. The parameters for the hub radius, rotational speed and bending-bending-torsion couplings are incorporated into the energy expressions. The shape functions are derived for the finite element application and the structural matrices, e.i. stiffness and mass matrices, are found using these energy expressions. Theodorsen theory is applied to rotarywing aerodynamics and the aerodynamic loads are calculated for a flapped rotor. Aerodynamic loads produce additional mass and stiffness matrices to be added to the structural ones. The system has no structural damping and the damping matrix appears as a result of the aerodynamic loading. Validations of both the structural and aerodynamic models are made. After the validation, the structural and the aerodynamic models are combined and the finite element equations of motion are obtained from Hamilton's principle. Effects of the several flap related parameters, i.e. flap length and spanwise location, flap chord ratio, flap effectiveness, etc. are investigated.

8345-84, Session 12a

Optimal topology and experimental evaluation of piezoelectric materials for actively shunted GE polymer matrix fiber composite blades

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In collaboration with GE Aviation, NASA Glenn Research Center (GRC) has started the development of a smart adaptive structure system with piezoelectric transducers to improve composite fan blade damping at resonances. However, traditional resonant damping approaches may not be realistically viable for rotating frame applications such as engine blades due to the difficulty of implementing a massive circuit size in the limited space and the risk of rotor imbalance at high centrifugal loads. Thus, we have developed a novel digital shunt scheme to replace the conventional electric passive shunt circuits that dissipates strain energy through the load capacitor on a power amplifier. In this work, GE has designed and fabricated a variety of polymer matrix fiber composite (PMFC) test specimens: wide and narrow beams for surface mounted piezoelectric (PE) transducers, piezoelectric embedded PMFCs, and subscale GEnx composite blades for spin testing. Glenn team has investigated optimal topology of PE sensors and actuators for each test specimen to discover the best PE transducer location of high modal strain energy for each target mode. Also several curved patches, with different material properties, were tested to identify the best performing piezoelectric material for controlling multiple target modes during normal engine operation. Our innovative shunt controller has achieved significant performance for all GE PMFC blades in terms of resonant damping and control power consumption at target modes. This work has been highlighted by accomplishing successful spin testing for subscale GEnx composite blades at GRC's Dynamics Spin Rig up to 5,000 rpm.

8345-85, Session 12a

Optimal placement of piezoelectric plates for active vibration control of gas turbine blades: experimental results

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It is well known that gas turbine blade vibrations can give rise to catastrophic failures and a reduction of the blade's life because of fatigue related phenomena (see e.g. [1]-[3]). In last two decades, the adoption of piezoelectric elements, has received considerable attention by many researcher for its potential applicability to different areas of mechanical, aerospace, aeronautical and civil engineering. Recently, a number of studies of blades vibration control via piezoelectric plates and patches have been reported [4]-[6]. These could be very interesting with reference to the problems mentioned above, indeed this type of materials are very efficient for active control of vibrations.

In their previous work [7], the authors studied a model to control the blade vibrations by piezoelectric elements and validated their results using a multi-physics finite elements package (COMSOL) and results from the literature.

An optimal placement method of piezoelectric plate has been developed and applied to different loading scenarios for realistic configurations encountered ingas turbine blades. It has been demonstrated that the optimal placement depends on the spectrum of the load, so that segmented piezoelectric patches have been considered and, for different loads, an optimal combination of sequential and/or parallel actuation and control of teh segments has been studied.

In this paper, an experimental investigation carried out by the authors using a simplified beam configuration is reported and discussed. The test results obtained by the investigators are then compared with the numerical predictions [7].

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8345-86, Session 12b

The impact of monitoring on decision making

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Bridge managers often make decisions based on experience or common sense, somehow regardless of the action suggested by instrumental monitoring systems. Managers weigh differently the monitoring results based on their prior perception of the state of the structure and make decisions keeping in mind the possible effects of the action they can undertake. We propose a rational framework to include the impact of these issues on decision making, based on the concept of Value of

Information. The methodology is demonstrated through the case study of the Streicker Bridge, a newly built pedestrian bridge on Princeton University campus.

8345-87, Session 12b

Non parametric estimation of the value of information for monitoring systems

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Structural Health Monitoring (SHM) systems are useful instruments for limiting the risk related to seismic events. Aside from the cost of the devices and the convenience of their operation, the selection of these systems should be guided by the quality of the information gained and by their effect on reduction of overall losses. This selection can be guided quantitatively by the Value of Information (VoI) principle of decision theory. VoI is essentially the difference between the expected loss of managing a structure without and with the SHM system. Indeed, while a monitoring system can provide improved information as to damage suffered by the structure, it is only by considering the savings resulting from subsequent decisions (e.g., inspection, repair, continued operation or closure of the structure) that the value of such a system can be determined.

An accurate estimation of the VoI generally requires running a large number of simulations, making use of complex numerical models, and its computational cost is high. Therefore, a procedure for obtaining an approximate estimate by a relatively small number of simulations is needed.

In this paper we investigate a numerical approach based on Monte Carlo simulation and non-parametric regression to estimate the VoI. Application of the proposed technique is presented on a bridge model subject to seismic excitation and instrumented with accelerometers.

8345-88, Session 12b

Application of Cu-Al-Mn superelastic alloy bars as reinforcement elements in concrete beams

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Experimental works to assess the seismic behaviour of concrete beams reinforced with superelastic alloy (SEA) bars have been done in this study. Applicability of newly developed Cu-Al-Mn SEA bars, characterized by large recovery strain, low material cost, and high machinability, have been proposed as partial replacements for conventional steel bars due to their inability to recover residual deformations in structures during and after intense earthquakes. Four-point reverse-cyclic bending tests were done on reduced scale concrete beams comprising three different types of specimens - conventional steel reinforced (ST-RC), SEA reinforced (SEA-RC), and SEA reinforced with pre-tensioning (SEA-RC-P). SEA reinforced beams involved placing of SEA bars of 150mm length around the centre, i.e., stress concentration region of beam. To provide continuation to these SEA bars, mechanical couplers were used to connect them to steel reinforcement. The results showed that the SEA reinforced concrete beams demonstrated significant enhancement in crack recovery capacity in comparison to steel reinforced beam. Average recovery of cracks for each of the specimens was 21% for ST-RC, 84% for SEA-RC, and 86% for SEA-RC-P. In addition, SEA reinforced beams demonstrated strong capability of recentering with comparable normalized strength and ductility relative to conventional steel reinforced beam specimen. Steel reinforced concrete beam on the other hand showed large residual cracks due to progressive reduction in its recentering capability with each cycle. Both the SEA reinforced specimens demonstrated superiority of Cu-Al-Mn SEA bars to conventional steel reinforcing bars as reinforcement elements.

8345-89, Session 13a

Tunable liquid dampers with multi cells for wind vibration control of tall buildings

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This study deals with tunable liquid dampers with multi cells for wind vibration control of tall buildings. A Tuned liquid column damper (TLCD) is used to reduce wind induced building acceleration by tuning its natural frequency to that of a building. A TLCD is manufactured and installed at a building in the design phase before building construction with the assumed building natural frequency. After a building is constructed, its natural frequency may differ from the original one. Thus, a TLCD is able to give the shifted natural frequency of a building without its serious modification. However, a conventional TLCD changes its natural frequency by only regulating liquid height, of which method is not recommended by destroying U shape of TLCD. This study proposes new concept of a TLCD which gives wide range of natural frequency with simple modification maintaining original shape. Sectional area ratio of vertical and horizontal columns of TLCD is a key parameter in determining its natural frequency as well as effective TLCD length. The vertical column of a TLCD is divided into several individual cell type small columns. The liquid in individual cell type columns cannot move by air pressure if its top is sealed according to Bernoulli's theory. By taking appropriate number of cell type columns in sealed condition, sectional area ratio is changed, which provides new natural frequency same to shifted natural frequency of a building. Tunable liquid dampers with multi cells are analytically evaluated in viewpoint of natural frequency and control force according to the number of sealed cell type small columns. Finally, shaking table test is carried out to verify the applicability of proposed dampers.

8345-90, Session 13a

Exploring efficiencies of SISO, multi-SISO, SIMO, and MIMO AVC schemes for floor vibration control

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Continued advancements in steel and concrete materials as well as improved computer-optimized designs are resulting in structurally more efficient floor structures. These turn out to be more longer span, more lightweight and have a tendency to be more open-plan with fewer internal partitions. They possess low and close natural frequencies, sometimes falling within the range of frequencies produced by human activities, as well as low damping levels. Vibration serviceability problems are thus arising more frequently than before. The tendency for developers to require floor structures suitable for a variety of types of occupation so as to increase their economic viability also has clear ramifications for their vibration serviceability.

Active vibration control (AVC) is emerging as a viable technology for mitigation of human-induced vibrations in problem floors. Past AVC research work, as demonstrated in analytical studies and successfully implemented in field trials have focussed predominantly on collocated sensor and actuator pairs in SISO or multi-SISO direct-output feedback schemes, for example, direct velocity feedback (DVF). The research work presented in this paper, an extension to past AVC research with direct-output feedback approaches in this field, demonstrates the potential benefits that may be derived from using model-based control approaches, for example, in isolating and controlling target problematic frequencies only. The AVC studies with model-based approaches comprise of SISO, SIMO, and MIMO control structures. Both the

analytical and experimental studies presented are based on a laboratory structure.

8345-91, Session 13a

Development and testing of a newly proposed continuously variable stiffness/damping device for vibration control

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In the past, many variable stiffness and damping devices have been proposed in an attempt to mitigate the effects of unwanted vibrations. While their nature allows them to control their respective properties in real-time, most have a limited range and/or a discrete number of possible stiffness or damping values. This study proposes a new variable stiffness/damping device that improves on the limitations of previous devices. The device is comprised of a sphere and rollers connected in series with a simple spring or damper. It is able to produce a large, continuous, and instantaneously varying range of stiffness or damping values. The proposed device can be placed into a number of vibration reducing roles, including but not limited to tuned mass dampers, base isolators, and semi-active bracing components. To demonstrate the device's ability to continuously vary stiffness or damping, a scale model was designed and machined for experimental testing. The model consists of a linear actuator connected in series with the device in its variable stiffness role. The actuator was programmed to produce a sinusoidal input to the device as force and displacement transducers recorded data. By adjusting the device's settings, it became possible to change the effective stiffness of the system. In addition, the experiment was performed with the device as a variable damper. The results were compared to numerical simulations performed with a theoretical model. Conclusions from the experimental and theoretical data demonstrate that the device can continuously and instantaneously vary stiffness or damping over a large range.

8345-92, Session 13a

A framework for advanced methods of control of human-induced vibrations

P. Reynolds, The Univ. of Sheffield (United Kingdom)

The vibration serviceability of civil engineering structures under human dynamic excitation is becoming ever more critical with the design and redevelopment of structures with reduced mass, stiffness and damping. A large number of problems have been reported in floors, footbridges, sports stadia, staircases and other structures. Unfortunately, the range of options available to fix such problems are very limited and are primarily limited to structural modification or the implementation of passive vibration control measures, such as tuned mass dampers.

This paper presents the initial development of a new framework for advanced methods of control of human-induced vibrations in civil engineering structures. This framework includes both existing passive methods of vibration control and more advanced active, semi-active and hybrid control techniques, which may be further developed as practical solutions for these problems. Through the use of this framework, rational decisions as to the most appropriate technologies for particular human vibration problems may be made and pursued further.

This framework is also intended to be used in the design of new civil engineering structures, where advanced control technologies may be used both to increase the achievable slenderness and to reduce the amount of construction materials used and hence their embodied energy. This will be an ever more important consideration with the current drive for structures with reduced environmental impact.

8345-93, Session 13b

Assessment of dynamic and long term performance of an innovative multi-story timber building via structural monitoring

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An innovative 3-storey timber building has recently been completed in Nelson, New Zealand and is expected to the trailblazer for taller structures to be more widely adopted. The structure uses self-centering, pre-stressed timber shear walls as the main system resisting horizontal loads from earthquakes and strong winds, and lightweight composite timber-concrete floors. Performance based standards require an advanced understanding of building responses, inter alia, at a range of serviceability level loads. High quality, in-situ data on building performance is needed as timber is increasingly used for medium and large commercial, industrial and multi-residential structures around the world but is still hardly available. In order to meet the need for in-situ performance data the building has been instrumented with a monitoring system comprising a total ~90 data channels to remotely capture its dynamic and long-term responses. The sensors included accelerometers, dynamic and static strain gauges, LVDTs, temperature and humidity sensors, and an anemometer.

The first part of the paper focuses on assessment of building dynamic performance under serviceability level earthquake excitations. Monitoring results together with those from several forced vibration tests using a shaker were used to update a detailed FEM model of the structure. Updating revealed a wealth of information about building performance, e.g. the low in-plane stiffness of floors and resulting loss of diaphragm action. The updated model was next used to assess seismic performance at the serviceability limit state level using both recorded and simulated responses and comparisons with design limits were made.

The second part focuses on the dynamic response of composite concrete-timber floor to walking forces. There is generally dearth of relevant in-situ data despite well known serviceability issues of light weight floors. The data captured by three accelerometers were used in system identification and floor FEM model updating. The recorded responses were compared to numerical simulations enabling both calibration of analytical floor vibration assessment procedures and comparisons with vibration acceptability criteria for human perception and comfort.

Finally, results of long term pre-stress force losses in the shear walls are analysed. Wall creep deformation and adjacent temperature and humidity were also monitored. The post tension load was observed to vary daily in direct relation to temperature but the clear trend over the first year was a reduction of approximately 10%. In addition, timber-concrete composite beam deformations were monitored for deflections. Factors influencing data continuity and measurement precision are discussed as well as the measured magnitudes of long-term responses versus predictions.

8345-94, Session 13b

Sensor agent robot with servo-accelerometer for structural health monitoring

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Recently, robots technologies have advanced remarkably and robots are gradually being used in many fields and places like hospital, school and office. We expect robots would be used in homes to mainly achieve many services for residents. Among these services we focus on Structural Health Monitoring (SHM) of buildings. SHM systems are becoming feasible with the growth of computer and sensor techniques during the last decade. However high cost prevents SHM to become common in general homes. The reason of this high cost is that SHM needs many acceleration sensors, and houses need to be restructured. In this research, we propose a free moving sensor agent robot mounted with acceleration sensors and a laser range finder (LRF). If this robot can get correct acceleration data, the cost of SHM would be cut down and this will help the spread of SHM.

Our goal is to perform SHM using the described robot. First, we designed the prototype of the robot to correctly detect the floor vibrations and acquire the micro tremor information. When the robots sense the ground to acquire the data, the tire and movement of the robot may affect the data. This is why we contrived a frame coming down to the ground and fixing the robot when necessary.

Secondly, the robot should figure out where it is, because it needs to know where the data is detected. We use the LRF sensor to do that.

8345-95, Session 13b

Active evacuation guidance using sensor agent robot

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Current smart buildings are designed based on scenarios, so they are not prepared for unexpected events. Additionally, people demand highly secured, more energy-efficient, and more comfortable spaces. Meanwhile, tools such as sensors and computers have advanced rapidly. Thus, using these tools we would like to make living spaces safer and more comfortable. “Biofication fo Living Spaces” is a concept of creating safe and pleasat living environments using a sensor agent robot. It is crucial that we first propose a service to keep living spaces safe using the robot to realize “Biofication of Living Spaces,” because safety is absolutely necessary to create comfortable environments. In this research, we propose a new model of active evacuation guidance using the robot for “Biofication of Living Spaces.” As the first step in this research, we determine which sensors are needed as the fundamental structural component of the robot for sensing environmental information and build a prototype of it. As the next step, the robot collects data which describe humans, buildings and surrounding environments. Then these data are calculated to understand situations. We propose a way to find proper actions for victims and to generate communication between robot and people to provide proper guidance for people to evacuate safely from dangers such as secondary disasters of earthquake and fire. Finally, we compare our model with existing evacuation guidance models and show advantages of using the sensor agent robot of “Bioficaiton of Living Spaces” to get an active evacuation guidance model.

8345-96, Session 13b

Estimation of uncomfortable feeling based on observation of unconscious behavior of residents for homeostasis control

M. Takase, A. Mita, Keio Univ. (Japan)

Intelligent spaces with devices controlled properly for residents have been researched along with the development of science and technology. However, these spaces are designed based on scenarios so it is difficult for them to handle unexpected circumstances and to adapt to the demands of people which change randomly by emotions and aging. Therefore, we suggest “Biofication of Living Spaces.” This research suggests an algorithm which simulates devices as body cells based on the broadcast communication method and decentralized autonomous control system. In this study, control models are aimed to maintain comfort of residents based on homeostasis. A resident is built in the control loop, and his uncomfortable feeling plays the role of a control signal. In order to acquire this uncomfortable feeling, we propose a method to identify feeling of residents by their movements using brainwaves. The advantage of using brainwaves is that results are precise and sincere to the changing emotions. In this research, we identify the relationship between human emotion and their unconscious behaviors. In “Biofication of Living Spaces,” it is necessary that a sensor agent robot acquires all the data, so we determine the relationship between the unconscious behaviors obtained by the robot and actual human emotions. The proposed method enables the sensor agent robot to acquire unconscious behaviors of residents and convert them as the control signal of the device control system.

8345-97, Session 14a

Sensing performance of electrically conductive suspension lines and capacitance sensor-embedded fabrics for parachutes

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The behavior of a parachute during operation is dependent on the porosity and geometry of the canopy. The ability to change these physical properties mid-flight will greatly enhance the performance and maneuverability of parachutes. In order to achieve variable porosity or geometry, an intelligent network of sensors must be implemented to acquire relevant data (i.e. strain, load, pressure) throughout the duration of the drop. Ideally, adjustments would be made to the canopy, utilizing actuators, based on feedback from the strategically placed sensors. In this proposed system, the intelligent network within the parachute would require a unique means of transmitting power or data to the actuators that does not compromise the mechanical behavior of the canopy or its suspension lines.

This paper quantifies the sensing capabilities and conductive properties of novel smart materials in an effort to enhance the performance of parachutes. In a previous review of sensing technologies, several materials showed potential for parachute implementation - specifically, electrically conductive textiles and dielectric electro-active polymers (DEAPs). Past efforts have been focused on researching and evaluating conductive fabrics and DEAPs. While some of the electrically conductive fabrics demonstrated sufficient sensing capability, they were not conductive enough to implement into an intelligent network as a means of transmitting power or data. Additionally, attaching or stitching DEAPs to the parachute fabric proved to be a challenge. The goal of this paper is to investigate more efficient smart material alternatives for these applications: silverized nylon suspension lines and DEAP-embedded fabrics.

The potential applications of an intelligent network of textile sensors are not limited to parachutes. Many other textile applications, including protective apparel and enclosures, could benefit from an unobtrusive sensor network comprised of smart materials.

8345-98, Session 14a

MEMS-based spectral decomposition of acoustic signals

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Many smart structure and embedded health monitoring applications require extremely low-power sensors and signal processing capabilities. In particular, the continuous monitoring of vibrations, impacts, and acoustic noise within a structure typically requires significant power for not only the transducers themselves, but also the signal conditioning, analog to digital conversion, and digital signal processing necessary to extract useful information from the captured waveforms. This paper presents a sensor methodology that performs spectral decomposition of acoustic and vibration waveforms using arrays of micromechanical resonant structures, mechanical filters, and embedded active films, with signal processing being performed in the mechanical domain. The use of embedded active films in these devices results in sensors that can be, in some instances, self-powered by the vibrations being detected. A MEMS-based spectral sensor employing an embedded electret film has been fabricated and tested in an impact environment. Sensor fabrication was performed using in situ polarization of the active film after completing the entire fabrication flow. This sensor consisted of an array of tuned micromechanical resonant elements with natural frequencies varying across the spectrum of interest. The sensor was incorporated into a ball drop apparatus in which controlled acoustic pulses could be

delivered to the structure under test. Spectral output from the sensor was collected and could be used to distinguish between impacts involving different material sets and impact energies without the use of digital signal processing and its associated power consumption.

8345-99, Session 14a

In-situ non-contact damage detection in SMA reinforced CFRP

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The research interest in materials capable of giving real-time information about their structural integrity (self-sensing materials) is strongly increasing [1,2]. However, a major problem with these classes of materials is that the embedding of sensors adds complexity to the system, affecting the mechanical properties and raising the manufacturing costs.

Composite material obtained embedding SMA wires within a traditional CFRP are a well known class of smart material, in which the NiTi network is used to increase the mechanical properties in terms of strength, tensile yield, impact properties and fatigue resistance [3].

The purpose of this paper is to analyse the possibility to manufacture and verify the non-contact self-sensing capability of a network of NiTi shape memory alloys (SMA) embedded in carbon fiber reinforced plastics plates.

Thermal material properties have been investigated in order to use pre-existing material for damage detection and health monitoring without modifying their mechanical properties. In our approach, using simple electrical connections, low amperage current is transmitted to the sample, resulting in a heat flow through the entire SMA network, generated by the Joule effect in the wires. Using a thermocamera it was possible to capture the emitted thermal waves form the sample in order to create an imaging of the integrity of the composite material. Consequently, by analysing the behaviour of the heating curves on different points of the sample, it was possible to identify potential distortion in the SMA grid caused by the presence of damages within the composite structure.

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8345-100, Session 14a

Modeling of vibration damping in microfibrous material

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MEMS gyroscopes are used in many applications including harsh environments such as high power high frequency acoustic noise. If the latter is at the natural frequency of the gyroscope, the proof mass will be overexcited giving rise to a corrupted gyroscope output. To mitigate the effect of the high frequency high power acoustic noise, it is being proposed to use Nickel Microfibrous Sheets as an acoustic damper.

For this purpose the modeling of vibration damping in Nickel Microfibrous sheets was done in this research work. The sheets were made form nickel fibers with cellulose as binding agent using a wet lay paper making technique. Sintering was done at 1000 oC to remove all the cellulose giving rise to a porous material. 8″ square sheets were made from three diameters of nickel fibers namely 4, 8, and 12 microns.

The sheets were cut into smaller pieces to fit the fixture specially designed for this project. The fixture was attached to a LDS V408 shaker with a mass sitting on top of the microfibrous sheet to simulate transmitted vibration by base motion with the sheet as a damper. A series of experiments were conducted using the three diameters of the fibers, different number of layers of microfibrous sheets and varying the vibration amplitude. Two sets of measurement were done, one using random vibration to obtain the natural frequency and the stiffness, and sine wave vibration to get the damping.

From the collected vibration data of stiffness and damping a mathematical model was developed.

8345-101, Session 14b

The connection technology based on high temperature silica fiber optic sensor

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With the development of hypersonic vehicle technologies, Some new materials, such as ultra-high temperature ceramics (UHTC), C/C and C/SiC have exhibit obvious potential in extreme environment, but the corresponding high temperature measuring technologies are relatively scarce, this lag of measuring technology has become an obstacle to the development of structural design and structural health monitoring. As we all know, silica fiber optic sensor is now relatively mature in application of low temperature environment, but the practical application of the silica fiber sensors in high temperature environment is still a key technical problems. The main work of this paper is to solve the connection technology between fiber optic sensor and UHTC at the temperature above 700. In this paper, a series adhesive were tested at different temperature to check the adhesive ability. So the best adhesive was selected, and many experiments were completed to determine the optimally cementation processing. Composition analysis was completed by XRD testing, and the adhesive selection guide for UHTC material was given based on the analysis and comparisons. The verification experiments of silica fiber optic sensor was conducted at 700, the output of the sensor demodulation data were measured and analyzed. The results of corresponding wavelength output can be described by a linear relationship between temperature and strain. It also proved that the brag formula is also effective at high temperature. The calibration of the high temperature fiber optic sensor was completed through a series experiments on UHTC at different temperature.

8345-102, Session 14b

Fiber optic shape sensing for monitoring of flexible structures

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Recent advances in materials science have resulted in a proliferation of flexible structures for high-performance civil, mechanical, and aerospace applications. Large aspect-ratio aircraft wings, composite wind turbine blades, and suspension bridges are all designed to meet critical performance targets while adapting to dynamic loading conditions. By monitoring the distributed shape of a flexible component, fiber optic shape sensing technology has the potential to provide valuable data during design, testing, and operation of these smart structures. This work presents a demonstration of such an extended-range fiber optic shape sensing technology. Three-dimensional distributed shape and position sensing is demonstrated over a 30m length using a monolithic silica fiber with multiple optical cores. A novel, helically-wound geometry endows the fiber with the capability to convert distributed strain measurements, made using Optical Frequency-Domain Reflectometry (OFDR), to a measurement of curvature, twist, and 3D shape along its entire length.

Laboratory testing of the extended-range shape sensing technology shows its accuracy to be better than 2% by length over 30m for a variety of shapes and configurations.

8345-103, Session 14b

* Coaxial cable Bragg grating sensors for large strain measurement with high accuracy

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In order to ensure the continued stability of civil structures, such as dams, bridges and buildings, in situ strain monitoring is of notable importance, especially for structures that possess large strains. A coaxial cable Bragg grating (CCBG) is reported for the first time, and the sensor's capacity for large range strain measurement is demonstrated. The sensor device is comprised of regularly spaced periodic discontinuities along a coaxial cable. The discontinuities are fabricated using a computer numerical controlled (CNC) machine to drill holes through the cable diameter. Each discontinuity generates a weak reflection to the electromagnetic wave propagating inside the cable. Through the superposition of the numerous weak reflections, a strong reflection is formed at discrete frequencies in accordance with Bragg grating theory. A positive feedback oscillation system is developed to enhance the measurement accuracy. The Q-factor was enhanced by 3500 times in this case. By monitoring the resonant frequency shift of the sensor's reflection or transmission spectra using the oscillation system, a minimum sensitivity of 20με and a maximum range of 50000με (5%) are demonstrated for axial strain measurements. The temperature responses of various types of CCBGs have also been investigated. The experimental results show that this CCBG performs well in terms of both linearity and sensitivity.

8345-104, Session 14b

Enhancing active vibration control performances in a smart structure by using fiber Bragg gratings sensors

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Fiber optic strain sensors, such as Fiber Bragg Gratings (FBG), have a great potential in the use in smart structures thanks to their small transversal size and the possibility to make an array of many sensors. They can be embedded in carbon fiber structures and their effect on the structure is nearly negligible. On the other hand, some critical aspects should be evaluated, such as higher cost and lower SNR respect to traditional technologies. In this work a simple carbon fiber structure has been developed, composed of a thin cantilever with 14 longitudinal FBG sensors and 3 piezoelectric actuators (PZT). A dynamic 1 kHz swept-laser interrogator was used to gather the FBG data: the output is a digital signal and the time delay introduced has been measured. This is a critical point that restricts the highest controllable frequency: our results show that the limit is at about 50 Hz. A control system has been developed and many control strategies have been evaluated to suppress vibration, from the simplest single-sensor to single-actuator strategy, up to modal control. The SNR of the input data has been found to be critical. The use of FBG sensors allows improving the performance of the control because they give a large number of measurements regarding the state of deformation of the whole structure. Modal control was found to have the best results thanks to its best use of all the sensors data.

8345-105, Session 14b

Structural health monitoring of CFRP airframe structures using fiber-optic-based strain mapping

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This paper proposes structural health monitoring (SHM) technology based on the strain mapping of composite airframe structures through their life cycles including the stages of molding, machining, assembling, operation and maintenance. Our SHM system detects damages and deformation harmful to the structures by strain mapping using fiber Bragg grating (FBG) sensors. FBG sensors are suitable for life-cycle strain monitoring because reflection spectra of FBG sensors correspond to the strain applied to FBGs, which enables us to measure the strain change since the sensors were installed in structures. In order to evaluate the strain mapping accuracy and damage detection ability of FBG sensors, we carried out the strain monitoring tests of two kinds of CFRP specimens; one is reduced-size CFRP pressure bulkhead specimen, the other is skin-stringer panel specimen. CFRP specimens have debondings with different sizes and inserted locations. Strains of the specimens were measured by FBG sensors under vacuum pressure or uni-axial tensile loading. It was confirmed that the strain distribution varied with damage configurations. Moreover, the change in strain distribution measured by FBG sensors agrees well with numerical simulation by FEM. These results demonstrate that FBG sensors can detect damages which arise in composite airframe structures due to operational load in flight.

8345-106, Session 15a

A preliminary study on the use of optical navigation sensor for two dimensional crack propagation monitoring

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Deterioration of concrete structures is usually accompanied by the formation and propagation of cracks which can lead to corrosion of reinforcement and affect the durability of the structure. In this paper, a preliminary study on the development of a wireless image-based crack sensor for two-dimensional crack propagation monitoring is reported. This sensor is developed by integrating an optical navigation sensor board into the Imote2 IPR2400 platform. The optical navigation sensor board (ADNS-9500 by the Avago Technologies) has a compact size of 14.4mm×15.6mm and provide a resolution up to 5,000 counts per inch with a programmable frame rate up to 11,750 frames per second. The ADNS-9500 is soldered onto a printed circuit board (PCB) that interfaces with the Imote2 IPR2400. The PCB is designed to provide necessary functional support to the ADNS-9500 as well as a communication channel between the Imote2 and the ADNS-9500. In addition to its on-board processing capability, the ADNS-9500 provides download of a full array of pixel values from an image frame which offers additional image processing and manipulation via the Imote2's PXA271 processor. For crack monitoring, the PXA271 sends a signal to the ADNS-9500 to switch on the laser and the CMOS camera to collect images reflected from the concrete surface. The captured images are processed by either the ADNS-9500 or the Imote2's PXA271 processor to obtain the relative displacement between two consecutive images. A series of tests have been conducted on a programmable XY table to calibrate the accuracy of the proposed crack sensor.

8345-107, Session 15a

Experimental study on impact force identification of ship-bridge collision using smart piezoelectric sensors

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The bridges over navigation waterways are exposed to ship collision and ship-bridge collision accidents have been widely reported worldwide. The measurement of ship impact force during a collision accident is of great importance for condition assessment of ship-collided bridges and subsequent strategic actions made by the bridge authority. The impact force of ship-bridge collision is usually evaluated by use of the measured structural responses during ship collision and an identification algorithm, but the accuracy is limited. In this paper, a method for direct impact force identification of ship-bridge collision using smart piezoelectric sensors is proposed. The feasibility and effectiveness of the proposed method has been demonstrated by conducting an experimental study with a scale pier model of a cable-stayed bridge. The piezoelectric sensors are embedded into the scale pier model and the impact force is generated by a hammer. Various impact sceneries in different combinations of the impact location, impact amplitude, and impact angle are taken into account to investigate the capacity of the piezoelectric sensors for impact force identification and localization. Through acquiring the voltage signals from the piezoelectric sensors at different locations, the impact force is identified with the aid of the calibrated relationship between the impact force and the voltage output. In recognition that the impact force imposed on the surface of the pier is different from the identified impact forces at the locations of the piezoelectric sensors which are embedded into the structure, a ship-collided-to-bridge numerical simulation is conducted to determine the conversion factor as the ratio of the surface impact force and the impact force at the embedment location of the sensor. The experimental results show that the identified impact forces using the smart piezoelectric sensors have a good agreement with the theoretical values.

8345-108, Session 15a

Damage detection of wind turbine blade with piezoelectric sensor array

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Development of renewable energy sources has gained much attention due to the worldwide energy crisis. Among the varieties of renewable energy technologies, the wind turbine technology has an edge because of its technological maturity and relative cost competitiveness. One of the key components in a wind turbine is the blade which could be damaged by moisture absorption, fatigue, wind gusts or lighting strikes. Therefore, it is important to detect the damage on the wind turbine blade before it fails catastrophically. In this paper, an experimental study is carried out for damage detection of wind turbine blade under both the static loading and the operational loading conditions. A piezoelectric sensor array is deployed on the wind turbine blade for detection, localization and growth monitoring of the simulated damage in the wind turbine blade. The voltage output signals from the piezoelectric sensors are transmitted via newly developed wireless transmission device and conventional tethered-based data transmission system with a rotary joint. A comparison of the measured data from these two transmission ways is conducted, and the feasibility and effectiveness of the wireless transmission system is testified. Two power spectral density (PSD) estimation methods (i.e., Welch method and Covariance method) are used to highlight the main frequency components of the measured original signals. An energy-based damage indication index is established for comprehensively reflecting the damage status of the wind turbine blade. Experimental results show that damage in the wind turbine blade could be detected and evaluated by the proposed approach.

8345-109, Session 15a

Real-time monitoring of bridge scouring using ultrasonic sensing technology

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Scour due to floods and rapid river flow is one of the major causes of bridge failures, which erodes the foundation materials below bridge piers and abutments. Sensors and monitoring provide vital information on the stability of bridges that are subjected to scour. In this study, an ultrasonic technology-based monitoring system is set up. Ultrasonic sensor is placed on a vertically-fixed trail housed in a protecting tube and can move upward and downward. The ultrasonic sensor sends, and the ultrasonic wave signal will be reflected at sediment-water interface. The exact location of the river bed can be calculated through the wave signal travel time from sending to receiving and wave velocity. Due to the sensor moving in a range in the vertical direction, the river bed map can be portrayed through the monitoring data. The feasibility and accuracy of the monitoring system has been validated through a test in laboratory. The test results indicate that the ultrasonic technology-based monitoring system can monitor the scour in real time under different flow conditions with various types of sediment.

8345-110, Session 15a

Dense vibration measurement of an arch-type bridge before and after its seismic retrofit using wireless smart sensors

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Fundamental functionalities of wireless smart sensors to measure full-scale bridge vibration, such as time synchronization, loss-less multihop communication, and capability to capture small ambient vibrations, are maturing; dense vibration measurement of large structures using wireless smart sensors is expected to reveal the detailed condition of existing structures. An arch-type bridge is chosen as a target bridge and densely instrumented by 49 wireless smart sensors. Traffic induced vibration of the bridge has been measured before and after its seismic retrofit. The differences between the measured dynamic characteristics are considered to represent the effects of seismic retrofit. The dense measurement allows comparison of spatial characteristics such as detailed mode shapes, in addition to comparison of natural frequencies. Comparison of densely measured mode shapes reveals unobvious changes, which are then used to update the finite element model of the bridge. The measurement, data analysis, and model updating indicate the potential use of dense instrumentation of wireless smart sensor network for structural condition assessment.

8345-111, Session 15b

Damage diagnosis algorithm using a sequential change point detection method with an unknown distribution for damage

H. Y. Noh, R. Rajagopal, A. S. Kiremidjian, Stanford Univ. (United States)

This paper introduces a structural damage diagnosis algorithm that uses a sequential change point detection method for the cases when the feature distribution is unknown for a damage state. This algorithm extracts features from structural vibration data using time-series analysis and then classifies those features into damage states using a sequential change point detection method. The change point detection method sequentially receives the extracted feature and performs a hypothesis test using the distribution of the previously collected features. The advantage of this algorithm is that it asymptotically minimizes the damage detection delay for a given false alarm rate. In addition, unlike the previous algorithm using the change point detection method

developed by the authors that assumes that the distribution of the feature is known for both the undamaged and the damaged cases, the algorithm presented in this paper assumes that the distribution of the features from the damaged structure is unknown, which is more applicable in practice. The algorithm is validated using a set of white noise shake table test data collected from a four-story steel special moment-resisting frame. The results show that although the damage detection delay is longer than that for the algorithm with a known distribution, the presented algorithm can detect damage with a reasonable delay.

8345-112, Session 15b

* Triboluminesence multifunctional cementitious composites with in-situ damage sensing capability

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Structural health monitoring of civil infrastructure systems (CIS)like concrete bridges and dams has become critical because of the aging and overloading of these CIS. Most of the available SHM methods are however not in-situ and can be very expensive. The triboluminesence multifunctional cementitious composites (TMCC) have in-built crack detection mechanism that can enable bridge engineers to monitor and detect abnormal crack formation in concrete structures such as bridges so that timely and appropriate action can be taken to prevent catastrophic failures. The TMCC incorporates the integrated sensing and transmission system of the in-situ triboluminescence optical fiber (ITOF) sensor to enable triboluminescence-based sensing in opaque structures like concrete. The ITOF mimics the sensory receptor of the neurons of the human nervous system by converting the mechanical energy of damage-causing events into triboluminescent signals. This article will report the fabrication process and some of the findings in the development and characterization of the TMCC. The TMCC characterization is by four point bending tests. The stress at failure and the crack size will be correlated to the triboluminescence signal received in order to characterize damage. When fully developed, the TMCC has the potential for wireless, in-situ, real time and distributed (WIRD) sensing capabilities.

8345-113, Session 15b

Development of damage assessment package for building with isolation system and its application to 2011 Tohoku Earthquake

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On March 11, 2011 the Tohoku Earthquake with magnitude 9 hit northeast part of Honshu Island, Japan. Among many buildings in this area, buildings with isolation systems performed well and no major damage has been reported. However, minor damage in expansion joints between isolated buildings and the supports was reported. In addition, some of the damping devices in the isolation layers were also damaged although the capacity of them are mostly kept intact. In the area where strong motions are recorded, the energy absorbed by the damping devices may be close to or even surpassed the design upper limit when considering the response to many aftershocks.

In this paper, a package of damage assessment tools for buildings with isolation system is proposed. It can evaluate the damage during the earthquake and after the earthquake focusing on the isolation system as well as the superstructure of the building. The package is designed to be distributed in a ready-to-use form and to be used on our internet based structural health monitoring system. It will be distributed to designers and engineers who are interested in the hidden damage in a building. The package gives us the status of the building quantitatively and can estimate the remaining capacity of the isolation system from the view point of energy input. The package is applied to buildings equipped with sensors and experienced the 2011 Tohoku Earthquake. The assessment is performed not only for the main shock but also for many aftershock.

8345-114, Session 15b

A novel kind of bridge scour monitoring system using thermal probes

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Bridge scour is a severe and expensive problem, and at the same time a problem often-overlooked. Failures caused by scouring tend to take place all of a sudden and hardly give any prior warnings or signs. Consequently scour monitoring is of great value and also of great difficulties.

In this study, a monitoring system for bridge scour, based on a chain of thermal probes, has been developed and tested preliminarily in the laboratory. The thermal probes, consisting of heating element, temperature sensors (DS18B20) and packing element, are placed vertically along the bridge pier for measuring thermal conductivities. The measurements are based on the transient heat flow method. Considering there is a considerable gap of thermal conductivities between water and sediment, the interface can be identified by picking the maximum thermal conductivities gap between neighboring thermal probes. And hence the scouring condition can be well reflected through the difference of liquid-solid interface between the measured one and the initial one. The system can also be used to monitor the variation of water level.

To justify the scour monitoring methodology and system, firstly, a simple thermal probe has been designed and tested separately in static water and sand. Results show that the behaviors of heat transfer are quite different between in sand and in water. The temperature curves differ in all the upward section, stable section, and downward section. The temperatures in water climb and drop with a sudden change and quickly get to stable stage, while those in sand climb and drop slowly and can hardly achieve a stable state though with a much higher temperature if achieved. Using these temperature curves, the thermal conductivities can be calculated and hence water and sand can be easily differentiated from each other, which validate the feasibility of the methodology of the thermal probe.

Then, a scour monitoring system based on the above thermal probe has been employed identifying the water-sediment interface in a simulated circumstance of river bed using static water and sand. It turns out that the scour system can give good results. In addition, a numeric model based on Fluent is built to simulate how the monitoring system works. Results substantiate the outcome of experiments in return and give further credits to the scour monitoring system. All the experiments are conducted in static water environment. For the pragmatic case in water flow, the convection of water can only enlarge the equivalent thermal conductivity gap and make the scour monitoring system even more reliable.

Furthermore, since in this study the key concern is just to identify the water-sediment interface, rather than obtaining the accurate thermal conductivities of the water or sediment, the thermal probe for the scour monitoring system can achieve satisfying results even if it's easily made and without careful calibrating. That's to say; the scour monitoring system is fairly stable and robust, simple making, applicable for manifold water and sediment environment, and to some extend free from experimental uncertainty.

8345-115, Session 15b

Inspection of wooden utility poles using a sonic/ultrasonic approach

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In recent in-house work, the authors studied the change in energy velocities and attenuations of acoustic/ultrasonic waves along the material principal directions in laboratory prepared wood samples due to increased amounts of decay, i.e., mass loss. The velocity and attenuation values of the two (polarized) shear waves along each of the material principal directions were also measured. The velocity and attenuation measurements as a function of mass loss were obtained for a frequency range of 4.5 kHz to 200 kHz and for an increasing mass loss up to 40%.

Towards developing a portable instrument to evaluate wooden poles in the field, the two-dimensional (2-D) wave field evolution due to impact is presented and discussed for a healthy wooden pole cross-section. Then, tomographic cross-sectional views of pole specimens are used to estimate the mass loss at different points in the same poles' cross-sections. These values of mass loss, and the corresponding changes in velocities and attenuations, are then used to simulate the 2-D wave field evolutions due to impact, and the results are validated with Laboratory impact measurements on the same poles' cross-sections. Simulations of the 2-D wave field evolutions on pole cross-sections with pockets of decay of different size, location, and levels of mass loss are then studied to established rules-of-thumb for easy use in the field. These rules-of-thumb will then lead to the development of a portable, easy-to-use instrument, that an operator can use in the field to detect and assess levels of decay in wooden utility poles.

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8346-01, Session 1

Coherent effects in graphene-based phononic crystals

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Phononic crystals have demonstrated a wide range of functionalities for controlling the propagation of elastic waves. However, for applications of phononic crystals to the control of high frequency phonons, preserving elastic Bragg scattering, a requirement for the control of phonon dispersion with periodic materials, remains a significant challenge because of the possible loss of phonon coherence due to inelastic scattering. High frequency (THz) phononic crystals would enable new functionalities through coherent phonon effects in sensing, thermal transport, or energy harvesting. For applications at ambient temperature, the transition between Bragg- and inelastic- dominated scattering depends on the characteristic length of the phononic crystal and the Debye temperature - phonon coherence length - of its constitutive materials. Here we demonstrate that submicron-scale graphene-based phononic crystals exhibit coherent phononic effects at room temperature. We use the raman D and G-peaks of graphene as probes of optical phonon dispersion in substrate-supported antidot graphene as a function of filling fraction. We demonstrate by contrasting the behavior of various periodic and random arrays of 100nm holes in graphene that elastic scattering of THz phonons with long coherence length enables the formation of folded optical phonons as seen in the broadening of raman peaks. We envisage that coherent phonon effects in periodic graphene-based structures to enable design of advanced materials and devices.

8346-02, Session 1

Phononic and phoxonic crystal slabs sensors

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During recent years we have investigated the engineering of the dispersion curves and bandgaps in phononic and dual phononic-photonic crystal slabs and waveguides. Currently, we study their potentialities for sensing applications. In contrast to photonics-based sensors, little work has been devoted to phononic and phoxonic sensors. For this purpose, we study theoretically the existence of well-defined isolated features in the transmission spectra of such structures showing a high sensitivity to the sound velocity and refractive index of a liquid environment. A first geometry consists of a periodic array of grooves designed on a Si membrane and eventually covered with a second membrane. The grooves are empty or infiltrated with a liquid. The incident acoustic and optical waves are launched parallel to the slab. We define the best geometrical parameters to obtain well-defined peaks and dips in the transmission spectra sensitive to the properties of the liquid filling the grooves. Alternatively, we study a new geometry dealing with the transmission of acoustic and optical waves normally incident upon a phoxonic crystal membrane constituted by a 2D periodic array of holes in a silicon slab. We discuss the possibility of zeros of transmission, extraordinary transmission and Fano resonances which are tunable with the properties of the liquid surrounding the phoxonic crystal. Finally, we study the transmission characteristics of acoustic waves normally incident upon a structure constituted by a set of empty or filled cavities between two substrates.

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8346-03, Session 1

Probing elastic modes localized within a defect in a phononic slab

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Heterostructures with periodic variations of both their optical refractive index and their elastic properties may induce band gaps for both electromagnetic and acoustic waves. As a consequence of the expected enhancement of the acousto-optic interactions, these artificial materials, called "PhoXonic crystals", are of primary interest for new sensing applications.

In this context, we have experimentally studied the localization of elastic energy within a defect. The heterostructures consist in arrays of voids periodically drilled throughout silicon plates (graphite symmetry) and featuring a vacancy, or a line of vacancies. An all-optical experimental technique allows for both the generation and the detection of the elastic guided waves. The non-contact probing allows one to monitor the displacements field inside the defects. First, we have measured the dispersion of broad band elastic waves guided in between the free surfaces of the sample. Then, narrow band elastic guided waves, whose central frequency corresponds to resonance modes of the cavity are generated. The optical probe allows for the measurement of the out-of-plane displacements associated to the elastic modes localized within the cavity or transmitted through the phononic structure. The spatial distribution of elastic energy inside the cavity is measured and compared with numerical predictions.

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8346-04, Session 1

Novel resonance-based phononic crystal structures

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In this paper, we report the design, analysis, fabrication, and characterization of a very high frequency (VHF) phononic crystal (PnC) micro/nano-mechanical resonator architecture based on silicon (Si) PnC slab waveguides. This architecture highly suppresses the support loss of the resonator to the surroundings while providing mechanical support and electrical signal delivery to the resonator. Qs as high as 13,500 in air at a frequency of ~134 MHz with a motional resistance of ~600 Ω, and 35 dB spurious-free range of ~20 MHz are obtained. Comparing the Q of this resonator with the previously-reported lateral bulk acoustic wave resonators with a similar architecture confirms the effective support loss suppression in this architecture. A series of integrated phononic devices based on these resonators will be reported, and their prospects for practical applications like wireless communications and sensing will be discussed.

8346-05, Session 2

Anisotropic metamaterials as sensing devices in acoustics and electromagnetism

J. Sanchez-Dehesa, D. Torrent, J. Carbonell, Univ. Politécnica de Valencia (Spain)

We will analyze the properties of acoustic and electromagnetic metamaterial with anisotropic constitutive parameters. Particularly, we will discuss the so called Radial Wave Crystals [1], which are radially periodic structures accomplishing Bloch theorem. These new type of crystals can be applied in acoustics as well are in Electromagnetism by using metamaterials with anisotropic constitutive parameters. In acoustics we have predicted that they can be employed as acoustic cavities with huge quality factors and also like acoustic antennas dynamically driven. Similar functionalities have been proven in the electromagnetic domain. We will review our recent works on anisotropic structures and will present a complete discussion between their properties in both fields of application [2].

[1]D. Torrent and J. Sánchez-Dehesa, Phys. Rev. Lett., Vol. 105, 174301 (2010); ibidem, Phys. Rev. Lett., Vol. 103, 064301 (2009); ibidem, New J. Phys., Vol. 12, 073034 (2010).

[2]J. Carbonell, D. Torrent and J. Sánchez-Dehesa, Multidisciplinary approach to cylindrically anisotropic metamaterials (submitted to publication)(2011).

8346-06, Session 2

Phononic crystal sensor for liquid property determination

R. Lucklum, Otto-von-Guericke-Univ. Magdeburg (Germany); M. Ke, Wuhan Univ. (China) and Otto-von-Guericke-Univ. Magdeburg (Germany); M. Zubtsov, A. Oseev, R. Grundmann, Otto-von-Guericke-Univ. Magdeburg (Germany)

Acoustic band gap materials, so-called phononic crystals, provide a new liquid sensor platform. Phononic crystals are periodic composite materials with spatial modulation of elasticity, mass density as well as longitudinal and transverse velocities of elastic waves. The sensor structure consists of a solid plate with an array of holes acting as scattering centers as well as containers for the liquid analyte. Two arrangements are introduced where a specific transmission peak is employed to determine properties of a liquid mixture: a thick steel plate having two arrays of holes arranged in a square and a cavity in-between and a thin steel plate with a square array of holes. In the first arrangement the ultrasonic wave travels in the plane of the crystal whereas in the second one the acoustic wave is incident normal to the plate. The frequency of the transmission peak is correlated to material properties, specifically to the speed of sound in the analyte. Sound velocity is related to several parameters of practical interest like concentration of one component in a mixture or conversion rate in a microreactor. As demonstrator of the sensor capability of phononic crystals a mixture of water and propanol has been employed. Furthermore, theoretical investigations based on FDTD, FEIT and COMSOL provide insides to the physical background. These analyses reveal that resonance effects are responsible for the smart properties of the device which are used for sensing purposes. In this sense phononic crystal sensors merge advantageous features of classical microacoustic and ultrasonic sensors.

8346-07, Session 2

Nonlinear phenomena in granular crystals

G. Theocharis, C. Daraio, California Institute of Technology (United States)

The effect of structural periodicity on wave propagation has been studied in a wide array of fields. This includes light waves in photonic crystals and sound and other mechanical waves in phononic crystals. Studying the linear response of these systems, many common properties are revealed, such as the existence of band gaps, which influence the transport properties. As the amplitude of the wave excitation is increased, the response of the material becomes nonlinear. Although myriad of such examples has been revealed in photonic systems, there are thus-far few examples of nonlinear periodic structures in the emerging field of phononics. One of those is the granular crystals.

Granular crystals are nonlinear periodic systems composed of tightly packed, elastically interacting particles, whose nonlinearity results from the geometry of adjacent particles. These crystals can be assembled as homogeneous, heterogeneous, or disordered structures, and can be tailored to have tunable responses, ranging from linear, to weakly and strongly nonlinear. In this talk, we present how the interplay of spatially periodicity and nonlinearity leads to the emergence of coherent structures such as solitons and discrete breathers. We also present how the presence of an extrinsic disorder leads to other interesting phenomena such as nonlinear defect modes, bifurcations and chaos. Such phenomena resulting from, and in combination with nonlinearity, enables the re-distribution of energy amongst other frequencies of the system. Taking advantage of the energy re-distribution, we have proposed a tunable acoustic rectifier.

Experimental observations of all the above nonlinear features are also presented.

8346-08, Session 2

Topologically evolved photonic crystals: breaking the world record in band gap size

O. R. Bilal, M. I. Hussein, Univ. of Colorado at Boulder (United States)

A photonic crystal is a periodic material that can be designed to exhibit band gaps in its frequency spectrum. The representative unit cell is usually composed of contrasting dielectric phases. Within band-gap frequencies, electromagnetic waves are attenuated in space - a feature that has many applications especially in optics. In order to inhibit the propagation of a broadband signal, or numerous signals spanning a broad frequency range, it is desired to select a band gap and maximize its size. Furthermore, keeping the location of the band gap as low as possible in the frequency domain is often targeted in order to keep the photonic unit cell size to a minimum. Pursuit of these two objectives by controlling the material distribution within the unit cell has been the focus of much research in recent years. In this work, we develop a specialized genetic algorithm and use towards searching for optimal unit cell designs. We also utilize the reduced Bloch mode expansion method to speed up the band structure calculations which are carried out many times in each evolutionary step. Focusing on two-dimensional transverse electric (TE) and transverse magnetic (TM) waves (considered separately and in combination), and examining different symmetry configurations, we obtain designs with exceptionally high relative band gap size. By exceeding the objective values reported in the literature for the same problems, our findings signify a new “world record” in photonic crystal performance.

8346-09, Session 3

Smart pressure and temperature measurement on paper machine rolls: an embedded fiber Bragg grating sensor system enables continuous nip monitoring during paper production

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Special fiber Bragg grating (FBG) sensor embedding and interrogation schemes have been designed in order to capture the momentary peak pressure forces (duration of only a few tens of microseconds) in the nip of adjacent paper machine rolls, and the spatial distribution of these nip forces along circumference and length of the roll, for production speeds of up to 2000 m/min. Additionally, this FBG sensor system measures also the temperature distribution in the roll cover.

FBG sensor embedment has been investigated and optimized for the implementation of the pressure force measurements in various roll cover materials. These measurements enable the immediate quality control during various stages of the production process. Draw tower fiber Bragg grating sensor arrays, exactly simultaneously performing spectrometer-based interrogation, and autonomous power supply technologies have been designed to result in an extremely robust fiber-optic sensor system for operation under centrifugal accelerations of 300g. The complete sensor interrogation and data transmission system proved its undisturbed operation at rotation speeds of up to 1500rpm.

8346-10, Session 3

Automatically produced GFRP beams with embedded FOS in complex geometry: process, material compatibility, micromechanical analysis, and performance tests

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The main goal of the presented work was to evolve a multifunctional beams composed out of glass fiber reinforced plastics (GFRP) and an embedded optical fiber with various fiber Bragg grating sensors (FBG). These beams are developed for the use as structural members for bridges or industrial applications. It is now possible to realize large scale cross sections, the embedding is part of a fully automated process and jumpers con be omitted in order not to influence the laminate negatively. The development includes the smart placement and layout of the optical fibers in the cross section, the coupling of the embedded fibers after production and micro-mechanical tests and analysis.

Despite other research works, the cross sections have transverse dimensions up to 0,5 m i.e. tubular members or H - beams. Therefore, in a first step, the optical fibers are placed onto glass fiber fabrics via robotic controlled application, the placement and orientation of the FBG is variable within a beam and between different specimens. This “sensor fabric” is embedded in the automatic lamination process (pultrusion); the structural members are continuously produced and cut into lengths necessary for the individual project. Due to the different lengths of the final beams produced, it was not possible to include jumpers in the material; the optical fiber has to be coupled at the trimmed edge. Therefore, a novel application procedure has been developed which allows for reliable coupling of embedded sensors at any possible location along the structural member.

The accompanying research concentrated on the effects of the production process on the optical fiber and coating due to strain, high ambient temperatures and possible buckling. Moreover, a Finite-Element-Analysis has been performed in order to specify the relation between strain within the optical fiber and the ambient fiber reinforced polymer. The analysis showed that soft coatings show best results as transverse strain effects can be reduced to a minimum while axial strain in the fiber still matches with the axial strain in the specimen.

8346-11, Session 3

Full spectral interrogation of fiber Bragg grating sensors for measurements of damage during steady-state vibration

S. Webb, K. J. Peters, M. Zikry, North Carolina State Univ. (United States); S. Chadderdon, N. Stan, R. H. Selfridge, S. Schultz, Brigham Young Univ. (United States)

The aim of this study is to better understand the effects of spectral distortion on the vibration response of fiber Bragg Grating (FBG) sensors. This spectral distortion is critical for embedded sensors within composite laminates. We evaluate measurements from fiber Bragg grating (FBG) sensors subjected simultaneously to a non-uniform static strain state and vibration loading. In this preliminary study, the FBG sensor is mounted near the notch of a double-edge-notched, thin aluminum plate. The full spectral response of the sensor is interrogated during two loading cases: with and without an added vibration load spectrum. The static tensile loading is increased between each test, in order to increase the magnitude of the non-uniform strain field applied to the FBG sensor. A multi-harmonic vibration spectrum is generated by mounting the specimen and tensile loader onto a 2’ x 2’ optical breadboard, suspended on a single axis. A single piezoelectric actuator is actuated at a frequency of 150 Hz to generate a vibration spectrum across the optical breadboard. The full spectral response of the FBG sensor is interrogated in reflection at 100 kHz using a high-repetition rate, full-spectral interrogator recently developed by the authors.

As the specimen was exposed to higher magnitudes of uniaxial strain, the FBG response became highly distorted, with primary characteristics of a broader bandwidth and lower reflectivity. This spectral distortion due to non-uniform strain was observed to change once the sensor was exposed to a multi-harmonic 150 Hz vibration spectrum. With the high-speed full spectral interrogation, it was possible to separate this vibration-induced spectral change from spectral distortions due to non-uniform strain. The spectral distortion contains valuable information on the static damage state of the surrounding host material. First a conventional, digital filter was applied to the spectral data to determine whether the effects of vibration could be eliminated from the signal without knowledge of the spectral distortion. A high-order Butterworth stopband filter was applied, commonly used for its reduced ripple in the passband. The amplitude of the frequency response of the raw data was observed to be wavelength dependent. This introduced non-uniform shifts in the spectral signal due to the vibration, which could not be eliminated through the filter. Finite element modeling of the FBG spectral response during vibration was then performed to better understand the source of this non-uniform distortion and potential methods to eliminate this from the FBG full-spectral data.

8346-12, Session 3

Nanofilm-coated photonic crystal fiber long-period gratings with model transition for high chemical sensitivity and selectivity

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Using long-period gratings (LPGs) inscribed in an endlessly single-mode photonic crystal fiber (PCF) and coating nanostructure film into air channels in PCF cladding with model transition, we have developed a fiber-optic sensing platform for detection of chemicals, owing to the fact that the PCF-LPG possesses extremely high sensitivity to the change in refractive index and chemical selectivity by localized binding and absorption events in analyte solution. In this work, we numerically and experimentally investigate the behaviors of model transition in the PCF-LPG where the air channels of PCF cladding are azimuthally coated with two types of nanostructure polymers as primary and secondary coatings by electrostatic self-assembly deposition technique. The primary coating does not affect on PCF-LPG parameters such as grating resonance wavelengths and its intensity that can be used for sensing, but it increase the sensitivity to refractive index of chemical analytes in the air channels. The secondary coating is for selectively absorption of analyte molecules of interest. Those two coatings significantly modify the cladding mode distribution of PCF-LPG and enhance the evanescent wave interaction with the external environment, which builds a high sensitive and selective chemical sensor. The integrated sensor has high potential in a variety of application, especially for the nanoliter scale measurement in situ. The functional nanofilms that response to different parameters can be introduced into the air channels of the PCF-LPGs as different transducers. We demonstrate a fiber-optic humidity sensor with

the proposed nanofilm-coated PCF-LPG for detection of corrosion in civil infrastructural health monitoring.

8346-13, Session 4

Stress wave propagation in curved granular crystals constrained by elastic guides

J. Yang, Univ. of South Carolina (United States); C. Daraio, California Institute of Technology (United States)

We study the stress wave propagation in a curved one-dimensional (1D) granular crystal constrained by elastic guides. We assemble a diatomic granular chain composed of alternating cylindrical and spherical particles constrained by bent elastic guides and statically precompressed. We vary the curvature of the guides and the amount of static precompression imposed to the chain, to tune the acoustic response of the system. We analyze the traveling signals with sensors placed within selected particles. We excite the granular crystal with small-amplitude, broadband perturbations using a piezoelectric actuator (ud/u0 > 1). Experimental tests demonstrate the formation and propagation of highly nonlinear compressive waves. We observe amplitude-dependent attenuation of acoustic waves, showing higher energy absorption efficiency under stronger impacts, resulting from the close interplay between the granular particles and the softer elastic medium. We demonstrate experimentally that we can control the attenuation level of nonlinear waves by variation of the granular chain's curvature. Numerical simulations, based on an approach that combines discrete element (DE) and finite element (FE) methods, agree well with the experimental results. The findings suggest that hybrid structures composed of granular particles and linear elastic media can be employed as new passive acoustic filtering materials that selectively transmit or mitigate excitations in a desired range of pressure amplitudes.

8346-14, Session 4

Influence of propagation distance on the acoustic emission parameters in metal plates

D. G. Aggelis, T. E. Matikas, Univ. of Ioannina (Greece)

Metal materials and structures are commonly inspected by the acoustic emission (AE) technique. Any event of crack propagation or corrosion development results in the emission of elastic waves which are captured by sensors on the surface of the material. Study of the AE signal incoming rate, as well as qualitative signal parameters, reveals crucial information on the extent of damage and the cracking mode. Based on laboratory experiments, classification criteria are established concerning the type of the active damage source. However, elastic wave propagation in metal plates is dispersive, forcing different frequencies to propagate on different velocities. This leads to shape distortion of the signals, altering their specific features, like duration, amplitude, number of cycles which are crucial for AE characterization. Due to dispersion, an AE event from a single source will be acquired with very different shape in distinct sensor positions and the differences will be accumulated as the propagation path increases. In the present paper numerical simulations of wave propagation in metal plates are conducted. The aim is to investigate plate wave dispersion, not from the classical ultrasonics, but from the AE point of view, quantifying the effect of distance on the shape of the propagating pulses and the specific AE parameters. Indicative experiments on metal plates confirm the effect of distance on the wave parameters. Consequently, a procedure to "correct" the AE parameters based on the propagating distance between the source crack and the sensor is discussed. This way the original AE parameters of the signal as emitted by the source are calculated and the effect of distortion which masks the original content is cleared out. It is shown that any classification scheme based on AE parameters, should incorporate the information of the source location relatively to the sensor since long propagation distance causes strong changes in the waveform, masking the information of the original source.

8346-15, Session 4

Investigation of co-travelling solitary wave collisions in a granular chain

P. Anzel, C. Daraio, California Institute of Technology (United States)

We present investigations into the collision of co-travelling solitary waves in a granular chain. A piezo stack is pulsed twice to create two solitary waves within the chain in rapid sequence and with different amplitudes-one small and one large-and the larger solitary wave (which travels faster) overtakes the smaller one. The progression of the waves is measured with calibrated piezoceramic discs embedded within selected granular particles. These results are compared to a numerical model of discrete masses connected by non-linear springs. The time of flight and amplitude of the solitary waves are compared to analytical predictions and experimental results for individual waves. Similar to other solitary wave-carrying systems, the amplitudes of the waves are relatively unperturbed and the primary effect of their interaction is a phase-shift in both solitary waves. Additionally, the formation of secondary solitary waves due the collision is observed in both numerical and experimental results. These secondary waves travel in the same direction and have two orders of magnitude less energy than the primary waves. The effects of the amplitudes of the primary solitary waves, their position of interaction, and system pre-compression on the strength of the secondary solitary waves are probed both experimentally and computationally. Insight into solitary wave interaction will be valuable for fully understanding the behavior of a granular crystal excited at high frequencies, which may allow for improved non-destructive evaluation methods and will be relevant for the development of a novel acoustic phased array.

8346-16, Session 4

Monitoring the efficiency of plasticizer in fresh cement using ultrasound

D. G. Aggelis, T. E. Matikas, Univ. of Ioannina (Greece)

The importance of evaluating the quality of cementitious materials at an age as early as possible is well known. High performance cementitious materials usually include chemical admixtures like accelerators, plasticizers or air entraining agents in order to tailor the properties of the material at the fresh or hardened state. Ultrasonic methods have been developed for monitoring the hydration process. Measuring the transit time and amplitude of the pulse at regular intervals, the elastic modulus development with time can be calculated and therefore, the contribution of the admixtures can be evaluated. However, this requires monitoring for a period of at least a few hours, which although fast compared to the standard compressive test, still is not fast enough to allow decisions about accepting the material before placement in the construction forms based on the suitability of concrete. The general quality of concrete and specifically the contribution of the admixtures should be assessed immediately. In the present paper fresh cementitious material is examined by ultrasound. The excited frequency is varied in order to apply different wavelengths, which are influenced differently by the constituent materials. The effect of chemical plasticizer is examined through the release of air bubbles and the change in viscosity it imposes. Wave velocity vs. frequency curves for different mixes show that the existence of sand plays an important role due to interaction with different wave lengths. The possibility to characterize the effectiveness of chemical admixtures by a single dispersion and attenuation measurement just after mixing is discussed.

8346-17, Session 5

Thermal conductivity reduction in phononic crystals: interplay of coherent versus incoherent scattering

I. El-Kady, Sandia National Labs. (United States)

Phonons propagating in a Phononic Crystal (PnC) lattice undergo two distinct types of scattering mechanisms coherent and incoherent scattering. Coherent Scattering is brought about by Bragg scattering events which result primarily in the creation of Phononic gaps where the propagation of phonons are prohibited, anomalous and flat dispersionless bands, and negative phonon group velocities. The combination of these phenomena results in a rich complicated band structure (dispersion) compared to that of the bulk solid in absence of PnC structuring accompanied by a redistribution of the phononic density of states (DOS). Incoherent boundary scattering, on the other hand, arises as a consequence of scattering due to the mechanical impedance mismatch between the host background matrix and the scattering centers, though the interference is not coherent. While coherent scattering phenomena have been readily validated to affect the low frequency (RF) phonons, in this communication we question the possibility of extending these effects to the high frequency THz phonons that dominate heat transfer process. We validate our claimes by presenting detailed theoretical data that is supported by experimental measurements. These findings may have a profound impact on the development of a new class of thermoelectric materials and devices, paving the way of ultra-high ZT devices.

8346-18, Session 5

High-frequency phonon boundary scattering effects on the transport of heat in semiconductor nanostructures

M. Maldovan, Massachusetts Institute of Technology (United States)

Understanding and controlling high-frequency phonons in semiconductors has recently become important for developing novel thermoelectrics and efficient micro-, nano- and opto-electronic devices. We study the effects of high-frequency phonon boundary scattering on the thermal conductivity of nanomaterials across multiple length scales and temperatures. We use a Boltzmann transport model that includes the dependence of the phonon mean free paths on the propagation direction. We calculate the thermal conductivity of Si and Ge thin films and nanowires for temperatures between 20 K and 500 K and length scales from 10nm to bulk values and investigate the physical mechanisms affecting the transport of thermal energy. The results of our calculations are compared with experimental measurements of thermal conductivities and good agreement is obtained across a broad range of temperatures and length scales.

8346-19, Session 5

Dynamically tuned zero-gap phoXonic systems

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A full electrodynamic and elastodynamic multiple scattering approach is employed to describe the optical and acoustic modes, and to account for their mutual interaction both in time and frequency domain in one-dimensional phoXonic crystal slabs. We report on the occurrence of nonlinear acousto-optic interactions and demonstrate the effect of the hypersonic tuning of photonic Dirac points in the optical and telecom frequencies. Potential sensing capabilities are examined under moderate and strong acousto-optic interactions in the proximity of crossing photonic bands enabling light to slow down, stop or reverse.

Quarter-wave stack arrangements are considered in the optical (polymeric slab of pHEMA and epoxy) and IR (slab of Si and Silica) frequencies. Such structures support two bands that cross symmetrically, without forming a photonic gap. In the vicinity of the Dirac point (crossing bands), dynamic tuning achieves efficient transfer of energy between the bands using weak and slow modulations of the wave velocity. Finally, the effect of hypersonic attenuation is also investigated.

8346-20, Session 5

Mechanical impedance in periodic media

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Recently there has been a surge in interest in acoustic meta-materials. In analogy to optical meta-materials, much of the interest is centered on the possibility of periodically patterning materials to create negative effective densities and moduli, with possible applications in superlensing, cloaking and liquid crystal sensing. Here, we examine a different possibility: that periodically patterned materials may also allow for dramatic increases in the mechanical transduction efficiency of signals into and out of the mechanical domain.

As an example, when a time harmonic optical force F is applied along some plane within a periodically patterned device, the resulting time-averaged harmonic power Pm generated within the medium is inversely proportional to the specific mechanical impedance Z: P_m=F^2/2AZ.

While the proper way to calculate F has been known for over a century, the calculation of Z continues to be revisited, with no less than five different definitions being proposed within the last 8 years. The principal aim of this talk will to explore different approaches to define effective mechanical impedance, and discuss the implications for mechanical transduction. In particular, we find that in many situations, Z reduces to the product of an effective density and the group velocity of the medium-a surprisingly simple result with practical applications. Experimental efforts at Sandia to modify Z and hence mechanical power flow will be presented.

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8346-21, Session 6

The implication of Dirac cones at k=0 in photonic and phononic crystals

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For EM waves, Dirac cones can be obtained for simple 2D photonic crystals consisting of dielectric cylinders in square or triangular lattices by employing accidental degeneracy of monoploar and dipolar modes. Such photonic crystals can behave as if they have permittivity and permeability simultaneously equal to zero, and such "zero refractive index" material is one in which waves do not experience any spatial phase change.

For elastic waves, Dirac cones at k=0 can be obtained in phononic crystals consisting of cylinders in a square array embedded in a host matrix, by exploiting accidental degeneracy of dipolar and quadrupolar scattering resonances. Interesting physics specific to an elastic wave system emerges near the Dirac point. For example, near the elastic wave Dirac point at k=0, the Dirac cone mode dispersion is isotropic, meaning the equi-frequency surface is a circle, but the Dirac cone eigenmodes exhibit the so-called "super-anisotropy" in the sense that only purely transverse waves are allowed along certain directions while only longitudinal waves are allowed along other directions. In addition, the

system behaves as if the effective density and 1/C44 is zero, while C11 = -C12 near the Dirac point.

8346-22, Session 6

Topological photonic structures

V. Yannopapas, Univ. of Patras (Greece)

In topological phases of matter, properties like conductivity and optical reflectivity are not determined by the crystalline order but by the topological order of the electronic states. Such states of matter are the integer quantum Hall state [1], and the recently discovered topological insulators [2]. A typical example of an integer quantum Hall state is graphene under the influence of a periodic magnetic field while topological insulators are binary alloys based on Bi, e.g., Bi1-xSbx. Here we propose that we can have topological states of the electromagnetic field in certain metamaterial structures operating as photonic analogues of the above electronic states of matter.

We show in particular, that a gyrotropic (chiral) medium supporting a longitudinal-wave excitation exhibits a Dirac point in the corresponding photon dispersion lines. By breaking the time-reversal symmetry in such a medium, the dispersion relation resembles the energy dispersion of a spin-polarized two-dimensional electron gas with Rashba spin-orbit coupling. The resulting split bands of the dispersion relation correspond to nonzero Chern numbers implying the existence of nontrivial topological states of the electromagnetic field [3].

We also show that a tetragonal lattice of weakly interacting particles with uniaxial electromagnetic response is the photonic counterpart of topological crystalline insulators, a new topological phase of atomic band insulators [4]. Namely, the frequency band structure stemming from the interaction of resonant modes of the individual cavities exhibits an omnidirectional band gap within which gapless surface states emerge for finite slabs of the lattice [5]. Due to the equivalence of a topological crystalline insulator with its photonic analog, the frequency band structure of the latter can be characterized by a Z2 topological invariant.

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8346-23, Session 6

Optical sensing elements based on ordered semiconductor and metal nanoparticle arrays and surface plasmons

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The optical properties of regular nanoparticle arrays consisting of spherical semiconductor and noble metal nanoparticles are providing interesting aspects for the development of novel and powerful sensor concepts. In this contribution, we demonstrate femtosecond laser-induced transfer of metallic and semiconductor thin films as a unique tool for realizing controllable 2D and 3D structures of any desired configuration of exactly spherical nanoparticles, having diameters between 40 nm and 1500 nm. Furthermore, the particles can be combined with 3D photonic structures fabricated using two-photon polymerization, providing new approaches to the development of nanophotonic devices and 3D metamaterials. Here, we demonstrate an optical sensor with a sensitivity of 365 nm/RIU and a figure of merit of 21.5 in the visible spectral range. The optical properties of single and arrays of nanoparticles are investigated spectroscopically and by scattering of surface plasmon-polaritons (SPPs). SPP-scattering constitutes a novel method to obtain insight into the contribution of different multipole moments to the scattering properties of the particles. Moreover, the interference of two or more SPP beams on thin metal films and the novel concept of SPP-ARROWs provide promising applications to nanophotonic metrology and sensing. As an example, we demonstrate measurements of femtosecond SPP pulse durations and thin film dispersion using first- and second-order SPP autocorrelation. The experimental results are supported by theoretical modelling using the Green's function method, FEM, and FDTD simulations.

8346-24, Session 6

THz hyperbolic metamaterials made of polaritonic media

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Hyperbolic metamaterials, i.e. anisotropic uniaxial systems with hyperbolic dispersion relation, have attracted recently more and more attention, due to the great potential that they show in imaging applications. The realization of such metamaterials in the THz regime is a particularly interesting problem, able to give unique solutions in imaging and security applications, as it combines the great potential of the hyperbolic dispersion relation with that of the THz radiation in imaging and security.

Although hyperbolic metamaterials in the optical regime can be realized quite easily employing metals, in the THz regime the strong spatial dispersion shown by metal-based systems impedes seriously the hyperbolic dispersion properties of those structures. A category of materials that naturally respond in the THz regime and can greatly replace metals in creating THz metamaterials is polaritonic materials. In polaritonic materials THz radiation can excite optical phonons, leading to strong resonant response in the permittivity of the material, involving both high positive and negative permittivity values. Thus, such materials can nicely replace both metals and high-index dielectrics for the creation of THz metamaterials.

In this work we study (both theoretically and experimentally) the transmission properties of two-dimensional periodic systems made of LiF polaritonic rods in NaCl or KCl host. We examine the potential of those systems to give hyperbolic dispersion relation and other interesting metamaterial properties, and we demonstrate sub-wavelength resolution imaging in those systems.

8346-25, Session 7

Photonic crystal fiber monitors for intracellular ice formation

R. M. Wynne, E. Battinelli, Villanova Univ. (United States)

An all-silica steering wheel photonic crystal fiber (SW-PCF) device with real-time analysis for cellular temperature sensing is presented. Results are provided for water-filled SW-PCF fibers experiencing cooling down near -40°C. Cellular temperature sensors with fast response times are of interest particularly to the study of cryopreservation, which has been influential in applications such as tissue preservation, food quality control, genetic engineering, as well as drug discovery and in- vitro toxin testing. Results of this investigation are relevant to detection of intracellular ice formation (IIF) and better understanding cell freezing at very low temperatures.

IIF detection is determined as a function of absorption occurring within

the core of the SW-PCF. The SW-PCF has a 3.3µm core diameter, 125µm outer diameter and steering wheel-like air hole pattern with triangular symmetry, with a 20µm radius. One end of a 0.6m length of the SW-PCF is placed between two thermoelectric coolers, filled with ~0.1µL water This end is butt coupled to a 0.5m length of single mode fiber (SMF), the distal end of the fiber is then inserted into an optical spectrum analyzer. A near-IR light source is guided through the fiber, such that the absorption of the material in the core can be measured. Spectral characteristics demonstrated by the optical absorption of the water sample were present near the 1300-1700nm window region with strongest peaks at 1350, 1410 and 1460nm, further shifting of the absorption peaks and line width narrowing are possible at cryogenic temperatures making this device suitable for IIF monitoring applications.

8346-26, Session 7

An iterative search method for strain measurement in EFPI sensors

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In this paper, a new method is given for estimating strain in extrinsic, Fabry-Perot, interferometric (EFPI) fiber-optic sensors under sinusoidal excitation. The algorithm is iterative and uses a mean-squared-error objective function. It has low complexity making it appropriate for low-cost applications and provides an estimate of the resting strain as well as the maximum time-varying strain due to the excitation. It is shown that, for a broad range of parameters, the algorithm converges to the global minima with a high degree of probability. Empirical test results for two fiber-optic sensors with different gauge lengths are shown to compare well with results from a resistive strain gauge. We also present ideas related to implementing this algorithm into real systems.

8346-27, Session 7

Performance optimization of bundled fiber optic displacement sensors

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Bundled intensity-modulated fiber optic displacement sensors offer high-speed (kHz-MHz) performance with micrometer-level accuracy over a broad range of axial displacements, and they are particularly well-suited for applications where minimally invasive, non-contacting sensing is desired. Further, differential versions of these sensors have the potential to contribute robustness to fluctuations environmental conditions. The performance limitations of these sensors are governed by the relationship between axial displacement and measured power at the locations of receiving fibers within a bundled probe. Since the propagating transmission's power level is spatially non-uniform, the relative locations of receiving fibers within a bundled probe are related to the sensor's output, and in this way fiber location is related to sensor performance.

In this paper, measured power levels are simulated using a validated optical transmission model, and a genetic algorithm is employed for searching the intensity-modulated bundled displacement sensor's design space for bundle configurations that offer high-overall combinations of desired performance metrics (e.g., linearity, sensitivity, accuracy, axial displacement range, etc...). The genetic algorithm determines arrangements of fibers within the bundled probe that optimize a performance-based cost function and have the potential to offer high-performance operation. Multiple converged results of the genetic algorithm generated using different cost function structures are compared. Two optimized configurations are prototyped, and experimental sensor performance is related to simulated performance levels. The prototypes' linearity, sensitivity, accuracy, axial displacement range, and sensor robustness are described, and sensor bandwidth limitations are discussed.

8346-28, Session 7

Photonic crystal fiber nanospectrometer chemical agent detection

R. M. Wynne, M. Reimlinger, W. Harkins, Villanova Univ. (United States)

A silica-based steering wheel core photonic crystal fiber (SW-PCF) with a nano-featured spectrometer chemical agent detection configuration is presented. The spectrometer chip acquired from Nano-Optic DevicesTM can reduce the size of the spectrometer down to a coin. Results are provided for PCF structures filled with sample materials for spectroscopic identification. Portable and compact spectroscopic detectors with long interaction lengths (> few mm) specially outfitted for extreme environmental conditions are of interest to both military and civil institutions who wish to monitor air/water composition. The featured PCF spectrometer has the potential to measure optical absorption spectra in order to detect trace amounts of contaminants in gaseous or aqueous samples. The SW-PCF measured spectra agreed with reference spectra.

The absorption spectrum of the SW-PCF detection system was measured as a function of the fiber interaction length and material volume. The SW-PCF has a core diameter of 3.9µm, outer diameter of 132.5µm. A nearly 50 cm length of the SW-PCF is butt-coupled to the surface of a thin nano-featured chip. The remaining end of the SW-PCF section is coupled to a laser light source centered at =635nm. The diffraction pattern produced by the nano-featured chip is captured by an objective lens and CCD camera for image analysis. The position of the intensity pattern extracted from the analyzed image indicates the spectral components of the absorption characteristics for the detected sample. This nano-featured spectrometer offers spectral resolution down to 0.1nm that makes it possible to detect substances with very detailed spectral features.

8346-29, Session 7

Self-repairing waveguide sensor with highly repeatable strain response

Y. J. Song, K. J. Peters, North Carolina State Univ. (United States)

In this article we present experimental demonstrations of a self-writing polymer waveguide strain sensor that can self-repair after failure. The original sensor is fabricated between two multi-mode optical fibers by ultraviolet (UV) lightwaves in the photopolymerizable resin system via a self-writing process. After the original sensor fails, the repaired sensor is grown from the existing waveguide to bridge the gap between the two optical fibers. Multiple self-repairs of a single sensor were demonstrated. The sensor interrogation is performed by measuring the infrared (IR) power transmission between the two silica, multimode fibers. The IR power transmission was measured through the original and repaired sensors at various strain levels during cyclic loading. When fabricated directly on a polyimide sheet, the sensor strain response showed considerable hysteresis. However, when the packaging was changed to the sensor encapsulation within a polyimide capillary, the cyclic response showed almost no hysteresis and was very repeatable between the original and rewritten sensors. Reducing the length of the sensor also decreased the initial bending of the fabricated sensor and yielded a better performance. One potential defect was identified, that of an air bubble trapped in the enclosed capillary, and its effects on the strain response measured. However, careful fabrication of the sensor packaging was able to eliminate this defect. Finally, the revised sensor packaging also increased the strength changed the dominate failure mode of the sensor, from axial deformation to bending of the sensor. This increased strength will improve the performance of the sensor when embedded in material systems.

8346-47, Poster Session

Aerosol printed strain sensors subjected to large strain

B. Thompson, H. Yoon, Tennessee Technological Univ. (United States)

In recent years, printed electronics have received attention as a method to produce low-cost macro electronics on flexible substrates. Inkjet and aerosol printing have been the primary printing methods used for producing passive electrical components, transistors, and a number of sensors. In this paper, a custom aerosol printer is utilized to create highly flexible strain sensors that can be used in applications such as feedback control of electroactive polymer actuators. These sensors are created by aerosol printing combinations of single wall carbon nanotubes, silver nanoparticles, and silicone. Mixtures of single wall carbon nanotubes and silver nanoparticles act as the conductive material while the silicone contributes to the sensors' elastic behavior and adheres to the host structure. After printing the different material combinations onto highly elastic substrates, the sensors are subjected to large strain loading and evaluated based on resistance change, maximum strain, and linearity. The proposed sensor could potentially be an effective and cost effective method for measuring strain of highly elastic structures.

8346-48, Poster Session

Diagnosis at a glance of biological non-Newtonian fluids with Film Interference Flow Imaging (FIFI)

R. Hidema, H. Furukawa, Yamagata Univ. (Japan)

In our body, a thin liquid layer exists between bone and bone in joint. It is called synovial fluids, which contain biopolymers such as hyaluronic acid and mucin. It is thought that these polymers play critical roles on the smooth motion of the joint. Indeed, luck of biopolymers in synovial fluid cause joint pain. Here we study the effects of polymer in thin liquid layer by using an original experimental method called Film Interference Flow Imaging (FIFI). A vertically flowing soap film containing polymers is made as artificial biological fluids. The thickness of water layer is about 4 m sandwiched between surfactant mono-layers. The interference pattern of the soap film is linearly related to the flow velocity in the water layer through the change in the thickness of the film. Thus the flow velocity is possibly analyzed by the FIFI. The grid turbulence was made in the flowing soap films containing the long flexible polymer polyethylene oxide (PEO, Mw=3.5x10^6), and semi-rigid polymer hydroxypropyl cellulose (HPC, Mw > 1.0x10^6). The decaying process of the turbulence is affected by PEO and HPC respectably. In the case of PEO, the turbulence became smoother, while the turbulence slightly affected by HPC. We assumed such a difference between PEO and HPC is due to the dynamics of polymer stretching, which is observed and analyzed by FIFI. We believe the FIFI will be applied in the future to examine biological fluids such as synovial fluids quickly and quantitatively.

8346-49, Poster Session

An introduction to a 'Cognitive network system' that establishes a 'to and fro' communication between a structure and the cognitive sensor network by processing the structure responses and the sensor feedbacks through a TRIZ system

D. Rajendra, Univ. of Pittsburgh (United States) and University of Tulsa (United States)

The idea of whether we should be using a multi agent theory or any viable multi sensor data fusion theory among sensors is undoubtedly a necessary step towards adaptive probing. But that is clearly a short sighted solution as the emergent of self healing smart materials are coming into the big picture now a days. The fact is that sensors are deployed to get info from the structure but the structure needs info from the sensors as well to pave path for the reliable deployment of self healing materials. In a time where the space industry is opting for commercialization, it is inevitable that we ensure safety via conditional monitoring with a real time non destructive testing. That begs for a system level cognitive thinking approach to establish techniques that bodes well with the reality and future envisioning. This will give a new perspective on creating smart materials that are with qualities like 'self healing' ability or possessing 'immunization' as like a superior fatigue strength but not limited. Ultrasonic sensors arranged as a spatially distributed cognitive sensor networks system can transmit and receive ultrasonic guided waves to interrogate structure defects such as cracks and corrosion. But can they used to give feedback to the structure This paper develops a hypothetical framework of a "cognitive system" through TRIZ (Theory of Inventive Problem Solving) that includes the network of sensory receptors, structure responses, sensor responses and the functionalities like immunization and self healing of the structure involved. This would make the transition from a model to a reality as smooth as possible. The performance was verified by finite element techniques on a thin plat structure.

8346-50, Poster Session

Injecting "smartness" into distributed structures

P. S. Sapaty, National Academy of Sciences of Ukraine (Ukraine)

A universal approach will be presented that can convert any distributed structures (skyscrapers, bridges, highways, robotized teams, critical national and international infrastructures, battlefields, etc.) into a sort of living organisms exhibiting consciousness and will, pursuing global goals, self-analyzing their states and recovering from indiscriminate damages, also timely reacting on asymmetric events. The approach is based on implanting numerous locally communicating copies of a special intelligent module into important system points (if needed, in a stealth manner) which collectively interpret compact high-level mission scenarios. The latter, capable of being created on the fly, are injected from any module and then split, modify, replicate and self-spread in a virus-like mode throughout the whole structure, creating distributed operational infrastructures and orienting local and global behavior in the way needed. Details of the related scenario language and its distributed networked interpreter will be revealed along with a variety of programming examples from different fields (ground, aerial, maritime, and space).

P. Sapaty, "Air & Missile Defense with Spatial Grasp Technology", Unmanned Systems Asia 2011, Pre-Conference Workshop B.

P. Sapaty, "Meeting the World Challenges with Advanced System Organizations", Informatics in Control Automation and Robotics, Lecture Notes in Electrical Engineering, Vol. 85, 1st Edition, Springer, 2011.

http://isarob.org/index.php?main_page=invited_speakers

8346-51, Poster Session

Smart-label-based behavior monitoring IOT system for the infrastructures under harsh environments

Z. Zhou, Dalian Univ. of Technology (China)

Structural behavior can be characterized as deformation, large strain, crack or failure, foundation release or scour, etc. As such, displacement is the significant parameter to assess the performance of structural stability and safety using the behavior information. A real-time, durable, reliable and low-cost monitoring technique for the exterior and internal displacements is still in great need for the infrastructures under harsh environments. In this paper, a novel displacement field technique

based on the smart-labels is proposed to monitor behavior of the infrastructures. The smart-labels mainly can be set up on any kind of wireless tags, such as magnetic matters, radio frequency identification (RFID) tags and even global position system (GPS) measuring sensors, etc. Each node can be used to describe and identify the local structural information at the fixed point, which can be used to configure a new network, internet of things (IOT). In practice, these smart-labels are packaged in certain highly-protected block, namely smart block or rock. The smart block can be attached or embedded directly on the structure so that the information of position and physical parameters can be recorded and transmitted accordingly. The proposed system can be regarded as a real-time, durable, reliable and low-cost displacement field monitoring IOT. And it is feasible to be widely applied in infrastructures ranging from high geological slop, dam embankment and bridge foundation.

8346-52, Poster Session

Nd:YAG pulsed laser based flaw imaging techniques for noncontact NDE of welded zones of aluminum plates

W. Park, C. Lee, T. Kim, S. Park, Sungkyunkwan Univ. (Korea, Republic of)

Recently, the longitudinal, shear and surface waves have been used to an ultrasonic wave exploration method to identify internal defects. The non-destructive testing using ultrasound is one of the key non-destructive inspection techniques for a health assessment about nuclear power plant, aircraft, ships, automobile manufacturing. Accordingly, a noncontact NDT method is implemented to detect the damage of a plate-like structure and to identify the location of the damage in this study. To achieve this goal, laser equipment is used to generate a guided wave and scans a specific area to find damage location. ND: YAG pulsed laser is used to generate Lamb wave and piezoelectric sensors are installed to measure structural responses. A stiffened aluminum plate is investigated to verify the effectiveness and the robustness of the proposed NDT approach. A notch is a target to detect, which is formed at a welded zone between a main plate and a stiffener. The damage-sensitive features are extracted by comparing the time of flight of the guided wave obtained from the piezoelectric sensors and make use of the flaw imaging techniques of aluminum plate.

8346-53, Poster Session

Simultaneous acoustic and dielectric real time curing monitoring of epoxy systems

A. S. Paipetis, G. Gkikas, S. A. Grammatikos, D. G. Aggelis, Univ. of Ioannina (Greece)

The attainment of structural integrity of the reinforcing matrix in composite materials is of primary importance for the final properties of the composite structure. The detailed monitoring of the curing process on the other hand is paramount (i) in defining the optimal conditions for the impregnation of the reinforcement by the matrix (ii) in limiting the effects of the exotherm produced by the polymerization reaction which create unwanted thermal stresses and (iii) in securing optimal behavior in matrix controlled properties, such as off axis or shear properties and in general the durability of the composite.

Dielectric curing monitoring is a well known technique for distinguishing between the different stages of the polymerization of a typical epoxy system. The technique successfully predicts the gelation and the vitrification of the epoxy and has been extended for the monitoring of prepregs. On the other hand, recent work has shown that distinct changes in the properties of the propagated sound in the epoxy which undergoes polymerization is as well directly related to the gelation and vitrification of the resin, as well as to the attainment of the final properties of the resin system.

In this work, a typical epoxy is simultaneously monitored using acoustic and dielectric methods. A purpose made fixture is manufactured to allow for secure positioning of the sensors. The system is isothermally cured in an oven to avoid effects from the polymerization exotherm. Typical broadband sensors are employed for the acoustic monitoring, while flat interdigital sensors are employed for the dielectric scans. All stages of the polymerization process were successfully monitored and the validity of both methods was cross checked and verified.

8346-54, Poster Session

Application research of distributed optical fiber temperature sensor in power system

J. Wang, China Jiliang Univ. (China)

Recently, many research projects of TDS system are carried out in China. Some of them focused on improving performance of the system. And the others focused on using the system in variety engineering projects, such as tunnels, oil pipelines, dam, oil wells, subway, coal mine, power cable and so on.

In power system, temperature is an important parameter. There many hot points in power system, such as large transformers, high voltage switchgear, high voltage cable channel and cable joints. Power system fires caused by high temperature of these parties happened every year. Great loss was caused. Interfered by strong electromagnetic field of power equipment, traditional thermometer, such as thermocouples and infrared thermometer can not work properly. In the DTS temperature measurement system, the sensing fiber is not charged, anti-electromagnetic interference. So DTS is an ideal Instrument for temperature measuring On such occasions.

Large transformers, high voltage switchgear and high voltage cable channel are key positions of power system in fire prevention. So methods installing DTS system in these parts are important study content. Temperature of transformer oil is very important to safe operation of large transformers. In order to measuring the temperature value, sensing optical fiber must be embedded in transformer. In temperature monitoring of high voltage switchgear, sensing fiber should be coiled into specific temperature probe in a certain size. For the high-voltage cable channel temperature monitoring, it is important that sensing fiber lay together with the power cable underground.

DTS has been successfully applied to power system in temperature monitoring and fire prevention. The two typical engineering projects in Shanghai World Expo underground substation and Shanghai Caojing thermal power plant are demonstrated. Test results show that reaction time is about 15s and spatial resolution can reach 5cm.

DTS system can measure temperature value of every point of power system real-timely. When the temperature exceeds the temperature setpoint an alarm signal will be send out. So using the DTS in power system can effectively prevent fires and improve the efficiency of the Power Grid.

8346-55, Poster Session

Structural health monitoring of materials used in aerospace industry using combined electrical methods

A. S. Paipetis, S. A. Grammatikos, G. Gkikas, Univ. of Ioannina (Greece)

The increasing use of composite materials in aerostructures has prompted the development of an effective structural health monitoring system. As known a safe and economical way of maintenance in needed in order for composite materials to be used more extensively. Critical defects may be induced during the scheduled repair which may degrade severely the mechanical properties of the structure. Low velocity impact damage is one of the most important and very difficult to detect as long as delaminations and flaws are generated and multiplied during the life of the structure. In that sense large areas need to be scanned rapidly

and efficiently without removal of the particular components. For that purposes an electrical potential mapping along with dielectric scanning method were employed for the identification of damage and the structural degradation of aerospace materials. Electric current was injected and used as for internal source for the thermal excitation of aerospace Alumininun (Al) and Carbon Fiber Reinforced Polymer (CFRP) structures both damaged and undamaged. Electrical potential mapping technique is performed for the impact damage inspection. 16 electrodes were placed at certain locations around the damaged area of the structure. For that purpose, a simple algorithm was deployed and the experimental data were imported in Matlab environment for the image construction. For a purposes of the dielectric scanning, a purposely made rigid flat interdigital sensor was employed for the scanning of the damaged area, providing information about the structural degradation both for the damage and undamaged aerospace structures. The experimental results of the two methods were compared and evaluated.

8346-56, Poster Session

Development of PVDF-ultrasonic sensor based aircraft landing gear control system: a work in progress

C. Byrappa, Bangalore Institute of Technology (India)

The paper presents a novel approach in order to develop a control system to help in aircraft landing which is intended to be independent of the currently employed radar based technology and uses PVDF based ultrasonic sensor to assist in landing. Ultrasonic sensor works on the principle that a sonic pulse is emitted from the sensor; when the pulse bounces off of an object, an echo is returned. This can be used to compute the distance of the aircraft from the land. It can be used as a feedback with appropriate signal conditioning at place to correct the error in rolling, pitching and yawing of the aircraft by employing a PID controller as the main decision making unit. The PID controller can be programmed for catering the standards of multiple navigation systems. The research application would help in reducing the number of accidents that take place round the globe due to radar failure. On a much serious note the most common problem today is that of bird strike which effects aircrafts both civilian and military. The sensor that is being used has two dimensional operations with both horizontal and vertical plane of operations capable of detecting even small birds as cone pulses are released by the sensors. Using multiple sensors we can even ensure that the landing gear has retracted completely in position for landing. The control system can as well be used for a wide range of combat operations and monitoring.

8346-57, Poster Session

Temperature and strain sensing techniques using Brillouin optical time domain reflectometry

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Distributed strain sensing based on Brillouin Optical Time Domain Reflectometry (BOTDR) is seen as one of the most promising monitoring tools for assessing the performance of civil and geotechnical structures. Due to the distributed nature of fiber optic sensor, BOTDR not only useful to monitor the structures deformation in terms of global behavior, but also effectively detects anomalies in localized scale. Since the sensor has the ability to measure strain and temperature simultaneously, it is important that methods to separate the temperature effects are fully understood. Four known methods used to compensate temperature from BOTDR strain readings are briefly reviewed. Regardless of what method being used, this paper aims to clarify the importance of firstly calibrating the thermal characteristic of optical cables and determine the coefficient thermal expansion of the measurement host or structure. Example of BOTDR thermal measurement of an earth retaining structure is presented.

8346-58, Poster Session

Development of a guided wave-based concrete strength estimation system using an integrated smart sensor

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During the construction of concrete structures, real-time monitoring for their strength development is very crucial to determine the structure's readiness for in-service. However, it is very hard to estimate the compressive strength of the concrete nondestructively and in real-time. To provide the solution for this limitation, this study proposes a guided wave-based concrete strength estimation model using an embedded smart sensor system. Because the guided waves could not propagate clearly inside the concrete, an integrated smart sensor was developed by attaching two piezoelectric ceramic sensors on a thin steel plate that could provide a propagating path for the guided waves. Because the boundary condition of the steel plate is changed according to the variation of the concrete strength, the guided wave signal obtained from the piezoelectric sensors might be changed with a certain pattern affected by the boundary condition. Therefore, the strength of the concrete can be estimated by analyzing the pattern-variations of the guided wave signals. To confirm the feasibility of the proposed methodology, an experimental study using a concrete specimen with the aforementioned embedded smart sensor system is carried out and the optimized strength estimation model is derived throughout a regression analysis.

8346-59, Poster Session

Damage detection and identification using support vector machines and neural networks

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A critical part of Structural health monitoring is the accurate detection of damages in the structure. This paper presents the results of two multi-class damage detection and identification approaches based on using Support Vector Machine and Neural Networks. SVM is relatively new and an efficient pattern recognition algorithm. The article under test is a fiber composite panel modeled by FEM. Static strain data are acquired at 5 predefined locations and mixed with Gaussian noise to simulate performance of real strain sensors. Strain data are then normalized by the mean of the strain values. Two sets of experiments are performed for the performance evaluation of the classifier. Each set of experiments consists of one healthy structure and two damaged structures with one and two small cracks. For each experiment, 90 simulations are performed for each case with varying material properties and loading conditions to replicate the uncertainties in real structures. Classifier models are trained with 70% of these samples and the remaining 30% samples are used for validation. The objective of this experiment is to detect the presence of damage. In this two class problem the average damaged detection accuracy for ANN and SVM are 93.2% and 96.66% respectively. The objective of second experiment is to detect the nature of the damage. In this three class problem the average prediction accuracy of the nature of the damage for ANN and SVM are 83.5% and 90.05% respectively. Results suggest that for noisy data, SVM may perform better than ANN for this problem.

8346-60, Poster Session

Automated machine vision approach for in situ localization and classification of corrosion defects

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This work introduces a novel approach of corrosion damage diagnosis corrosion classification based on image processing for quantitative evaluation of stonework degradation. This methodology can be applied in situ in association with a variety of non-destructive monitoring schemes, and on images acquired from several imaging modalities, capturing from micro- to macro-scale characteristics. Once corroded areas have been accurately detected, they are subsequently processed in order to extract some robust features indicating structural aspects of decay. The extracted features are selected to form a multivariate feature space which in turn is clustered through unsupervised clustering techniques to obtain the different types of corrosion.

Introduction

The degradation phenomena encountered on stonework form an aspect of high importance nowadays. Several investigations were carried out with the aim of studying the factors, extent and phenomenology of stone decay [1]. In a polluted environment, the most frequently observed decay phenomena on stone surfaces are the formation of black crusts. Thus the necessity of developing robust techniques of estimating the characteristics of corrosion is a prerequisite for determining accurate reconstruction strategies.

The methodology is tested across a large collection of images depicting corrosion damage of various phenomenologies which have been illustrated in terms of different monitoring modalities capturing from micro- to macro-scale characteristics. Further to evaluating the method accuracy in extracting corrosion topology and extent we also aim at quantizing the severity of degradation and the efficacy of cleaning interventions in terms of accurate statistical metrics based on multivariate tests of statistical significance.

Materials & Methods

In order to address the effective shape detection of decay spots, we tested a category of local morphological operators in combination with sensitive blob detectors to approach the exact topology of decay regions on the surface matrix. A Morphological fusion algorithm was finally proposed to expand the areas detected by the local region growing approach up to the size derived by the morphological operators thus guaranteeing better segmentation results. A further contribution of this work is finally that it attains to establish associations between the type of corrosion and the shape of the decayed regions obtained through our automated multivariate statistical testing framework [3] Affine invariant shape features where extracted via considering the boundary cross-sections and evaluating the statistical norms on the cross-sections length distribution Furthermore, we have also developed an automated framework for clustering the degradation type according to shape, colour and size features. For the classification and the formation of corrosion feature clusters we have employed the unsupervised clustering (un-supervised refers to the algorithms ability to define the number of clusters without any prior knowledge regarding their shape, distribution etc) algorithm DBSCAN [3] based on forming clusters of arbitrary shape according to their proximity in the N-dimension feature space.

Results

Our automated framework is tested through wide image datasets depicting representative decay effects. The directionality of corroded areas is studied through evaluating the standard deviation on the distribution of corroded areas orientations. Larger values of standard deviation reflect corroded areas encountered at arbitrary orientations with respect to the surface axes. On the other hand, low values of standard deviation represent corroded regions directed at specific orientations. Compactness, eccentricity and higher order boundary moments were also studied in association with the severity of degradation and the type of corrosion. Summarizing the results derived by series of experiments, it was assessed that the decay patterns detected on more severely corroded surfaces tend to be more compact than decay regions remaining after the cleaning interventions or decay regions encountered on rain-washed surfaces. Thus, decay areas detected on untreated surfaces tend to form patterns of circle-like shape while the shape of decay regions detected on treated surfaces deviate significantly from circle. The tendency of decayed particles to attain a spherical shape can be adequately explained on account of the second thermodynamic law.

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8346-61, Poster Session

Transient thermography as a smart tool to assess cleaning interventions on marble surfaces

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Transient thermography (TT) is a thermographic technique where the sample surface is heated (usually by a short pulse, i.e. flash lamp) and the thermal transient at the surface is monitored by an infrared - thermal camera. In the last decade many experimental approaches using TT can be found in bibliography for the non destructive evaluation of near surface structures concerning the investigation of the depth or the diameter of different type of defaults. In this work, transient thermography was applied on marble samples collected on site before and after pilot cleaning interventions with the intention of evaluating cleaning interventions on marble surfaces. Temperature - time plots, displaying the intensity of pixels against time were plotted from the acquired transient - pulsed thermographic images, and the temperature falling rate for the investigated samples was studied. A first order kinetic model was used to describe the cooling rate of the investigated marble samples. From the result obtained, it is concluded that TT can be a skilful means of inspecting marble architectural surfaces, before and after cleaning.

8346-62, Poster Session

Optical sensors for electrical elements of a medium voltage distribution network

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The aging of most of the components of the National transmission and distribution system can potentially influence the reliability of power supply in a Medium Voltage (MV) network. In order to prevent possible dangerous situations, it is required an efficient assessment of selected diagnostic indicators - performed time by time or continuously during service - on electrical parts by means of reliable and potentially low-cost sensors.

In this framework, this paper presents results concerning the development and application of innovative optical sensors for the diagnostic of MV electrical components.

In particular two main research activities are described. The first concerns the development of a multisensor prototype for detection of pre-discharges in MV switchboards: it is based on the combination of three different types of optical sensors operating simultaneously to detect incipient failure and to reduce the occurrence of false alarms. The system is real time controlled by an embedded Personal Computer (PC) and by a software interface under LabView environment.

The second activity refers to a diagnostic tool to provide significant real time information about early aging of MV/Low-Voltage (MV/LV) transformers by means of its vibration fingerprint. A miniaturized Micro Electro-Mechanical System (MEMS) based unit has been assembled for vibration measurements, wireless connected to a remote PC and

controlled via LabView interface. Preliminary comparative tests were carried out with standard piezoelectric accelerometers in laboratory on a conventional MV/LV test transformer under open circuit and in short-circuited configuration.

8346-30, Session 8

Wireless vibration sensor using frequency modulation technique

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In recent years, wireless strain sensors have received attention as an efficient method to measure response of a structure in a remote location. Wireless sensors developed for remote measurement include RF wireless sensor modules and microstrip antenna-based sensors. In this paper, a simple wireless vibration sensor based on a piezoelectric sensor and the Frequency Modulation (FM) technique is developed for wireless measurement of vibrating structures. The piezoelectric sensor generates a voltage signal proportional to dynamic strain of the host structure. The voltage signal is then frequency modulated and transmitted wirelessly to a remote station by a simple FM transmitter circuit. Finally, the received signal is demodulated by a modified FM radio, and the vibration measurement data can be restored. Since this type of wireless sensor employs a simple FM circuit, they do not require any wireless signal protocols allowing a low-cost wireless sensor with a compact format. The proposed concept of the wireless vibration measurement is experimentally verified by measuring vibration of a cantilevered beam at several locations using multiple wireless sensors. The proposed sensor could potentially be an effective and cost effective method for measuring vibration of remote structures for dynamic testing or structural health monitoring.

8346-31, Session 8

System identification of a tied arch bridge using reference-based wireless sensor networks

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Vibration-based methods of structural health monitoring are generally founded on the principle that localized damage to a structure would exhibit changes within the global dynamic response. Upon this basis, accelerometers provide a unique health monitoring strategy in that a distributed network of sensors provides the technical feasibility to isolate the onset of damage without requiring that any sensor be located exactly on or in close proximity to the damage. While in theory this may be sufficient, practical experience has shown significant improvement in the application of damage diagnostic routines when mode shapes characterized by strongly localized behavior of specific elements are captured by the instrumentation array. In traditional applications, this presents a challenge since the cost and complexity of cable-based systems often effectively limits the number of instrumented locations thereby constraining the modal parameter extraction to only global modal responses. The advent of the low-cost RF chip transceiver with wireless networking capabilities has afforded a means by which a substantial number of output locations can be measured through reference-based testing using large-scale wireless sensor networks. In the current study, this approach was applied to the Prairie du Chien Bridge over the Mississippi River to extract operational mode shapes with high spatial reconstruction, including strongly localized modes. The tied arch bridge was instrumented at over 240 locations with single-axis accelerometers conditioned and acquired over a high-rate lossless wireless sensor network with simultaneous sampling capabilities. Acquisition of the dynamic response of the web plates of the rib girders was specifically targeted within the instrumentation array for diagnostic purposes. Reference-based operational modal analysis of the full structure through data-driven stochastic subspace identification is presented alongside finite element analysis results for confirmation of modal parameter plausibility. Particular emphasis is placed on the identification and reconstruction of modal response with large contribution from the rib girder web plates.

8346-32, Session 8

An RFID approach to corrosion monitoring

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Radio Frequency IDentification (RFID) technology is a fast growing capability enabling increased manufacturing efficiencies, improved supply chain operations, and enhanced logistics. In recent years, the characteristic associated with the RFID technology have been targeted by several industries to reduce reliance on wired and battery powered sensing systems including corrosion sensing systems.

This work details an extensive investigation of the performance of a passive Ultra-High-Frequency (UHF) RFID based system in changing environments to facilitate the technology exploitation for corrosion detection and propagation. The investigation addresses the impact of temperature and humidity variation on the system response as well as the impact of corrosion on the RFID sensor. Experimental results will demonstrate the ability of the RFID based system to detect variation in temperature, humidity and corrosivity both in controlled and uncontrolled environments. The approach presented in this research employs a cost effective methodology coupled with a simple concept leading to its ease of implementation into a commercial environment, particularly in an aircraft environment.

8346-33, Session 9

Application of non-destructive techniques to assess the state of Hagia Sophia's mosaics

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The church of Hagia Sophia in Istanbul, is a world heritage monument, decorated with mosaics dating back to the 4th century. A significant portion of the mosaic decoration that has survived through centuries, has been covered during the conversion and subsequent use of Hagia Sophia as a Mosque. Since 1935, when the monument was converted into a museum, conservation of the mosaic decoration has been in progress, including those that have been revealed from areas where the plaster was removed during the conservation process of the building. In the framework of a bilateral Greek-Turkish cultural cooperation agreement the decay state of the mosaics at the south upper gallery was assessed using an array of non-destructive techniques. Specifically, infrared thermography, fibre optics microscopy, ground penetrating radar and ultrasonics were employed to assess the current state of the mosaic decoration, focusing on the cohesion between the mosaic layer and the masonry structure. Areas where the risk of decohesion was high were identified. In addition, plaster areas where examined to verify the presence of underlying mosaics. The integrated use of non-destructive techniques proved to be a valuable tool to assess the state of mosaics.

8346-34, Session 9

Investigation of the contribution possibilities of non-destructive methods of testing for the diagnosis and quality control of building materials with emphasis given on sustainable construction

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In this work, the contribution potential of non-destructive methods of testing is studied in order to assess, diagnose and assert building materials' diagnosis & quality control, with emphasis given on sustainable construction.

To this end, the following techniques are implemented: fiber-optics microscopy, digital image processing, scanning electron microscopy, pulse/lock-in thermography, acoustic emission as well as ultrasounds.

Furthermore, in addition to the above, the maturity method for measurement of compressive strength is applied and correlated to the array of full field non-destructive methods of testing.

The results of the study clearly demonstrate how effective non-destructive methods of testing can be, in revealing and determining highly applicable & reliable data in a real-time, in situ and efficient manner.

8346-35, Session 9

Application of infrared thermometry and ultrasonic velocity for the investigation of the building materials of historic monuments of Dion, Greece

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The sanctuaries of Demeter and Asklepios are part of the Dion archaeological site that sits among the eastern foothills of Mount Olympus and covers roughly 100 hectares. The excavations finds from this area are dated since the Hellenistic, Roman and Early Christian times. The main building materials are limestones and conglomerates. Travertines, marbles, sandstones and ceramic plinths were also used. The materials consist mainly of calcite and/or dolomite, whereas the deteriorated surfaces contain also gypsum, recrystallized calcite and dolomite, various inorganic compounds, fluoroapatite, microorganisms and other organic compounds. Cracks and holes were observed in various parts of the stones.

The most proper approach to select effective methods for the structural and surface consolidation, the cleaning, the protection and the overall conservation of these structures is the knowledge of the processes contributing to their deterioration.

The influence of the water presence to the behavior of the materials was examined by in situ IR thermometer measurements. Temperature values increased from the lower to the upper parts of the building stones and they significantly depend on the orientation of the walls. The results indicate the existence of water in the bulk of the materials due to capillary penetration as it is observed an intensive surface and underground water presence in the whole surrounding area. To confirm these observations measurements of porosity, capillary rise, water and water vapor permeability were realized. These conditions led to loss of the structural cohesion and the surface stability of the material.

Stone consolidation treatments were applied to restore the cohesion of the weathered stones. The consolidation materials used were Rhodorsil RC 70 (Ethyl Silicate) and Rhodorsil RC 70 with Hombicat UV 100 or P25 Degussa (Titanium oxides). Non-destructive testing (IR thermometry and ultrasonic velocity) and evaluation was performed in order to assess the effectiveness of the consolidation, which was found to depend on the building material and the consolidation material used.

8346-36, Session 10

Critical and subcritical damage monitoring of bonded composite repairs using innovative non-destructive techniques

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Infrared Thermography (IrT) has been shown to be capable of detecting and monitoring service induced damage of repair composite structures. Full-field imaging along with portability are the primary benefits of the thermographic technique. Pulsed, pulsed phase and lock-in techniques are subsequently employed increasing the resolution of the system ensuring smaller defect as well as higher depth discrimination. In the case of loaded structures, on-line lock-in thermography may be performed in order to monitor damage propagation or/and concentration in the composite structure. Mechanical stresses in structures induce heat concentration phenomena around flaws. This gives the opportunity of critical and subcritical damage identification and monitoring during fatigue, as long as cycle loading plays the role of the heating source. At the same time, the Electrical Resistance Change Technique (ERCT) may be used as an innovative method for damage identification and monitoring. The measurement of electrical resistance changes of Carbon Fiber Reinforced Polymers (CFRPs) under load enables the monitoring of strain and damage accumulation. Along with the aforementioned techniques Acoustic Emission (AE) method is used in order to provide more information about the critical and subcritical damage. Damage accumulation due to cyclic loading imposes differentiation of certain parameters of AE like duration and energy. Within the scope of this study, infrared thermography is employed along with AE and ERCT methods in other to assess the bonded repair integrity and to monitor critical and subcritical damage induced by the mechanical loading. The combined methodologies were effective in order to identifying damage initiation and propagation of bonded composite repair.

8346-37, Session 10

Environmental barrier coating (EBC) durability modeling using a progressive failure analysis approach

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Ceramic matrix composites (CMCs) are getting the attention of most engine manufacturers and aerospace firms for turbine engine and other related applications. This is because of their potential weight advantage and performance benefits. As a protecting guard for these materials, a highly specialized form of environmental barrier coating (EBC) is being developed and explored in particular for high temperature applications that is greater than 1100 °C [1, 2]. The EBCs are typically a multilayer of coatings and are in the order of hundreds of microns thick. CMCs are generally porous material and this feature is somewhat beneficial since it allows some desirable infiltration. Their degradation usually includes coating interface oxidation as opposed to moisture induced matrix which is generally seen at a higher temperature. Variety of factors such as residual stresses, coating process related flaws, casting conditions, may influence the strength of degradation. The cause of such defects which cause cracking and other damage is that not much energy is absorbed during fracture of these materials. Therefore, an understanding of the issues that control crack deflection and propagation along interfaces is needed to maximize the energy dissipation capabilities of layered ceramics.

Thus, evaluating components and subcomponents made out of CMCs under gas turbine engine conditions is suggested to demonstrate that these material will perform as expected and required under these aggressive environmental circumstances. Progressive failure analysis (PFA) is being performed to assess the crack growth of the coating

under combined thermal and mechanical loading conditions. The PFA evaluation is carried out with the Genoa [3] software using a full-scale finite element model to account for the average material failure at the microscopic level. Results related to crack growth; behavior and life assessment of the coating at the interface of the EBC/CMC will be presented and discussed.

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8346-38, Session 10

Numerical analysis for structural health monitoring of a damaged composite panel using PZT actuators and sensors

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Reliable damage detection is crucial for assessing the integrity of a structure. In this paper, a numerical study of a composite panel fabricated to simulate a crack is undertaken using finite element methods (FEM). The damage to be considered is a crack which pre-exists in the structure but is not visible to the naked eye. The FEM models are developed for an undamaged and a damaged composite panel to compute the change in stress-strain distribution due to the existence of the crack. The model is validated using shear lag analysis applied at the crack. The results are verified experimentally by comparing the results for an undamaged composite panel and a composite panel fabricated with a simulated crack using the vacuum assisted resin transfer molding (VARTM) process. The responses for each panel are obtained using surface mounted PZT actuators and sensors. PZT is used to generate Lamb waves which produce stress throughout the panel thickness. Propagation characteristics of lamb waves and the related strain are varied by the presence of damage. The sensor results thus provide reliable information about the integrity of the structure. Numerical results are compared to the sensor output to ensure accuracy of the damage detection setup.

8346-39, Session 10

An optimal sensor configuration strategy for decentralized structural damage detection

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With the advancements of wireless communication technologies and smart devices, SHM is no longer a concept limited only to theory and research. In order to obtain optimum use of an SHM system, proper and accurate system designing and implementation is vital. The number of sensors to be employed in the system and their locations in the structure are two major factors considered during the design of the SHM system. A systematic design can minimize the number of sensors required in the system while increasing the accuracy and robustness of the system. Acquisition of structural response data in an SHM system is a crucial task which reflects on the success of the system. Compressive Sensing (CS), a very recent development, introduces the means of reproducing a signal with much less number of acquired samples than that defined by the Nyquist's theorem. Data acquisition with CS will vastly reduce the energy and storage cost associated with SHM systems.

In this paper an improved sensor configuration strategy with compressive sensing for distributed structural damage detection using WSNs is presented. An efficient sensor placement method is developed to maximize the network lifetime by optimally determining locations and number of sensors for a structure. Compressive sensing is used along with this new configuration strategy for sensor data acquisition. This strategy is implemented in a simulation environment and the results show that efficient SHM can be achieved through optimization of sensor configuration. Compressive sensing gives promising results with lower data rates than the traditional sampling methods with comparable accuracy.

8346-40, Session 10

Investigation of a moiré based crack detection technique for propulsion health monitoring

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The development of techniques for the health monitoring of the rotating components in gas turbine engines is of major interest to NASA's Aviation Safety Program. As part of this on-going effort several experiments utilizing a novel moiré pattern optical based concept along with external blade tip clearance and shaft displacement instrumentation were conducted on a simulated turbine engine disk as a means of demonstrating a potential optical crack detection technique. A moiré pattern results from the overlap of two repetitive patterns with slightly different periods. With this technique, it is possible to detect very small differences in spacing and hence radial growth in a rotating disk due to a flaw such as a crack. The experiment involved etching a circular reference pattern on a subscale engine disk that had a ~50mm long notch machined into it to simulate a crack. The disk was operated at speeds up to 12,000 RPM and the Moiré pattern due to the shift with respect to the reference pattern was monitored as a means of detecting the localized radial growth of the disk due to the defect. Additional experiments were made and blade displacement data was acquired using external blade tip clearance and shaft displacement sensors as a means of corroborating the data obtained from the optical technique. The results of the crack detection experiments and its associated analysis will be presented in this paper.

8346-41, Session 11

Turbine engine disk rotor health monitoring assessment using spin tests data

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Detecting rotating engine components malfunctions and structural anomalies is increasingly becoming a crucial key feature that will help boost safety and lower maintenance cost. However, achievement of such technology which can be referred to as a health monitoring attribute remains somewhat challenging to implement. This is mostly due to the fact that presence of scattered loading conditions, crack sizes, component geometry and material property hinders the simplicity of imposing such applications. Whereas exploitation of other approaches is ongoing through usage of other means of health monitoring and or nondestructive techniques to pre-detect hidden flaws and mini cracks before any catastrophic event occurs. These approaches or techniques extend more to assess materials' discontinuities and other defects that have matured to the level where a failure is very likely.

This paper is focused on presenting experimental data obtained from spin tests experiments of a turbine engine like rotor disk and their input to the development of a structural health monitoring and fault detection system. The data collected include blade tip clearance, tip timing

measurements and shaft displacements. The experimental results are gathered at a range of rotational speeds and the tests are conducted at the NASA Glenn Research Center's Rotordynamics Laboratory, a high precision spin rig. Measurements and data observations obtained from the experimental tests are evaluated and scrutinized to explore their relevance towards the development of a crack detection system and a supplemental physics based fault prediction analytical model.

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8346-42, Session 11

Real-time characterization of damage in metal matrix composites using IR thermography

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Infrared lock-in thermography is one of several non-destructive testing techniques which can be used for detection of damage in materials such as metal matrix composites. The purpose of this study is to develop an innovative non-destructive methodology for analyzing the thermal effects in metal matrix composites caused by fatigue. Mechanical stresses induced by cyclic loading cause heat release in the composite due to failure of the interface, which results in increasing the material's temperature. The heat wave, generated by the thermo-mechanical coupling and the intrinsic energy dissipated during mechanical cyclic loading of the sample were detected by an infrared camera. The coefficient of thermo-elasticity allows the transformation of the temperature profiles into stresses. Mechanical hysteresis phenomena were analyzed to identify the metrics of damage, which relates to thermal parameters, characterizing the level of damage of the material as a function of fatigue cycles.

8346-43, Session 11

Application of compressed sensing in full-field structural health monitoring

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Developing new sensing technologies to obtain desired and accurate diagnostic information more efficiently from limited sensors is one of the critical challenges in structural health monitoring (SHM). The limitation on the number of sensors is often due to high deployment cost or lack of feasible sensor placement region. The original theory of compressed sensing (CS) enables a signal to be recovered from incomplete information if the signal is known to be sparse in some domain. The work presented here extends this seminal theory into the field of SHM whereby diagnostic images are recovered from data acquired by spatially sparse (few) sensors. To demonstrate the validity of our approach, we recovered the full-field strain image from a rectangular test specimen using limited number of strain sensors and compared the strain field with one obtained using digital image correlation technique. We pose the problem as follows; let F be the number of discrete strain sensing nodes measuring the object S of the strain field at each pixel locations, where F is much smaller than S. Then if select measurements are taken using matrix A, then AS = F. The sparsest solution to such underdetermined linear system is estimated using L1-minimization. Indeed, it is observed that for a typical specimen configuration and loading, the strain field has sparse representation in Cosine and Fourier domains. The paper will also report experimental results and detailed accounts of the analytical formulation and extensions of the CS theory to solve some of the enduring challenges of SHM.

8346-44, Session 11

The application of compressed sensing to long-term acoustic emission-based structural health monitoring

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The acoustic emission (AE) phenomena generated by a rapid release in the internal stress of a material represent a promising technique for structural health monitoring (SHM) applications. AE events typically result in a discrete number of short-time, transient signals. The challenge associated with capturing these events using classical techniques is that very high sampling rates must be used over extended periods of time. The result is that a very large amount of data is collected to capture a phenomenon that rarely occurs. Furthermore, the high energy consumption associated with the required high sampling rates makes the implementation of high-endurance, low-power, embedded AE sensor nodes difficult to achieve. The relatively rare occurrence of AE events over long time scales implies that these measurements are inherently sparse in the spike domain. The sparse nature of AE measurements makes them an attractive candidate for the application of compressed sampling techniques. Collecting compressed measurements of sparse AE signals will relax the requirements on the sampling rate and memory demands. The focus of this work is to investigate the suitability of compressed sensing techniques for AE-based SHM. The work explores estimating AE signal statistics in the compressed domain for low-power classification applications. In the event compressed classification finds an event of interest, l1 norm minimization will be used to reconstruct the measurement for further analysis. AE measurements often suffer from the presence of noise sources with band-limited random and/or harmonic contents (e.g. rotating machinery). The suitability of Justice Pursuit to remove unwanted signal components is investigated.

8346-45, Session 11

Low-velocity impact damage identification using a novel current injection thermographic technique

A. S. Paipetis, S. A. Grammatikos, E. Z. Kordatos, T. E. Matikas, Univ. of Ioannina (Greece)

Composite materials are widely used especially in the aerospace structures and systems. Therefore, inexpensive and efficient damage identification is crucial for the safe use and function of these structures. One of the most frequent ways of damage in those structures is the low-velocity impact, usually imposed during the scheduled repair. Flaws caused by low-velocity impact are very dangerous as they often develop to delaminations. For that purpose an effective inspection of defects and delaminations is necessary during the service life the aerospace structures. Within the scope of this work, an innovative technique is developed based on current stimulating thermography. Electric current is injected in order to thermally stimulate Carbon Fiber Reinforced Polymers (CFRPs) and aerospace aluminium (Al) structures. For reference, both damaged and undamaged structures are inspected. Also low-velocity impact damaged structures at different energy levels are employed. In that sense, pulsed, pulsed phase and lock-in thermographic methods are subsequently utilized for the identification of low-velocity impact damage at various energy levels. In all cases conventional ultrasonics (C-scan) were performed for the validation and assessment of the results of the innovative thermographic method.

8346-46, Session 11

Sensor topologies for application of strain energy damage diagnostics and prognostication

T. Kernicky, M. J. Whelan, The Univ. of North Carolina at Charlotte (United States)

Structural health monitoring methodologies devised over the past two decades have increasing shown improved robustness in capability to identify the onset of structural damage and locate the source of the damage. However, the pathway to prognostication and life-cycle assessment through structural health monitoring remains stalled by a lack of success in the diagnostic step of experimentally quantifying the severity of damage in suitable, engineering quantities. Of the methods devised, strain energy approaches have demonstrated not only strength in identifying and localizing structural damage but also uniquely provide a theoretical basis for quantifying damage through measurement of relative stiffness loss in individual members. Conventional applications of strain energy methods use distributed accelerometers, often being single-axis and oriented in the same direction. The limited degrees-of-freedom measured limits the modal parameter extraction to a reduced subset and yields only partial reconstruction of the strain energy in the system. Furthermore, it has been shown experimentally and proven analytically that improvement in strain energy methods through increased spatial density of the sampling array is constrained by the effect of measurement noise on the accuracy of the numerical computations. In this paper, alternative sensor topologies are explored for improving the reconstruction of strain energy estimates. An experimental component of the research includes strain energy estimates for a simply-supported beam heavily instrumented with accelerometers. Prescribed damage is incrementally applied to the beam to permit a basis for comparison amongst the sensor topologies in addressing the damage diagnostics problem with specific emphasis on quantification of severity through stiffness loss.

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8347-01, Session 1

A damage assessment model of slender bridge members based on 1D linear member theory with frequency dependent parameters

C. Yu, C. Cheng, J. Lai, C. Chiang, Chaoyang Univ. of Technology (Taiwan)

It is well known that the linear nature of a frequency domain formulation prevents the direct use of such formulation to dynamic problems associated with nonlinear response. Several phenomena related to bridge responses can be categorized in this type of dynamic problems, such as vibration of stay cables under varying axial forces, nonlinear dynamic responses of beams with respect to damage spreading or other time varying factors like crack opening, etc. However, a frequency domain formulation can sometimes provide relatively useful expressions with better intuitive insights than their time domain counterparts. Therefore, analysis procedures in the frequency domain may still be helpful to the simulation of some particular problems.

In this study, a linear model with frequency dependent structural property was used to generate the corresponding frequency response function and dynamic stiffness for selected dynamic problems where certain nonlinearity can be resulted from time/space varying characteristics of the bridge vibrations. Derivation of the proposed formula is based on the vibration theory of the elementary member with frequency dependent elastic properties, in which Modulus of Elasticity can be interpreted as serial and parallel connections of springs and dashpots. This paper first describes the use of the proposed formulation to reasonably depict the nonlinear cable vibration associated with the varying tension forces over time. The proposed formulation can also be used to simulate flexural vibration of damage beams in which the elastic property involves certain space varying or time varying characteristics. Simple experimental data was next used to demonstrate and confirm the potential application of such simulation idea. Consquently, it is concluded that such assessment model with frequency dependent parameters can also be practically useful in providing particular analysis procedures regarding dynamic problems of slender bridge members.

8347-02, Session 1

Vibration analyses of electrical transmission spun-cast concrete poles for health monitoring

K. Dai, Tongji Univ. (China); S. Chen, The Univ. of North Carolina at Charlotte (United States)

Spun-cast concrete poles have been increasingly used for electrical transmission structures in the United States in the past decades. Design of concrete poles is typical governed by wind loads. Although detailed dynamic analyses usually are not performed in current design practices for most utility companies, understanding vibrational characteristics of the transmission structures is critical for safe design and monitoring of power lines under extreme winds and strong ground motions. However, free vibration of the transmission pole structures has been rarely studied and existing design guidelines do not provide clear information related to pole vibration natural frequencies. The American Society of Civil Engineers (ASCE) published the manual on “Guidelines for Electrical Transmission Line Structural Loading” in 1991 with Table G.3-2 for “Approximate Dynamic Properties for Transmission Structures”. The fundamental frequency of pole structures is listed in the table as between 0.5 and 1.0 Hz. However, the paragraph beneath the table specifically warned the use of this table due to the fact that it is developed through limited review works instead of dynamic analysis. And this data remained unchanged in the 2009 release of the same document. In order to update these figures, analyses of transmission line spun-cast concrete poles of various sizes and classes were performed in this paper by using three-dimensional finite element modeling. Field tests of several pole structures in operations were performed by the authors with wired accelerometers and wireless MEMS sensors. These modal testing results reveal unique vibrational characteristics of pole structures and they were used to verify the finite element models developed for the transmission poles. With the simplified and verified finite element models, sensitivity study was conducted to identify the effect of geometric parameters on pole vibration frequencies. Based on this study, empirical relations between geometric parameters and the natural frequencies of spun concrete poles were developed. These relations can be used for future structural health monitoring planning for the transmission power lines.

8347-03, Session 1

Rapid identification of structural properties using vibration measurements

J. Tang, R. Christenson, Univ. of Connecticut (United States)

This paper presents a new methodology that is built upon existing hardware such as shaker force generator and accelerometers that are both portable and convenient to use for a variety of civil and mechanical structures. Our key idea is to use a moving load that is placed successively at a number of locations on the structure, and measure the corresponding frequency responses. These frequency response measurements will then be used to extract the structural equivalent mass and stiffness. Our new methodology enables the direct extraction of the equivalent stiffness and mass of the critical members of a structure without using a priori information of the structure. A number of case studies are carried out to demonstrate the accuracy and efficiency of its usage in structural health monitoring applications.

8347-04, Session 1

Assessment of seismic performance of an RC building via long term monitoring and finite element modeling including soil-structure interaction

F. Butt, P. Omenzetter, The Univ. of Auckland (New Zealand)

This paper presents a study of the seismic performance of a reinforced concrete building monitored for a period of four years. The three storey reinforced concrete building is instrumented with five tri-axial accelerometers and a free-field tri-axial accelerometer is also installed at some distance from the building. The time domain subspace state-space system identification technique was used to obtain the frequencies and damping ratios considering fixed base and flexible base models taking into account the soil-structure-interaction (SSI) under a selection of significant earthquakes. Trends of variation of seismic response were developed by correlating the peak response acceleration at roof level with identified frequencies and damping ratios during earthquakes. A general trend of decreasing frequencies and increasing damping ratios were observed with increased level of shaking. The frequencies identified considering SSI are smaller than those without SSI. To simulate the behavior of the building, a three dimensional finite element model (FEM) of the building was developed. To incorporate real in-situ conditions, soil

underneath the foundation and around the building was modeled using spring elements and non-structural components (claddings, in-fills and partitions) were also included. The developed FEM was then calibrated using sensitivity based model updating technique. The updated model was next used to assess seismic performance at the serviceability limit state level using both recorded and simulated responses and comparisons with design limits were made. It was concluded from the investigation that knowledge of variation of seismic response of buildings is necessary to better understand their behaviour during earthquakes, and also that the participation of soil and non-structural components is significant towards the seismic response of the building and these should be considered in models to simulate the real behavior.

8347-05, Session 2

Developing an optimal acoustic reflector for air-coupled impact-echo sensor

S. Kee, N. Gucunski, F. A. Fetrat, Rutgers, The State Univ. of New Jersey (United States)

The objective of the study was development of an optimal acoustic reflector, which will be used as a part of an air-coupled impact-echo device for delamination detection in concrete bridge decks. The study was conducted on a series of 2D and 3D finite element (FE) models. 2D FE models included both solid concrete plate and air domains. The models were developed to investigate interaction of leaky stress waves (in particular, S1 resonance mode in Lamb waves) with a parabolic reflector. A series of parametric studies was conducted to determine the optimal geometry of parabolic reflectors (cylinders). The main variables were the rim angle and width of the reflectors, and location of air-coupled sensors. The validity of the findings from the 2D FE models was verified to be equivalently effective for the optimal design of parabolic domes in 3D FE models. Furthermore, numerical simulations using 3D FE models, including delaminations in concrete decks, show that the optimal parabolic dome is effective in enhancing the amplitude of S1 resonance modes for delaminations at various depths. Finally, the results clearly demonstrate that the optimal parabolic domes can significantly improve signal-to-noise ratio in the air-coupled IE measurements. This will increase the feasibility of air-coupled sensing in actual impact echo testing on concrete bridge decks.

8347-06, Session 2

Multisensor data fusion and visualization for impact echo testing of bridge decks

Y. Zhang, Z. Xie, X. Wei, Georgia Institute of Technology (United States)

As the bridge components directly carrying loads and moving traffic, bridge decks are prone to various deteriorations, such as corrosion of reinforcement, cracking, delaminations, and voids. Impact echo has been widely used as a nondestructive evaluation (NDE) method for delamination detection of bridge decks. Impact echo is a point-wise detection method. The frequency spectrum of measured surface motion at a testing point, which results from a short-duration mechanical impact nearby, provides the depth of reflector beneath the testing point. However, in actual measurements, the surface motion of a testing point above sound concrete may also have strong response from the internal delamination if the testing point is close to the defect region. That makes it a challenge to accurately determine defect regions. Additionally, it is sometimes difficult in practice to interpret the individual impact echo signal due to strong contamination of surface waves, converted modes and other noises.

In this paper, a multisensor data fusion approach is proposed to locate internal delamination using impact echo sensor arrays. Numerical simulation of a concrete slab with an artificial delamination is conducted to derive the fusion rules. The spatial distribution of surface motion resulting from mechanical impacts applied at different locations is analyzed. The variations of relative amplitudes of reflected P-wave from the delamination and the concrete slab bottom with source and receiver locations show some interesting patterns that can be used to accurately locate delamination boundaries and depth. A multisensor data fusion process is developed based on these observations. The data fusion process is further verified using experimental data. In addition, a multisensor data visualization platform is developed to provide an effective way to visualize the internal defect of concrete bridge decks based on impact echo testing. The multisensor data fusion and visualization framework can not only facilitate the interpretation of the impact echo data, but also enhance the accessibility of the impact echo NDE method for non-specialists, which provides better decision support tools for the bridge management systems.

8347-07, Session 2

Structural flexibility identification by integrating substructures' measurements

J. Zhang, Southeast Univ. (China)

Traditional multi-reference hammer impact testing (MRIT) can produce reliable estimates of structural flexibility. A new experimental method will be proposed for faster structural flexibility identification by pairing rapid, mobile testing devices and related St-Id. In the proposed method, a mobile testing system with an integrated impact device, limited number of sensors, and data acquisition will be used to perform an impact test on a localized portion of a larger structure. Each structure will be subdivided into smaller substructures that will be tested independently and linked together at the end of the test period. This t method requires limited instrumentation and can rapidly conduct impact testing of large structures. The challenges to implementation of the technique lie in the coupling of the independent impact test datasets into a global dataset describing the behavior of the structure.

New data processing techniques will be developed to integrate independent test datasets from the proposed method to identify global modal parameters and ultimately the flexibility matrix of the structure. Two methods will be explored to couple the independent impact tests into a global dataset fully describing the structure. The first approach is using test data acquired at the interface of each substructure as reference measurements to link each test together and fully populate at least one row of the FRF matrix. A second proposed method involves developing techniques to couple independent tests without the use of interface measurements which would increase the speed with which a structure could be tested.

The proposed method will be utilized to identify the flexibility matrix of a laboratory grid structure and a real reinforced-concrete highway bridge. Its merit will be demonstrated by a rigorous comparison to the flexibility matrix identified through traditional multi reference impact testing.

8347-08, Session 2

Research on interface separation damage detection of concrete-filled steel tubular arch rib based on using transient impulse response

S. Pan, X. Zhao, X. Lv, Z. Zhang, Dalian Univ. of Technology (China)

The interface separation between the filled-concrete and the steel tube would reduce tremendously the bearing capacity of the concrete-filled steel tubular (CFST) arch bridge. However, there is no efficient method to monitor and detect the separation of the in-service CFST bridge so far, which is a potential hazard to the safety of this type of bridge. In this paper, a vibration test method aiming at the local vibration of the steel tube was proposed. Distributed MEMS accelerometer array installed along the tube is used to acquire the vibration signal by quantitative excitation via telecontrol. The zone boundary of interface separation

can be detected by the data processing of the signal. The proposed real-time system has the advantage of low-cost, simple-equipment, easy-integration and high-durability, enhancing the development of CFST arch bridge health monitoring and damage detection theory. Firstly, the distributed MEMS accelerometer array was designed and installed on the separation area and the non-separation area respectively on the CFST members in the laboratory. Then, the signal data of distributed MEMS accelerometer array were collected respectively under the same transient quantitative excitation. Finally, through the contrast experiment and analysis, the zone boundary of interface separation can be detected via the dynamic characteristics parameters changes including the signal attenuation, damping radio, frequency and amplitude of the steel tube based on the theory of surface wave transmission. Results show that this kind of method can satisfy the demand of the real-time monitoring of interface separation of the CFST arch bridge.

8347-09, Session 2

Temperature insensitive all-fiber accelerometer using a photonic crystal fiber long-period grating interferometer

S. Zheng, Y. Zhu, S. Krishnaswamy, Northwestern Univ. (United States)

Fiber-optic accelerometers have attracted great attention in recent years due to the fact that they have many advantages over electrical counterparts because all-fiber accelerometers have the capabilities for multiplexing to reduce a cabling work and for transmit signals over a long distance without amplification. They also can immune from electromagnetic interference. We propose and develop a compact and robust photonic crystal fiber (PCF) long-period grating (LPG) Mach-Zehnder interferometer (MZI) that can be implemented in an accelerometer for measurements of vibration and displacement. To excite core mode to couple out and recouple in with cladding modes, two long-period gratings (LPGs) with identical transmission spectra are written in an endless single-mode PCF using a CO2 laser to make interference between the core mode and cladding modes. The dynamic strain is interrogated by the PCF-MZI that is attached on a spring-mass system. The shift of interference fringe can be measured by photodetector, and the transformed analog voltage signal is proportional to the acceleration of the sensor head that can be modeled as a single-degree-of-freedom mechanical system. Based on the numerical analysis of the PCF-MZI accelerometer, we can get the sensitivity of ~ 0.08 nm/g which is comparable with fiber Bragg grating (FBG) accelerometers. The proposed accelerometer has a capability of temperature insensitive; therefore, no temperature-compensation scheme is needed. Experimental results indicate that the PCF-MZI accelerometer may be a good candidate of integrated system for applications in civil engineering infrastructures and aeronautical platforms.

8347-10, Session 3

On the development of a self-calibrating and adjustable robotic scanner for NDT on nuclear nozzle-vessel welds through a specially designed 2D phased array UT probe

V. Papadimitriou, G. Roditis, Ctr. for Research and Technology, Thessaly (Greece); P. Chatzakos, Innora Ltd. (Greece); D. Liaptsis, T. Gan, TWI Ltd. (United Kingdom)

In this paper we present the development of a robotic scanner for non destructive inspection of the nozzle-vessel weld in nuclear energy production reactors. The scanner handles and drives a specially designed ultrasonic (UT) 2D matrix phased array probe.

The 3 - d.o.f. robotic scanner, mounted on the nozzle, drives the UT probe over selected areas above the weld on the vessel at predefined paths, via a 2-link manipulator mounted on a carriage sliding on a precision 360 degrees circular ring. The end-effector of the manipulator consists of a gimbal joint that incorporates the UT probe holder mounted on a system of springs, acting as the system's interface with the vessel. The system is controlled using hybrid position-force control for 3D trajectory following.

The scanner's novelty lies in the very low set-up time needed by operators, but mainly in its self-calibration capability by utilizing a variety of sensors (distance, inclinometer, motor encoders), drastically minimizing the operators' exposure to nuclear radiation. Moreover, it is able to fit on nozzles of various diameters (nominal dia. +/- 20%) thanks to a rigid and precision synchronized mechanism, as well as to operate on nozzles non-vertically (vertical +/- 30 degrees) welded on the vessel.

The UT probe was designed to electronically steer its beam between 35 to 80 degrees and achieve skewing, electronically, between 10 / -10 degrees for improved detection capabilities of the inspection technique. The developed 2D matrix phased array probe is positioned in a local immersion bath and combined with a flexible membrane front, complying on any curvature variations along the nozzle circumference.

8347-11, Session 3

Ultrasonic phased array evaluation of control rod drive mechanism (CRDM)nozzle interference fit and weld region: NDE results and destructive analysis

A. D. Cinson, S. Crawford, P. MacFarlan, B. Hanson, R. Mathews, A. A. Diaz, Pacific Northwest National Lab. (United States)

In this investigation, non-destructive and destructive testing were used to evaluate potential boric acid leakage paths around an Alloy 600 CRDM penetration (Nozzle 63) from the North Anna Unit 2 reactor pressure vessel head that was removed from service in 2003. A previous volumetric examination of this nozzle sponsored by the Electric Power Research Institute identified a probable leakage path in the interference fit between the penetration and the vessel head but this was not confirmed by destructive analysis. Subsequently, Nozzle 63 was made available to the U.S. Nuclear Regulatory Commission (NRC) for independent tests which PNNL conducted. For this investigation, Nozzle 63 was examined using phased array ultrasonic testing (UT) with an immersion eight element annular 5.0 MHz probe from the nozzle inner diameter. Prior to examining Nozzle 63, a CRDM penetration mockup with known electrical discharge machining notches and boric acid deposits was used to assess probe sensitivity, resolution and calibration. A variety of focal laws were employed to evaluate the interference fit regions and J-grove weld, where applicable. Responses from the mock-up specimen were evaluated to determine detection limits and characterization ability as well as to contrast the ultrasonic response differences with the presence of boric acid in the interference fit region. Following the non-destructive testing of Nozzle 63, the nozzle was destructively examined to visually assess the leak paths. These destructive and nondestructive results are compared and results are presented. The results of this investigation may be used by NRC to evaluate licensees' volumetric leak path assessment methodologies and to support regulatory inspection requirements.

8347-12, Session 3

Monitoring thermal fatigue damage in 304 stainless steel specimens using acoustic emission

R. M. Meyer, T. Roosendaal, B. Watson, P. Ramuhalli, L. Bond, Pacific Northwest National Lab. (United States)

The prospect of existing nuclear power plants entering a period of extended operation (beyond 60 years) and safety concerns magnified by the recent crisis in Fukushima, Japan provide motivation for adopting a more proactive approach to monitoring component degradation. A proactive approach to managing the aging degradation of components

ensures the detection of degradation before the structural integrity of a component is significantly compromised. Early detection of degradation can be achieved through more frequent sampling of component degradation requiring monitoring of degradation "online".

Acoustic emission (AE) is currently the only technique to be successfully deployed for online monitoring of crack propagation in the pressure boundary components of Light Water Reactors. Further, AE is the only NDE technique currently sanctioned by the ASME Boiler and Pressure Vessel Code for performing continuous online monitoring for nuclear power plant components. Thus, AE is recognized as a candidate technology for implementation of proactive aging management plans by facilitating early detection of degradation.

Four channels of a digital AE system are deployed to monitor aging degradation caused by thermal fatigue in 304 stainless steel tube specimens. The tube specimens have an outer diameter of 1 inch and a wall thickness of ¼ inches. The tube specimens are thermally cycled from near 50° C to over 500° C using a cartridge heater placed in the tube inner diameter and water jet to cool the specimen at regular intervals. AE sensors are coupled to the specimens through 1/8 inch diameter waveguides and arranged in a linearly spaced array along the length of the specimens. Results of the experiment will be presented at the conference.

8347-13, Session 3

Experimental findings of acceleration-based identification of breaks in a scaled water pipe network

K. Papakonstantinou, M. Shinozuka, Univ. of California, Irvine (United States)

Accelerometers, mounted inexpensively and non-intrusively on pipe walls, can detect a sudden change in the flow velocity and pressure of a pipeline system. Therefore, they can provide a rapid, efficient and convenient way to identify and locate sudden anomalies in a pipe network, under normal operational conditions. Along this line, this work presents a series of experiments that provide valuable insights in a variety of topics, such as proof of correlation between pipe breaks, pressure variations and pipe vibrations, role of acceleration amplitude and frequency content of the recorded signals in damage identification, appropriate sensor placement, random noise effects, filtering techniques, signal dissipation, etc. The experimental model used is a scaled water pipe network, with approximate dimensions 20x20 meters, consisting of small (½"-1 ½") and large (4") diameter PVC pipes. The model was instrumented with piezoelectric accelerometers, pressure gauges and our low-cost Duramote wireless sensing system, which consists of MEMS-based accelerometers and is specifically designed to monitor disastrous events of water pipe networks. Results between the different sensors are also compared and discussed in this paper. The outcomes of this study offer advanced, practical understanding of the proposed method for identification of sudden pipeline failures and contribute to the development and implementation of our new generation Supervisory Control and Data Acquisition (SCADA) system for continuous health monitoring of pipe networks, which is currently under development.

8347-14, Session 3

GPR survey for pipe leakage detection: experimental and analytical Study

L. Dong, S. Carnalla, M. Shinozuka, Univ. of California, Irvine (United States)

To evaluate the potential of detecting leakage of water pipes using ground-penetrating radar (GPR), a lab experiment is conducted as well as numerical modeling. In the experiment, an artificial 'leakage' is put under, beside and above a pipe buried in dry soil, simulating different leakage locations. By scanning such an experimental model using commercial GPR, more understanding is gained regarding the signature of leakage in GPR profile. Compared to a distinct hyperbola as shown in GPR profile of intact pipes, the leakage zone is disturbed by the wave reflection caused by saturated soil. Furthermore, a numerical model is constructed to simulate such a phenomenon. Maxwell's equations, permittivity distribution of dry and saturated soil, and artificial absorbing boundary conditions are the three key points of such a model. Numerically simulated results seem to be in agreement with field experiments. And the signature of leakage is also visible in the simulated GPR profile. Therefore, GPR survey seems to be promising as an efficient and nondestructive leakage detection approach. And such a numerical model can be used to study the effects of underground inhomogeneity and ground-surface roughness to GPR profiles, and it can also be used as a basis for studying the inverse problem-GPR tomography.

8347-15, Session 4

Advanced sensing, degradation detection, diagnostic and prognostic capabilities for structural health management

D. R. Darr, J. Morse, B. C. Laskowski, Analatom Inc. (United States); R. Betti, Columbia Univ. (United States)

Corrosion Health Monitoring systems and Prognostics are key elements in assuring the performance and reliability of high value, critical structures. Analatom is developing a multiplexed Structural Health Monitoring (SHM) system that obtains data from a variety of sensors, including its MEMS micro Linear Polarization Resistance (µLPR) corrosion and strain sensors, in a package a few mils thick combined with a TI MSP430 microcomputer performing real-time intelligent algorithms to detect, monitor, and predict corrosion rates. The MEMS sensors can be permanently installed on a high-value structure such as a building, bridge, or aircraft, and are connected to a data acquisition node. Data transmission uses a ZigBee wireless self-organizing network that has low power requirements. This enables SHM monitoring of local regions for negative impact arising from multiple, interacting states of degradation, and early alerting that preventative maintenance needs to be undertaken to prevent future expensive repairs and/or replacement.

The µLPR sensors have been installed on a mock-up bridge cable at Columbia University as a part of large project, sponsored by FHWA, on the development of a corrosion monitoring system for main cables of suspension bridges. These sensors were extensively tested in a QFog 1100 Accelerated Corrosion Chamber, before being placed inside a full-scale mock-up of a suspension bridge cable. This cable mock-up has a diameter of 21 in. and its length reaches 34 ft. 8 µLPR sensors were embedded inside the cable which was then placed in a large environmental chamber and subjected to accelerated corrosion conditions for one year. During this time, the µLPR sensors recorded corrosion rate measurement at 8 different locations inside the cable, showing excellent agreement with the temperature measurements. The next step on the project will consist in the deployment of such sensors at two locations on the main cable of the Manhattan Bridge in NYC.

8347-17, Session 4

Condition assessment of rebar corrosion in concrete bridge decks using ground-penetrating radar

H. Liu, T. Yu, Univ. of Massachusetts Lowell (United States); M. L. Wang, Northeastern Univ. (United States)

In this experimental study, a ground-penetrating radar (GPR) system was used for the nondestructive evaluation of rebar corrosion in several decommissioned reinforced concrete (RC) bridge decks. Amplitude attenuation of GPR signals, due to the presence of concrete cracking and rebar corrosion, was quantitatively measured. It is known that, while steel rebars are ferromagnetic, main corrosion products such as Fe2O3 is non-magnetic which could cause attenuation of electromagnetic waves.

In this work, attenuation properties of GPR signals were investigated using GPR signals at 1.5GHz and 2.6GHz. GPR measurement was also compared with half-cell measurement collected from same RC bridge decks. A threshold value of GPR signal attenuation was determined and used as the criterion for assessing the condition of rebar corrosion in RC bridge decks. It is found that, using the proposed approach, the degree of rebar corrosion can be quantitatively estimated without reference GPR measurement from other intact structures.

8347-18, Session 4

A reflectometer-based reader for passive wireless electronic structural surveillance sensors

P. Pasupathy, T. Trivedi, The Univ. of Texas at Austin (United States); F. Raffaeli, National Instruments Corp. (United States); Y. Chen, D. P. Neikirk, S. L. Wood, The Univ. of Texas at Austin (United States)

This paper discusses the design of a reader for embedded electronic structural surveillance sensors used to monitor corrosion in infrastructure systems. These passive wireless electronic structural surveillance sensors have been developed and proven effective in monitoring localized defects. They are interrogated by inductively coupled magnetic fields where the input impedance is monitored to determine whether a corrosion threshold has been reached. We previously used an impedance analyzer to obtain the impedance data. Such systems have good sensitivity and moderate speed but are bulky and heavy.

The reader is designed addressing the need of portability, sensitivity, rapid read speed, and long read range. The design is a reflectometer and was implemented using the National Instruments (NI) modular RF instrumentation platform. It consists of a 3-port directional coupler, a reader coil and a transceiver. The input, output and coupled ports of the directional coupler are connected to a signal generator (transmitter), reader coil, and signal analyzer (receiver) respectively. The NI-RF instruments are used to generate the excitation signal and analyze reflected signals that are related to the input impedance of our electronic structural surveillance sensor. The configuration of reader coil is optimized for desired read range and sensitivity. We also report on our efforts to acquire analog impedance data using this design showing that the real-time reader system produces fast detection for threshold type sensors.

8347-19, Session 4

Detection of multiple corrosion thresholds in reinforced concrete structures using passive sensors

A. E. Abu Yosef, P. Pasupathy, S. L. Wood, D. P. Neikirk, The Univ. of Texas at Austin (United States)

The researchers at the University of Texas at Austin have developed a novel class of low-cost, unpowered, wireless sensors for detecting corrosion of reinforcement in reinforced concrete structures. The sensors are powered through magnetic coupling between an external reader coil and the embedded sensor. Measured AC impedance is used to interpret the state of the embedded sensor. The sensors are envisioned to be placed during construction and interrogated periodically over the service life of the structure.

The current design incorporates a sacrificial corroding element that is placed entirely outside the sensor components and interacts with the resonant circuit by inductive coupling and shielding of the magnetic fields. As the resistance of the sacrificial element increases due to corrosion, the measured frequency response changes gradually indicating corrosion initiation within concrete. Circuit simulation algorithms are being developed to extract analog output describing the level of corrosion from the measured response. In addition, the design allows for using corroding elements of different materials and geometries, hence, permitting the detection of multiple corrosion levels.

The reliability of the non-contact sensor was demonstrated in a long-term accelerated corrosion testing program. Sensors were embedded in reinforced concrete members and were able to detect the onset of corrosion in the reinforcement.

The results of an experimental study demonstrating the potential for multi-threshold detection will be presented. Furthermore, ongoing developments in the reader design to increase the detectable read range and interrogation speed will be discussed.

8347-20, Session 4

Rebar corrosion detection by active wave propagation approach

W. Zhou, H. Li, H. Jiang, Harbin Institute of Technology (China)

Durability is essential for reinforced concrete structures to bear design load and fulfill functionality. Rebar Corrosion is key factor for structures' loss of durability and collapse. In this work, PZTs were utilized as actuators for active stress wave monitoring method. The received signals of intact and corroded steel rebar were compared. At first, the phase velocity and frequency relationship of the single frequency narrow band impulse wave which propagated along the rebar was worked out. Specific central frequency was chosen for the actuator's signal. The mechanic models of PZTs glued on the rebar which worked as actuators and sensors were set up. It was figured out that longitudinal and flexural mode guided wave would propagate along the specimen rebar. Three PZTs were attached to a four meter long round rebar. Three stress wave pitch-catch experiments were carried out. The phase velocities of two modes were measured and the propagation paths were illustrated according to boundary condition. Two rebars were immersed into chloride ion solution and accelerated corroded by electrochemical method. The stress wave pitch-catch experiments were carried out along the corrosion process. The received signals were studied to study the pit severity and cavity position. This work proved that active wave propagation could be used to inspect the global pitting and the cavity's location and extent.

8347-21, Session 4

Ultrasonic guided waves monitoring and evaluation for steel rebar corrosion damage

D. Li, Dalian Univ. of Technology (China)

Ultrasonic guided wave (UGW) is a promising method of non-destructive testing (NDT). Considering the steel rebar in the concrete easily corrosion, there is an urgent need to investigate the corrosion damage on the response of UGW pitch-catch systems, which are used for Structural Health Monitoring (SHM). Firstly, the propagation properties of UGW in steel rebar waveguide are presented, as well as the piezoelectric and dielectric permittivity properties of the piezoelectric transducers (PZT). Guided wave propagation in different conditions is simulated using finite software of analysis. The result of simulating of passive film rupture process in corrosion by two-dimensional Fourier transform demonstrated the effect of waveguide dispersion. The method of using two-dimensional Fourier transform to indentify damage is given. Secondly, the corrosion test accelerated by direct current to steel rebar is made, using UGW system to collect and storage signals generated in the different corrosion degree, select some appropriate signal processing methods to analysis and study the law of corrosion. At last, time-domain and frequency-domain analysis are employed in processing the received signals and correlative curves are obtained. The study shows obvious changes in longitudinal modes amplitudes response caused solely by corrosion degree. The conclusion provides a certain experimental foundation for the steel rebar corrosion damage monitoring via UGW technique.

8347-22, Session 5

Evaluation of nano/micro composites for nondestructive repair of micro cracks and delaminations

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Results of an experimental evaluation of nano/micro inorganic composites are presented in this paper. Alkali alumino silicates matrices reinforced with nano/micro fibers were used to repair (glue) prisms fractures in three point bending. Further, shear strengths of matrices were also obtained using push-up tests. The variables evaluated were mix composition, temperature and specimen size. It is observed that flexural tensile strength of 1000 psi can be achieved from the developed matrices. In some instances when repaired broken beams were tested, the failure occurred by creation of a new fracture surface. The developed matrices had the fluidity to fill very thin delaminations, which will be pumped to reach delamination through small drilled holes. The results show that the compositions obtained in this study have promising potential for application involving the repair of micro cracks and delaminations.

8347-23, Session 5

Laser-generated ultrasound with liquid crystal on silicon (LCoS) technology in the thermoelastic regime

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Composite materials like carbon fiber reinforced plastics (CFRP) are used more and more in commercial applications and offer several attractive ways for tailored solutions. But for many safety issues these materials require adequate nondestructive testing. The extension of the ultrasound technique for nondestructive purpose with laser technology brings new possibilities into the production processes for example manufacturing of small complex components with the capability of an inline observation. In laser ultrasound technology a short pulse laser is used for generation and a long pulse or a continuous wave laser for detecting ultrasound waves. The generation process depends on the laser energy, the laser pulse length, the thermal conductivity of the material and the optical penetration depth into the component. One problem is the conventional Gaussian beam shape and an inappropriate thermal penetration when using for example a YAG-laser, which is usually destructive for the properties of the material under test. We describe the successful introduction of laser-based ultrasound using Liquid Crystal on Silicon (LCoS) technology. A LCoS display optimized as phase-only modulator is used to adapt the intensity dispersal of the laser to a predetermined spatial light distribution for nondestructive optoacoustic interaction with CFRP materials in the thermoelastic regime.

8347-24, Session 5

On the development of an automatic sample geometry identification robotic scanner for NDT on 1-plane curved composite parts using thermography and near infrared cameras or a UT array

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This paper presents the development of a low cost four axis mobile robotic scanner for non destructive inspection of one plane curved composite parts used in the transport. The design is oriented for in situ applications and is able to integrate inspection equipment such as transient thermography (TT) and near infrared (NIR) cameras as well as a UT probes' array.

The robotic scanner has a size of around 1m3 and is mounted on a movable wheeled base for easy transport by one operator. It incorporates three linear degrees of freedom (XYZ) and one rotational axis placed on the Z axis carriage acting as the end effector. On it an operator can very easily and fast mount several NDT cameras or a UT array as an option. With this configuration it is possible to inspect flat or curved, in one plane, samples.

Apart from self-calibration elements, one significant novelty of this system refers to its ability to automatically identify the sample's geometry as well as the total inspection area. This way it can guide itself to predefined points in the space keeping the camera at a constant distance from the sample and perpendicular to the inspection surface, unless otherwise requested. All these can be accomplished through the usage of a system of motor encoders and a laser distance sensor as well as effective guidance algorithms.

The cameras ability to distinguish impact damages, as well as delamination defects, has been verified with the usage of the scanner after several preliminary tests on CFRP and GFRP curved samples.

8347-25, Session 5

Impact damage characterization in cross-plied carbon fiber/thermoplastic composites using thermoelastic stress analysis

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Carbon fiber (CF)-plastic composites are expected from the view point of light weighting vehicle structures. The CF/thermoset plastic laminates have low damage resistance to out-of-plane impact as a problem to be solved, because they behave as a low strength inter-laminar as compared with high-strength in fiber direction. In general, out-of-plane impact damages that are generated in FRP by the low velocity impacts consist of delaminations and transverse cracks. And the damaged area extends form the impact side toward the opposite side. Therefore it is strongly desired to develop CF-composite materials based thermoplastics that have higher toughness than CF-thermoset composites, for vehicle use.

In the present paper, stitched, non-crimp fabric CF/NY6 composites were newly developed as s thermoplastic matrix composite materials. The [0°/90°]4s laminate specimen fixed at a rim of 40 mm in diameter were subjected to impact load with a spherical tip impactor. The damage feature was investigated from the opposite side of impact side by using a lock-in thermography system with a focal plane array detector, which can provide thermoelastic stress information as TSA images. In order to extract accurately the impact damage information from the TSA image they were measured before and after the impact loading. The post-process of the difference between the images resulted in thermoelastic damage image (TDA image). The TDA image were free from the structure noise of materials and offered clear damage information showing the morphology of internal damages that extended with increasing impact energy for the range of energies examined. In addition, the damages estimated by the TDA image were confirmed through SEM (Scanning Electron Microscopy) observation of a cross-section of the specimen tested, and they both were approximately well corresponded.

8347-26, Session 5

Thermoelastic estimation of fatigue damage growth in orthotropic CF/NY6 laminates

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Carbon fiber reinforced plastics (CFRP) have high specific strength and

stiffness, and is expected to be applied as materials for automotive lightweighting. In order to improve of reliability and secure safety of composite automotive, development of techniques for evaluating fatigue damage growth has been required.

This research deals with investigation of fatigue damage development in stitched carbon fiber/Nylon-6 laminates under cyclic loadings with a lock-in thermography system mounted with a focal plane array detector. Lock-in thermography is one of the techniques to improve thermal resolution by process of temporal averaging. The signal has amplitude and phase components. The intensity component gives thermoelastic stress image (TSA image) through an algorithm selecting the largest temperature change for each pixel constituting image data. In order to detect early fatigue damage information correctly, TSA images that were measured before and after applying cyclic loadings were post-processed to obtain the difference between the images. The image obtained from the post-processing showed damage information (TDA image) that had less noise caused by reinforcement architecture, and also presented damage feature and the progression. Intensity information of TDA images was closely corresponded to damage density. The fact was confirmed by using scanning electron microscopy. Furthermore, in order to acquire depth information of the damage, phase images were reconstructed from the phase component of the raw signal. Phase difference information given from the phase image discriminated interlaminar defect and micro delamination deriving from longitudinal splitting from transverse cracks distinctly.

8347-27, Session 5

Predictive modeling of composite material degradation using piezoelectric wafer sensors electromechanical impedance spectroscopy

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Electromechanical impedance spectroscopy (EMIS) using self-sensing piezoelectric wafer sensor utilizes high frequency excitations, typically higher than 30 kHz, to monitor changes in the structural mechanical impedance by measuring the electrical impedance at the sensor terminals; thus offering a highly desired capability to measure incipient damage at very small scales.

Over the past decade, substantial efforts have been devoted to the analytical and numerical modeling of various aspects of the EMIS method. However, the majority of prior studies are focused on fundamental understanding of the sensor transduction mechanism and sensor-structure interaction. Analytical models often consider simple structures such beams, plates and shells with easy to simulate boundary conditions. More importantly, most of the previous work is on isotropic (such as metallic) or heterogeneous (such as concrete) structures. EMIS applications to orthotropic laminated composites have also been studied and discussed in literature to a lesser extend. With the help of powerful commercial software, this paper presents predictive finite element modeling of EMIS on woven glass fiber composite structures. Issues related to energy dissipation in the piezoelectric sensor and host composite structure, as well as its effect on detectability of structural damage were studied using multi-physic based modeling. The study shows that sensor position may directly control damage manifestation in EMIS signature; effect of adhesive bond thickness is comparable in magnitude to the effect of bond stiffness; influence of piezoelectric mechanical losses on the impedance signature is different for damaged and undamaged cases.

8347-28, Session 5

Textural analyses of carbon fiber materials by 2D-FFT of complex images obtained by high frequency eddy current imaging (HF ECI)

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Carbon fiber based materials are used in many lightweight applications in civil and military applications. By the increasing automation in the production process of CFRP laminates a manual optical inspection of each resin transfer molding (RTM) layer is not practicable. The Imaging Eddy-Current (EC) NDT is the only cost effective inspection method for non-resin materials. This method has the capability to find layer displacements of same angle orientations in a multilayer structure. For non-bearing parts short fleece particles are placed together and can be inspected. The thickness of such material is a factor for quality and that's why the overlapping must be as small as possible. EC technique can measure this value by the increasing conductivity properties. There are also other quality parameters which can be determined like the detection of foreign polymer particles, the estimation of the gap-size between each roving or the visualization of undulations.

For all of these typical parameters an imaging classification process chain based on a high resolving directional EC-Imaging device named EddyCus® MPECS and a 2D-FFT with adapted preprocessing algorithms are developed to help the industry optimizing there production performance and quality.

8347-84, Poster Session

Millimeter-wave nondestructive evaluation of pavement conditions

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The United States is suffering from an aging civil infrastructure crisis. Key to recovery are rapid inspection technologies like that being investigated by the VOTERS project (Versatile Onboard Traffic Embedded Roaming Sensors), which aims to outfit ordinary road vehicles with compact low-cost hardware that enables them to rapidly assess and report the condition of roadways and bridge decks free of driver interaction. A key piece of hardware, and the focus of this paper, is a 24 GHz millimeter-wave radar (MWR) system that measures the reflectivity of pavement surfaces. To account for the variability of real-world driving, such as changes in height, angle, speed, and temperature, a sensor fusion approach is used that corrects MWR measurements based on data from four additional sensors. The corrected MWR measurements are expected to be useful for various characterization applications, including: material type; deterioration such as cracks and potholes; and surface coverage conditions such as dry, wet, oil, water, and ice. Success at each of these applications is an important step towards achieving the VOTERS objective, however, this paper focuses on surface coverage, as whatever covers the driving surface will be most apparent to the MWR sensor and if not accounted for could significantly limit the accuracy of other applications. Contributions of the paper include findings from static lab tests, which validate the approach and show the effects of height and angle. Further contributions come from lab and in-field dynamic tests, which show the effects of speed and demonstrate that the MWR approach is accurate under city driving conditions.

8347-85, Poster Session

Test assessment of RC structures in marine environment: the Geiger Key Bridge

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Reinforced concrete marine structures are highly vulnerable to corrosion due to chloride ion attack, the severity of the attack being dependent on among other factors the prevailing climatic condition. The aggressiveness of the warm marine environment of Florida has led to the premature deterioration of numerous bridges and building along the coastline. This paper describes a methodology for predicting the time to onset of corrosion of reinforcing steel in a concrete bridge while incorporating parameter uncertainty. The procedure includes the use of visual, electrochemical and non-destructive methods in order to define the cause and the level of concrete deterioration. A probabilistic mechanistic model is used to generate the distribution of the time to corrosion initiation based on statistical models of the governing parameters obtained from field data. These tools are integrated with the MCS (Monte Carlo Simulation) technique to generate the distribution of the corrosion initiation time using the distributions of the governing parameters. The proposed methodology was applied to predict the time to corrosion initiation of the reinforcing steel in the concrete girders of the Geiger Bridge in Key West, FL.

8347-86, Poster Session

Experimental investigation of Graphene-polymer Bucky- paper on electro-thermal properties

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In this study, chemical-oxidized graphite powder was successfully striped into graphene nano-sheet using ultrasonic wave. By the process of down-flow -high-rate filtration, the prepared grapheme nano-sheet was assembled and deposited on the surface of membrane. Graphene-polymer Bucky-paper (GPBP) was formed subsequently with high temperature treatment and consolidation. The investigation of temperature and/or tension -dependent resistivity demonstrated that GPBP dose not only holds the more excellent electrical properties than other paper materials with pretty high electrical conductivity (such as CNTs Bucky-paper, Carbon nano-fiber paper), but also inherits the remarkable mechanical and thermal properties of graphene nano-sheet. Furthermore, GPBP also was verified the outstanding electro-thermal property and better electro-thermal sensitivity than other low electrical-conductive materials. Based on the admirable electrical/mechanical/thermal properties, GPBP will be extremely competitive as a promising candidate in developments of sensor, high-efficient thermal source, thermal conductive material and many other applications.

8347-87, Poster Session

Evaluating vehicular-induced bridge vibrations for energy harvesting applications

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Highway bridges are vital links in the transportation network in the United States. Identifying possible safety problems in the approximately 600,000 bridges across the country is generally accomplished through labor-intensive, visual inspections. Ongoing research sponsored by NIST seeks to improve inspection practices by providing real-time, continuous monitoring technology for steel bridges. A wireless sensor network with a service life of ten years that is powered by an integrated energy harvester is targeted. In order to achieve the target ten-year life for the monitoring system, novel approaches to energy harvesting for use in recharging batteries are investigated. Three main sources of energy are evaluated: (a) vibrational energy, (b) solar energy, and (c) wind energy. Assessing the energy produced from vehicular-induced vibrations and converted through electromagnetic induction or piezoelectric materials is the focus of this paper. The goal of the study is to process acceleration data and analyze the vibrational response of steel bridges to moving truck loads. Through spectral analysis and harvester modeling, the feasibility of vibration-based energy harvesting for long-term monitoring can be assessed. The effects of ambient temperature, truck traffic patterns, and harvester position on the power content of the vibrations are investigated. With sensor nodes continually recharged, the proposed real-time monitoring system will operate off the power grid, thus reducing life cycle costs and enhancing inspection practices for state DOTs. The dynamic response study is underway, and this paper will present the initial results of estimating the vibration energy of several steel bridges in Texas and Oregon.

8347-88, Poster Session

Acoustic emission monitoring of concrete columns and beams strengthened with fiber reinforced polymer sheets

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Acoustic emission (AE) technique is an effective method in the nondestructive testing (NDT) field of civil engineering. During the last two decades, Fiber reinforced polymer (FRP) has been widely used in repairing and strengthening concrete structures. The damage state of FRP strengthened concrete structures has become an important issue during the service period of the structure and it is a meaningful work to use AE technique as a nondestructive method to assess its damage state. The present study reports AE monitoring results of axial compression tests carried on basalt fiber reinforced polymer (BFRP) confined concrete columns and three-point-bending tests carried on BFRP reinforced concrete beams. Conventional AE parameters analysis was firstly utilized to give preliminary results of the damage process of these specimens. It was found that cumulative AE hits can reflect the damage development trend of both BFRP confined concrete and BFRP reinforced concrete beams and AE hits had an abrupt increase at the point of FRP breakage. Then the fracture process of BFRP confined concrete columns and BFRP reinforced concrete beams was studied through mechanical analysis and RA value-average frequency analysis. The RA value-average frequency tendencies of BFRP confined concrete were found different from that of BFRP reinforced concrete beams. The variation tendency of concrete crack patterns during the loading process was revealed.

8347-89, Poster Session

The application of strain field intensity method in the steel bridge fatigue life evaluation

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ASCE ‘s survey shows that 80%--90% bridge damage were associated with fatigue and fracture problems. With the operation of vehicle weight and traffic volume increases constantly, the fatigue of welded steel bridge is becoming more and more serious in recent years. A large number of studies show that most prone to fatigue damage of steel bridge is part of the welding position.Thus,it’s important to find a more precise mentod to assess the fatigue life of steel bridge.

Three kinds of fatigue analysis menthod is commonly used in engineering practice,such as nominal stress method, the local stress strain method and field intensity metho. The first two methods frequently used for fatigue life assessment of steel bridge , but field intensity method uses less ,and it widely used in fatigue life assessment of aerospaceand mechanical. Nominal stress method and the local stress strain method in engineering has been widely applied, but not considering stress gradient and multiaxial stress effects, the accuracy of calculation stability is relatively poor, so it’s difficult to fully explain the fatigue damage mechanism.Therefore,it used strain field intensity menthod to evaluate the fatigue life of steel brigue.

The fatigue life research of the steel bridge based on the strain field method and the fatigue life of the I-section plate grider was analyzed. Using ansys on the elastoplastic finite element analysis determined the dangerous part of the structure and got the stress-strain history of the dangerous point . At the same time ,in order to divide the unit more elaborate introduced the sub-structure technology.Finally,it applies K.N.Smith damage equation to calculate the fatigue life ot the dangerous point. In order to better simulating the actual welding defects,it dug a small hole in the welding parts.It dug different holds from different view in the welding parts and plused the same load to calculate its fatigue life. Comparing the results found that the welding defect in different parts had different influence on the fatigue life . Simultaneously,it based on S-N curve the I-shaped beam and combined with Palmgren - Miner linear cumulative damage theory to calculate the fatigue life of the dangerous part . The corresponding calculation results proved the superiority of the strain field intensity menthod.

8347-90, Poster Session

Improved magneto-inductive waveguide as wireless sensor array net for structural health monitoring

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This paper summarizes ongoing work on applying passive magneto-inductive waveguide (MIW) as a wireless sensor array to monitor corrosion in infrastructure systems. The wireless sensor array is built with a finite array of uniformly spaced capacitively-loaded loops with environmentally exposed wire as a resistive transducer. We previously used an intentional discontinuity in the array as a reference forming a Fabry-Perot cavity when another sensor element in the chain has been triggered by corrosion. The location of the corrosion can be determined since the Fabry-Perot cavity introduces clear peaks and troughs in the passband that relate to the gap between the defect and the reference.

To make the best use of each sensor and avoid missing corrosion at the reference locationa new method to detect corrosion with an initially “perfect” MIW is proposed. Although one defect within magneto-inductive waveguide gives rise to more insertion loss and small ripples in the passband, they could be easily neglected because it doesn’t show clear difference with the responses of perfect waveguide. The time-domain responses of the magneto-inductive waveguide can instead be used to locate this defect by observing the magneto-inductive wave reflections caused by the impedance discontinuity. If a second defect is introduced, Fabry-Perot cavity is formed. The number of peaks appearing in the passband determines the distance between two defects. Combined with time domain analysis, a second defect can be located with respect to the first defect. The new combined technique can provide both improved sensitivity and defect location capability.

8347-91, Poster Session

Nondestructive methods of integrating energy harvesting systems for highway bridges

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This paper describes a methodology for designing attachment structures of energy harvesting systems onto existing structures while minimizing impact to the surroundings. Specifically, this paper delineates the proper heuristics of integrating energy harvesting systems onto existing man-made structures, such as highway bridges. Designing a robust universal mount which can easily integrate an energy harvester to any type of bridge is an ideal goal for any structural health monitoring system, however factors such as the variation in design, environment, and location of bridges presents a tremendous design challenge. Understanding these variations and recognizing common physical traits can aid a designer in addressing these challenges. The methodology described in this paper builds upon this and will be a general guideline for making important design decisions. Current designs for solar and wind energy harvesters and their respective attachment structure as part of an ongoing research project to power sensors.

8347-93, Poster Session

Instrumented composite turbine blade for health monitoring

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A health monitoring approach is investigated for hydrokinetic turbine blade applications. In-service monitoring is critical due to the difficult environment for blade inspection and the cost of inspection downtime. Composite blade designs have advantages that include long life in marine environments and great control over mechanical properties. Experimental strain characteristics are determined for free vibration and dynamic loads. These experiments are designed to simulate the dynamic characteristics of hydrokinetic turbine blades. Carbon/epoxy symmetric composite laminates are manufactured using an autoclave process. Four-layer composite beams, eight-layer composite beams, and two-dimensional eight-layer composite blades are instrumented for strain. Experimental results from fiber optic sensors are validated with strain measurements from electrical resistance gages. Also, experimental results are validated with theoretical characteristics obtained from in-house finite-element analysis for all sample cases. These preliminary tests on the composite samples show good correlation between experimental and finite-element strain results. Damage to the composite structure, e.g. delamination and fiber breakage, causes shifts in the strain frequency behavior. Signal profiles for extrinsic Fabry-Perot interferometric (EFPI) fiber optic sensors are discussed for the special cases of vibration events. A health monitoring system is proposed based on embedded fiber optic sensors and embedded motes in which strain information is demodulated for wireless transmission.

8347-94, Poster Session

Infrared image filtering for pedestrian surveillance

K. N. Rodhouse, S. E. Watkins, Missouri Univ. of Science and Technology (United States)

A surveillance approach is investigated which has low computational complexity and which uses near-infrared imaging. The target application is a monitoring system for pedestrian traffic. Near-infrared light has potential benefits including non-visible illumination requirements. An image-processing algorithm for monitoring pedestrians is implemented in an outdoor scene with traffic on a walking bridge. The image sets consist of persons walking across the bridge in the presence of foreground objects at different times of the day and with different clothing. Some image sets with non-person objects, e.g. bicycle, are also considered. This complex, cluttered environment is highly variable, e.g. shadows and moving branches. The system performance for near-infrared images is compared to that of traditional visible images. The approach consists of creating a silhouette of new objects in the scene. Filtering is used to eliminate noise. Multiple features are calculated by MATLAB© code for each identified object. These features are analyzed for usefulness in people discrimination, i.e. classification of the objects as persons or non-persons. Effective filtering operations and minimal combinations of features are proposed for effective automated discrimination. The results show that the algorithm can effectively manipulate near-infrared images and that effective objection classification is possible even in the presence of system noise and environmental clutter. The potential for automated

surveillance based on near-infrared imaging and neural-network-based feature processing are discussed.

8347-95, Poster Session

Spatial and diffusion prefiltering in surveillance video compression

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Video is an important component in modern security and infrastructure monitoring, but it is sometimes underutilized due to restrictions on bandwidth and data storage. Motion estimation and discrete transforms are popular means of reducing redundancy for video compression. The mechanics of these methods often result in artifacts in the decompressed video. In addition, noise and image regions with lots of moving texture can be more expensive to compress, since these often require additional data for pixel-level corrections. Compression is improved if such effects are reduced without compromising video quality. A surveillance-centric video compression algorithm is discussed that exploits motion estimation, truncated difference correction, entropy encoding, and a background model. The algorithm supports image quality tradeoffs and allows compression to be targeted within regions of salient activity. A set of windowed spatial filters (mean, median, and Laplacian) and heat diffusion PDE filters (linear, geometric, and Perona-Malik) is examined for their utility in improving compression ratio and signal-to-noise ratio. The application of these filters is explored at two points in the algorithm: at the start of the compression process and immediately following motion estimation to reduce pixel-level correction data. Results show that prefiltered techniques can be effective at reducing certain terms' contribution to the data stream while imposing minimal impact of image quality. Results from other compression codecs are included for comparison. The test set comprises a diverse range of surveillance scenes that feature vehicular and pedestrian traffic and several layers of foreground and background complexity.

8347-96, Poster Session

Hybrid architecture for building secure sensor networks

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Sensor networks have various communication and security architectural concerns. This paper analyzes the communication and security concerns in detail and defines three approaches to address these concerns for sensor networks. The first area is the utilization of new computing architectures that leverage embedded virtualization software on the sensor. Deploying a small, embedded virtualization operating system on the sensor nodes that is designed to communicate to low cost cloud computing infrastructure in the network is the foundation to delivering low cost, secure sensor networks. The second area focuses on securing the sensor. Sensor security components include developing an identification scheme, and leveraging authentication algorithms and protocols that address security assurance within the physical, communication network, and application layers. This function will primarily be accomplished through encrypting the communication channel and integrating sensor network firewall and intrusion detection/prevention components to the sensor network architecture. Hence, sensor networks will be able to maintain high levels of security. The third area addresses the real-time and high priority nature of the data that sensor networks collect. This function requires that a quality-of-service (QoS) definition and algorithm be developed for delivering the right data at the right time. We propose a hybrid architecture that combines software and hardware features to handle network traffic with diverse QoS requirements.

8347-97, Poster Session

Rapid NDT of polycrystalline silicon wafers by hybrid noncontact ultrasonics

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A hybrid, non-contact technique of non-destructive testing of polycrystalline silicon wafers used in solar photovoltaics has been developed combining air-coupled ultrasonics and laser induced ultrasonics. Experiments were conducted in pitch-catch mode where a focused, frequency doubled pulsed, Q-switched Nd-YAG laser beam was used to generate lamb waves and unfocused, gas matrix piezo(GMP) air coupled tranducer from NCU Ultran Group, having central frequency of 200 kHz were used for detection of lamb waves in thin samples of polycrystalline silicon wafers in the form of plates of dimension 175 mm x 175 mm x 0.2 mm. The distance between the transmitter and receiver was set at 100 mm and the reception angle was fixed at 24 deg calculated using a software that generated dispersion curves for polycrystalline silicon. The received signal from the air coupled transducer was amplified in series of stages by a Panametrics 5058PR high voltage pulser/receiver. The signal filtered with a band pass filter was then acquired by a high-speed NI PXI analog to digital converter (ADC) card on a PXI 1033 Chassis before being transferred to a computer for further processing. For this study, thin cracks were generated on a good silicon wafer by tapping with the help of a sharp scribe. With baseline data on a good sample, a damage index could be defined and estimated using the present system for cracked wafers. The damage index can be compared with other samples from the B-scan images generated using an automated line scanner for rapid rejection of cracked samples.

8347-98, Poster Session

Novel designed magnetic leakage testing sensor with GMR for image reconstruction algorithm

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Over the past few years, the authors have developed an image reconstruction algorithm that can accurately reconstruct images of flaws from data obtained using conventional ECT sensors. The algorithm is simple and fast and involves few steps, thus making it suitable for implementation on a PC.

The developed reconstruction algorithm is designed for data which is assumed to be obtained with spatial uniform magnetic field on the target surface. On the other hand, the conventional ECT sensor author used is designed in such a manner that when the magnetic field is imposed on the target surface, the strength of the magnetic field is maximized.

This violation of the assumption ruins the algorithm simplicity because it needs to employ complemental response functions called "LSF" for long line flaw which isn't along original algorithm design.In order to obtain an experimental result which proves the validity of simplest original algorithm with one response function, the authors have developed a prototype sensor for magnetic flux leakage testing that satisfy the requirement of original algorithm last year.

The developed sensor comprises a GMR magnetic field sensor to detect a static magnetic field and two magnets adjacent to the GMR sensor to magnetize the target specimen.

However, obtained data had insufficient accuracy due to weakness of the strength of the magnet. Therefore author redesigned it with much stronger magnet this year.

Obtained data with this new sensor shows that the algorithm runs well with one response function for this sensing system and proved it's validity.

8347-99, Poster Session

Rapid sensing and structural identification for large populations of bridges

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To date, most advances in sensing and simulation applications in structural engineering have targeted a single structure of interest, however the challenges facing transportation agencies that oversee large populations of bridges are incompatible with such advances. This disconnect between refined technology applications and broad populations of structures demands research into rapidly deployable technologies that may serve as quantitative screening tools to augment visual inspection procedures. The goal of the research reported herein is to develop feasible solutions to the trade-off between increased cost and increased value. As a first step, two novel technologies, termed Global Structural Assessment (GSA) and the Automated Structural Identification (Auto St-Id), were employed for performance assessment on a dozen highway bridges in New Jersey. The GSA System includes both an impact loading source for modal identification as well as a sensor suite for stress and static measurements. The goal of the GSA is to obtain information about the specific bridge and to obtain metrics that may be used to place the bridge in context within the overall population. The Auto St-Id System aims to leverage the sensing information together with available databases to develop and calibrate finite element models in an automated manner. The paper will compare the results of the rapid sensing and modeling system to analysis performed using traditional visual inspection data and will report on the performance of this novel system compared to that of past in-depth, refined analysis.

8347-100, Poster Session

Enhanced bridge inspection through the integration of sensing and decision making technologies

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The importance of bridge inspection as a component in bridge management has achieved national prominence. This can be contributed to the failure of the I-35 Bridge in Minnesota and the resulting needs to improve the bridge inspection process. In addition the ever increasing costs of keeping the aging bridge inventory healthy necessitate an efficient and more accurate inspection process. Bridge inspection relies on human in-field observations and qualitative visual evaluations of the bridge. Such evaluations are then reported in a qualitative fashion to bridge decision makers. Many maintenance, rehabilitation, and retrofit decisions are based on bridge inspector's reports. Several efforts have emerged recently to improve the qualitative nature of bridge inspection. Among such efforts are reliance on Non-Destructive Testing (NDT) methods and the potential utilization of risk-based methods in bridge inspection.

This paper presents an integrated method for advanced bridge inspection. The method acknowledges the primacy of human role in bridge inspection. However, it offer several integrated technological methods that would complement human inspection. Such technological advances include cyber reporting, advanced electronic visual recording and archiving, and accurate position tracking. Another component in the method is the integration with the concept of risk-based decision-making via complete utilization and integration with a parallel structural health monitoring (SHM) process. The grounds-up automation is also utilized in improving the current rating system by accommodating potential uncertainties as well as integration with any available NTD or SHM processes. The integration of these technologies is made possible by an decision making tool that can be made available to bridge manager in real time. The holistic advanced inspection process promises to improve the accuracy and reliability of bridge inspection, thus improving bridge safety while decreasing overall bridge perating costs.

8347-101, Poster Session

Status of program to develop low cost application of carbon fiber to strengthen water and other pipes

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In early 2010, Fibrwrap Construction LP and Fyfe Company LLC joined with the University of California Irvine to develop a robot that could provide full structural repair to damaged pipes without the need to excavate or intensive manual labor by internally applying carbon fiber reinforced polymers (CFRP) to the pipe walls. Many buried large-diameter prestressed concrete cylinder pipes and reinforced concrete pipes are aging and reaching the end of their design life or rapidly deteriorating and failing prematurely. Repairing these large-diameter pipe failures can be very costly and furthermore, cause great societal impacts. This leads to the need for a low cost and efficient repair method. While repair using carbon fiber is not a new method, it is labor intensive and costly, and automating the process poses many distinct advantages. The overall goal of the research project is to develop a robot to replace current hand lay-up CFRP repair methods to produce an efficient and low cost repair option. Much of the research being performed utilizes new technology, and as such, poses many difficulties and obstacles to overcome. This paper will provide an overview of the research program, including the research plan, joint venture partners, and long term and interim goals, as well as the status of development, including milestones and unique new concepts.

8347-102, Poster Session

Computer-aided ultrasound non destructive testing analysis

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As matters are atomic and molecular combinations source under physical, chemical and mechanical/energy... laws, Nde/Ndt research and experiments guide us to the study and investigation of material behavior under different mechanical, chemical, electro or dynamical solicitations. Computer analysis, simulation, and modeling methods could help to these insights, perhaps by adding new knowledge or findings, or for more emphasis on specific ideas or research thematics.

In this research, results based on computer aided ultrasound non destructive testing analysis obtained by means of a combination of signal processing, regression analysis, computing theory and dynamical systems (inspired from chaos theory); point to interesting results of material micro structural nature. In addition confirm as well an attractor occurrence, and other results not explained yet needing more investigations, experiments and analysis. For this purpose the study and correlation with physical and chemical laws and matter behavior is deeply required.

8347-104, Poster Session

Collaborative mobile sensing and computing for civil infrastructure condition assessment: framework and applications

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Multi-function sensing and imaging devices, GPS, communication and computing devices are being pervasively used in field by engineers in

civil engineering and emergence response practice, which have enabled rapid field data collection and processing. Field engineers, however, still have difficulty to balance between ever-increasing data collection demand, management of heterogeneous devices, and need of real-time data fusion. In addition, field engineers usually work collaboratively in a geospatially large area; however, the existing sensing and computing modalities used in the field are not designed to accommodate this condition. In this paper, we present a solution framework of collaborative mobile sensing and computing for civil infrastructure condition assessment, with the Android-based mobile devices (AMDs) as the basic nodes in the framework. Currently, commercial AMDs are equipped with computing units, touch-based screens, imagers, GPS, motion sensors and various modes of communication capabilities, which have provided field engineers an unprecedented opportunity that can collect, share and process data in real time. Two experiment applications are demonstrated in this paper. The first is for surface crack detection for concrete structures at spatially different locations. The second is to collaboratively reconstruct building information by combining satellite imagery data and locally acquired detailed images for different buildings. Difficulties in mixed C and Java code programming that are critical to realize the above framework and examples are discussed. We envision that field engineers can collaboratively conduct sensing, augment contextual information, perform real-time processing, and share knowledge through using the proposed framework for civil infrastructure condition assessment.

8347-105, Poster Session

Measurement of nonlinear elastic constants of rail steel at elevated temperatures

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Buckling caused by temperature stresses is highly dangerous for Continuous Welded Rails (CWR). Linear and nonlinear elastic constants of rail steel are critical for the analysis of the buckling of CWRs. The current elastic constants are only available at the room temperature. In this article, measurements of the stress-induced changes in ultrasonic wave speeds at elevated temperatures (250 C-700 C) in rail steel are performed. The variation of time of flight was measured by the pulse-echo method. All of the linear and nonlinear elastic constants are determined from the measured relation between the ultrasound wave speed and applied uniaxial homogeneous stress at elevated temperatures. The results provide an important reference for the modeling of the rail buckling.

8347-29, Session 6a

Nondestructive methods of integrating energy harvesting systems with structures

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A methodology is described for designing subsystems for attaching energy harvesting systems onto existing structures while minimizing impact to the surroundings. Specifically, this paper delineates heuristics for integrating energy harvesting systems onto existing man-made structures, such as highway bridges. Our motivating application is to harvest energy to provide power to structural health monitoring systems for bridges. Designing a robust universal mount that can easily integrate an energy harvester to any type of bridge is an ideal goal for any structural health monitoring system. However, factors such as variations in design, environment, and the locations of bridges present a tremendous design challenge. Understanding these variations and recognizing common physical traits can aid a designer in addressing these challenges. The methodology described in this paper addresses these issues and provides general guidelines for making important design decisions. Designs for attachment subsystems for solar and wind energy harvesters used to power structural health monitoring systems for bridges are provided as example applications of the methodology.

8347-30, Session 6a

Low power wireless sensor networks for infrastructure monitoring

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Sensors with long lifetimes are ideal for infrastructure monitoring. Miniaturized sensor systems are only capable of storing small amounts of energy. Prior work has increased sensor lifetime through VDD scaling, necessitating voltage conversion from storage elements such as batteries. Sensor lifetime can be further extended by harvesting from solar, vibrational, or thermal energy. Since harvested energy is sporadic, it must be detected and stored. Harvesting sources do not provide voltage levels suitable for secondary power sources, necessitating DC-DC up-conversion. We demonstrate a 8.75mm3 sensor system with a near-threshold ARM microcontroller, custom 3.3fW/bit SRAM, two 1mm2 solar cells, a thin-film Li-ion battery, and integrated power management unit. The 7.7µW system enters a 550pW data-retentive sleep state between measurements and harvests solar energy to enable energy autonomy.

As modern devices integrate increasingly more wireless connectivity into a small form-factor, traditional wireless architectures have to be abandoned in favor of digital-dominant approaches. Our receiver and transmitter architectures achieve good performance by employing a design strategy that shifts circuit complexity to mixed-signal and digital circuits that perform well in advanced CMOS integrated circuit technologies. The Zigbee transmitter comprises a mostly-digital fractional-N PLL modulator and simple power amplifier. Phase or frequency modulation can be achieved with a PLL by adjusting the feedback divider ratio. The fractional-N based PLL architecture enables non-integer divide ratios permitting small changes in output frequency or phase. A prototype transmitter implemented in 0.13um CMOS satisfies the requirements for Zigbee but with far less power consumption than state-of-the-art commercial devices.

8347-31, Session 6a

High power density energy harvester with high permeability magnetic material embedded in a rotating wheel

Q. Wang, Y. Zhang, N. Sun, J. G. McDaniel, Jr., M. Wang, Northeastern Univ. (United States)

This work presents an alternative design of a rotating energy harvester, which possess the capability of powering any electronic sensor and wireless sensor network within vehicle. This energy harvester design is based on magnetostatic coupling between a stationary circular-arc hard magnet array and rotating magnetic solenoids, which consists of a unique core with high permeability (>10,000) to significantly increase the output power density. The hard magnet array consists of magnets with anti-magnetization producing a spatially inhomogeneous bias magnetic field, which switches the flux inside the solenoids during relative motion between the magnets array and magnetic solenoids. A prototype of this rotating energy harvesting system has been fabricated and demonstrated on a rotating wheel at speeds from 10 to 60 miles/hour (mph). Results of different rotating frequencies show average power densities from 1 to 5 W/cm3. Comparisons of different magnetic solenoids as well as different power storage circuits have been carried out. A numerical and experimental study of powering a real-time wireless tire pressure monitoring system (TPMS) reveals that the energy harvester design generates constant and steady power sufficient for continuous operation of the TPMS.

8347-32, Session 6b

Issues in bridge deck damage evaluation using aerial photos

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Damage evaluation is highly essential to maintain the standards as well as to have a risk-free environment to live in. Sub-inch aerial imaging using small format aerial photography is used to scan the bridges. The various bridge deck problems, which ultimately lead to the failure of the structure, can be identified; analyzed and quantified using high resolution images obtained using under-belly, vertical photography technique. The conventional method involves scanning the bridges using truck-mount or vehicle mount equipment, which require a large number of sampling in order to study the entire bridge - which is time consuming and challenging when the size and location of the bridges are taken into account. High resolution aerial image processing technique, on the other hand, requires fewer numbers of sample when compared to the terrestrial methods. However, performance of aerial imaging is hindered by obstacles such as shadows from trees, power lines and vehicles and signs or luminaries structure. Aerial imaging requires high resolution images to avoid uncertainty. They need good pilot skills and flying conditions. In order to devise a complete tool, various image processing tools have to be integrated. The various challenges faced in aerial imaging are discussed with preliminary results.

8347-33, Session 6b

Sensitivity study of lidar based bridge inspection algorithms

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Remote sensing is becoming more and more popular and starts to take the place of vision based inspection method in transportation facility management. LiDAR is a typical remote sensing technology which can measure the surface geometry of the surrounding objects with a high accuracy. The LiDAR scan has been used in bridge inspection, and several applications such as clearance measurement, damage detection programs were developed so far. In this paper, the purpose of the sensitivity study is to find out the limitation of the two newly developed LiDAR based bridge damage inspection programs. The artificial generated point cloud data which contains a series of gradually changed damage portions is used to determine the sensitivity of this technology. The results of the damage detection using these two different methods are compared with the designated value. Further analysis is also conducted to find out the reasons that make the inspection result different from the right value. The study shows the sensitivity of this technology can reach the standard requirement for bridge inspection, and it could also provide us information for the future improvement of the algorithms.

8347-34, Session 6b

Strain quantification using 3D lidar scan

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Strain is a dimensionless quantity describing the unit length deformation of a material subject to force loading. There are tactile and remote methods to measure strain in structural members, and currently no methods involving light distancing and ranging (LiDaR) technology. Ranging LiDaR systems operate by utilizing a reflective, rotational, surface to emit specific wavelengths of light to generate immense point cloud data fields of position information. Multiple point cloud compilations allow comparative analyses to indicate a subject's minute position changes and behaviors. The introduction of LiDaR image processing into material strain monitoring expands the capabilities of remote sensing. The immediate objective of the study is to compare strain values extracted from LiDaR image processing to strain gauge values, so that development of a standard procedure can be initialized. The LiDaR experiment was conducted in conjunction with a universal testing machine on August 16th, 2011, on a concrete beam equipped with six strain gauges. The strain gauges were assembled at 1/3 beam lengths, both above and below the neutral axis, resulting in gauge values indicating tensile and compressive strain. Strain gauges measure strain through a comparison of change in resistivity to change in length. A structural analysis aided by LiDaR will calculate strain values to be assessed in conjunction with the gauge values. A later objective of the analysis is to optimize and semi-automate the established procedure for comparing LiDaR extracted data and instrumental data so that the process can be implemented on large surfaces and structures. This study increases the current knowledge of the capabilities of LiDaR implementation and remote sensing.

8347-35, Session 7a

Obtaining more information from time-of-flight-diffraction measurements

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Time of Flight Diffraction (TOFD), is a well established technique in non-destructive evaluation and testing. With conventional TOFD, the Rayleigh wave and surface skimming compression waves detected are relatively small in amplitude. In other ultrasonic measurements, such as when using laser generated ultrasound for example, these waves may have amplitudes much larger than bulk wave signals that have been scattered from defects. Even in conventional TOFD measurements, there are a number of back-wall echoes that can make it difficult to identify defect signals in B-scan or D-scan images. We present some images and signal processing methods that can be used to help highlight signals from defects in such images, whilst at the same time can be used to produce a cross-sectional image of the sample if more than one detector is used in the TOFD arrangement. We have named this approach Time of Flight Diffraction and Imaging (TOFDI).

8347-36, Session 7a

A multipoint ultrasonic detection approach to fretting crack detection in an aircraft component

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A nondestructive technique is needed for the detection of fretting cracks in aircraft stabilizer formers. Since these are generally surface cracks, a technique employing surface acoustic waves (SAW) would be the natural choice. Among different types of SAW, surface shear horizontal wave (SSHW) has the potential to propagate in the structure with much less attenuation by the adhesive layer between the stabilizer former and a fairing, owing to its in-plane polarization. A challenge in implementing the SSHW-based approach is generation of clean SSHW while keeping the wave-generation device small enough to be utilized in a limited access area. In this work, a naturally cracked aircraft stabilizer former was examined. A bronze wedge and a 0.25-inch diameter 5 MHz shear wave transducer were used to generate SSHW and receive echo signals. Due to wave reverberations inside the wedge, the received signal was so noise-like that echoes reflected from cracks could be completely masked. To tackle this issue, a multi-point detection approach was

developed whereby the wedge transducer was operated in pulse/echo mode at several locations on the stabilizer former, then a signal processing technique was used to remove spurious background signal by identifying a common pattern in all signals, and finally the processed data were displayed as an image for the cracks to be visually discernable. A fretting crack, 0.2-inch long, 0.03-inch deep and at 0.06-inch to a rivet hole has been clearly identified. The proposed approach significantly reduces the noise effects and provides a simple to interpret sensor output without imposing additional transducer performance requirements.

8347-37, Session 7a

Waterless coupling of ultrasound from planar contact transducers to curved and irregular surfaces during non-destructive ultrasonic evaluations

K. M. Denslow, A. A. Diaz, M. Jones, R. M. Meyer, A. D. Cinson, M. Wells, Pacific Northwest National Lab. (United States)

The Applied Physics group at the Pacific Northwest National Laboratory in Richland, WA has evaluated a method for waterless coupling of ultrasonic energy from planar ultrasonic contact transducers to irregular test surfaces for ultrasonic non-destructive evaluation applications. Dry couplant material placed between a flat transducer surface and a curved or uneven thin-wall, steel surface allows for effective sound energy coupling and preserves the integrity of the planar transducer sound field by serving as an acoustic impedance matching layer, providing good surface area contact between geometrically dissimilar surfaces and conforming to rough and unsmooth surfaces. Sound fields radiating from planar ultrasonic contact transducers coupled to curved and uneven thin-wall, steel surfaces using the dry coupling method were scanned and mapped using a Pinducer receiver connected to a raster scanner. Transducer sound field coverage at several ultrasonic frequencies and several distances from the transducer contact locations were found to be in good agreement with theoretical beam divergence and sound field coverage predictions for planar transducers coupled to simple, planar surfaces. This method is valuable for applications that do not allow for the use of traditional liquid-based ultrasonic couplants due to the sensitivity of the test materials to liquids and for applications that might otherwise require curved transducers or custom coupling wedges. The selection of ultrasonic transducer parameters-including frequency, bandwidth, shape and size-and the selection of dry coupling material will be presented along with the results of theoretical sound field predictions, the laboratory testing apparatus and the empirical sound field data.

8347-38, Session 7a

Acoustic emission based monitoring of surfaces subjected to friction

K. M. Asamene, M. Sundaresan, North Carolina A&T State Univ. (United States)

Monitoring state of surfaces in mechanical elements such as bearings, gears and turbine blades is very essential aspect of machinery condition monitoring. The contacting surfaces in these elements are subjected to friction which, with extended period of service, cause wear and fatigue crack. The operation life of these elements is determined by the extent of damage present on these surfaces.

The relative motion between the surfaces is source of acoustic emission signals. The information contained in these signals is indicative of the nature and type of the source of the emissions. During service, the basic information contained in these signals could change with change surface properties. Interpretation of the obtained information helps to monitor the rate at which the surface characteristics are changing and helps to take the appropriate measures.

The objective of this research is to study changes in characteristics of acoustic emission signals which occur due to changing surface characteristics with extended duration of relative sliding. A test fixture used to simulate fretting between pads of different geometry and flat bar is subjected to higher number of cycles of loading. The acoustic emission signals are recorded at selected intervals of loading. The changes in the basic contents of the signals are studied.

8347-39, Session 7b

Scanning array radar system for bridge subsurface imaging

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Early damage detection of bridge has been an important issue for modern civil engineering technique. Existing bridge inspection techniques used by State Department of Transportation (DOT) and County DOT include visual inspection, mechanical sounding, rebound hammer, cover meter, electrical potential measurements, and ultrasonics; other NDE techniques include ground penetrating radar (GPR), radiography, and some experimental types of sensors. Radar technology like GPR has been widely used for the bridge structure detection with a good penetration depth using microwave energy. The system to be presented in this paper is a different type of microwave sensing technology. It is focus on the subsurface detection and trying to find out detail information at subsurface (10 cm) with high resolution radar imaging from a flexible standoff distance. Our radar operating frequency is from 8-18 GHz, which is different from most of the current GPR systems. Scanning array antenna system is designed for adjustable beamwidth, preferable scanning area, and low sidelobe level. From the theoretical analysis and experimental results, it is found that the proposed technique can successfully capture the presence of the near-surface anomaly. This system is part of our Multi-Modal Remote Sensing System (MRSS) and provides good imaging correlations with other MRSS sensors.

8347-40, Session 7b

Highway speed ground penetrating radar system developments

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This paper will discuss the development of a ground penetrating radar system for measuring subsurface conditions in bridge decks and roadways at highway speeds. This is a daunting technical challenge using present-day techniques. The challenges include pulse signal generation, data acquisition, data pipelining to storage, vehicular position registration and electromagnetic radiated emission restrictions. This paper will give an overview of the technical challenges and the development of a multi-threaded approach to dealing with the problem. Two key technologies are the use of shaped ultrawideband signals and full waveform high-speed digitization to mitigate FCC 02-48 radiated emission constraints. The shaped ultrawideband pulses need to be generated, launched out an antenna and then received at pulse rates sufficient to produce spatial resolutions on the order of 10 mm while traveling at speeds on the order of 30 m/s. The high-speed digitization produces data streams instantaneously on the order of 16 GBs, but somewhat lesser when time averaged. Storage to disk of the captured returned waveforms uses a multiprocessor pipeline approach. The need for full-lane coverage in a single pass leads to multi-antenna designs. This then leads to the need for high-speed high-fidelity channel switching between pulse generators data acquisition systems and antennas. Many of the pieces for a prototype system have been developed individually and are now being assembled into a complete prototype system. Data from shaped ultrawideband tests using full waveform data acquisition and high-speed data pipelining will be presented as well as progress towards a fully functional prototype system.

8347-41, Session 7b

Extended defect diagnosis using time-reversal tomography technique

S. Liu, F. Yuan, North Carolina State Univ. (United States)

An extended defect diagnosis based on time reversal and diffraction tomography concept is proposed to diagnose the extended defects in a plate-like structure. Some time-reversal based technique like back propagation and MUSIC has been proposed before to imaging point-like defects in plate. They are all basically implemented by performing an eigenvalue or singular value decomposition of the transfer matrix. However, for extended scatters, each single singular vector does not correspond to an illumination vector which can be refocused back on the scatter because an extended scatter cannot be viewed as a collection of point scatter. In this paper, the reconstruction for diffraction tomography has been shown to be essentially represented by a time-reversal process. Time-reversal that uses only the measured scattered wave field on a linear sensor array has been derived for diffraction tomography application for imaging extended scatterers. A new procedure based the time-reversal tomography using plane wave excitation configuration is developed to recover the extended defects of a plate structure. Different numerical simulation cases for circular and rectangle defects detection are presented to verify the feasibility of this technique.

8347-42, Session 7b

Civil infrastructure damage detection and condition monitoring with digital image correlation photogrammetry

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Photogrammetry, particularly digital image correlation (DIC), is gaining rapid acceptance as a general purpose full-field 3D displacement, strain and shape measurement tool. This remote sensing tool can rapidly provide data at thousands of points, with robustness and ease of use, simultaneous in-plane and out-of-plane displacement analysis, insensitivity to rigid body motion, mapping of data onto both the 3D shape and camera images, and the ability to present deviation maps between multiple data sets and/or reference CAD shapes.

This paper reviews how DIC is now being exploited for civil infrastructure NDT and condition monitoring. Surface strains and crack growth can be monitored during structural integrity tests. Pothole and surface spalling shapes can be quantified using projected dot patterns. In addition, DIC can be used in conjunction with core drilling to directly measure the operational stress level in pre-stressed girders, which is a critical indication of structural integrity. DIC also supports sensor fusion in combination with other methodologies such as ground penetrating radar.

8347-43, Session 8a

Experimental comparison of 2D arrays topologies for SHM of planar structures

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Ultrasonic arrays, due to their beam-steering capability are a promising tool for structural health monitoring (SHM) of plate-like structures using Lamb waves (LW). A serious disadvantage of linear arrays applied to SHM of planar structures, which prevents unequivocal damage localization, results from the mirrored images that they produce. 2D arrays do not have this drawback and they even are capable of mode selectivity when generating and receiving LWs. Performance of 2D arrays depends on their topology as well as the number of elements (transducers) used, and their spacing in terms of wavelength.

Directional characteristics (beampatterns) of a 2D array can be to some extend evaluated analytically and using numerical simulations but in most cases, they require experimental verification. The analytical solutions usually assume narrowband signals and cannot account for dispersion and multimodal nature of LWs. Numerical simulations require precise knowledge of material properties and are usually time-consuming. Experimental performance evaluation of various 2D topologies requires considerable work related to manufacturing their prototypes.

In this paper we present a new methodology for theoretical, numerical and experimental investigations of various 2D arrays' topologies. The theoretical evaluation will be performed using frequency-dependent structure transfer function that affects LWs propagation through the dispersive medium, which enables investigation of the arrays' performance for a defined excitation signal. The numerical simulations will be conducted using local interaction simulation approach (LISA) implemented on the NVIDIA® CUDA® graphical processing unit (GPU), which facilitates 3D simulations of LWs propagation in a short time period. Finally, scanning laser vibrometer will be used to sense the LWs excited by PZT transducers, in multiple points corresponding to the locations of 2D array elements. In this way performance of various array architectures in the reception mode will be evaluated experimentally without the need of physical prototype - a change of topology requires only straightforward modification of the measurement points' distribution at the tested plate.

8347-45, Session 8a

Anti-symmetric flexural modes propagating along a wedge tip with a defect

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Antisymmetric flexural (ASF) modes are guided acoustic waves propagating along a wedge-shaped wave guide with their energy tightly confined near the tip. Motivated by the potential application of enploying ASF modes in inspecting defects in machine tool blades with sharpe edges, this study is focused in investigating the behaviors of ASF modes propagating along the wedge tips with defect. More specifically, we investigate the quatitative behaviors of ASF relection, transmission, scattering and mode conversion while the ASF modes intreract with a defect along a wedge tip. This investigatoin include numerical simulations with finite element analysis (FEA) and experimental measurements with a laser ultrasound technique . Defect parameters including depth and width are discussed regarding to their influences on the reflection coefficient (RC) and transmission coefficient (TC). The RC is found to increase as the ration between the defect depth and the ASF wavelength increases, while the TC decreases. Also degerenation of a higher-ordered ASF mode to lower order mode is observed both numerically and experimentally while the ASF modes interact with a defect.

8347-46, Session 8a

Ultrasonic phased array sound field mapping through large-bore coarse grained cast austenitic stainless steel (CASS) piping materials

A. D. Cinson, S. Crawford, M. Prowant, A. A. Diaz, M. T. Anderson, Pacific Northwest National Lab. (United States)

A sound field beam mapping exercise was conducted to further understand the effects of coarse grained microstructures found in CASS materials on phased array ultrasonic wave propagation. Laboratory measurements were made on three CASS specimens with different microstructures; the specimens were polished and etched to reveal measurable grain sizes, shapes and orientations.

The beam mapping experiment was performed in an immersion environment. A phased array (PA) probe was fixed on a specimen's outside diameter surface with the sound field directed toward one end (face) of the pipe segment. The probe was excited in the transmit-longitudinal mode at a given angle, and a point receiver (pinducer) was raster scanned over the surface of the specimen face. Data from the pinducer response was recorded and an image of the sound field was generated from energy received at the face of the specimen for a given angle, probe frequency and axial position, with a range of angles being applied for each probe. Three probes were evaluated with center frequencies of 0.5, 0.8, and 1.0 MHz. A 0.25 inch (6.4 mm) thick slice of CASS material was then removed from the specimen end and the beam mapping exercise repeated on the new specimen face. The slicing and rescanning operation was repeated 3 times for each specimen. A constant metal path length was maintained throughout the experiment for a given frequency and insonification angle for one set of data. A second set of data was acquired at a constant position, therefore a variable metal path. The sound fields acquired were analyzed for spot size, coherency, and beam redirection. Additionally, correlative analyses were conducted between the resulting sound fields and the microstructural characteristics of each specimen.

8347-92, Session 8a

Monitoring corrosion in prestressed concrete beams using acoustic emission technique

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Corrosion damage is a main durability issue in reinforced concrete structures. Early detection of corrosion can help reduce the cost of maintenance and extend the service life of the structure. In this study, acoustic emission (AE) monitoring will be used to detect corrosion. AE results will be compared to standard electrochemical techniques to detect corrosion which are; half-cell potential, and linear polarization resistance (LPR). The test program composed of four prestressed concrete T-beams; three of the beams have a length of 16 ft. 4 in. (4.98 m), and one is 9 ft. 8 in. (2.95 m). Each beam was reinforced with two ½ in. (13 mm) 7-wire low-relaxation prestressing strands with a concrete cover of 2 in. (51 mm). In order to corrode the specimens a 3% NaCl solution was prepared, which is representative to sea salt concentration. The beams were subjected to wet-dry cycles to accelerate the corrosion process. Two of the three longer beams were also cracked at 0.016 in., and 0.032 in. (0.41, and 0.81 mm) to examine the effect of crack presence. AE data were recorded continuously while half-cell potential measurements and LPR were measured daily. Corrosion current was also recorded continuously to monitor any change in the concrete resistivity. The onset stage of corrosion was clearly detected using AE parameters. This was verified using the electrochemical results. Corroded areas were located using AE source triangulation technique. The results indicated that cracked specimens showed corrosion activity prior to un-cracked specimens and has higher corrosion rate.

8347-47, Session 8b

Numerical simulations of mechanical properties of innovative pothole patching materials featuring high toughness, low viscosity nano-molecular resins

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As asphalt pavements age and deteriorate, recurring pothole repair failures and propagating alligator cracks in the asphalt pavements have become a serious issue to our daily life and resulted in high repairing costs for pavement and vehicles. To solve this urgent issue, pothole repair materials with superior durability and long service life are needed. In the present work, revolutionary pothole patching materials with high toughness, high fatigue resistance that are reinforced with nano-molecular resins have been developed to enhance their resistance to traffic loads and service life of repaired potholes. In particular, DCPD resin (dicyclopentadiene, C10H12) with a Rhuthinium-based catalyst is employed to develop controlled properties that are compatible with aggregates and asphalt binders. In this paper, a multi-level numerical micromechanics-based model is developed to predict the mechanical properties of these innovative nano-molecular resin reinforced pothole patching materials. Coarse aggregates in the finite element analysis are modeled as irregular shapes through image processing techniques and randomly-dispersed elliptical shape by non-overlapping numerical generation. The overall properties of asphalt mastic, which consists of asphalt binder, cured DCPD and air voids, are theoretically estimated by the homogenization technique of micromechanics in conjunction with the elastic-viscoelastic correspondence principle. Numerical predictions are compared with suitably designed experimental laboratory results.

8347-48, Session 8b

Dielectric dispersion of cement paste and cement mortar specimens in the frequency range of 0.5GHz to 2GHz

T. Yu, S. R. Madarshahian, Univ. of Massachusetts Lowell (United States)

Dielectric properties of cementitious composites are the basis for the use of microwave/radar NDE in concrete structures. Cementitious composites such as cement paste and cement mortar, in their nature, are multiphase (solid, liquid and gaseous) due to the porosity of the composites. Distribution and volume fraction of these phases, as well as their individual dielectric dispersion, determine the global/effective dielectric properties and dispersion of cementitious composites. In this paper, the frequency-dependent dielectric dispersion of hardened cement paste and cement mortar specimens in the frequency range of 0.5GHz to 2GHz is experimentally investigated using a contact coaxial probe system and a network analyzer. Various values of the water-to-cement ratio (0.35, 0.40, 0.45, 0.50, 0.55) were considered, and 1ft-by-1ft-by-1in panel specimens were manufactured and conditioned in two environments (room temperature and oven-dried). It is found that cement paste and cement mortar panels exhibit different dielectric dispersion patterns and different dielectric deamplification behaviors.

8347-49, Session 8b

High-toughness, low-viscosity DCPD resins for reinforcing pothole patching materials

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The potholes and alligator cracks in the asphalt pavement of our country's roadways have become an annoying part of our daily life. In order to reinstate and maintain our pavement infrastructure integrity and durability, we have identified dicyclopentadiene (DCPD) resin for this purpose due to its unique properties - low cost, low viscosity at beginning and ultra-toughness after curing, chemical compatibility with tar, tunable curing profile due to catalyst design. DCPD resin can penetrate into high porous pavement area to reinforce them and block water or moisture seeping channels. It also can strongly bond the pothole patches with original pavement, and hold them together for a whole. With the catalyst design, DCPD could apply for all the weather, cold or hot, wet or dry. In this paper, we will investigate the DCPD reinforcement for cold mix and hot mix for pothole repair, as well as the bonding strength improvement between repair materials and original pavement, and show that DCPD is promising materials for application in reinforced pothole patching materials.

8347-50, Session 8b

Automatic road surface defect detection from grayscale images

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Video health monitoring of large road networks requires the repeated collection of surface images to detect the defects and their changes over time. Vehicle mounted video equipment can easily collect the data, but the amount of data that can be collected in a single day prohibits interactive or semi-automated processing schemes as they would also not be cost-effective.

A new approach that is fully automated to detect road surface defects from large amounts of high-resolution grayscale images is presented. The images are collected with a vehicle-mounted rear-facing 5MP video camera complemented by GPS based positioning information.

Our algorithm starts by correcting the images for radial and angular distortion to get a bird's-eye view image. This results in images with known dimensions (consistent in width per pixel). Combining them with the positioning data allows us to accurately place the images on georeferenced maps.

A canny edge detector is used for preprocessing where potential crack pixels are identified. Each of these pixels are labeled as crack or non-crack using a Markov Random Field (MRF) approach. The parameters for potential functions along with the size of the Markov blanket to be used around the target pixel are determined from the training data. The data used for testing and training are disjoint sets of images collected from the streets of Boston.

We compare our road surface defect detection results with other techniques/algorithms described in the literature for accuracy and robustness.

8347-51, Session 8b

Statistical analysis of acoustic measurement for assessing pavement surface condition

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This work presents a method for assessing pavement surface condition using measurements from a microphone mounted underneath a moving vehicle. Such measurements will include tire-generated sound, which carries much information about the road condition, as well as noise generated by the wind and vehicle. The proposed method uses Principal Component Analysis (PCA) to extract the tire-generated sound from the noisy measurements. The analysis begins with acoustic pressure measurements made over constant and known road conditions. Fourier transforms are taken over various time windows and a PCA is performed over the resulting vectors, yielding a set of principal component vectors for that road condition. Road conditions are varied and the analysis is repeated, so that each road condition is characterized by a set of principal component vectors. These vector sets are used to analyze measurements from a road with unknown road conditions by finding the vector set that best represents the acoustic measurements from that road. Successful applications of this method are demonstrated by accurate estimations of the mean texture depth (MTD) of pavement directly from acoustic measurements.

8347-52, Session 9a

Real-time aircraft structural damage identification with flight condition variations

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The structural uncertainty and environmental variation, such as boundary condition uncertainty and temperature variation, result in the uncertainty of analytical dynamic model and the variation of the identified parameters. This brings a challenging problem to vibration-based structural health monitoring (SHM) methods, which compare the change of the identified modal parameters and the change of the analytical model due to damage.

Aircraft structural damage and component damage can cause unwanted aerodynamic effects and may lead to a catastrophic structural failure of the flight vehicle. If these anomalies can be identified, they can be used as input to an adaptive control system to properly adjust to accommodate these conditions. The real-time structural damage identification of aircraft is a challenging task due to the flight environmental uncertainty and flight condition variation.

This paper presents a real-time structural damage identification approach for aircraft with flight condition changes. The proposed method integrates real-time system identification, uncertainty quantification, and damage identification. First, time-domain system identification techniques, such as OKID and subspace system identification techniques, are applied to synthesize the collected time-domain input/and output data to get the identified models in various time periods with changing flight conditions. Based on these identified models, singular value decomposition (SVD) is used to characterize and quantify parameter uncertainties of the identified models. Singular values and vectors are used to compute uncertainty coordinates corresponding to principal directions. The interval length of each uncertainty coordinate is computed to determine the distribution and number of dominant uncertainty coordinates. The uncertainty coordinates corresponding to the healthy structure with uncertainty can be estimated as functions of time. The residual errors between the identified uncertainty coordinates of the tested system and the estimated uncertainty coordinates of the health structure are used to generate the threshold values for damage status identification. A damage identification approach, which is based on a correlation method by comparing the change of the identified model with the change of the analytical model due to damage, is developed to identify the damage type and intensity. The proposed approach is demonstrated by application to the Benchmark Active Controls Technology (BACT) wind-tunnel model, which was developed by the researchers in the NASA Langley research center to address the flutter problem. The results of the examples based on the BACT model with various flight conditions show that the proposed damage identification technique can effectively identify damage status, damage type, and precisely estimate the intensity of damage.

8347-53, Session 9a

Damage visualization enhancement by the wave field filtering and processing

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The aim of this paper is to present overview of methods for enhancing damage visualization in structures based on wave propagation phenomenon. The methods utilizes filtering and processing of full wavefield acquired by the laser vibrometer. Laser vibrometer allows to register full wavefield in elements of a structure instead of single point measurements acquired by e.g. piezoelectric sensor. In this way new possibilities for Nondestructive Evaluation arise enabling visualization of elastic waves interacting with various types of damages. Measurements obtained with a scanning laser vibrometer can be combined with effective signal and imaging processing algorithms to support damage identification. Root mean squared (RMS) value applied to signals measured by laser vibrometry is recently most popular tool for damage localisation. Obtained results constitute RMS map, regarded also as damage index, that forms the basis for damage localisation. Another procedures which operate in frequency-wavenumber domain have the objective of removing the wave generated by the transducer to obtain a residual wavefield that contains only contributions of scattering waves. The residual wavefield analysis can be used for baseline-free detection and characterization of defects.

Alternatively to the methods currently available in the literature new method is proposed. The new method for wave filtering of propagating waves is tested on both numerical results and experimental data obtained from laser vibrometry measurements of composite plates. Processing of signals registered at a rectangular grid of measurement points covering inspected area of the plate involve 2D DFFT (Discrete Fast Fourier Transform), wavenumber filtering and inverse DFFT. As a result new damage index is proposed and compared with other methods like RMS and frequency-wavenumber filtering.

8347-54, Session 9a

Nonlinear self-sensing impedance-based fatigue crack detection under a low-frequency vibration

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This paper reports the application of a non-linear impedance technique under a low-frequency vibration to detect structural defects of contact type such as fatigue crack. If the contact-type damage is developed within the structure due to the low-frequency dynamic load, the vibration can cause the fluctuation of structural impedance nonlinearly because of the contact acoustic nonlinearity (CAN). This nonlinear effect can lead to amplitude modulation and phase modulation of the current flow. The nonlinear characteristics of the structural impedance can be extracted by observing coupled electromechanical impedance of a piezoelectric active sensor and a nonlinear wave modulation spectroscopy. For experiment, a low-frequency vibration is applied to a notched coupon at a certain natural frequency by a shaker so that the nonlinear fatigue crack can be formed artificially at the notch tip. Then, the nonlinear features are extracted based on a self-sensing impedance measurement from a host structure under a low-frequency vibration. Damage metric is established based on the nonlinear fluctuation of the impedance due to CAN.

8347-55, Session 9a

Impedance measurement to monitor fresh concrete property using bender elements

J. Zhu, Y. Tsai, X. Dai, The Univ. of Texas at Austin (United States); J. Cai, Zhejiang Univ. (China)

Piezoelectric impedance based health monitoring has been used to evaluate damage in concrete structures and to monitor strength development in early age concrete. However, due to the large mismatch of mechanical impedance between fresh concrete and piezoceramic material (PZT), the impedance measurement usually cannot be applied to very early age concrete (before initial setting). This paper proposes a low cost impedance measurement method to monitor hardening process of fresh cement and concrete by using piezoceramic bender elements. Previous study by the authors showed that bender elements are effective to generate and sensor shear waves in fresh cement and concrete. Compared to typical PZT sensors vibrating in the thickness mode with very small deformation, the bender element vibrates in flexural mode with large tip deflections. The low flexural stiffness of bender elements allows improved impedance match with fresh concrete. Therefore the bender elements show good potential to be used for impedance measurement in fresh concrete. The impedance measurement can also be combined with the shear wave measurement to obtain comprehensive mechanical properties of concrete in fresh state. Finally, the embedded bender elements also show potential for long term health monitoring of concrete structures.

8347-56, Session 9a

Piezoelectric accelerometer for high temperature (1300°C) sensing

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Technologies for use in ultra-high temperatures (>1000°C) are in great demand particularly in the aerospace and power turbines industries. Piezoelectric devices have gained popularity due to their low complexity, low mass and low cost as compared with other high temperature technologies. Despite these advantages, currently piezoelectric sensors for high temperatures are limited by the temperature limits of piezoelectric materials and electrodes to under 1000°C. A shear mode piezoelectric accelerometer using yttrium calcium oxyborate piezoelectric single crystals was developed in the authors' group and operated successfully at 1100 °C. During this study, a sensor capable of operating in temperatures up to 1300°C will be developed. The shear mode design is featured with low profile and insensitive to mass-loading effects. In addition, the housing and seismic masses of the sensor are made of Inconel 601 alloy. Because current electrode materials cannot withstand temperatures above 1000°C for an extended period, an electrode-less design was implemented. The sensor will be tested in a furnace in air for sensitivity, reliability, bandwidth, response time and dwell time at temperatures up to 1300°C. Finally, different conductive barrier coatings will be investigated and tested to be applied between the yttrium calcium oxyborate crystals and the Inconel metal interface to prevent diffusion. The results of this study would then be compared to other high temperature sensors, and will provide great insight into further developing this accelerometer to smaller scales and higher temperatures in the future.

8347-57, Session 9b

Image processing for the laser spot thermography of composite materials

A. Vandone, P. Rizzo, Univ. of Pittsburgh (United States); M. Vanali, Politecnico di Milano (Italy)

In this paper an algorithm for the analysis of raw thermal infrared images obtained by using the nondestructive evaluation method of the laser spot thermography is proposed. A laser was used to scan a test specimen through the generation of single pulses. The temperature distribution produced by this thermoelastic source was measured by an infrared camera and processed with a two-stage algorithm. In the first stage few statistical parameters were used to flag the presence of damage. In the second stage the images that revealed the presence of damage were processed computing the first and second spatial derivative. Two spatial filters were also used to enhance contrast, and to locate and size the defect.

The algorithm was experimentally validated by scanning the surface of a CFRP composite plate with induced defects.

8347-58, Session 9b

Compton imaging tomography for single-sided NDE/NDT of large and complex structures

V. Grubsky, V. Romanov, E. Patton, T. P. Jannson, Physical Optics Corp. (United States)

We describe a new technique, Compton Imaging Tomography (CIT), for NDE/NDT of complex structures. CIT is based on irradiating the sample with a planar x-ray beam and measuring two-dimensional Compton scattering intensity distributions one cross section at a time. The information collected from multiple cross sections is used to reconstruct

a complete three-dimensional internal structure of the object, which permits accurate detection and localization of defects, cracks, and corrosion in a virtually any materials. To increase the collected signal and improve the resolution, we use x-ray imaging optics based on apodized coded apertures with specially designed three-dimensional profiles. The typical spatial resolution of a CIT system is ~1 mm, field of view 10-20 cm, and sensitivity <5% of material density variation. Because the CIT hardware can be positioned entirely on a single side of the inspected objects, the technique is especially useful for large or hard-to-access structures, such as external and internal components of sea vessels, airplanes, spaceships, turbines, and large infrastructure. Theoretical and experimental results will be presented.

8347-60, Session 9b

High-speed full-spectrum interrogation of fiber Bragg grating sensor application in reducing sensor strain sensitivity

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We used high-speed full-spectrum interrogation of Fiber Bragg Grating (FBG) sensors to measure the strain sensitivity in electric field sensor packages in real-time. Based on the dynamic test results we reduced the strain sensitivity by a factor of more than 52. In this effort we performed solenoid impact tests on a variety of mounting structures, including FR4, steel, and carbon fiber composite materials. The 40 kHz repetition rate of the FBG spectral interrogation was the key that allowed us to measure and compare dynamic strain of the structures. Our results show that the FR4 board with soft epoxy responded with a maximum dynamic strain in the order of 3000 microstrain. However, the FR4 board mounted in a free-floating configuration using hard epoxy reduced the maximum dynamic strain to a value below the noise threshold. The high repetition rate interrogator allowed us to have a dynamic strain resolution on a millisecond scale. We will use these results to enhance the performance of our electric and magnetic field sensors in environments with high static and dynamic strain.

8347-61, Session 9b

Recent progress on fiber optic distributed sensing for structural health monitoring using stimulated Brillouin and coherent Rayleigh (SBCR) interrogation method

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We report on the recent progress made across several technical areas in the development of an integrated fiber optic distributed sensing system based on Stimulated Brillouin and Coherent Rayleigh (SBCR) scattering measurements for civil infrastructure integrity monitoring. The SBCR approach utilizes two complimenting fiber optic sensing techniques to simultaneously measure and monitor static and dynamic changes in structural condition by combination of a Brillouin Optical Time Domain Analyzer (BOTDA) and a Demodulated Coherent Rayleigh scattering system (CR).

In monitoring the static changes, dual pulse approach (DP-BOTDA) has been used to achieve high spatial resolution down to 10cm. Also, progress has been made on developing a method of separating the influence of strain and temperature to enable simultaneous measurement of both parameters. For the purpose of detecting and characterizing the occurrence of dynamic event, Coherent Rayleigh system is developed with modulation/demodulation method to produce linear response to the detected event. Prototypes have been developed and successfully tested in the lab, and their results are presented.

8347-62, Session 10a

Large-scale surface strain gauge for health monitoring of civil structures

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Health monitoring of civil structures is a method that aims to diagnose and localize structural damages. It is typically conducted by visual inspections, where its efficiency is derived primarily from the monitoring frequency and judgement of the inspectors. The automation of the monitoring process would be greatly beneficial, as it could increase life expectancy of civil structures via timely maintenance, thus also improving their sustainability. In this paper, we present results on a recently introduced sensing method for automatically localizing strain over large surfaces. The sensor consists of several soft capacitors arranged in a matrix form, which can be applied over large areas. Measurements of changes in capacitance among soft capacitors are converted into local static strains within the matrix of sensing patches, permitting damage localization. The proposed sensing method has the fundamental advantage over conventional health monitoring methods of being inexpensive to apply over large-scale surfaces, which allows local monitoring over very large regions, analogous to biological skin. In addition, its installation is simple, necessitating only limited surface preparation and deployable utilizing off-the-shelf epoxy glue. Here, we demonstrate the performance of a new generation of the sensor for damage localization on a large-scale concrete beam. Results show that the sensing method is successful at diagnosing and localizing cracks on a large-scale surface.

8347-63, Session 10a

Long-term gage reliability for structural health monitoring of steel bridges

V. Samaras, J. Fasl, M. Reichenbach, T. Helwig, S. L. Wood, The Univ. of Texas at Austin (United States); K. H. Frank, Hirschfeld Industries (United States)

Real-time monitoring of fracture critical steel bridges can potentially enhance inspection practices by tracking the behavior of the bridge. Significant advances have occurred in recent years on the development of robust hardware for field monitoring applications. These systems can monitor, process, and store data from a variety of sensors (e.g. strain gages, crack propagation gages etc.) to track the behavior of the bridge. Thus, for a long-term monitoring system to be successful, the reliability of gages that are to be relied upon for several years is very important. This paper focuses on the results of a research study focused on developing a wireless monitoring system with a useful life of more than 10 years. An important aspect of the study is to identify strain gages and installation procedures that result in long lives as well as characterizing the effect of temperature fluctuations and other environmental factors on the sensor drift and noise. In long-term monitoring applications, slight sensor drift and noise can build up over time to produce misleading results. Thus, a wide variety of gages that can be used to monitor bridges have been tested for over a year through environmental tests. The environmental tests were developed to determine the durability of the gages and their protective coatings (e.g. zinc-based spray, wax and silicon, etc.) against humidity, sun exposure and other environmental effects that are expected in long-term bridge monitoring applications. Moreover, fatigue tests were performed to determine the fatigue category of the weldable gages and to reveal any debonding issues of the bondable gages. This paper focuses on the results of laboratory tests on gage durability.

8347-64, Session 10a

Development of a wireless strain node and the software required to monitor fracture-critical bridges

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The US and many other countries around the world face the challenge of an aging infrastructure. In the US, there are 600,000 bridges in its inventory and a significant percentage of those bridges are nearing the end of their intended design life. Labor-intensive, visual inspections are used to identify possible safety problems in bridges and determine which ones can be safely kept in-service. This paper outlines ongoing research sponsored by NIST to improve inspection practices by providing the technology and methodology for real-time monitoring of steel bridges.

Strain gages can be used to monitor the number and size of stress cycles in fatigue-sensitive members. From the cycle count, Palmgren-Miner's rule can be used to determine an effective stress. The remaining fatigue life can then be calculated and compared to existing conditions and the age of the bridge. Because damage is expected to escalate over time, more frequent inspections may be needed when a bridge approaches its fatigue life. A low-power, wireless, strain data acquisition device has recently been developed to acquire dynamic strain data. The strain node can be programmed in LabVIEW to detect critical events or perform a rainflow analysis. To aid in system interaction, a software interface will be designed to allow for automated processing and transmission of data to a cloud server, thereby allowing engineers and bridge owners to access the data from anywhere so as to make informed decisions when prioritizing inspections. This paper will present the development of the strain node and the software interface.

8347-65, Session 10b

Characterization of AE from fatigue crack growth in steel bridge components

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Single edge notches provide a very well defined load and fatigue crack size and shape environment for estimation of the stress intensity factor (K). A modified versions of the SE(T) specimen has been examined to provide small scale specimens with improved acoustic emission (AE) characteristics while still maintaining accuracy of fatigue crack growth rate (da/dN) versus stress intensity factor range (ΔK). The specimens intend to represent a steel beam flange subjected to pure tension, with a surface crack growing transverse to a uniform stress field. Acoustic emission data recorded during stages of crack growth is utilized to investigate sources of AE activity from the crack. Pattern recognition techniques are used when characterizing AE activity. The position of the onset of fatigue crack extension in a stress cycle is discussed. Scanning electron microscopy (SEM) of the crack surface is presented to enrich data interpretation.

8347-66, Session 10b

Acoustic emission noise assessment of loaded members in laboratory and field environments

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The acoustic emission (AE) technique plays a progressively significant role in the field of non-destructive testing (NDT) especially in structural health monitoring (SHM). AEs are commonly defined as transient elastic waves in a material caused by the of localized stress release. In using AE for mechanical diagnostics, noise has always been a potential barrier. AE can be produced from sources not related to material damage including traffic or friction. The major challenge is the differentiation of signals relevant to the purpose of the test - such as crack growth in a member - from noise of various origins. This paper deals with noise discrimination and noise interpretation in AE data. AE activities recorded in field and lab environments for concrete and steel specimens are investigated in this study. Approaches for clustering and separation of AE signals based on multiple features extracted from experimental data are presented. Source location technique is used to aid the diagnosis. A decision making algorithm to identify relevant signals is proposed.

8347-67, Session 10b

Multi-physics modeling of sensor-structure interaction for quantitative acoustic emission

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The influence of mechanical noise in an AE testing still obscures its successful application in monitoring various structures and systems. While advances in pattern recognition algorithms are helpful to differentiate relevant data from captured noise, the algorithms fail if the characteristics of relevant data are unknown. The ability to accurately model elastic waves using numerical methods offers a potential to understanding the frequency content of elastic waves. However, classical finite element models require fine meshing to be able to get a stable numerical approximation considering the oscillatory nature of the wave equation. Because of size of civil structures, numerical modeling of full scale geometry is not feasible. In this study, spectral element approach is implemented for numerical modeling of elastic waves in sub-scales in order to reduce the computation time. The numerical model includes PZT-5H with geometry for 60-kHz resonant frequency, coupled to the structure for multi-physics models. The output signal in the form of current is identified by the convolution of the transfer function of a typical piezoelectric sensor and the surface displacement. The approach is demonstrated for 1D and 2D structures and compared with conventional finite element model using COMSOL Multiphysics program. The comparison includes numerical efficiencies and computation times of spectral element and classical finite element. The importance of including sensor transfer function in numerical models for quantitative AE is discussed.

8347-68, Session 11a

Status in the development of self-powered wireless sensor node for structural health monitoring and prognosis

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This paper discusses the development status of a self-powered wireless sensor node for steel and concrete bridges monitoring and prognosis. By the end of the third year in this five-year cross-disciplinary project, the 4-channel acoustic emission wireless node, developed by Mistras Group Inc, will be already deployed in concrete bridges by University of Miami and steel bridges by University of South Carolina. Also, extensive testing will be underway with the node powered by structural vibration and wind energy harvesting modules developed by Virginia Tech. The development of diagnosis tools and models for bridge prognosis, which will be discussed in the paper, continues and the diagnosis tools are expected to be programmed in the node's FPGA during the 4th year of the project. The impact of this development extends beyond the area of bridge health monitoring into several fields, such as offshore oil platforms, composite components on military ships and race boats, combat deployable

bridges and wind turbine blades. Some of these applications will also be discussed. This project was awarded to a joint venture formed by Mistras Group Inc, Virginia Tech, University of South Carolina and University of Miami by the National Institute of Standards and Technology through its Technology Innovation Program Grant #70NANB9H007.

8347-69, Session 11a

Dynamic decision-making for sustainable infrastructure integrating life cycle assessment, wireless structural monitoring systems, and system optimization

M. D. Lepech, Stanford Univ. (United States)

Increasingly, infrastructure owners, managers, engineers, and maintenance personnel are asked to provide higher levels of infrastructure performance with fewer resources. Moreover, the definition of performance is broadening beyond traditional metrics such as downtime, initial or life cycle agency costs, or vehicle ride quality to include social and environmental metrics such as passenger exposure to vehicle emissions in traffic congestion, life cycle energy consumption, and global warming impacts. To aid infrastructure owners in achieving higher performance across a diverse range of metrics, the fields of (1) wireless sensing for infrastructure deterioration and damage detection, (2) industrial ecology/life cycle assessment for comprehensive performance evaluation and (3) system optimization are brought together to create a decision analysis and support framework for sustainable infrastructure maintenance and management.

Within this framework, wireless structural sensing systems are used to capture the real-time state and rate of deterioration or damage in infrastructure. Combined with structural analysis tools, data collected from these sensing networks provide a measure of structural capacity and safety while supplying information on potential maintenance and repair options. Process-based, probabilistic life cycle assessment models are used to quantify the comprehensive economic, social, and environmental impacts of potential maintenance and repair options thereby providing a wider range of metrics to evaluate infrastructure performance. Test bed applications of this framework show it to be effective for managing infrastructure systems for increased sustainability.

8347-70, Session 11a

Incorporating structural health monitoring and decision making concepts in bridge management framework

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Asset management approach emphasizes timely actions such as bridge preservation, rehabilitation, and replacement through cost-effective planning and resource allocation decisions. When key bridges are instrumented with sensors to obtain current condition of key components, vast quantities of data can be collected. But, there is still a lack of support for using information effectively by bridge owners for appropriate decision-making based on the available data. An innovative new software solution known as a Decision Making Toolbox is described in this paper to bridge that gap. This has ability to transform raw and processed data into appropriate action required to manage these instrumented bridges in a cost effective manner.

8347-71, Session 11a

Distributed cyberinfrastructure tools for automated condition assessment of civil infrastructure systems

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Emerging cost-effective sensing technologies enable the monitoring of the behavior and condition of large-scale civil infrastructure systems. However, the continuous operations of large sensor networks installed in an infrastructure element create new challenges for managing the massive amounts of data streamed into a database. This paper presents a cohesive set of cyberinfrastructure tools which hierarchically control multiple sub-networks of a wireless monitoring system deployed within a large civil infrastructure system (e.g., bridges, pipelines, dams). The internet-enabled cyberinfrastructure centrally manages data flow for the entire monitoring system. A client-server model built upon the communication of middleware provides data-provider and system end-users with the secured transfer of multi-layered information of the structure under study. In the system, information on structural behavior (e.g., acceleration, strain, displacement) and climate (e.g., wind speed, wind direction, temperature, humidity) are uploaded from the sensor networks and queried by various data interrogation services interfaced via client middleware. The current research focuses on the assessment of the scalability and long-term robustness of the proposed cyberinfrastructure system using wireless sensor sub-networks permanently deployed on the New Carquinez (Alfred Zampa Memorial) Suspension Bridge in Vallejo, CA. Many data interrogation tools are under development using real-life sensor data. Presented here includes the detection of faulty sensors by an automated sensor logging tool, the long-term monitoring of variations of bridge modal properties through an automated system identification tool, and the mode-verification and -updating of a high-fidelity finite element model of the bridge by a model updating tool.

8347-72, Session 11b

Signal identification in acoustic emission monitoring of fatigue cracking in steel bridges

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In the application of acoustic emission (AE) techniques to structural bridge health monitoring, signal identification may include noise filtering and reduction of acquired AE signals. Noise filtering is to ensure that genuine hits from crack growth are involved in AE data interpretation to achieve efficient and accurate estimation of fatigue damage and remaining fatigue life. Reduction of acquired AE signals is desirable in the application of remote AE monitoring because it can conserve energy for the sensing system in the data transmission through wireless means.

The spatial filtering techniques based on the source location, guard sensors, and time of arrival have been developed in laboratory testing to separate mechanical noise from cracking signals. In laboratory testing crack may initiate at man-made defects such as sharp notch and weld seams, and grows along the notch/flaw plane. The techniques used to minimize mechanical noise in laboratory testing may not be entirely applicable for acoustic emission bridge-monitoring because the crack location, the environmental noise and loading amplitudes can be less predictable in the field. The pattern recognition and waveform feature analysis have therefore been proposed to interpret AE signals. Waveform parameters such as amplitude, rise-time, duration, and signal energy are usually involved in pattern recognition and waveform feature analysis.

In the work described, wave frequency analysis as well as the combination of pattern recognition and waveform feature analysis was involved in the signal identification. Data filtering and reduction

procedures were demonstrated using the results from AE monitored fatigue tests. The cleaned sparse dataset was proved to be able to evaluate fatigue damage. The presented methodology may be well suited for laboratory testing and field implementations.

8347-73, Session 11b

Comparative study of active and passive sensing with AE and PWAS transducers

L. Yu, V. Giurgiutiu, J. Yu, P. Ziehl, Y. Shen, L. Zhao, Univ. of South Carolina (United States)

Monitoring of fatigue cracking in bridges has been approached. Acoustic emission monitoring has shown to be able to detect crack growth behavior by picking up the stress waves resulting from the breathing of cracks while active sensing can quantitatively assess structural integrity by sensing out an interrogating pulse and receive the structural reflections from discontinuity. In this paper, we present a comparative study of active and passive sensing with two types of transducers: (a) acoustic emission (AE) transducers, and (b) embeddable piezoelectric wafer active sensors (PWAS). The study was performed experimentally on steel plates. Both pristine and damaged (notched) conditions were considered. For active sensing, pitch-catch configuration was examined in which one transducer was the transmitter and another transducer acted as the receiver. The ping signal was generated by the acoustic emission hardware/software package AE-Win. For passive sensing, 0.5-mm lead breaks were executed both on top and on the edge of the plate. The comparative nature of the study was achieved by having the AE and PWAS transducers placed on the same location but on the opposite sides of the plate. The paper presents the main findings of this study in terms of (a) signal strength; (b) signal-to-noise (S/N) ratio; (c) waveform clarity; (d) waveform Fourier spectrum contents and bandwidth; (e) capability to detect and localize AE source; (f) capability to detect and localize damage. The paper performs a critical discussion of the two sensing methodology, conventional AE transducers vs. PWAS transducers.

8347-74, Session 11b

Improvements in air-coupled sensing of concrete structures

J. Zhu, Y. Tsai, X. Dai, M. Haberman, The Univ. of Texas at Austin (United States)

Air-coupled sensing of stress waves in concrete structures was proposed in 2001. This non-contact NDT technique has shown great potential for rapid scanning of large concrete structures. However, ambient noise and contact requirement of the impact source are two challenges that limit applications of the air-coupled sensing in field testing. This paper presents recent progress in air-coupled sensing, and proposes possible solutions to the challenges. To improve signal quality, a parabolic reflector is proposed to focus in-air waves radiated from the concrete surface. Preliminary results indicate that the parabolic reflector significantly improves signal amplitude and S/N ratio, through two mechanisms: acoustic focusing and multiple reflections between the reflector and concrete surface. The authors also explore the feasibility of using electrical sparks as a low cost and powerful acoustic source.

8347-75, Session 11b

Measurement of pore size distribution in concrete by advanced ultrasonic analyses

Y. Sun, X. Yu, Case Western Reserve Univ. (United States)

The structures of concrete, especially the pore sizes, are crucial for the freeze-thaw durability of concrete in cold regions. This paper presents studies on the use of advanced ultrasonic techniques to measure the capillary porosity and entrained air content in concrete. Modeling of ultrasonic attenuation are used to estimate the volume fraction and size distribution of entrained air voids. An inversion procedure based on a theoretical attenuation model was studied to predict the size distribution and volume fraction of entrained air voids. Results from the preliminary study are encouraging. The ultrasonic analyses are being extended to determine the pore characteristics of porous materials.

8347-76, Session 12

A web-based SDSS-aided visualization system for volunteer network sensing

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To better manage highway bridges, optimized strategies for maintaining, operating and repairing bridge are needed. Considering the conventional data collection approaches including In-site inspection and remote sensing, there are very limited real-time data. If a human sensor network, which has a large number of sensors (volunteers) with intelligence, is used for bridge data collection, a huge amount of real-time data can be uploaded to bridge database. In this study, a web-based spatial decision support system (SDSS) aided visualization system is developed through the integration of WebGIS, Internet, Database, remote sensing and visualization technologies for evaluating the national bridge condition. The web-based system makes human sensors upload data possible. This Web-based Geospatial Visualization Bridge Evaluation System (WGeoVisBES) incorporates national bridge inventory (NBI) data, remote sensing data generated by LiDAR, human sensing data, decision-making support modules, and visualization into a general framework through user-friendly interface with easy accessibility from internet. This system provides interactive interfaces for user to input, output, analysis, interpret, and visualize bridge data, and allow qualified system users can be involved in the model selection and decision-making processes. Spatial decision-making model can generate bridge maintenances solutions which cannot be obtain from conventional bridge management systems; it also can guide the qualified user to maintain the bridge effectively and optimally. Interactive visualizations provide various data interpretations and mapping including general bridge information, bridge condition distribution mapping, statistical graphs, conditional bridge search, pre-caution alarm, maintenance decision support, and 3D LiDAR scan data visualization. A bridge locator module helps inspector to locate bridge and entry bridge data easily via Internet. Integration of NBI data, LiDAR bridge data and human sensing data provides further analysis for bridge condition and better maintenance prediction. The internet security and database reliability issues are discussed in the paper.

8347-77, Session 12

Probabilistic structural risk assessment for fatigue management using SHM

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The Army is transforming its way in conducting maintenance in numerous ways. Most pronounced in this transformation is the move toward a condition-based maintenance (CBM) strategy. This approach makes it more effective in Army's ability to rapidly repair platforms by seamlessly collecting critical platform information that can be used for risk and remaining useful life assessment. To support this effort for fatigue-critical structural maintenance, inspection methods either using conventional NDI or SHM systems are being developed. Those systems are also being validated and verified that structural degradations can be detected, localized and/or quantified reliably and the risk of structural failure is within an acceptable level.

Probability of detection (POD) is one of the critical measurements for the inspection reliability of a given NDI or SHM system. Although SHM

is an extension of NDI via permanently mounted or embedded sensors for diagnostics and prognostics, the implications of PODs of NDI and SHM systems on probabilistic structural risk assessment (PSRA) are statistically different. If one would treat the outcome of each inspection as a probabilistic event, the outcomes from the consecutive NDI inspections are considered to be independent events. On the other hand, the outcomes from the consecutive SHM inspections would then be correlated.

PSRA using conventional NDI method has been well developed by numerous research organizations. Analysis software such as PROF (Probability of Fracture), RPI (Recursive Probabilistic Integration) and DARWIN (Design Assessment of Reliability with Inspection) were all developed based on the assumption of independent inspection outcomes. However, PSRA using SHM has not yet been developed. The major issue under investigation is how to include the correlated inspection outcomes in the PSRA framework.

This paper addresses the probabilistic structural risk assessment using SHM with a proper consideration of correlations among inspection outcomes. A PSRA framework is developed and a new probabilistic formulation is derived. The risk assessment is conducted based on a system reliability methodology and a semi-analytical probabilistic method (SAPM). SAPM considers all uncertainties including material properties, repair quality, crack growth rate and related parameters, loads, POD etc. in the analysis. A correlated random field made of inspection outcomes is uncorrelated and represented by a set of uncorrelated random variables. The probability of missing all previous inspections at a given time is calculated using the structural reliability algorithm. The risk-based inspection schedule and remaining useful life is also determined for a given acceptable risk.

8347-78, Session 12

Probabilistic load rating based on family of models approach for decision making

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The effective use of SHM and NDE can be measured by means of the objective, quantified decision-making metrics. Load rating and reliability analysis are the two main types of bridge assessment metrics, which are critical for decisions such as retrofit, maintenance, load posting, etc. Load rating is the most common approach for assessment of bridges; however, it has some limitations due to the uncertainties in models, loading, data acquisition, sensors and modeling. On the other hand, reliability techniques can better quantify the bridge safety in probabilistic terms with the uncertainties. This study performs both a load rating analysis and a reliability analysis based on family of models approach that incorporates the possible uncertainties to the models using SHM data.

8347-79, Session 12

Evaluation of risk metrics in structural health monitoring process

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Traditional bridge, and infrastructure, safety are based on evaluating system, or component, reliability metrics: namely capacity and demands. Safety is then deemed adequate if / when capacity metrics exceed demand metrics. Consequently, infrastructure, including bridges, management is based on optimal processes that would produce safe infrastructures. These processes include inspection, maintenance, rehabilitation, or even replacement. Structural health monitoring (SHM) emerged lately as a mean to quantify some of these as-built metrics such as capacity, demands, inspection, etc. Unfortunately, the linkages between the traditional safety measures, i.e., reliability, and infrastructure management processes are not well defined. This can result in non-optimal management processes, even with the help of SHM technologies.

Risk has emerged as a decision making tool for civil infrastructures lately in the field of infrastructure security. At its foundations, it integrates capacity, demands, and consequences. As such it has the promise of integrating all aspects of infrastructure safety (capacity and demands) with all aspect of infrastructure management (inspection, maintenance, rehabilitation, replacement, etc.). Thus, it is obvious that utilization of risk as the basis of an integrated infrastructure management system offers a potential solution to the above inefficiency. This paper explores efforts of using SHM techniques in applying risk processes in bridge management. The paper will show how to utilize sensor measurements (which are the basis of any SHM project) to decision making practices (which should be the ultimate fruit of any SHM project) that are based on risk paradigms.

8347-80, Session 12

Finite element model updating of a skewed highway bridge using a multivariable sensitivity-based optimization approach

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This paper presents the implementation of the Finite Element (FE) model updating for the New Carquinez Bridge using real-time sensor data. The New Carquinez Bridge is a 1.06 km long suspension bridge in California. The bridge, built in 2003, is instrumented with a wireless sensory system to collect the vibration response of the bridge under ambient vibrations. The dynamic characteristics of the bridge have been studied through the field measurements as well as a high-fidelity FE model of the bridge. The developed finite element model of the bridge is updated with the field measured response of the bridge so that the FE computed and field measured modal characteristics of the bridge match each other closely. A comprehensive sensitivity analysis was performed to determine the structural parameters of the FE model which affect the modal frequencies and modal shapes the most. In addition, the important modal frequencies which govern the vibration response of the bridge are identified for the updating procedure. A multivariable sensitivity-based objective function is constructed to minimize the error between the experimentally measured and the FE predicted modal characteristics. The selected objective function includes information about both modal frequencies and mode shapes of the bridge. An iterative approach has been undertaken to find the optimized structural parameters of the FE model which minimizes the selected objective function. Appropriate constraints and boundary conditions are used during the optimization process to prevent non-physical solutions. The final updated FE model of the New Carquinez Bridge provides modal results which are very consistent with the experimentally measured modal characteristics.

8347-81, Session 13

Nonlinear modeling of the vehicle/structure interaction on a skewed highway bridge using an iterative uncoupled approach

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Interaction of the vehicle/ structures is extremely important in determining the structural performance of highway bridges. However, an accurate prediction of the generated vibrations and forces requires a high-fidelity nonlinear 3D model which is sufficiently representative of the actual

vehicle and bridge structure. Although the computing power has been improved tremendously over time, there are many technical difficulties to obtain an efficient solution from a highly nonlinear and highly damped multi-axle system traversing another nonlinear structure. This paper presents an iterative uncoupled approach to obtain an accurate estimation of the vehicle/structure interaction. The multi-axle vehicle is simulated using a nonlinear 3D multibody dynamics model, with realistic spring and damper characteristics. The bridge model also contains several nonlinear components to accurately model the vehicle/structure interaction especially when the vehicle passes critical locations such as the bridge expansion joints. The final vehicle/bridge interaction results are obtained through an iterative solution by exchanging the outputs of two uncoupled nonlinear models: the vehicle reactions are used to obtain the deformed profile of the bridge, and the deformed profiles are passed to the vehicle model to obtain the new reactions. A convergence criterion is set to obtain a reliable solution after several of these iterations. Finally, a parametric study is performed to investigate the effect of passing vehicle speeds on the interaction forces induced on a skewed highway bridge. Also, the effects of pavement roughness on the vehicle/structure interaction are briefly studied in this paper.

8347-82, Session 13

Bridge scour monitoring with spatially distributed wireless smart rocks as field agents

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This paper describes the overall goal of a new research program for bridge foundation scour monitoring. Representative results will be presented to illustrate main concepts. The key challenges to develop a real-time scour monitoring system will be reviewed and discussed. The objectives of this study are (1) to integrate several alternative commercial measurement and communication technologies into a scour monitoring system with passive and active sensors embedded in ‘smart rocks’, (2) evaluate the comparative effectiveness of these communication technologies in laboratory and field conditions and improve them for better performances and/or reduced costs in bridge applications, and (3) analyze the movement of smart rocks during testing for determination of scour depth. Smart rocks function as spatially-distributed field agents that can be deployed around a bridge foundation to register both temporal and spatial information on scour process and transmit critical data in real time for an engineering evaluation of scour depth and area. Scour vulnerability of multiple bridges affected by a flood event can then be reported anytime to engineer-in-charge and first responders through a cellular network as needed. The monitoring system can be integrated with intervening techniques to potential foundation erosion, leading to a cost-effective scour management technology. For example, rocks are traditionally used to protect a bridge from scouring effects, but now, with embedded electronics, become part of a wireless, early-warning network that can monitor the process of bridge scour in real time.

8347-83, Session 13

Bridge scour monitoring system: a pilot field evaluation

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Scour is a major threat to the safety of bridges. Instruments for the measurement and monitoring of bridge scour are necessary to study scour processes and to support bridge management. The lack of robust and economical scour monitoring devices prevents the implementation of a bridge scour monitoring program among bridge owners. This paper explores the design and analyses of scour sensors using principles of Time Domain Reflectometry (TDR). The performance of a scour probe was first tested in laboratory simulated scour experiments. The sensing principles and analysis algorithms were validated from simulated scour tests under various conditions which are expected to be encountered in the field. The field conditions considered included: variation of sediment types, water conductivity, turbidity, air entrapment, and water elevation. Six TDR bridge scour sensor were installed at BUT-122-0606 bridge on SR 122 over the Great Miami River in Butler County, with assistance of project partners GRL Engineers Inc., and J&L laboratories. Automatic monitoring units were installed to automatically taking scour sensor signals and wireless transmitting the sensor data. The sensors were installed using routine geotechnical site investigation tools and procedures. High quality signals were obtained, from which the development of scour adjacent to bridge piers were measured. The results are reasonable.

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8348-01, Session 1a

Comparison of analog and digital correlation methods suitable for ultrasonic structural health and load monitoring based on high temporal resolution

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Ultrasonic load and structural health monitoring schemes, based on high temporal resolution of the transport times of ultrasound, have lately been refined such that, even for center frequencies in the lower MHz-regime, the achievable temporal resolution can reach 1 ps. Whereas this technique was initiated with signal processing based on digitization and subsequent correlation by software controlled digital processing of the data, equipment has lately been designed and manufactured, allowing rather universal processing of low level analog signals by analog based correlations, employing digital references converted to respective analog signals. The signal and data processing schemes are presented and illustrated with experimental results. The advantages and disadvantages of both methods are discussed, including the limiting effects concerning restrictions given by technological and theoretical aspects. Basic features are demonstrated based on the actually developed and adapted instrumentation including software based operations for both principles of signal and data processing. Even though these methods are also used in ultrasonic imaging, the range of applications presented here focuses dominantly on ultrasonic structural health and load monitoring with bulk and guided acoustic waves.

8348-02, Session 1a

Bimodal warped frequency transform (BWFT) for guided wave mode conversion characterization

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Guided wave (GW) testing for Structural Health Monitoring (SHM) is complicated by the dispersive and multimodal characteristics of the propagation regime and by mode conversion phenomena associated with damage-induced reflections. These issues are often tackled by single mode selection through narrowband excitation and wavelength tuning. However, this results in accuracy limitations and loss of information relevant to defect characterization. A recently proposed Warped Frequency Transform (WFT) provides dispersion compensation for a given propagating mode, thus enabling high-resolution damage localization through broadband waveguide illumination. The WFT is here extended to properly track the time-frequency structure of propagating waves undergoing mode conversion in dual-mode environments such as plate-like structures with dominant A0 and S0 propagation. The Bimodal WFT provides a two-dimensional representation of a recorded time trace in a modal distance vs. total distance plane. Each incoming wave packet is maximally compressed in a region of this domain whose coordinates provide the overall traveled distance and its subdivision into modal (e.g. A0 and S0) contributions when mode conversions occur. This “modal path history” retrieval can effectively improve damage detection and characterization in broadband, multimodal regimes. The approach is numerically validated through GW simulation in the presence of single or multiple scatterers with various mode conversion coefficients. Experimental tests performed on aluminum plates further confirm effectiveness of the proposed mathematical tool. Moreover, the method could be straightforwardly extended to account for a higher number of modes.

8348-03, Session 1a

AE source localization using extended Kalman filter

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This paper presents a method for Acoustic Emission (AE) source localization in isotropic plate-like structures based on the Extended Kalman Filter (EKF). The accuracy of the traditional triangulation methods depends on the time of flight (TOF) measurements and on the group velocity assumption so uncertainties in both should be taken into account and filtered out. At this aim TOF measurements and Lamb Wave group velocity have been treated as Gaussian random variables. An algorithm based on the Extended Kalman Filter (EKF), capable of filtering out the uncertainties, has been developed for the estimation: 1) of the AE source location and 2) the wave velocity. Experimental tests have been carried out on an aluminum plate. AE sources have been simulated by a pencil lead break. The results show accuracy and robustness of the proposed approach for AE source location using a sparse array of piezoelectric sensors.

8348-04, Session 1a

Fingerprinting the Lamb wave signals by using S-transformation

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Many structural health monitoring (SHM) techniques uses Lamb waves. The received signals from the sensor(s) may be processed by using the S-transformation to obtain the envelope of the lamb wave signals. The magnitudes of the time-frequency plot of the s-transformation on single row which corresponds to the excitation frequency represent the smoothened envelope of the received signal. The propagation of the Lamb waves may be estimated from the bumps of the envelope. In this paper, use of the multiple rows of the time-frequency plot of the s-transformation will be proposed to identify the defect from 3-D spectral characteristics.

Two piezoelectric elements were attached on the opposite sides of aluminum beams. Two series of experiments were performed. First, the width of an aluminum beam was reduced at the middle step by step by cutting narrow slots first one, later from the other side. Secondly, a crimper was used to compress the beam at different locations along the beam.

The study indicated that the 3-D spectrum around the time of the first arriving waves and excitation frequency has unique properties depending on the defect and may be used for identification of the type of the defect.

8348-05, Session 1b

Damage detection of wind turbine blades with auto-associative neural networks

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The structure of a wind turbine blade plays a vital role in the mechanical and structural operation of the turbine. As new generations of offshore wind turbines are trying to achieve a leading role in the energy market, key challenges such as a reliable Structural Health Monitoring (SHM) of the blades is significant for the economic and structural efficiency of the

wind energy.

In this study the features used for SHM are Frequency Response Functions (FRFs) acquired via experimental methods based on an LMS system by which identification of mode shapes and natural frequencies is accomplished. An Auto-Associative Neural Network (AANN) is trained by adopting the FRF data for normal condition.

Fault diagnosis of wind turbine blades is a “grand challenge” due to their composite nature, weight and length. The damage detection procedure involves additional difficulties focused on aerodynamic loads, environmental conditions and gravitational loads.It will be shown that vibration dynamic response data combined with AANNs is a robust and powerful tool, offering on-line and real time damage prediction. The AANN is a method which has not yet been widely used in the condition monitoring of composite blades.

This paper is trying to introduce a new scheme for damage detection, localisation and severity assessment by adopting simple measurements such as FRFs and exploiting multilayer neural networks.

8348-06, Session 1b

State estimate of wind turbine blades using geometrically exact beam theory

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As wind turbine blades fatigue, the dynamic response of the blade to loading can be expected to change. The kinematic quantities exhibiting significant changes as the blade ages are important for wind turbine blade operation from the perspective of measurement, estimation, and prediction. A state estimate providing accurate information on these features would lead to better estimates of remaining fatigue life and provide valuable information to the turbine control systems for the purpose of maximizing total energy output of a wind turbine system. In this work, we extend the Kalman filter for use with a nonlinear, geometrically exact beam model of a wind turbine blade in order to dynamically estimate its state. We utilize this method to estimate and predict blade response both in a pristine state and in an aging, fatigued state. We compare our method with the traditional Kalman filter implementation for a beam model using modal superposition, as well as with other methods for estimating useful kinematic quantities that have recently appeared in the literature. Experimental results from 2.1-m and 9-m wind turbine blades are presented and discussed.

8348-07, Session 1b

Ultrasonic NDE of porous ceramics and cementitous materials using fast and slow waves

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Rapid and accurate ultrasonic NDE for porous ceramics and cementitous materials has been developed using fast and slow longitudinal waves. Both conventional contact piezo-tranducers and non-contact laser induced ultrasonics have been deployed for generation and detection of bulk waves in porous samples under dry and water saturated conditions. Using a high voltage Panametrics 5058 PR pulser receiver and contact tranducers at various frequencies (100 kHz to 2 MHz), longitudinal ultrasonic waves have been launched and detected with the help of NI PXI ADC cards. A technique has been developed for accurate estimation of elastic moduli (Young’s modulus, shear modulus and Poisson’s ratio) of dry porous ceramic materials based only on the longitudinal ultrasonic velocities in a green/partially sintered compact and a theoretically dense or pore free material. A laser induced ultrasonic system was set up for generation and detection of slow waves in dried and water saturated cement pastes. Both freshly prepared and aged cement paste samples with varying water to cement ratios in the range 0.35 to 0.65 were subjected to ultrasonic slow wave measurements in a water tank with pulsed laser generation of wide band, short duration ultrasonic waves at a wavelength of 1064 nm. The detection of the slow wave was carried out using a 3.5 MHz immersion trandcuer. The phase velocity of slow wave was obtained from the measured data using the substitution technique in through-transmission mode. Slow wave was observed in the freshly prepared cement paste, but not in the aged cement paste. The absence of the slow wave is assumed to be due to a change in the pore connectivity with age since the slow wave speed results from wave propagation through the pore fluid. The velocity changes obtained was interpreted as the influence of changes in the elastic properties and pore structure of the specimens with processing (drying and re-saturation). The preliminary results obtained shows that this approach may be a viable approach to monitoring the durability of cementitious materials.

8348-08, Session 1b

Improvement method for impedance based non-destructive evaluation on concrete structures using a piezoceramic material

S. Na, H. Lee, KAIST (Korea, Republic of)

Up to date, electro-mechanical impedance (EMI) method using a piezoceramic material has gained a considerable amount of importance for structural health monitoring. Throughout the service time of a building, it may suffer crack damage due to factors such as excessive use and bad environmental conditions. Therefore, it is vital to advance the monitoring technology for civil infrastructures to possibly prevent catastrophic events from a structural failure. Although many research have been conducted with the EMI method, damage detection on concrete structures have been relatively low compared to metallic structures. In general, a real part of impedance (inverse of admittance) is measured in order to quantify the damage level by using a statistical method known as root mean square deviation (RMSD). Increasing the severity of the damage to a host structure will normally increase the RMSD value. However, the non-homogenous property of concrete material creates a difficult condition for EMI method to successfully detect any change in the structure, due to a vague change in the impedance signature subjected to damage. In this study, a method is proposed for concrete structures to increase the damage detection ability when using the EMI method to ensure successful damage detection of structural changes in concrete.

8348-09, Session 2a

A permanently installed guided wave system for pipe monitoring

A. Galvagni, P. Cawley, Imperial College London (United Kingdom)

Ultrasonic guided waves are routinely used to inspect pipes. The advantage of this technique is that it enables a fully-volumetric screening of several metres of pipe from a single transducer location, resulting in substantial time and cost savings. However, it suffers from limitations such as relatively low damage sensitivity and difficulties in dealing with intricate pipe networks; furthermore, for a pipe that is buried, submerged or high up in a plant, access to even a single point can be prohibitively expensive. The use of permanently attached sensors can overcome these limitations since access needs to be obtained only once during installation and they enable the use of baseline subtraction, so that any reading from a sensor can be compared to previous readings thereby allowing tracking and trending of signal changes. This paper discusses the advantages of baseline subtraction in the context of guided wave

pipeline inspection as well as methods to address the unique challenges that this application presents in terms of compensating for signal changes due to effects other than the growth of damage. It is shown that the use of baseline subtraction allows significant damage sensitivity improvements, particularly in the vicinity of large reflectors. Data from four years of field experience is backed up by accelerated laboratory testing.

8348-10, Session 2a

Imaging of pipeline defects based on extraction of mode-converted guided waves

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Guided waves are becoming popular for pipeline monitoring because of its sensitivity to small defects and long sensing range. Several research groups have explored ultrasonic imaging techniques for pipeline monitoring by fully utilizing the advantageous characteristics of guided waves. They have generated torsional mode and measured torsional reflections from pipe defects using expensive shear-mode piezoelectric transducers or electromagnetic acoustic transducers (EMAT), and then extracted crack-induced flexural modes as a post processing step. In this study, these existing techniques are further advanced to perform ultrasonic imaging by measuring the crack-induced flexural modes only, eliminating the necessity of the torsional mode information. This enables us to replace the expensive shear-mode transducers used to measure the torsional reflections with inexpensive compression-mode macro fiber composite (MFC) transducers. First, a magnetostrictive transducer attached at one end of the pipe is used for the excitation of a pure torsional mode in the pipe specimen. Then, the torsional mode propagates through the pipe, and the reflections are created by the interaction of the incident torsional mode with the crack. Due to the sensing characteristics of MFC transducers, only the crack-induced flexural modes can be measured by multiple MFC transducers placed along the circumference near the excitation magnetostrictive transducer. Using the normal mode expansion technique, each individual flexural mode among all reflected signals is extracted. By propagating this crack-induced flexural mode back in the space considering its dispersion characteristics, the location of the crack is visualized.

8348-11, Session 2a

Bayesian probabilistic modeling for damage assessment in a bolted frame

C. M. Haynes, M. D. Todd, Univ. of California, San Diego (United States)

The viability of structural health monitoring techniques depends on the ability to detect the presence damage in complicated systems such as those used in the civil and aerospace engineering fields. This paper presents the application of statistical damage detection techniques to a geometrically-complex, three-story structure with bolted joints. A sparse network of PZT sensor-actuators is bonded to the structure, using ultrasonic guided waves in both pulse-echo and pitch-catch modes to inspect the structure. Received waveforms are processed by using a baseline subtraction scheme, applying a matched filter and then taking the envelope of the result. Receiver operating curves are used to quantify the performance of multiple features (or detectors) taken from the literature. Multiple types of simulated damage are used, including bolt loosening at the joints and simulated mid-element damage, in order to compare the detection rate across different types and levels of damage. A Bayesian cost model is then implemented, assigning costs to the detection rate, false alarm rate, and sensor count of a given network. Using this cost model, the best performing network is evaluated. Different methods of fusing data from multiple sensor pairs are explored, and it can be shown that such techniques provide a significant improvement in detection performance.

8348-12, Session 2a

Guided waves for monitoring heat treatment duration and material hardness

N. Korde, T. Kundu, The Univ. of Arizona (United States)

Elastic properties of materials can be easily determined from the ultrasonic wave velocity measurement. However, material hardness cannot be obtained from the ultrasonic wave speed. Heat treatment and aging affect the microstructure of materials changing their hardness and strength. In this study it is investigated how the attenuation of ultrasonic guided waves is affected by the duration of heat treatment and varying material hardness.

Six Aluminum 2024 alloy plate specimens were subjected to different durations of heat treatment at 150oC and were inspected nondestructively propagating Lamb waves through the specimens. Attenuation of the Lamb wave was found to be inversely related to the hardness. Rockwell Hardness test was performed to corroborate the ultrasonic observations. In comparison to Rockwell hardness test the ultrasonic inspection was found to be more sensitive to the heat treatment duration. From these results it is concluded that guided wave inspection method is a reliable technique for characterizing the hardness of heat treated materials.

8348-13, Session 2a

NDE of immersed structures by means of leaky guided waves

E. Pistone, P. Rizzo, Univ. of Pittsburgh (United States)

The non destructive inspection of immersed structures is gaining popularity as it keeps costs at minimum avoiding unexpected and costly failures. In this paper we present a non-contact laser/immersion transducer technique for the inspection of underwater structures. In particular, a laser operating at 532 nm is used to excite leaky guided waves in two series of tests. The first type of test aims at investigating the effect of temperature on the amplitude and frequency of the leaky guided waves. Therefore, a plate is immersed in a tank full of water. The temperature of the water is progressively increased and the laser-generated signals are detected by a pair of conventional immersion transducers. Then, a series of test aimed at detecting defects in a plate is conducted. A bigger plate is immersed in water at constant temperature and damage is simulated by devising a series of rectangular notches and small circles on the face of the plate exposed to the probing system. The laser and four immersion transducers are used to generate and detect leaky guided waves, respectively. The detected waveforms are processed using the joint time-frequency analysis of the Gabor wavelet transform to identify and locate the presence of the defects.

8348-14, Session 2b

On the damage identification of glass-fiber reinforced polymers with aligned carbon nano-tube networks and electrical impedance tomography

T. Tallman, Univ. of Michigan (United States); F. Semperlotti, Univ. of Notre Dame (United States); K. Wang, Univ. of Michigan (United States)

Structural health monitoring (SHM) is an important and challenging task for composite materials. An ideal health monitoring technique should be highly sensitive to damage evolution while being minimally invasive.

In recent years, new fabrication techniques enable the dispersion and alignment of carbon nano-tube (CNT) networks through composite polymer matrices. This imparts a controlled and highly anisotropic conductivity to otherwise insulating composites such as glass-fiber

reinforced polymers (GFRP). Such a feature may enhance the use of conductance monitoring as a SHM technique, where the change in conductivity of the polymer due to damage can be used as an index. The goal of this research is to explore and analyze such an idea.

In this investigation, sensitivity to damage as measured by percent change in conductivity before and after damage occurs is compared for polymer matrices with aligned and random CNT distributions. Results show that materials with high anisotropic ratios are much more sensitive to damage perpendicular to the CNT alignment direction than materials with random CNT distributions.

Electrical impedance tomography (EIT) is an imaging technique which maps a body's internal conductivity by boundary measurements. The necessity of only boundary measurements makes EIT a powerful candidate for SHM. However, EIT has theoretical and practical limitations when used on highly anisotropic materials. In this study, we show that these limitations can be mitigated by using conductive meshes along the boundary. Coupling EIT and the high sensitivity of aligned CNT networks, an effective SHM technique for GFRP is illustrated.

8348-15, Session 2b

Inductively coupled transducer system for damage detection in composite

C. H. Zhong, A. J. Croxford, P. D. Wilcox, Univ. of Bristol (United Kingdom)

The laminated construction of composite offers the possibility of permanently embedding sensors into the structure, for example, ultrasonic transducers which can be used for NDE applications. An attractive and simple solution for probing embedded sensors wirelessly is via inductive coupling. However, before this can be achieved it is necessary to have a full understanding and proper design strategy for the inductively coupled system. This paper presents the developments of both system design procedure and a computer program for one dimensional inductively coupled transducer system mounted on solid substrate. The design strategy in this paper mainly focuses on issues of maximizing the electrical coupling with the bonded transducer, localization of transducers, and optimizing the signal to noise level. Starting from a three coil equivalent circuit, this paper also explains how the measured impedance of bonded piezoelectric disc is implemented into the system model representing a transducer bonded to an arbitrary solid substrate. The computer programme using this model provides immediate predictions of electrical input impedance, acoustic response and pulse-echo response. A series of experiments and calculations have been performed in order to validate the model. This has enabled the degree of accuracy required for various parameters within the model, such as mutual inductance between the coils and self-inductance of coils, to be assessed. Once validated, this model has been used as a tool to predict the effect of physical parameters, such as distance, lateral misalignment between the coils, and the coil geometry on the performance of an inductively coupled system.

8348-16, Session 2b

Sensitivity enhanced piezoelectric admittance based damage detection using higher order inductive circuits

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The conventional piezoelectric impedance/admittance based methods are of high cost and huge in size due to the heavy impedance analyzers and hence difficult to implement in real time. In recent times impedance based methods using piezoelectric resistive circuits integrated to the structure has gained importance because of low cost and easy implementation. In this paper a low cost piezoelectric admittance based damage detection method using higher order piezoelectric inductive circuits integrated to the structure is analyzed. A single degree of freedom (SDOF) and two degree of freedom (2DOF) inductive higher order circuits integrated to the structure are explored for localized damage detection. The analysis is carried out on a cantilever beam structure integrated with piezoelectric inductive circuits and the damage is simulated as a change in the structure stiffness. The circuit parameters like inductance and resistance are optimized using numerical optimization to enhance the sensitivity of the damage metric, Root Mean Square Deviation (RMSD) for structural damage. The single degree of freedom inductive (SDOF) circuit will increase the admittance based damage detection metric (RMSD) sensitivity over the simple resistive based circuit. The two degree freedom (2DOF) inductance circuit will increase the admittance based damage detection metric (RMSD) further more than the single degree freedom (SDOF) inductive circuit and also broadens the admittance change duet o structural damage over the frequency range.

8348-17, Session 2b

Fabrication and characterization of a planar and miniaturized solid-state reference electrode (SSRE) for corrosion sensors

Y. Liu, J. P. Lynch, Univ. of Michigan (United States)

One of major challenges in implementing integrated corrosion sensors for structural health monitoring is the design of a reference electrode that can operate for long periods of time (e.g., decades) in harsh environments. Commercially available Ag/AgCl reference electrodes contain an electrolyte solution that is unable to survive harsh field conditions over long periods of time. Degradation in the presence of high alkaline environments and hydroxide ions also accounts for the short lifetime of Ag/AgCl electrodes. Alternatively, this paper explores a miniaturized and planar solid-state Ag/AgCl reference electrode. The electrolyte solution commonly used is replaced with agarose gel saturated with NaCl powder which serves as an ion-diffusion channel and provides the electrochemical equilibrium inside the electrode. A microfabricated silver electrode is deposited on a glass substrate using a plasma sputtering technique. Then, the silver layer is chlorinated to produce the coating silver chloride layer. Deposition of NaCl saturated agarose gel is achieved using spin coating and natural evaporation methods. The resulting microfabricated Ag/AgCl reference electrode eliminates the need of inner filling solution while satisfying the electrochemical equilibrium conditions necessary for a reference electrode. Comprehensive characterization of the proposed planar reference electrode reveals that open circuit potential measurements taken with the electrode are insensitive to varying NaCl molarities, thus proving the applicability of the concept in practice.

8348-18, Session 2b

On optimized placement of multidirectional piezoelectric layers for multimodal energy scavenging: a theoretical study

S. Banerjee, Univ. of South Carolina (United States)

No abstract available

8348-19, Session 3a

Local interaction approach modeling for guided-wave propagation in composite plates and sandwich panels

K. S. Nadella, C. E. S. Cesnik, Univ. of Michigan (United States)

Composite structures are being widely employed in modern industries because of the superior strength to weight ratio, high stiffness, and long fatigue life. Their unique physical properties along with the ability to tailor

the material properties along different directions are constantly increasing their avenues of applicability. The increase in demand and dependency on composite structures, particularly for aerospace applications, necessitates the development of sustainable and efficient structural health monitoring (SHM) systems. Studies have shown guided waves (GW) as an efficient method for damage detection in metallic structures, which motivates similar research in the field of composites. An important component in the development of robust GW SHM systems is the ability to accurately model the excitation and propagation of GW. Composite materials due to their inherent anisotropy have significantly different GW propagation characteristics than their isotropic metallic counterparts because of which the development of the SHM methods is significantly more complex and challenging.

A complete 3D-elasticity based formulation for GW propagation is intricate to model complex composite structures (interface conditions) and to account for the shape in the formulation. Moreover, modeling GW with finite element method is not efficient because of the large computational cost involved in resolving short wavelengths with small time increments. This paper aims to present an efficient alternative based on the local interaction simulation approach (LISA). It is based on iterative equations (IE) for “unit cells” that are used to represent/discretize the model. The actual IEs are derived from the elastodynamic equilibrium equations. The coefficients in these iterative equations depend only on the local physical properties. The actual conditions that are enforced at the interface between the cells are continuity of displacements and stresses (sharp interface method). Therefore, changes in stiffness, density, or attenuation can be accounted for as the IE coefficients in adjacent cells with different properties will be different.

Other researchers have used LISA previously, mostly for wave propagation in isotropic plate-like structures. Similar study in composites is very limited. The proposed paper will present the LISA development for 3-D orthotropic materials with wave propagation along non-principal directions. Simulation results will be validated against experimental data and finite element based simulations. Numerical analysis will be carried out for layered composite plates and further enhanced to address more complex constructions such as composite sandwich panels.

8348-20, Session 3a

Elastic waves simulation using CUDA technology and multiple GPU workstations

P. Packo, T. Uhl, W. J. Staszewski, AGH Univ. of Science and Technology (Poland)

Elastic waves are frequently employed in Nondestructive and Structural Health Monitoring systems for damage detection and evaluation. Accurate and fast simulation of structures’ response due to high frequency excitation is possible by application of graphical processing units (GPUs). Increasing demands on model size and therefore a GPU memory, pushed authors to development of multi-GPU approach for the simulation of elastic wave propagation as well as searching for means of model size reduction. The paper presents new developments of the simulation framework for elastic wave propagation. Proposed software uses modified local interaction simulation approach and graphical processing units to calculate wave propagation in structures. Due to increasing demands on model size, the method has been enhanced to utilize multi GPU workstations, which allows calculation of structures’ components or whole structures. Apart from the decomposition approach, authors present absorbing boundary conditions for the model, enabling the reduction of model size and replacing missing part of the model by infinite space.

8348-21, Session 3a

Assessment of the excitelet algorithm for in situ mechanical characterization of orthotropic structures

P. Masson, P. Ostiguy, N. Quaegebeur, Univ. de Sherbrooke (Canada)

Damage detection and localization accuracy of imaging algorithms on composites can be impaired by inaccurate knowledge of the mechanical properties of the structure. In order to overcome this limitation, this paper demonstrate the feasibility of using a chirplet-based correlation technique, called Excitelet, to evaluate in situ the mechanical properties of orthotropic carbon fibre-based composite laminates. The method relies on the identification of an optimal correlation coefficient between measured and simulated signals. Experimental validation is conducted on two 2.45mm thick laminates composed of unidirectional plies oriented at [0]16 and [0,90]4s respectively. Surface bonded piezoceramic (PZT) transducers were used both for actuation and sensing of Lamb waves bursts measured at 0 and 90 degrees with respect to upper ply fibre orientation. The characterization is performed at various frequencies below 400 kHz using A0 or S0 modes and comparison with the material properties measured following standard ASTM testing is presented. The results indicate that large correlation coefficients are obtained between the measurements and simulated signals for both A0 and S0 modes when accurate properties are used as inputs for the model. Strategies based on multiple modes and multiple frequencies correlation are also assessed in order to improve the accuracy of the characterization approach. The mechanical properties obtained using the proposed approach are in agreement with ASTM tests results within +/-4% while the proposed method is non-destructive and can be performed prior to each imaging result.

8348-22, Session 3a

Guided-wave based structural health monitoring of built-up composite structures using spectral finite element method

A. Vezhapparambu, S. Gopalakrishnan, Indian Institute of Science (India)

Composite skin-stiffener structures are frequently used in aerospace components to increase the bending stiffness of the component without a severe weight penalty. However, structural health monitoring of these composite structures is a major challenge, faced by the aircraft industry. In case of composite structures, guided waves offer a great potential for health monitoring applications since their propagation mechanism interact strongly even with small damage. In fact, due to the difficulty in setting up the experiment, there is always a severe demand for a numerical model to study the wave propagation in these built-up structures. In this work, spectral finite element method (SFEM) is used for modeling wave propagation in a healthy composite built-up structure. The structures, which we consider for our study, are stiffened plate structure and box-type structure. The modeling of theses structures can be performed as an assemblage of spectral plate elements (SPE). In the wave propagation analysis of three dimensional structures, using 2D SPE, the stiffness matrix obtained using SPE needs to be transformed from local element coordinate to the global coordinate, which is performed using a transformation matrix. The spectral finite element model thus developed is used to detect skin-stiffener debonding in stiffened plate and box-type structures. The damage force indicator (DFI) technique, which is derived from the dynamic stiffness matrix of the healthy structure along with the nodal displacements of the damaged structure, is used to find the damage due to debond in the structure. This technique is in the frequency domain and is ideally suited to the frequency domain SFEM. Further, in DFI, damage location can be bounded within the region of the sensing points. Using SFEM, the number of sensors required can be reduced since the number of measurements complying with SFEM degrees of freedom is many orders smaller than that required when using conventional FEM. In this work, stiffness matrix of the healthy structure is obtained from the newly developed spectral finite element model for the built-up structures. A conventional 2D finite element method (FEM) is used as surrogate experimental results, to obtain the nodal displacements of the debonded composite structure. In FEM, debond between the plate and the stiffener is modeled by varying the stiffness properties of the corresponding elements.

8348-23, Session 3a

Imaging non-classical elastic nonlinearities using reciprocal time reversal and phase symmetry analysis

M. Meo, Univ. of Bath (United Kingdom)

This paper presents a nonlinear method for imaging damage in composite materials. The proposed technique, based on a combination of phase symmetry analysis with FM excitation and nonlinear time reversal, is applied to a number of waveforms containing the nonlinear impulse responses of the medium. Phase symmetry analysis was used to characterize the third order nonlinearity due to cracks, by exploiting its invariant properties with the phase angle of the input waveforms. Then, a “virtual” reciprocal time reversal imaging process, using only one sensor, was used to “illuminate” the damage. Using the multiple wave scattering, an optimal focusing at the nonlinear source was achieved by a compensation of the distortion effects in the dissipative medium. The robustness of this technique was experimentally demonstrated on a damaged sandwich panel, and the nonlinear source, was retrieved with a high accuracy with little computational time. Its minimal processing requirements make this method a valid alternative to the traditional nonlinear elastic wave spectroscopy techniques for materials showing either classical or non-classical nonlinear behaviour.

8348-24, Session 3a

Evaluation of Hertzian contact state using guided waves

N. Kim, Korea Univ. of Technology and Education (Korea, Republic of)

Contacting solid surface such as bearings and joints is one of the critical sources of wear and failure in precision machinery and steel structures. This paper presents an acoustic method to evaluate the pressure and area of solid-solid contact surfaces, which is a guided wave propagating between the joining boundaries with different wave velocity depending on contact pressure. Mathematical formulation for acoustic wave propagation at contacting solids is made to obtain the dispersive relation between acoustic wave and contact pressure. Three different kinds of cylindrical steel blocks are machined and pressed together at various compression loads to form contact surfaces of different contacting condition. Reflected guided wave generated at the edge of the block is analyzed to determine the wave speed using time-of-flight, which increases sensitively with the load. Theoretical and experimental results prove that contact states like contact force and area between two solid surfaces is closely related to acoustic wave speed of guided wave in the interface.

8348-25, Session 3a

Characterization of mode selective actuator and sensor systems for Lamb wave excitation

D. Schmidt, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

This study presents the development of mode selective actuator and sensor systems which are able to generate a particular Lamb wave mode. These actuator-sensor systems are based on interdigital transducer (IDT) design. The transducers are made of monolithic piezoceramic plates with an interdigitated electrode structure which is realized by laser ablation process.

In a first step the effects of transducer and bonding layer thickness, transducer width as well as eigenfrequencies are experimental investigated using monolithic piezoceramic plates. In a second step the interdigital transducer layout is used to design a set of actuators and sensors for different wavelengths and frequencies. Parameters such as number and apodization of electrodes, phased array excitation as well as eigenfrequencies are experimental analyzed. The eigenfrequencies of the different transducers are measured by impedance spectroscopy. Within the diverse experimental tests the acoustic response of the A0 and S0 mode is measured over a frequency range of 10 to 1000 kHz. The tests are carried out on 2 mm thick aluminum as well as composite plates. The experimental tests are accompanied by examination of an analytical model. The analytical model is based on the delta function model which is used to design surface acoustic wave filters.

The results show that the different parameters under investigation influence the acoustic response of the A0 and S0 mode. Nevertheless, a mode selectivity of the A0 or S0 mode can be achieved by the interdigital transducer design.

8348-26, Session 3b

Pulse thermography for quantitative nondestructive evaluation of sound, de-mineralized and re-mineralized enamel

M. Ando, Indiana Univ. (United States); D. E. Adams, N. D. Sharp, Purdue Univ. (United States)

The current limitations for diagnosing the mineralization state of tooth enamel can lead to improper or unnecessary surgical treatments. A method is investigated by which the tooth health state is characterized according to its thermal response, which is hypothesized to be sensitive to increased porosity in enamel that is caused by demineralization.

Twenty four specimens consisting of previously extracted human teeth are prepared by exposure to Streptococcus mutans A32-2 in trypticase-soy-broth-supplemented with 5% sucrose at 37oC for 3 or 6days to de-mineralize two 1mm 1mm-windows on each tooth. One of these windows is then re-mineralized with 250 or 1,100ppm-F as NaF for 10days by pH-cyclic-model. Pulse thermography is used to measure the thermal response of these sections as well as the sound (healthy) portions of the specimen. A spatial profile of the thermal parameters of the specimens is then extracted from the thermography data and used to compare the de-mineralized, re-mineralized, and sound areas.

Results show that the thermal parameters are sensitive to the mineralization state of the tooth and that this method has the potential to accurately and quickly characterize the mineralization state of teeth, thereby allowing future dentists to make informed decisions regarding the best treatment for teeth that have experienced demineralization.

8348-27, Session 3b

Design and fabrication of mechanical resonance based optical scanner using push-pull actuator

W. Wang, Univ. of Washington (United States) and National Cheng Kung Univ. (Taiwan)

The current design has improved performance of our previously developed microfabricated SU8 cantilever beam scanner for the purpose of endoscope examination with the implementation of a new MEMS based push-pull actuator. With this new device, a fully integration of the waveguide, actuator, light source and detector are achieved as compared to the previous method where external actuators are required. Fabrication of the SU-8 rib waveguide was measured to be ~3.5 m as compared to our previous method of ~50 to 100 m, has further improve our spatial resolution. An overall larger device and a U-shaped groove for optical coupling makes coupling a fiber into the waveguide much easier and increases the amount of light coupled into the beam (~98% coupling efficiency). The proposed rib cantilever waveguide design also allows a relatively large waveguide cross section (4 m in height and 20 m in width) and broader band single mode operation (= 0.7 m to 1.3 m) with a minimum transmission loss (0.85% output transmission efficiency with Gaussian beam profile input) . Written here is the fabrication and

test analysis of a MEMS optical scanner. Concept of rater motion using a push-pull actuator was verified by the transient finite element analysis (FEA). Scanner's line resolution and field of view (FOV) are optimized by the parametric study using modal and harmonic analyses. The novel design has provided a new way of creating a 2-D scanning using a 1-D actuation.

8348-28, Session 3b

Noninvasive ultrasonic monitoring of the mechanical properties of selected muscles and connected tendons

M. Zakir Hossain, W. Grill, Univ. Leipzig (Germany)

The force-length relation is one of the most important mechanical properties of skeletal muscular tissue. Due to the rather limited availability of non-invasive methods suitable to quantify the in-vivo biomechanical properties of activated human muscles and connected tendons, the quantification of the bio-mechanical properties is difficult. The measurement principle applied here is based on the detection of the dynamics of the muscle under observation by an ultrasonic caliper and monitoring of the externally present forces by a synchronously operated ultrasonic force sensor. The developed monitoring scheme is exemplified for gradual increasing voluntary isometric contraction (MVIC) of the gastrocnemius muscle up to maximum contraction, with the force sensor restricting the flexion of the joint. The temporal resolution for the monitoring is 0.01 s, relating to a monitoring rate of 100 Hz and is achieved with a spatial resolution concerning the observed lateral extension of the muscle of 0.01 mm. The employed low power, economic, and non-intrusive detection scheme and respective instrumentation has the demonstrated potential to quantify the in-vivo hysteretic behavior of the observed force-length relation for MVIC of the human gastrocnemius muscle for the first time. The purpose of this study was to determine in-vivo the force-length relations for the human gastrocnemius and biceps muscles noninvasively by suitable experimental techniques with high temporal and spatial resolution concerning monitoring of the biomechanical relevant parameters involved in the dynamics of activated muscle. The data is collected and analyzed to derive quantitative information on force-length relations, essential for the analysis of muscle performance and interpretation by musculoskeletal models. The involved technologies are demonstrated and the respective results are presented and discussed.

8348-29, Session 3b

Fabrication and characterization of polymer gel for MRI liver phantom with embedded lesion particles

E. In, H. E. Naguib, Univ. of Toronto (Canada)

Magnetic Resonance Imaging (MRI) is a medical imaging technique used in radiology to visualize the detailed internal structure and body soft tissues in complete 3D image. MRI performs best when optimal imaging parameters such as contrast, signal to noise ratio (SNR), spatial resolution and total scan time are utilized. However, due to a variety of imaging parameters that differ with the manufacturer, a calibration medium that allows the control of these parameters is necessary. Therefore, a phantom that behaves similar to human soft tissue is developed to replace a real human. Polymer gel is novel material that has great potential in the medical imaging. Since very few have focused on examining the behavior of polymer lesions, the motivation of this study is to develop a polymer gel phantom, especially for liver, with embedded lesions. Both the phantom and lesions should be capable of reflecting T1 and T2 relaxation values through various characterization processes.

In this paper, phantom and lesion particles were fabricated with carrageenan as a gelling agent by physical aggregation. Agar was used as supplementary gelling agent and T2 modifier and Gd-DTPA as T1 modifier. The polymer gel samples were fabricated by varying the concentrations of the gelling agent, and T1 and T2 modifiers. The lesion particles were obtained by extracting molten polymer gel solution in chilled oil bath to obtain spherical shape. The polymer gel properties including density, elastic modulus, dielectric constant and optical properties were measured to compare with human tissue values for long period of time.

8348-30, Session 3b

Compact Fourier transform spectrometer without moving parts

W. Wang, Univ. of Washington (United States) and National Cheng Kung Univ. (Taiwan)

Fourier transform spectroscopy (FTS) is a fundamental analytical tool utilized in many chemical and biological analysis applications. It is especially well-known and widely used for its powerful analytical techniques to measure the spectra of a weakly extended source. The purpose of this study is to create a compact, low-cost FTS system utilizing a miniature liquid crystal interferometer. This design is unique because the optical path difference (or phase difference) is controlled by the applied voltage. The optical path difference is further improved by incorporating two reflective mirrors between the two polarizers. In this paper, we will present the theoretical model, numerical simulation and experimental results of the proposed FTS. Based on the experimental results, the FTS performs in accordance with the theoretical predictions, achieves a maximum optical path difference of 210 , and a resolution of 1nm at a wavelength of 630nm. The instrumental response refresh rate is just under 1 second. Absorbance measurements were conducted for single and mixed solutions of deionized water and isopropyl alcohol, successfully demonstrating agreement with a commercial system and literature values.

8348-31, Session 4a

Integral ultrasonic structural health and load monitoring on a fiber reinforced polymer based composite helicopter tail boom

G. Birkelbach, W. Grill, Univ. Leipzig (Germany); I. J. Aldave, I. López, Fundación Centro de Tecnologias Aeronáuticas (Spain)

Results achieved with the developed health and load monitoring schemes based on high resolution temporally resolved observation of the transport properties of guided ultrasonic waves are presented and discussed. The methods are illustrated and results covering monitoring of ablation and delamination, time resolved load detection, and monitoring of impact positions with axial resolution are presented. The detection schemes have been primarily developed for integral monitoring of the presence and occurrence of damages including scaling of damages respectively determination of the occurrence of overloading and impact. Sensitivities and methods suitable for damage scaling are presented and discussed. The developed schemes are as well suitable for on-ground as for in-flight monitoring, with the exception that the impact position detection requires continuous operation at least in a stand by mode. Concerning the rather compact size and moderate power consumption the developed instrumentation is already suitable for in-flight respectively on-ground hand hold and battery powered operation. The achievements and results are presented, explained, and discussed.

8348-32, Session 4a

Integral structural health and load monitoring of a helicopter tail boom manufactured from aluminum sheet metal with support from frames and stringers by guided ultrasonic waves

G. Birkelbach, W. Grill, Univ. Leipzig (Germany); V. Pavelko, S. Kuznetsov, Riga Technical Univ. (Latvia)

Based on mode selective monitoring of the transport of guided ultrasonic waves with high temporal resolution achieved by correlation techniques, a helicopter tail boom section, manufactured from aluminum, has been monitored concerning structural health and load including monitoring under shaker driven conditions. The characteristic sensitivities of the developed health and load monitoring schemes are presented together with methods suitable for the compensation of the influence of temperature variations during monitoring. Concerning the detection of loose joints, a novel monitoring scheme has been introduced capable to detect fluctuations in joints including riveted joints and connections by high-locks. The currently operated system is fully remote controlled and can be operated by internet. Concerning the rather compact size and power consumption, the developed instrumentation is already suitable for in-flight respectively for on-ground hand hold and battery powered operation. The observations, achievements, and results are presented, explained, and discussed.

8348-33, Session 4a

Damage detection in sandwich plates using shear horizontal wave

K. K. S. Rao, D. K. Harursampath, R. Ganguli, Indian Institute of Science (India)

The detection of facesheet-core debonding, and core damage detection in sandwich structures is an important topic. Several nondestructive testing (NDT) techniques are currently used for the detection and sizing of defects in plates. Guided waves have the edge over other ultrasonic wave-based NDT's, as guided waves can propagate along the plate with minimal attenuation, and moreover guided waves produce stresses through the thickness of the plate enabling an examination of the entire thickness of the plate.

In general, two different families of guided waves can exist in a free plate: Lamb waves, characterized by the fact that the particle displacement is in the plane of propagation, and Shear Horizontal (SH) waves in which the particle displacement is perpendicular to the plane of propagation. Many researchers have succesfully demonstrated the usage of Lamb waves for damage and delamination detection in composite plates. But usage of Lamb waves has not yielded the same quality of results for damage detection in sandwich structures. This could be primarily attributed to the fact that Lamb waves in sandwich plates travel within the face sheet on which the transducer is attached, and hardly any displacement (propagation of wave) is seen through the core and in the opposite facesheet. The Lamb waves in sandwich structures rather behaves as a leaky Lamb waves. On the other hand usage of SH wave as a potential wave for damage detection in sandwich structures has not been studied well and reported in the literature.

The aim of the present research is to study the interaction of SH waves in sandwich structures with facesheet debonding and core damage. The key idea behind using SH wave for damage detection in sandwich structure is, itself based on the design philosophy that the core is primarily meant to carry shear load, hence shear waves may give better estimate, on the presence of damage in the core. Interaction of the fundamental model SH_0 and the first antisymmetric mode SH_1 in the presence of facesheet-core debonding and core damage in sandwich structure will be studied using finite element tool. The phase velocities of undamaged sandwich plate finite element model, will be validated with the results obtained by Transfer matrix method. Isotropic homogenous material facesheets and isotropic material core will be considered in the study. Plate under consideration will have debonding and core cracked through the width of the plate, allowing the problem to be modeled as a 2 dimensional one. Interference of SH waves due to facesheet-core debonding and core crack will be studied separately.

8348-34, Session 4b

Cointegration as a data normalization tool for structural health monitoring applications

D. Y. Harvey, M. D. Todd, Univ. of California, San Diego (United States)

In structural health monitoring literature, there exists an abundance of damage features shown to be sensitive to various types of damage in laboratory tests. However, robust feature extraction in the presence of varying operational and environmental conditions has proven to be one of the largest obstacles in the development of practical structural health monitoring systems. Reliable data normalization procedures for SHM systems on real structures are needed to eliminate the occurrence of false positive damage indications. Cointegration from the field of econometrics has recently been introduced to the SHM field as a solution to the data normalization problem. Response measurements and feature histories often show long-run nonstationarity due to fluctuating temperature, load conditions, or other factors that leads to the occurrence of false positives. Cointegration theory allows nonstationary trends common to two or more time series to be modeled and subsequently removed. Thus, the residual retains sensitivity to damage with dependence on operational and environmental variability removed. This study further explores the use of cointegration as a data normalization tool for structural health monitoring applications.

8348-35, Session 4b

Uncertainty propagation of transmissibility-based structural health monitoring features

Z. Mao, M. D. Todd, Univ. of California, San Diego (United States)

Features derived from estimations of transmissibility (output-to-output response) are now widely used in vibration-based structural health monitoring (SHM) applications. However, for realistic conditions, transmissibility measurements are always subject to environmental and operational variability, and the uncertainty will propagate through to any features derived from it, leading to misinterpretation and false alarms. This paper proposes a statistical model that quantifies that uncertainty so that confidence intervals on feature estimates are possible, leading to diminished false alarms and the possibility of minimum detection performance calculation. The uncertainty quantification model is validated via a clamped plate structure, and for a stricter validation requirement, additive noise is contaminated to the lab measurements to simulate more realistic in-situ conditions. A good consistency is observed between the proposed statistical model and real test results, and leads to promising applications for structural health monitoring with quantified uncertainty.

8348-36, Session 4b

An experimental study on disbond detection in a thermal insulation system using guided waves under a load-temperature environment

Y. Wang, S. Ma, Z. Wu, K. Liu, Dalian Univ. of Technology (China)

The potential of integrity monitoring of foam based thermal insulation systems is investigated under a load-temperature environment. The test piece is fabricated by bonding 25 mm thick polyimide foam to a 3 mm thick aluminum alloy plate using the polyurethane. Guided

wave propagation studies are conducted using the pitch-catch approach. Forty circular piezoelectric sensors are bonded onto the plate using the epoxy resin adhesive. Twenty sensors as transmitter, while the others as receiver, are arranged near to two sides of the foam respectively. To receive only the guided wave, the interval distance is 20 mm between two adjacent sensors. The appropriate guided wave modes are generated by changing the excitation signal. To simulate the thermal and load environment of the thermal insulation system, the test piece is assembled on the load-temperature test machine, where the compression load gradually up to 3 tons is applied to the test piece along its axial direction. Different temperatures are applied to two sides of the test piece. The side without the foam is cooled using Liquid nitrogen to -170, while the other with the foam is heated by the thermocouple to 100. The guided wave signals are obtained before/after the experiment begins/ends, and also received periodically in the joint work process of the pressure and the different temperatures. Signals processing and damage imaging techniques are combined to demonstrate the possible disbond defect. Experiment results show that the disbond defect could be conclusively detected, and its expansion could be identified.

8348-37, Session 5a

Multiple scattering of Lamb waves by multiple corrosion pits in a plate

B. W. Strom, S. Krishnaswamy, J. D. Achenbach, Northwestern Univ. (United States)

The scattering of Lamb waves from multiple corrosion pits on the surface of a plate is investigated. Previous work produced a model which solved for the scattered field when a Lamb wave is incident on a single corrosion pit, and we present an improvement on that model, and use it to study the case of multiple corrosion pits. The solution technique solves for the scattered field by replacing the corrosion pits with equivalent point loads applied to the surface of the plate, and the reciprocity theorem is used to calculate the various scattered field terms. For the case of multiple corrosion pits, an implicit set of equations are derived using the self consistent method, and an approximation is advanced which results in an explicit set of equations which approximate the scattered field. The second order approximation to the multiple scattering problem is considered and solved semi-analytically for an ensemble of corrosion pits.

8348-38, Session 5a

Structural health monitoring through a wave finite element method

M. Collet, Univ. de Franche-Comté (France); M. Ichchou, O. Bareille, Ecole Centrale de Lyon (France)

The main focus of the present paper is damage detection in the context of structural health monitoring. The main characteristic of the work is the extensive use of numerical methods in view of structural health monitoring effective implementation. Damage detection through guided waves is the ultimate target. Precisely, this paper describes a spectral method to study the wave scattering by the local defect in the structural waveguide. The force response is decomposed into some subproblems by combination of standard finite element method with lower computational cost. Dynamic reduction method was used for both the narrowband and wideband analysis of wave scattering at defects or at some standard structural features. Numerical study of plate mode scattering by defects indicates that the mode conversions will complicate the resultant signal, and a set of modes with different frequency are necessary to properly estimate the defect type and severity. If the wideband wave modes are generated, some signal processing such as time frequency analysis should be used for mode identification or defect localization. Numerical study can also be extended to more complex structures, and some conclusions from presented investigations are also suitable to those cases.

8348-39, Session 5a

High-frequency guided ultrasonic waves for the detection of hidden defects in multi-layer aerospace structures

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High-frequency guided ultrasonic waves allow for the non-destructive testing of aerospace structures. This type of structure often contains multi-layer components subjected to cyclic loading conditions, where fatigue cracks and localized disbonds can develop. Using standard ultrasonic transducers, high frequency guided wave modes were generated that propagate along the structure and penetrate through the complete thickness. A model structure, consisting of two adhesively bonded aluminum plates, was considered. The wave propagation along the specimen was measured experimentally using a laser interferometer. Good agreement with 2D finite element simulations was found. Two types of hidden defects were considered: localized lacks of sealant and small defects in the aluminum layer facing the sealant. The interaction of the high frequency guided waves with the hidden defects was investigated. The simulation results were evaluated to determine the reflected and transmitted modes and to quantify the influence of defect location and size. Standard pulse-echo measurements were conducted to verify the detection sensitivity and influence of the stand-off distance predicted from the finite element simulation results. The high frequency guided waves have the potential for fatigue crack growth monitoring at critical and difficult to access fastener locations in aerospace structures from a stand-off distance.

8348-40, Session 5a

Ultrasonic characterization of LiNbO3 single crystal using scanning acoustic microscope

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LiNbO3 single crystal has a great potential in the development for bulk wave and SAW devices. Longitudinal, shear and surface acoustic wave speeds of LiNbO3 are measured from its V(z) curves, also known as acoustic material signature (AMS) curves. AMS shows the variation of the output voltage as a function of the distance between the acoustic lens focal point and the reflecting surface. In the present study results are presented for single crystalline LiNbO3 wafers, where velocities of different ultrasonic waves such as the longitudinal bulk, the quasi-transversal bulk and the surface acoustic wave are calculated from its acoustic material signature (AMS) curve. The acoustic wave propagation in the piezo-electric material is modeled and the direction of the wave vectors and the velocities of the involved acoustic waves are determined.

8348-41, Session 5b

Inkjet fabrication of spiral frequency-steerable acoustic transducers (FSATs)

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The frequency-based beam steering concept effectively supports Guided-Wave-based Structural Health Monitoring (SHM) by enabling directional waveguide inspection. This is implemented by acoustic transducers whose peculiar shapes provide different wavelength tuning in different directions. When these devices are used for GW sensing, spatial

filtering of the propagating wavefield results in a prominent frequency component within the recorded signal spectrum, which can be uniquely associated with the direction of the incoming wave. A sensor geometry whose 2D spatial Fourier Transform produces a spiral-like distribution of maxima in the wavenumber domain allows for one-to-one frequency-angle correspondence in the [0°, 180°] range. Prototypes of this spiral frequency steerable acoustic transducer (FSAT) have been fabricated by patterning the electrodes' shape on a metallized polyvinylidene fluoride (PVDF) substrate through inkjet printing. A Microfab Jetlab II system has been used in combination with a ultraviolet (UV) curable optical epoxy (Norland 89) ink, resulting in highly reproducible features with 100μm resolution, which is sufficient for the present application. The printed polymeric pattern is used as a mask for wet etching of the metal and subsequently stripped away, leaving the desired electrodes' geometry. Prototype testing in various pitch-catch configurations demonstrates accurate 2D localization of acoustic sources and scattering events by processing a single output signal. Extremely easy, quick and inexpensive fabrication approach, along with very low hardware and computational requirements make the proposed FSAT an ideal candidate for a wide range of in-situ, low-cost and wireless SHM applications.

8348-42, Session 5b

Non-destructive evaluation of acoustic properties of fuel cell proton-exchange membranes by vector contrast acoustic microscopy

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In recent years, the interest in the research and development of "green energy" has increased dramatically, with numerous research grants and investment in the areas of wind power, solar power and fuel cell technology. We present results obtained from the evaluation of the acoustic properties of proton-exchange membranes used in hydrogen fuel cells and their relation to the microelastic properties of such membranes. These properties play an important role in the durability and applicability as well as the efficiency of such membranes. DuPont Nafion membranes are the most commonly used polymeric membranes in hydrogen/oxygen fuel cells and are therefore used as examples in this study. The microscope used in this non-destructive characterization study is a vector-contrast version of the scanning acoustic microscope which yields images in magnitude- and phase contrast.

8348-43, Session 5b

Study of waveforms effect on PEDOT inkjet printing

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micro-electromecanical systems based on inkjet printing has proven to be a promising process fabrication technique in recent years. To improve the resolution of the print-out patterns, the accurate control of micro-droplet volume is critical. In this paper, we report an in-house inkjet system which is able to achieve user-defined pattern printing under the different waveforms. The investigation of the waveforms includes unipolar, bipolar, M-shaped and W-shaped waveforms. The Newtonian fluid (DI water) and non-Newtonian fluid (PEDOT ink) under the different waveforms are also studied. The results with PEDOT ink show a significant volume size reduction under the M-shaped and W-shaped waveforms, achieving 50% resolution improvement. The bipolar waveform demonstrated the most obvious effect on the volume size reduction with the DI water. The reported inkjet system is proven to be effective and can be used in a wide range of applications.

8348-44, Session 5b

Laser ultrasonic imaging of a rotating blade

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Although there are many laser ultrasonic imaging techniques developed so far, it still remains challenging to create such images from a rotating object. In this study, an advanced laser ultrasonic imaging technique is developed so that wavefield images can be constructed from a rotating blade using an embedded piezoelectric sensor and a scanning pulse excitation laser. First, training ultrasonic signals are measured at the fixed sensing point by scanning the excitation laser beam over the target surface of the blade when the blade is in a stationary condition. Once the training is complete, the scanning laser is synchronized with the encoder of the rotating blade so that an ultrasonic signal is generated using a scanning Nd:Yag laser and measured by the sensor. Here, the biggest challenge is to precisely estimate and control the exact excitation point when the blade is rotating with additional ambient vibrations. In this study, this laser excitation point is estimated by computing the correlations between the measured response signal and the ones in the training data sets. The correlation between the measured response and a training response is maximized when they correspond to the same excitation point. Finally, ultrasonic images are generated by scanning the excitation laser over the target surface of the blade. The effectiveness of the proposed imaging technique and its applicability to damage detection is investigated through experimental tests performed on a rotating blade specimen.

8348-45, Session 6a

Temperature effect on the accuracy of vibration-based damage detection of thin plates

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This paper applies the vibration-based health monitoring technique to analytically study the effect of ambient temperature variations on the vibratory characteristics of a cracked plate. Change in the ambient temperature alters material properties of the plate, such as the Young's modulus of elasticity. It also causes thermal moments inside the beam which will add terms in both the equation of motion and the boundary conditions of the vibrating beam. These all, together with the thermoelastic coupling of the plate, change the vibratory response of the plate, which if not taken into consideration, may cause false positive is the health monitoring of a structure. In the present paper, the effect of temperature variations is initially modeled into the equation of motion of a plate having a crack parallel to one of the edges. This is done through considering the thermoelasticity and formation of thermal moments inside the cracked plate. Then, the effect of temperature variations on the modulus of elasticity and the resultant effect on the natural frequency of the cracked plate is studied analytically for different boundary conditions of the plate. The analytical results are numerically studied for a special geometry and support conditions of an aluminum plate.

8348-46, Session 6a

Application of multi-objective optimization to structural damage estimation via model updating

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This paper presents a novel damage detection method which simultaneously updates the undamaged as well as damaged structure model in a multi-objective optimization process. Structural health monitoring has received considerable attention in the previous decade

and is important for assessment of existing infrastructure for conducting safe operations. Dynamic testing results in the form of identified natural frequencies and mode shapes can reveal important information about the structure and its condition. In dynamic finite element (FE) model updating, experimental modal properties are compared with their FE model counterparts to assess the physical characteristics of the structure.

Contemporary damage detection and estimation methods which are based on model updating typically require an updated baseline FE model of the undamaged structure. The updated undamaged model is then compared with an updated damaged model for assessment of damage severity. There might be many errors associated with model updating process, e.g. experimental errors, updating procedure errors, modelling errors or parametric errors. These errors can aggregate in the subsequent model updating runs.

This paper presents a damage detection algorithm which simultaneously updates undamaged as well as damaged structure in a multi-objective optimization process for improving performance of the damage estimation procedure. Compared to the single objective optimisation, which gives one optimal solution, multi-objective formulation gives a Pareto set of alternative solutions. The best solution is selected which gives a trade-off between the two objective functions (related to the undamaged and damaged structure). Genetic algorithms have been used as an optimization algorithm in this research. A structure with multiple damaged elements has been studied. Different noise levels have been added to the identified frequencies and mode shapes to assess the performance of the proposed procedure for accurate damage estimation. It has been found that the proposed method has been successful in updating both the undamaged and damaged model. Also the procedure is less sensitive to experimental errors and is more efficient in accurately estimating the damage compared to the single objective updating.

8348-47, Session 6a

Robust method to identify damages in beams based on frequency shift analysis

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The paper presents a method to assess damages in beams, based on how natural frequencies of bending vibration modes of beams change due to damages. The authors have contrived a correlation between the strain energy stored in a segment of the beam, which is proportional with the mode shape curvature of a considered frequency mode at the location where the segment is placed, and the frequency change for this mode if damage appears on that segment. For a certain mode, damages placed on inflection points of the mode shape curvature, where the strain energy is null, will not produce changes in frequency, while damages placed on maxima will produce the highest changes in frequency. For other locations of the damage, the change in frequency will be proportional with the mode shape curvature of that vibration mode. We worked out a general relation, which gives the frequency shift of all bending modes, with one coefficient depending on the support type. To evaluate damages of a given beam, we determined the relative frequency shift as ratio between the frequency change and the natural frequency of the undamaged beam, for the first ten vibration modes, considering various damage depths and locations. The results, included in a database, can be compared with that obtained by measurements on the similar real beam. The use of the relative frequency shift for ten vibration modes make possible the detection, location and assessment of damages in beams with high accuracy. The method was validated by experiments.

8348-48, Session 6a

On optimized placement of multidirectional piezoelectric layers for multimodal energy scavenging: a theoretical study

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The piezoelectric transduction mechanism has received a great attention in the energy harvesting field. Although there are many energy harvesting possibilities where piezoelectric transduction can be suitably employed, design of piezoelectric energy harvesters are typically restricted within the cantilever beams. As an example the energy scavenging from the wings of a Micro Air Vehicles (MAV) will certainly beneficial for its sustainable missions and which is predominantly a plate type harvester of arbitrary shape. In this paper a generalized multi directional and multimodal placement of piezoelectric layers on the substrate is discussed in order to maximize the power output. A theoretical study has been conducted using a mathematical model for the plate type harvesters and an optimization problem is solved to maximize the power output from the harvesters. This will provide harvesting of the energy from wide band of frequency and thus it is called energy scavenging. It is quite well known that the cantilever plate with straight edge has one directional bending whereas the wings of arbitrary shapes will have two directional bending in association with torsion. Thus potentially all these possible modes of bending can generate energy. A preliminary mathematical study is conducted in this paper.

8348-49, Session 6a

Simulation of ultrasonic NCF composites testing using 3D finite element model

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Composite materials offer many advantages for aerospace applications, e.g., good strength to weight ratio. Different types of composites, such as non-crimp fabrics (NCF), are currently being investigated as they offer reduced manufacturing costs and improved damage tolerance as compared to traditional pre-impregnated composite materials. NCF composites are made from stitched fiber bundles (tows), which typically have a width and thickness in the order of millimeter. This results in strongly inhomogeneous and anisotropic material properties. Different types of manufacturing imperfections, such as porosity, resin pockets, tow crimp and misalignment can lead to reduced material strength and thus to defects following excessive loads or impact, e.g. fracture and delaminations. The ultrasonic non-destructive testing of NCF composites is difficult, as the tow size is comparable to the wavelength, leading to multiple scattering in this inherently three-dimensional structure. For typical material properties and geometry of an NCF composite, a full three-dimensional Finite Element (FE) model has been developed in ABAQUS. The propagation of longitudinal ultrasonic waves has been simulated and the effect of multiple scattering at the fiber tows investigated. The effect of porosity as a typical manufacturing imperfection has been considered. The potential for the detection and quantification of such defects is discussed based on the observed influence on the ultrasonic wave propagation and attenuation.

8348-50, Session 6b

Vibration-based monitoring to detect mass changes in satellites

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Vibration-based structural health monitoring could be a useful form of determining the health and safety of space structures. A particular concern is the possibility of a foreign object that attaches itself to a satellite in orbit for adverse reasons. A frequency response analysis was used to determine the changes in mass and moment of inertia of the space structure based on a change in the natural frequencies of the structure or components of the structure. Feasibility studies were first conducted on a 7 in x 19 in aluminum plate with various boundary conditions. Effect of environmental conditions on the frequency response was determined. The baseline frequency response for the plate was then used as the basis for detection of the addition, and possibly the location, of added masses on the plate. The test results were compared to both analytical solutions and finite element models created in SAP2000. The

testing was subsequently expanded to aluminum alloy satellite panels and a mock satellite with dummy payloads. Statistical analysis was conducted on variations of frequency due to added mass and thermal changes to determine the threshold of added mass that can be detected.

8348-51, Session 6b

In situ measurement of viscoelastic effects in composite tape springs

A. J. Makuch, W. D. Reynolds, Air Force Research Lab. (United States)

Due to their high compaction ratio and self-deployment, composite tape springs provide useful applications for deployable space structures. However, viscoelastic effects can influence the ability of these structures to deploy after long periods in storage. This study investigates proposed methods to track the viscoelastic effects by taking in situ measurements. Initial tests were conducted by employing a custom load cell to detect stress relaxation in a bent tape spring over a period of time. The strain was measured over a three day period at room temperature and an unstressed dummy gauge was used for temperature and zero drift compensation. The results showed the expected trend for stress relaxation but exhibited significant noise after the second day. A test was run with a thermocouple and showed that the fluctuations in strain corresponded to the same variations in temperature. The results indicate that the system is sensitive enough to record changes in composite behavior due to temperature.

8348-52, Session 6b

Structural assurance testing for post-shipping satellite inspection

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Current satellite transportation sensors can provide a binary indication of the acceleration or shock that a satellite has experienced during the shipping process but do little to identify if significant structural change has occurred in the satellite and where it may be located. When a sensor indicates that the satellite has experienced shock during transit, an extensive testing process begins to evaluate the satellite functionality. If errors occur during the functional checkout, extensive physical inspection of the structure follows. In this work an alternate method for inspecting satellites for structural defects after shipping is presented. Electro-Mechanical Impedance measurements are used as an indication of the structural state. In partnership with the Air Force Research Laboratory University Nanosatellite Program, Cornell's CUSat mass model was instrumented with piezoelectric transducers and tested under several structural damage scenarios. A method for detecting and locating changes in the structure using EMI data is presented.

8348-53, Session 6b

Design, development, and assembly of sub-orbital space flight structural health monitoring experiment

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The paper presents a discussion of design, development, and assembly of Structural Health Monitoring (SHM) experiments launched in space on a sub-orbital flight. Experiments focused on investigating utility of piezoelectric wafer active sensors (PWAS) as active elements of spacecraft SHM system and the electro-mechanical impedance method as a promising SHM methodology for space systems. Magneto-elastic active sensor (MEAS) was utilized to record in-flight dynamics of the payload. A list of PWAS experiments included a bolted-joint experiment, an adhesive endurance experiment, and an experiment to monitor PWAS condition during spaceflight. Electromechanical impedances of piezoelectric sensors were recorded in-flight at varying input frequencies using onboard microcontroller units. PWAS and MEAS data were recovered from the payload after landing. Details of the sub-orbital flight experiments are considered and conclusions pertaining flight results are presented. The paper discusses issues encountered during design, development, and assembly of the payload and aspects central to successful demonstration of the SHM during sub-orbital space flight.TML>

8348-54, Session 6b

Condition-based maintenance: an aerospace perspective

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Structural Health Monitoring (SHM) is a component of an aircraft advanced maintenance program for continued airworthiness, enhanced operational safety and reduced life cycle cost. SHM is further considered to constitute a major building block of any Condition Based Maintenance (CBM) Program activity. With 65% to 80% of the Life Cycle Cost (LCC) devoted to operations and support, the aerospace industry and the military sectors continue to look for opportunities within the technology developer community to exploit reliable SHM and CBM systems, capability and tools. The reduced reliability, lack of standards, and regulations are among the impeding factors for SHM implementation on a commercial scale. However, such factors have not hampered the continued engagement of the industry, OEMs, aircraft maintainers and operators, to explore implementation approaches due to the anticipated benefits associated with SHM and CBM. Some of these benefits include contribution to maintenance, operation and future platform design and analysis, improved system reliability, decreased maintenance costs, and decreased number of maintenance operations.

The aerospace industry is very interested in the exploitation of technologies that could enhance fleet safety and availability, improve operational reliability, and reduce maintenance costs. This document provides an overview of our current SHM and CBM activities with a main objective of enhancing the total life cycle system maintenance and logistics. It introduces the development of emerging concepts and technologies, presents a synopsis of some of our current developmental activities, and discusses several implementation challenges within the aerospace sector.

8348-55, Session 7a

Real-time prediction of impact-induced damage in composite structures based on numerical failure analysis and efficient database methods

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Real-time damage detection and characterization capabilities in aerospace structures will offer immense potential for reducing the down-time and operational costs incurred during the preventive maintenance operations. Non-penetrating in-service impacts on composite aerospace structures such as bird-hit, debris collision and similar loading events may pose a serious threat to the structural integrity by inducing hidden damages in the form of intra-ply matrix cracking and inter-ply

delaminations. These hidden damages, if left undetected at the inception stage, will grow progressively during the subsequent loading-unloading cycles and may cause catastrophic failure of the structures. Thus, there is a strong need for future health management systems, having instant decision-making capabilities, to obtain instantaneous damage predictions after any adverse impact event.

The current paper presents a novel strategy to achieve real-time predictions for non-penetrating impact-induced damage on composite laminated structures using an advanced passive impact monitoring system. The methodology aims to create an efficient database of pre-simulated damage information on a given structure using numerical failure models and unsupervised data-clustering algorithm. Based on the outputs of the passive sensing system, the pre-generated database of impact-induced damage information will provide real-time estimate of the damage size and location within certain confidence bounds.

First, the database approach employs the Finite Element model of the structure to identify unique regions having the potential to represent the damage response of the entire structure. Structural regions with similar damage characteristics are clustered by a data clustering algorithm using specific set of features. The numerical damage prediction model is a stress based failure criteria for composites which accounts for the effect of changes in the material stiffness and strength over the different regions of the structure. Analytical failure models along with the Finite Element simulations are then used to calculate the location and extent of damage on those unique set of regions for a discrete range of service loads. The damage information can either be interpolated or extrapolated from the stored simulated database using the identified impact force and impact location submitted from the passive impact monitoring system.

The efficiency of the proposed approach lies in optimizing the size of the database and thus offering two-fold advantages. The first one is large reduction in computation time involved in the database generation stage and second being the flexibility for any subsequent modification of the damage information due to changes in loading, boundary conditions or material characteristics of the structure. In this manner the information of potential damage for the entire structure is stored and maintained efficiently which will deliver real-time capabilities for the damage prediction during in-service impact events.

8348-56, Session 7a

SHM system using rectangular versus circular piezoceramic for the inspection within the bond of a composite bonded joint

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A bonded joint between an aluminum plate and CFRP plate (7 plies) is considered using a Titanium spar. The bonding is ensured by double sided adhesive that is prone to degradation with aging structures. The problem is to detect the disbond occurring at the CFRP plate/ Titanium spar interface using guided waves generated by piezoceramic transducers (PZT) bonded on the CFRP plate. The objective of the present work is to optimize the SHM configuration (PZT location, Lamb wave mode, size and shape of the PZT) for pitch and catch measurements. For experimental investigation, coupon structure was manufactured with four different zones (undamaged, sub-critical damaged, critical damaged and over-critical damaged); synthetic damages are inserted using two hemispherical Teflon tapes between adhesive and titanium spar in order to simulate a disbond between both sub-structures. The structure was instrumented for inspection within the bond by using circular PZT or rectangular PZT. The experimental results show the advantages to use rectangular PZT to ensure the best repeatability, and consequently to improve the detectability of disbonds. 3D FEM simulations of the instrumented structure were performed with COMSOL Multiphysics to interpret the experimental results. It appears that the rectangular shape can ensure a plane wave front within the bond, since the circular shape generates complex wave fronts.

8348-57, Session 7a

Damage detection in underwater composite structures using ultrasonic guided waves

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An ultrasonic guided wave based damage detection technique has been developed for nondestructive evaluation (NDE) and structural health monitoring (SHM) of composite structures submerged in water. Specially designed guided wave transducers are utilized to selectively excite and receive guided waves with dominate shear horizontal particle displacements. It has been shown that the SH type waves are insensitive to water loading conditions. With appropriate water sealing, the transducers can be applied to composite structures submerged in water. The guided wave signals collected from an underwater composite structure are almost identical to the signals that are obtained before the structure is submerged. Experiments have been conducted to demonstrate the feasibility of damage detection in underwater composite structures. A thick carbon/epoxy composite beam is used as the test sample. Excellent damage detection results were obtained for both dry and underwater tests.

8348-58, Session 7a

Nonlinear guided wave based debonding detection in honeycomb sandwich structures

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In this study, an experimental study of nonlinear wave modulation responses of debonded honeycomb sandwich structures is conducted by using a piezoelectric actuator/sensor network. It is found that the presence of skin/core debonding can induce the composite to behave in a nonlinear elastic manner, characterized by the presence of higher harmonics in the spectrum of received sensor signals. The presented nonlinear guided wave based method can be used to detect small debonding areas with high sensitivity in honeycomb sandwich structures.

8348-59, Session 7a

Ultrasonic guided wave based damage detection in foam-core sandwich panel using PWAS and LDV

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Foam core sandwich panels with metal and composite face sheets are widely used in marine structures. However, foam core sandwich panels suffer from defects caused during manufacturing, impact loading, debonding of face sheets, foam fracture and other environmental effects including hydrated pockets, chemical degradation of foam etc.. Environmental effect can accelerate face sheet delamination, core crushing/cracking etc. due to underwater explosion and low velocity cyclic loading, which are difficult to detect. A guided wave based method has been developed which provides insights into various mechanisms of Lamb wave breakdown/conversion due to foam interface properties and modes of damage. Piezoceramic phased array exciters are used for generating the waves. Non-contact 3D Laser Doppler Vibrometry (LDV) is employed to extract damage features. A developed theoretical model is used to optimally propagate certain guided wave modes. Group velocity dispersion curve and wave transmission spectra at various sensor locations have been estimated experimentally. Relation between the excitation signal amplitude and the sensed signal amplitude is obtained. With this information, the nature of damping of the guided wave modes has been analyzed. Laser Doppler Vibrometer (LDV) has been used to

scan a wide area of a laboratory scale sandwich panel. Damage details are successfully detected using the developed analytical technique and optimal scanning with LDV. Quantitative estimates regarding damage size and severity is obtained using a newly developed wavelet spectral filtering technique.

8348-60, Session 7a

Damage localization and quantification on a CFRP panel using guided waves

A. J. Vizzini II, A. Chattopadhyay, Arizona State Univ. (United States)

Composite materials are becoming evermore present in advanced structures in the aerospace industry due to their high strength to weight ratio. However, delamination can occur in the structure due to impact or fatigue, and this can cause failure in the overall structure. As a result, being able to detect the damage as well as the breadth of the damage will enable a better understanding of the useful life of the structure.

Using an active piezoelectric network, a Lamb wave based damage quantification technique was developed. This method utilizes an existing localization technique with an updated damage index (DI) developed in previous work by the authors. A relationship was made between the estimated damage size, the position of the actual damage, and the DI for each actuator-sensor pair. The resulting model is data and physics driven, accounting for wave dispersion, attenuation, boundary reflections, and other adverse effects resulting from the use of Lamb waves.

Previously, the mode conversion phenomenon was used as a feature for identification of damage within the sensor signal and furthermore used to quantify the DI. To enhance the accuracy of the DI, the damage size and position were related to the energy contained in the converted mode, S0, and A0 modes. A series of experiments were then conducted to build a relationship between the DI and the relative distance between the damage and a sensing path. In conjunction with the localization results, the DI for each sensing path and the relative distance between the estimated damage location and each sensing path were used to determine an accurate estimation of damage size. The method was verified through a series of impact studies.

8348-61, Session 7a

Guided wave based damage detection in a composite T-joint using 3D scanning laser Doppler vibrometer

G. K. Geetha, D. Roy Mahapatra, S. Gopalakrishnan, Indian Institute of Science (India)

Composite T-joints are commonly used in modern composite airframe, pressure vessels and piping structures, mainly to increase the bending strength of the joint and prevents buckling of plates and shells, and in multi-cell thin-walled structures. Here we report a detailed study on the propagation of guided ultrasonic wave modes in a CFRP composite T-joint and their interactions with delamination in the co-cured co-bonded flange. A well designed guiding path is employed wherein the waves undergo a two step mode conversion process, one is due to the web and joint filler on the back face of the flange and the other is due to the delamination edges close to underneath the accessible surface of the flange. A 3D Laser Doppler Vibrometer is used to obtain the three components of surface displacements/velocities of the accessible face of the flange of the T-joint. The waves are launched by a piezoceramic wafer bonded on to the back surface of the flange. What is novel in the proposed method is that the location of any change in material/geometric properties can be traced by computing a frequency domain power flow along a scan line. The scan line can be chosen over a grid either during scan or during post-processing of the scan data off-line. It eliminates the necessity of baseline data and disassembly of structure. Various features of a delamination are characterized using cross-correlation among the kinetic and strain energy components.

8348-62, Session 7b

Development of a 2D electro-optic scanner

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Medical endoscope is used to examine the inside of human body. Diseases such as breathing disorders, internal bleeding, stomach ulcers and urinary tract infections are commonly checked using endoscope. Endoscope can be also used in a biopsy procedure to assist the diagnosis of cancer. Current commercially available endoscopes suffer from the compromise between high image quality and small equipment sizes. In this paper, we introduce a polymer based electro-optic scanner system, which can be potentially used for endoscope system. The embodiment of the electro-optic scanner includes collimating lens array, prism light beam deflector, Bragg grating system and photo detector array. This paper only includes the first two compositions, the collimating lens array and the prism light beam deflector. The collimating lens array functions by collimating the light and reducing the size of light beam before coupling the light beam to the prism deflector. The prism light beam deflector array drives the incident light beam by using electro-optic effect and Snell's law. Our design of polymer based electro-optic scanner has reduced size compare to traditional endoscope while improves the image quality. It can also be combined with other medical devices such as biosensors, portable microscopes and portable endoscopes.

8348-63, Session 7b

Prediction of ultrasonic guided waves excitability to support the non-invasive assessment of human long bones

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The characterization of bones via axial ultrasonic transmission techniques can be fully exploited only once the complexities of guided wave propagation are unveiled. Generally, plate/cylindrical waveguide models, where the soft tissues and their damping role are generally neglected, are used to identify the propagating waves in the bone.

Here, a numerical strategy for a more rigorous simulation of guided wave propagation in elongated bones is proposed. First, from a computed tomography image of a human arm a three-dimensional finite element (FE) mesh of the problem is built by converting voxels into elements. At this level, the mechanical properties of bones and soft tissues can be obtained converting the Hounsfield units. If necessary, the FE mesh can be enhanced by smoothing the outer surfaces of the bone and/or skin. Next, a representative bi-dimensional cross-section of the limb is used to set the forced guided wave equation by means of a Semi-Analytical Finite Element (SAFE) formulation. Via SAFE, the dispersive branches of waves excited by forcing functions generally applied by medical devices are finally obtained.

Such information is validated by a full time-transient three-dimensional FE simulation of the problem and then by processing the bone time-responses with a 2D-FFT transform suitable for guided waves extraction. The proposed strategy can support the research on non-invasive techniques based on stress waves for the assessment of long bones.

8348-64, Session 7b

Mechanical property quantification of endothelium cell using scanning acoustic microscopy

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The mechanical properties of cells reflect dynamic changes of cellular organization which occur during physiologic activities like cell movement, cell volume regulation or cell division. Thus the study of cell mechanical properties can yield important information for understanding these physiologic activities. Endothelial cells form the thin inner lining of blood vessels in the cardiovascular system and are thus exposed to shear stress as well as tensile stress caused by the pulsatile blood flow. Endothelial dysfunction might occur due to reduced resistance to mechanical stress and is an initial step in the development of cardiovascular disease like, e.g., atherosclerosis. Therefore we investigated the mechanical properties of primary human endothelial cells (HUVEC) cultured on flexible substrates or exposed to fluid flow using scanning acoustic microscopy at 1 GHz. To study the effect of fixation and substrate, endothelial cells were cultured on glass and flexible silicone substrate and then were fixed with formaldehyde and glutaraldehyde. Longitudinal sound velocity, attenuation and geometrical properties of cells (thickness) were determined using the material signature curve V(z) method for variable culture condition along spatial coordinates. The plane wave technique with normal incidence is assumed to solve two-dimensional wave equation. The size of the cells is modeled using multilayered (solid-fluid) system. The propagation of transversal wave and surface acoustic wave are neglected in soft matter analysis. The simplex method has been adopted for optimization of mechanical properties of the cells. Using the longitudinal wave velocity the elastic stiffness of cells at various conditions is quantified.

8348-65, Session 7b

A full-scale foot pressure/shear sensor based on fiberoptic bend loss sensor

W. Wang, Univ. of Washington (United States) and National Cheng Kung Univ. (Taiwan)

The proposed research is aimed at developing, fabricating and implementing a flexible fiberoptic bendloss sensor for the measurement of plantar pressure and shear stress for diabetic patients. The successful development of the sensor will greatly impact the study of diabetic foot ulcers by allowing clinicians to measure a parameter (namely, shear stress) that has been implicated in ulceration, but heretofore, has not been routinely quantified on high risk patients. A full-scale foot pressure/shear sensor involves a tactile sensor array using intersecting optical waveguides is presented. The basic configuration of the optical sensor systems incorporates a mesh that is comprised of two sets of parallel optical waveguide planes; the planes are configured so the parallel rows of waveguides of the top and bottom planes are perpendicular to each other. The planes are sandwiched together creating one sensing sheet. Two-dimensional information is determined by measuring the loss of light from each of the waveguide to map the overall pressure distribution. The shifting of the layers relative to each other allows determination of the shear stress in the plane of the sensor. This paper presents latest development and improvement in the sensors design. In this report, fabrication and results from the latest tests will be described. Algorithm of two-layer neural network will be used to train the full-scale foot sensor to recognize three different heel shapes and five applied load magnitudes.

8348-98, Poster Session

Bayesian networks to prognoses and monitor the prostate cancer

C. Gavrila, N. Teodorescu, Univ. Tehnica de Constructii Bucuresti (Romania)

Causal or inference networks are used in a number of areas to represent patterns of influence among variables. They consist of connected causal relations. Generally, causality can be seen as any natural ordering in which knowledge of an event influences opinion concerning another event. This influence can be logical, physical, temporal, or simply conceptual. In this paper, we describe an application of Bayesian networks to the prognoses of prostate cancer. Diagnosis, as presented in this article is derived from data supplied by St. Ioan's Hospital and Panduri's Hospital in Bucharest. Bayesian-network and decision theoretic systems intend to assist medical doctors in diagnosing prostate cancer, and predicting likely outcome and selecting appropriate treatment. The diagnoses concerning prostate cancer represent the original contribution of our research team. Based on the patient's symptoms, the doctors make a prediction connected to the diagnosis. The main reason for this is that it is still a major undertaking to develop systems for problems of the complexity in monitoring prostate cancer. At the end of the paper we are going to illustrate the practical applications of the theoretical knowledge discussed throughout the article in a case study on a number of patients who present a set of prostate problems.

8348-99, Poster Session

Damage detection using cloud-based optimization algorithm

J. Zhou, A. Mita, Keio Univ. (Japan)

In this study damage detection problem is described as a multi-modal optimization problem with high dimension via minimizing the discrepancy between computed responses of established mathematical model and the measured data of a real structural system. Population-based stochastic algorithm has attracted much attention and yielded promising results in recent years in the research arena of computational intelligence. By selecting the structure parameters as optimization variables, an optimization algorithm is applied to create successive generations that better reflect the measured response, until a certain tolerance is met. However, when dealing with damage detection problems for civil structures, uncertainties and complexities of the structural system and the measured signals make it a choke point. Cloud theory is the innovation and development of member-ship function in fuzzy theory, and is a model of uncertainty transformation between qualitative concepts and their quantitative expressions. A novel cloud-based optimization algorithm was proposed to detect damages of the structure in this study. Backward cloud generator is used to estimate three digital characteristics values of the selected solution from good solution regions during optimization. Then, the next population is produced by forward cloud generator according to three digital characteristics values of cloud. Simulation results for damage detection of a multiple degree-of-freedom structure under conditions including limited output data and no prior knowledge are presented to demonstrate the effectiveness of the proposed method.

8348-100, Poster Session

Fatigue damage monitoring for fiber reinforced polymer composites by using acoustic emission technique combining with real time scanning electronic microscope image observation

W. Wang, H. Li, Harbin Institute of Technology (China)

In this paper, a new fiber-reinforced composite material with 14 basalt fiber layers (BFRP) was made for fatigue test. Acoustic emission technique (AE) combining with scanning electronic microscope technique (SEM) was presented in this study to monitor the fatigue damage of BFRP. Firstly, in order to analyze the AE signals, time-frequency description using wavelet transform was proposed instead of peak frequency method. Then, comparing the time-frequency graphs and the SEM photos, three frequency bands standing for three failure modes in the damage of BFRP material were obtained. Moreover, according to the statistical analysis by stage, the amplitudes and the frequencies of AE signals would rise on with the cumulative damage of BFRP material.

8348-101, Poster Session

Structural damage detection using Lamb wave and DORT method

W. Qu, X. Li, Wuhan Univ. (China)

Structural health monitoring (SHM) is an emerging research area with multiple applications. Among SHM techniques, Lamb waves are ultrasonic elastic waves that travel inside and along thin plates and is frequently used as diagnostic tools to detect damage in plate-like structures. As a kind of baseline free method, time reversal (TR) method applied to ultrasonic detection and focusing with arrays of transducers has been proposed. The decomposition of the time reversal operator (DORT) method is a selective detection and focusing technique using an array of transmit-receive transducers. Unlike body waves, the propagation of Lamb waves is complicated due to their dispersive and multimode characteristics. So Lamb wave is hard to locate different scatterers on the plate using DORT method because of the asymmetry of the time reversal transfer matrix. In this paper, a proposed approach based on the DORT method is developed to distinguish and locate two simulated damages on the plate using Lamb wave through finite element simulation on the commercial finite element code ANSYS platform. The behavior of reflected waves is analyzed by studying the eigenvalues and eigenvectors of the time reversal transfer matrix, showing that the number of significant eigenvalues is not exactly the number of damage targets and two significant eigenvalues correspond to one target. This method, which uses PZT array and operates under multi-modes pulse-echo mode, can estimate the position of the damaged zone in 2D image by numerically backpropagating selective eigenvector using the S0 or A0 Lamb wave propagation analytical solution.

8348-102, Poster Session

A nonlinear structural damage detection using autoregressive support vector

X. Li, W. Qu, Wuhan Univ. (China)

Due to randomness of measured dynamic response data and the complexity of operational and environmental variabilities, statistical approaches have received more and more attention in the structural health monitoring (SHM) field. Statistical pattern damage recognition techniques based on support vector machine (SVM) have been demonstrated to be competitive with other methods when applied to real engineering datasets, and to generalise well from the small datasets usually encountered in damage identification problems.

An actual structure including connections and interfaces may be exist nonlinear in both its undamaged and damaged states. Because of many complicated problems about nonlinear SHM, few works have been done in this aspect. In this paper, a vibration-based structural health monitoring when the structure exists initially nonlinear is investigated with autoregressive support vector machine(AR-SVM).Vibration experiments are carried out with a model frame. Time-series data in different cases such as: initial linear structure undamaged, initial linear structure damaged, initial nonlinear structure undamaged, initial nonlinear structure damaged, are acquired. AR model of acceleration time-series is established and the AR coefficients as damage features are extracted. Different kernel types and corresponding parameters are chosen and compared, which can more accurate, more effective locate the damage. AR-SVM method for the insufficient training samples is proved to be practical and efficient on structure nonlinear damage detection.

8348-103, Poster Session

The defect analysis and preventive measures of in-service bridge in the city

S. Li, Zhengzhou Univ. (China)

To solve the bridge security problem in the city of Pingdingshan, on the basis of ordinary bridge detection methods, pavement condition, crack condition of concrete structure, settlement of foundation for bridge pier and abutment, and reinforcement corrosion are examined in detail about 43 bridges in the city. The database of disease for the city bridge is made up. The safety of bridges is assessed and the preventive measures are advanced.

8348-104, Poster Session

Micro-organism index analysis of soil around pier on the riverside of yellow river

S. Li, Zhengzhou Univ. (China)

The microorganism index such as the pH value, water content and organic matter of soil around pier on the riverside of yellow river. These get ready to research the microorganism corrosion of pier on the riverside of yellow river and have very important theoretical significance and realistic meaning for researching systematically the microorganism corrosion of bridge pier in the yellow river.

8348-105, Poster Session

Micro-organism index of water around bridge pier in the typical area of the Zhengzhou Yellow River Bridge

N. Jiang, Zhengzhou Univ. (China)

The microorganisms, such as the Sulfate reducing bacteria, Neutral thiobacillus, Iron bacteria, Ancidity thiobacillus, Fungus etc. have the obvious corrosive effect. To research the corrosive effect of the microorganisms on bridge piers, the microorganisms of water around bridge pier are analysed in the typical area of the Zhengzhou Yellow River Bridge. The results can supply the research basic for durability of the reinforced concrete bridge piers and have very important theoretical significance and realistic meaning.

8348-106, Poster Session

Defect detection in underwater pipeline using ultrasonic guided waves

S. Ma, Z. Wu, Y. Wang, K. Liu, Dalian Univ. of Technology (China)

Subsea pipelines and offshore risers are the fundamental equipment in offshore oil and gas production. Pipes corrosion caused by the surrounding sea-water and pipe contents is one of the most critical problems. To ensure the safety of these pipelines, developing appropriate techniques used to regular check the integrity of the offshore pipelines is urgently required.

Ultrasonic guided wave technology has been applied to pipelines inspection on land since its benefits such as long-distance propagation, time efficiency, and cost effectiveness. There are a variety of promising transducers used to excite longitudinal, torsional, and flexural modes in pipes, including electromagnetic-acoustic, magnetostrictive, and piezoelectric array transducers.

In this study, a detachable transducer system is designed and fabricated for the detection of corrosion in underwater pipelines using ultrasonic guided waves. First, for the theoretical analysis of the propagation characteristics of guided waves in underwater pipelines, appropriate guided waves which suitable for the inspection of underwater pipelines are selected; then, the piezoelectric elements and the structure of transducer design are discussed in detail. For the experimental study, a new detachable transducers holding device is designed to clamp against the pipe. It is shown that the axisymmetric T(0,1) mode guided wave at a frequency of about 30kHz is a suitable mode to use for long-distance inspection of underwater pipelines. A series of tests are carried out on pipelines in underwater environment. The results showed that the

transducer system can be used to excite and receive the desired signals. The echo signal from artificial notch is significant and correlated well with the notch size and location. This investigation shows that the designed transducer system can be effectively used for inspection of underwater pipelines using guided waves.

8348-107, Poster Session

Effects of honeycomb-patterned porous films on the morphologies and functions of stem cells

M. Sato, T. Kawano, H. Yabu, M. Shimomura, Tohoku Univ. (Japan)

The effects of microtopography on cellular behavior have been well documented such as changes in cell growth, adhesion, cytoskeletal organization, and defferentiation of stem cells. These studies show that cell shape and function are controlled by cellular microenvironment.

Specifically, the synthesized polymer substrates for cell-culture with geometric subcellular patterns have been fabricated by various fabrication methods and have been extensively used to investigate how cells respond to surface topography. We reported that honeycomb-patterned porous films (honeycomb films) with uniform-sized pores ranging submicron to micron size, which can be obtained by casting polymer solution under humid condition, had used as cell-cultured substrate.

In this report, we investigated that cellular behaviors of mesenchymal stem cells (MSCs) , which were multipotent cells that can differentiate into many cell types, were regulated by orderly porous surfaces of honeycomb films.

The morphorogies of MSCs cultured on polystyrene honeycomb films with pore sizes of 3 μm, 5 μm and 9 μm were spread, spindled and branched shapes, respectively. The honeycomb films affected cellular morphology by changing topographical features due to resticting their attachhment areas. Especially, on honeycomb films with pore size of 5 μm, MSCs become spindle shaped cells similar in shape to myoblsts and expressed muscle transcription factor myoD1 by immunofluorescece images. These results indicated the possibility that honeycomb-patterned surface topographies affected cellular extension and induced differentiation to myoblast.

8348-108, Poster Session

Data analysis for long-term structural health monitoring on a continuous rigid frame bridge

L. Wang, Harbin Institute of Technology (China)

A series of bridges collapsed in china in recent years in earthquakes, floods or ship accidents. Also bridges are faced with fatigue problems caused by increased traffic demand, continued materials aging and deterioration, but are lack of maintenance. Sustainability of bridges is affected by environmental conditions such as traffic load, temperature, humidity, wind and so on. Long-term structural health monitoring (SHM) system has been developed to monitor the operational process of bridge structures, to estimate the bridge structural safety and serviceability by damage diagnosis, safety assessment and service life evaluation. Fiber brag grating (FBG) sensors are widely used in SHM to monitor environmental conditions, static and dynamic properties because of their high-durability. A mass of data is collected during the long-time monitoring; therefore methods for reducing data and prediction for future modal properties are main concerns in data analysis of SHM.

Dongying Yellow River Bridge is a continuous rigid frame concrete bridge with main span of 220 meter, which is implemented with 180 FBG sensors for temperature, 1688 for stain and 32 for acceleration. This paper analyses 5 months continuous monitoring data in year 2006. Because of abundant amounts of data, principle components analysis (PCA) method is utilized to reduce excessive information from raw data. The correlations between temperature and modal parameters and between strain and modal parameters are simulated by Support Vector Machine (SVM). The results show that PCA is an effective data deduce tool; with appropriate inputs for SVM, modal properties are predicted accurately and effectively.

8348-109, Poster Session

Quantitative structural health monitoring using statistical methods

J. Liu, Nanjing Univ. of Aeronautics and Astronautics (China)

Structural health monitoring (SHM) has become of major interest to the engineering community. Applications cover a broad bandwidth from civil engineering to aerospace applications. Structural health monitoring can be distinguished into three levels: the first level of monitoring is whether the damage/impact occurred; the second level of monitoring is the location of damage/impact; the third level of monitoring is the size of damage/impact, which is a quantitative result of structural health monitoring. Quantitative results of structural health monitoring are of great importance for the remaining life prediction of structure, major basis of determining whether composite structures need to maintain. Especially in the aircraft industry for the extensive use of composite materials, current concerns such as ageing aircraft, necessary enhanced performance and the need to reduce operational cost call for quantitative Structural Health Monitoring.

This paper poses the process of structural health monitoring in the context of a statistical pattern recognition paradigm based on guide-wave in composite material structure. The size of possible damage and impact will be distinguished, and the quantity of possible damage will be obtained according to theoretical analysis and experimental verification. First, piezoelectric actuators and sensors will be distributed in a large area of composite board. Second, the upper and lower limits of damage size will be selected. Next, different region paths scanning according to piezoelectric actuators generating and sensors receiving guide wave will be performed. Finally, Identification model, statistical methods and damage index will be used for quantitative damage monitoring results. Then, the size and quantity of possible damage will be determined.

8348-110, Poster Session

Harvesting strain energy from an aircraft wing under gust loading for structural health monitoring

M. Pozzi, S. Guo, M. Zhu, Cranfield Univ. (United Kingdom)

Weight reduction and maintenance simplification are high in the agenda of companies and researchers active in the aerospace sector. Energy harvesters are being investigated because they enable the installation of wireless sensor nodes, providing structural health monitoring of the aircraft without additional cabling. This paper presents both a weight-optimized composite wing structure and a piezoelectric harvester for the conversion of mechanical strain energy into electrical energy. Finite elements modelling was used for the minimum-weight optimisation within a multi-constraints framework (strength, damage tolerance, flutter speed and gust response). The resulting structure is 29% more compliant than the original one, but is also 45% lighter. A strain map was elaborated, which details the distribution of strain on the wing surface in response to gust loading, indicating the optimal locations for the harvesters. As piezoelectric materials directly convert strain into charge, a piezoelectric sheet can be applied to the surface of the wing to harvest energy from the elastic deformation of the wing. To assess the potential for energy generation, a piezoelectric sheet mounted on a portion of the wing is modelled with finite elements . The multi-physics model is solved with transient analyses, whose load history is supplied by the time-domain waveforms of the strain when the aircraft encounters a gust. Different gust lengths are considered, corresponding to gust frequencies of 1, 2, 5 and 10 Hz. With the first bending mode of the wing at a frequency of

5.4 Hz, much ampler vibrations and energy generation are observed with 5 and 10 Hz gusts than with slower gusts. The high energy density, low profile and weight of the piezoelectric sheet are greatly advantageous for the envisaged application.

8348-111, Poster Session

Experimental characterisation of macro fibre composites and monolithic piezoelectric transducers for strain energy harvesting

M. Pozzi, A. Canziani, M. Zhu, Cranfield Univ. (United Kingdom)

Compact and lightweight energy harvesters are needed to power wireless sensor nodes (WSNs). WSNs can provide health monitoring of aircraft structures, improving safety and reducing maintenance costs. A simple solution, which meets the requirements for lightness and compactness, is represented by piezoelectric generators fixed to the surface of the wing (i.e. the wing skin). Such piezoelectric patches can harvest the strain energy available when the wing is flexed, as occurs, for example, in the presence of gust loading. For this study, monolithic piezoelectric sheets and macro fibre composite (MFC) generators were fixed to plates made of two materials commonly used for aircraft wing skin: Al-2024 aluminium alloy and an epoxy-carbon fibre composite. The plates then underwent harmonically varying loading in a tensile testing machine. The power generation of the harvesters was measured at a selection of strain levels and excitation frequencies, across a range of electrical loads. The optimal electrical load, yielding maximum power extraction, was identified for each working condition. The generated power increases quadratically with the strain and linearly with the frequency. The optimal electrical load decreases with increasing frequency and is essentially independent on strain at high frequency. Absolute values of generated power were highest with the MFC, reaching 12mW (330μW/cm^2) under 570μstrain excitation at 10Hz with a 64kΩ load. Power generation densities of 600μW/cm^2 were achieved under 460μstrain amplitude with the monolithic transducers at 10Hz. Hence, it is found that MFCs have a lower power density than monolithic transducers, but, being more resilient, could be a more reliable choice.

8348-112, Poster Session

Development of muscular strength training system for the lower limbs using magneto-rheological dampers

T. Kwon, M. Yu, Y. Park, G. Jeong, K. Kim, W. Chong, Chonbuk National Univ. (Korea, Republic of)

The Purpose of this study is to suggest a new muscular strength training system with unstable platform which is controlled by electric current to the Magneto-Rheological dampers. For evaluation of this training system, we performed experimental studies on the muscular activities in the lower limbs of 10 subjects during maintaining and moving training protocol. The electromyography signals of the eight muscles in lower extremities were recorded and analyzed: rectus femoris (RF), biceps femoris (BF), tensor fasciae latae (TFL), vastus lateralis (VL), vastus medialis (VM), gastrocnemius (Ga), tibialis anterior (TA), and soleus (So). During the moving training, the TA in anterior-posterior direction and TFL in medio-lateral direction were highly activated, respectively. However, the TFL was rather highly activated compared to TA muscle in 45 and -45 direction, and the current supplied to MR damper affected the increase rate of muscular activation. During the maintaining training, the increase rate of muscular activation analyzed by the spectral energy was the highest in the Ga muscle in anterior, anterior-right and right directions, while the increase rate of the TFL was high in anterior-left, posterior and posterior-left directions. The VL and VM muscles showed the high increase rate in left direction and posterior-right direction, respectively. The experimental results suggested the choice of different maintaining and moving trainings could selectively train each muscle with varying intensity. (“This work was supported by the Ministry of Knowledge Economy and the Grant of the Korean Ministry of Education, Science and Technology ” (QoLT Technology Development, No. 10036494, The Regional Core Research Program/Center for Healthcare Technology Development))

8348-113, Poster Session

Moving force identification method for cable-stayed bridges with uncertain parameters and noisy measurements

F. Zhang, H. Li, Harbin Institute of Technology (China)

An identification method based on interval analysis for moving load on cable-stayed bridge with uncertain parameters and noisy measurements is presented. Although there have been many reports on moving force identification methods on bridges, they did not pay much attention to the problem of identifying loads on cable-stayed bridge. The influence matrix model of cable-stayed bridge was derived from the finite element model or in-field test in this study and the sensitivity matrix model to the uncertain parameters was calculated from the finite element model. The upper and lower boundaries of the uncertain loads can be obtained by interval analysis to the influence matrix and sensitivity matrix based on the interval theory. In order to improve the performance, the Taylor series is adopted to connect the uncertain parameters and moving load to be identified. If the test data is sufficient, probabilistic model can be adopted for a more accurate estimation. Because the identification problem is a typical inverse problem, the Tikhonov and TSVD regularizations are used to overcome the ill-poseness. The numerical and in-field data demonstration and validation are carried out based on the structure health monitoring data from Nanjing No.3 Yangtze River Bridge.

The main contributions of this paper are: a. to propose a regularized identification method for cable-stayed bridge with uncertain parameters and noisy measurements; b. the location, speed and magnitude of vehicle loads can be estimated simultaneously with the upper and lower boundaries.

8348-114, Poster Session

An Investigation of Photoacoustic Tomography for Inflammatory Tissues

C. H. Yang, T. C. Wu, C. H. Chang, Y. H. Yeh, T. W. Chen, National Taipei Univ. of Technology (Taiwan)

Photoacoustic tomography (PAT) has been widely used as a diagnostic imaging tool in pre-clinical or clinical applications. Major advantages of PAT include the inherited imaging contrast mechanism and high spatial resolution. This research is focused on the investigation of PAT applied to the imaging of inflammatory tissue. In clinical practice, tissue inflammation, such as cellulitis, is diagnosed by experience-based physical examination which sometimes may be biased. The physiological change of inflammation includes increasing metabolism, perfusion and angiogenesis. These symptoms are closely associated with the abnormal gathering of blood cells which can be easily recognized with PAT. In this PAT application, we show reconstructed tissue images of the optical absorption in biological tissues by an advanced algorithm. To generate photoacoustic sources in biological tissues, a pulsed laser with optically tunable output stage was employed for pulses of different wave lengths. A focused ultrasonic transducer was adopted to detect the acoustic pressure around the cross section of the samples. Boundaries of the inflammatory tissues are mapped by the PAT with a comparison with the physiological examination.

8348-115, Poster Session

Low-cost low-power wireless system for health monitoring applications

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In the last decade, the performance of health monitoring networks is enhanced by improving their abilities to accurately measure, record, and analyze data. On the other hand, health monitoring network problems became more complicated due to the increasing number of systems who still need health monitoring services. This makes the development of reliable, low-cost, and low-power health monitoring network a must. Although near range, short range, and long range based wireless health monitoring systems were successfully introduced, full mobility and data size are still representing limitations to be overcome. Future health monitoring systems must be able to deliver services anywhere and anytime with minimum power, minimum cost, and best quality. The previous goals are steadily achieved by the continuous research efforts to enhance the performance of health monitoring sensors, to improve the capabilities of short range and long range wireless communication networks, and to develop more efficient data monitoring and management systems.

In the present work, a low-cost low-power wireless system for health monitoring applications which is compatible with common platforms and operating systems is designed and implemented. The main advantages of our suggested system are the ability to extend the number of the monitored quantities, the usage of efficient programming techniques to allow all features of monitoring, controlling, and data processing to be implemented with minimum power requirements, and the ability to transfer measurement data automatically either over short range or over long range wireless communication networks. In addition to all of the above mentioned features, minimum cost requirements are achieved by implementing the system with reliable components which achieve the minimum costs without scarifying accuracy. The use of standard wireless communication networks, standard software environments, and standard hardware components makes our suggested monitoring system reliable for all capital projects with minimum costs and ensures upgradability to adapt additional user requirements.

8348-117, Poster Session

Stochastic optimization using automatic relevance determination prior model for Bayesian compressing sensing

Y. Huang, Harbin Institute of Technology (China); J. L. Beck, S. Wu, California Institute of Technology (United States); H. Li, Harbin Institute of Technology (China)

Compared with the conventional monitoring approach of separately sensing, compressive sensing (CS) is a novel data compression framework whereby the compression is done during the sampling. If the original sensed signal would have been sufficiently sparse in terms of some orthogonal basis the decompression can be done essentially perfectly. In structural health monitoring (SHM) systems for civil structures, novel data compression techniques such as CS are demanded to reduce the cost of signal transfer and storage. In this article, Bayesian compressive sensing (BCS) is investigated. By explicitly considering the uncertainty in the signal, the BCS technique exhibits obvious benefits over the existing norm-minimization CS. However, current BCS algorithms suffer from a robustness problem; sometimes the reconstruction errors are large. The source of the problem is that inversion of the signal then becomes a severely ill-posed problem that leads to sub-optimal signal representations. This problem induces a tradeoff between efficiently compressing data and accurately decompressing it. To ensure the strong robustness of data reconstruction, even at a high compression ratio, an improved BCS algorithm is proposed which is a stochastic optimization implementation for the automatic relevance determination prior model to reconstruct the underlying signal based on CS measurements. The improved method is introduced from the consideration of reducing the uncertainty in the signal model from an information entropy perspective. Numerical experiments and actual acceleration data collected from a SHM system on a bridge are used as examples; compared with the state-of-the-art CS reconstruction algorithms, the improved BCS algorithm demonstrates superior performance.

8348-118, Poster Session

Development of a novel health remote monitoring system with mechanoluminescence material

C. Li, C. Xu, L. Zhang, N. Ueno, N. Terasaki, Y. Sakata, S. Guo, H. Yamada, National Institute of Advanced Industrial Science and Technology (Japan); H. Sakai, T. Tsuji, Logical Product Corp. (Japan)

A novel wireless sensor network system with mechanoluminescence materials has been developed and used for remote health monitoring in an in-service bridge. This system includes mechanoluminescence mechanical sensors coated on structure surface to sense abnormal deformation by emitting visible light, lab-made supersensitive photo-detectors to detect the light emission from ML mechanical sensors, and a wireless network to transmit the signals detected by photo-detectors to remote control center.

Mechanoluminescence (ML) mechanical sensor is an essential part in this system. ML is an interesting phenomenon whereby mechanical energies such as tension, compression and friction are converted directly to “light”. Recently, a film composed of ML materials has been developed as a mechanical sensor to be coated on the surface of targets. Since the target structure and the ML mechanical sensor are deformed equally due to the strong adhesion between them, the distribution of mechanical deformation on the detected structure surface can be described by the emitted visible ML and evaluated quantitatively with the linear relationship between ML intensity and von Mises stress. This is advantageous over the conventional measurement method by use of a strain gage, because a strain gage cannot give any correct information if the major deformation direction is not along the gage direction.

In this work, the health monitoring for the in-service bridge in Tokyo was performed. The ML emissions due to even micrometer crack opening of the existing cracks on the concrete surface once trucks passing the bridge, were detected and monitored in the remote control center one thousand kilometers away. A timely condition assessment has been achieved.

8348-119, Poster Session

Amplifier design for an extensometer in high temperature deformation monitoring

X. Hu, J. Jia, S. Tu, East China Univ. of Science and Technology (China)

In this paper a displacement amplifier is designed in order to integrate an amplifier into an extensometer, so that the precision and resolution of the extensometer can be improved for strain monitoring of high temperature components. At the first, the displacement amplifiers are investigated and the requirements for displacement amplifiers applied for high temperature deformation monitoring is summarized. At the second, a lever-type mechanical displacement amplifier for the extensometer is designed and the amplification ratio is derived. At last, feasibility of the designed displacement amplifier is analyzed from three items using FEA. They are loading force, amplification ratio and environmental temperature, which is ineluctable when the extensometer working in harsh environment for online strain monitoring. Analyzed results show that the loading force coming from the torque moment of the flexure hinge can be forced by the extensometer rods, amplification ratio equation is proved correct, and the thermal effect on accuracy can be corrected in data processing.

8348-120, Poster Session

Numerical studies on a novel damage localization approach of cantilever beams

Y. An, J. Ou, Dalian Univ. of Technology (China)

It is important to study a damage localization method which can be used in the simply supported beam. However, accurate damage localization in engineering is suffering from limitations due to high noise and low accuracy of the structural finite element (FE) model. To address the issues, a new damage localization approach is proposed: the Curvature Difference Probability Method of Waveform Logarithms of Standard Deviation (CDPWLSD). Firstly, the feature, the common Logarithms of Standard Deviation (LSD) for the response signals before and after damage can be computed at every measured node. Then, the curvature changes of the waveform LSD are selected as candidates for the potential damage locations. Lastly, the probability is considered in multiple identifications to determine the finally damaged elements. Numerical results of both single and multiple damage cases show that the proposed approach can be used to locate damage of simply supported beams very well. And it is robust enough against the noise: it is effective even if the noise level is up to 10%.

8348-66, Session 8

Particle trapping and focusing in liquid based on acoustic metamaterials

X. Cai, Q. Guo, J. Yang, The Univ. of Western Ontario (Canada)

Trapping and/or focusing particles are key techniques for a broad range of chemical and biological assays. Particle trapping or focusing in a limited space remains a tough task for applications such as lab-on-a-chip. In the last decade, the concept of metamterials stirs great interest among scientists and engineers. In contrast to naturally existing materials, metamaterials possess abnormal properties such as simultaneously negative density and bulk modulus for acoustics, or simultaneously negative permittivity and permeability for electromagnetic. Physical wave travels in metamterials may have inverse phase velocity and group velocity, which thus induces abnormal phenomena such as negative refraction, inverse Doppler effective, and so on.

In this work, we propose a new approach based on acoustic metamaterials for particle trapping/focusing. In the proposed method, particle trapping/focusing occurs at the interfaces between traditional material zones and metamaterial zones. While acoustic waves propagate in a liquid from a traditional material zone to a metamaterial zone, it is found that the particles in each zone experience opposite forces, both of which are toward the interface. As a result, particles are trapped or focused at the interfaces that can be well-defined and patterned in lab-on-a-chip devices. Here acoustic radiation forces exerted onto particles have been numerically characterized, and the structural parameters of the acoustic metamaterial and its influence on particle trapping/focusing have been analyzed.

8348-67, Session 8

Dissipation-triggered phenomena in periodic acoustic metamaterials

M. J. Frazier, M. I. Hussein, Univ. of Colorado at Boulder (United States)

Periodic acoustic metamaterials, can be designed, via band engineering, to control the propagation of sound and/or elastic waves at subwavelengths within solids, or within solid-fluid systems. In doing so, these modern materials have opened up a new technological frontier in acoustic and elastic devices. It is in the designer's discretion to have one or more of the constituent materials to be damped (i.e., lossy/dissipative), for example a viscoelastic material such as rubber can used to form the matrix phase in the acoustic metamaterial. The presence of damping results in temporal attenuation of the acoustic/elastic waves as they freely propagate through space in the periodic media. Such damped free wave propagation characteristics can be of high importance if, for example, a structure composed of a viscoleastic acoustic metamaterial is subjected to continuous forcing (i.e., a sustained source of energy input). The short-timed response to a shock load is also influenced by the level of damping. In this work we develop Bloch wave propagation models for damped periodic acoustic metamaterials and study the effects of damping on the dispersion relation. We demonstrate several intriguing phenomena that get triggered due to the presence of inherent dissipation.

8348-68, Session 8

Numerical effective formulation for guided wave propagation in a metamaterial plate with anisotropic mass density

G. Huang, Univ. of Arkansas at Little Rock (United States)

A numerical method for obtaining the effective anisotropic mass density of elastic composite with arbitrary periodic microstructure is presented and the effective anisotropic mass density is proved to be a second-order tensor. Using the proposed method, a new metamaterial plate with strong anisotropicity in mass density is obtained. Using 3-D elasticity theory, the metamaterial plate is modeled as a continuum medium with obtained effective material properties. The accuracy of the continuum model was evaluated by comparing the dispersion curves with those obtained by exact finite element analysis. Moreover, mode coupling and level repulsion in the anisotropic metamaterial plate are discussed. Finally, preferential directions of wave propagation and energy flow are studied through the comparison of the difference between the phase velocity and group velocity directions.

8348-69, Session 9

Estimation of changes in modal parameters of a seismically isolated building during the 2011 off the Pacific Coast of Tohoku Earthquake

T. Saito, Shimizu Corp. (Japan)

Monitoring data, which are absolute acceleration wave time histories with 980 second duration recorded at a seismically isolated building in Tokyo during the 2011 off the Pacific coast of Tohoku Earthquake, are investigated to estimate the changes in the modal parameters of the building during the earthquake.

The isolation system reduces the peak response acceleration of the upper structure to half of the peak ground acceleration, showing its effectiveness.

We take a 20 second frame from the response time history to identify the modal parameters, especially the natural frequency and the damping ratio, and shift the frame repeatedly by 10 seconds.

AR models are used for system identification, by which modal parameters are appropriately estimated from short data. The order of an AR model is determined by the Bayesian model class selection framework where the model class with a certain model order which maximizes the marginal likelihood (the evidence) is selected.

The results show that the natural frequency decreases as the response increases and then regains its value as the response fades, where the value at the end is lower than that at the beginning.

We also conduct system identification using microtremor data observed before and after the earthquake, which shows that the value of the natural frequency after the earthquake is lower than that before the earthquake. It suggests the possibility of evaluating the response amplitude of the building during the earthquake from the change in the modal parameters before and after the earthquake.

8348-70, Session 9

Synergistic combination of systems for structural health monitoring and earthquake early warning for structural health prognosis and diagnosis

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Earthquake early warning (EEW) systems are currently operating nationwide in Japan and are in beta-testing in California. Such a system detects an earthquake initiation using online signals from a seismic sensor network and broadcasts a warning of the predicted location and magnitude a few seconds to a minute or so before an earthquake hits a site. Such a system can be used synergistically with installed structural health monitoring (SHM) systems to enhance pre-event prognosis and post-event diagnosis of structural health. For pre-event prognosis, the EEW system information can be used to make probabilistic predictions of the anticipated damage to a structure using seismic loss estimation methodologies from performance-based earthquake engineering. These predictions can support decision-making regarding the activation of appropriate mitigation systems, such as stopping traffic from entering a bridge that has a predicted high probability of damage. Since the time between warning and arrival of the strong shaking is very short, probabilistic predictions must be rapidly calculated and the decision making automated for the mitigation actions. For post-event diagnosis, the SHM sensor data can be used in Bayesian updating of the probabilistic damage predictions with the EEW predictions as a prior. Appropriate Bayesian methods for SHM have been published. In this paper, we use pre-trained surrogate models (or emulators) based on machine learning methods to make fast damage and loss predictions that are then used in a cost-benefit decision framework for activation of a mitigation measure. A simple illustrative example of an infrastructure application is presented.

8348-71, Session 9

Earthquake damage detection of MDOF structure using fractal dimension and analytical mode decomposition

D. Tao, H. Li, Harbin Institute of Technology (China)

A data-driven approach for earthquake damage detection and localization in multi-degree of freedom (MDOF) system subjected to strong ground motion is proposed. The new method is based on the combination of analytical mode decomposition (AMD) and fractal characteristics. Due to the non-stationarity of structural response, AMD combined with Hilbert transform is used to separate the response into components contributed by different normal modes. The AMD has the advantage to decompose time series to separated signals whose Fourier spectra are non-vanishing over mutually exclusive frequency ranges, and it is insensitive to noise. Then the box counting method is employed to obtain the fractal dimension of the Hilbert spectrum of the separated components within the first natural frequency. It is verified that the proposed fractal dimensions at each DOF of linear system are identical, while the fractal dimension at the DOFs with nonlinearity will be different from those at the DOFs with linearity. Therefore, the nonlinearity of the structure caused by strong ground motion can be detected and localized through comparing the fractal dimensions at the measured DOFs. The numerical simulation on a 10-story shear-type shows that the aforementioned approach is capable of detecting and localizing single or multi seismic damage of shear-type building structure under various seismic excitations and is robust to measurement noise.

8348-72, Session 9

On the effect of material and geometrical uncertainties in structural health monitoring

H. Teimouri, A. S. Milani, R. J. Seethaler, The Univ. of British Columbia (Canada)

Sensitive engineering structures are designed to be safe such that catastrophic failures can be avoided. Traditionally this is achieved by considering safety factors and following ‘safe life’ or ‘fail safe’design strategies to create a margin between real-time operational loadings and residual strengths remained in structural materials.Although these methodologies have been used for many years, the increasing impact of economical considerations and emerging inspection technologies has led designers to newer strategies such as the ‘damage tolerance’ strategy; however, some inherent limitations still persist in this strategy such as the absence of continuous health assessment. In more recent years, the advancement of nondestructive inspection technologies, economical limitations and some historical catastrophic failures has directed designers to the introduction of the concept of Structural Health Monitoring (SHM). Essentially, SHM is an integration of sensing and possibly actuation devices to allow the loading and damage state of a structure to be monitored, recorded, analyzed, localized, quantified and predicted in a way that nondestructive testing becomes an integral part of the system.

In this paper, a historical background of Structural Health Monitoring (SHM) in different industrial areas including condition monitoring of machinery, oil platforms, railways, civil infrastructures and aeronautical engineering is first presented. In each area, a brief discussion is presented regarding the concept and application of SHM, current status and the state-of-the-art technologies developed or under development. Next, focusing on a strained-based SHM approach, the effect of material/geometrical uncertainties in the effectiveness of the predictions by SHM is highlighted. To this end, a benchmark problem from the literature is used along with a finite element analysis and design of experiment (DOE) method.

8348-73, Session 10

Experimental performance of an active acoustic metamaterial with simultaneously programmable density and bulk modulus

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Acoustic metamaterials are those structurally engineered materials that are composed of periodic cells designed in such a fashion to yield specific material properties (density and bulk modulus) that would affect the wave propagation pattern within in a specific way. All the currently exerted efforts are focused on studying passive metamaterials with fixed material properties. In this paper, the emphasis is placed on the development of a new class of composite one-dimensional active acoustic metamaterials (CAAMM) with effective densities and bulk moduli that are programmed to vary according to any prescribed patterns along its volume. A cylindrical water-filled cylinder coupled to two piezoelectric elements form a composite cell which acts as the basic building block of a biologically-inspired periodic metamaterial structure. The cell has a face-mounted piezoelectric panel to control its effective density and an active Helmholtz resonator with piezoelectric base panel to control the bulk modulus.

The experimental performance characteristics of the CAAMM cell are presented for different control strategies over a very wide frequency range. The obtained characteristics demonstrate the feasibility of the proposed CAAMM cell as a simple means for controlling the effective density and bulk modulus of a composite medium independently and in an uncoupled fashion.

Accordingly, the proposed CAAMM presents a viable approach to the development of effective domains with controllable wave propagation

patterns that can suit various applications ranging from simple acoustic beam shifting to the more complex development of acoustic invisibility cloaks.

8348-74, Session 10

A chiral elastic metamaterial: theory and experiment

G. Huang, X. Liu, Univ. of Arkansas at Little Rock (United States); G. Hu, Beijing Institute of Technology (China)

In this work, an elastic metamaterial consisting of only one type of natural material which exhibit dynamically simultaneous negative density and bulk modulus is proposed. The unit cell of the metamaterial is chiral in nature. The effective properties of the proposed metamaterial are numerically determined by a boundary effective theory, and the doubly negative feature is confirmed by the obtained band structure. Further, a full-size transient simulation in the metamaterial is performed to demonstrate the negative refraction. Finally, we conducted an experiment based on the proposed metamaterial to verify the numerical observation.

8348-75, Session 10

An approximate method for controlling solid elastic waves by transformation media

J. Hu, Z. Chang, G. Hu, Beijing Institute of Technology (China)

By idealizing a general mapping as a series of local affine ones, we derive approximately transformed material parameters necessary to control solid elastic waves within classical elasticity theory. The transformed elastic moduli are symmetric, and can be used with Navier's equation to manipulate elastic waves. It is shown numerically that the method can provide a powerful tool to control elastic waves in solids in case of high frequency or small material gradient. Potential applications can be anticipated in nondestructive testing, structure impact protection and seismology.

8348-76, Session 10

Multi-displacement continuum modeling of wave propagation in two-dimensional chiral metamaterials

G. Huang, A. Liu, Univ. of Arkansas at Little Rock (United States); G. Hu, Beijing Institute of Technology (China)

In this paper, an elastic metamaterial with chiral microstructures is considered. Conventional continuum models are insufficient to describe the dipolar resonance, and a multi-displacement continuum model is proposed to capture dynamic behavior in the composite. In the formulation, additional displacement and rotation kinematic variables are introduced to describe global and local deformations, respectively. The macroscopic governing equations are explicitly derived. To verify the current model, the wave dispersion curves from the current model are compared with those from the finite element simulation. The good agreement is observed in both the longitudinal and transverse wave modes.

8348-77, Session 10

Thin-plate metamaterials: physics and applications

P. Li, X. Zhou, S. Yao, Beijing Institute of Technology (China); G. Huang, Univ. of Arkansas at Little Rock (United States); G. Hu, Beijing Institute of Technology (China)

Thin-plate structures are widely used in various kinds of vehicles and industrial facilities, and are often working under the dynamic loading. Metamaterials are artificial composite materials having superior dynamic properties. It is expected that the dynamic performances of thin-plate structures can be improved if the metamaterial concept is introduced. Thin-plate metamaterials is thus proposed and may be used because of their notable advantages, such as high-strength, lightweight, and ability that common metamaterials possess. Here a thin-plate metamaterial is designed by placing locally resonant structures periodically on a thin plate. When the resonant microstructures are represented by mass and spring structures, analytical solutions are derived for plane sound waves incident on the metamaterials at arbitrary angles. According to the homogenization method, negative effective mass of metamaterials can be achieved by either local resonances of single unit or nonlocal resonances of adjacent units. In the normal incident case, a general expression of effective mass that includes the effect of local and nonlocal resonances are given. For the oblique incident waves, metamaterials are modeled as materials with anisotropic mass density. As an example of potential applications, the sound insulation effects of multilayered thin-plate metamaterials are studied. It is found that high transmission loss can be achieved in a finite-layered metamaterials at negative-mass frequencies. When each layer of metamaterials has different operating bands, the multilayered thin-plate metamaterials are possible to block sound waves in a wide band of low-frequency regimes. Their applications to noise control can be anticipated.

8348-79, Session 11

Probability-based bridge health monitoring strategy considering environmental effects

S. Jang, Univ. of Connecticut (United States)

Structural health monitoring (SHM) has drawn significant attention for effective maintenance of our infrastructure. To date, many SHM algorithms had been developed and become more applicable to practice. However, SHM of in-service field structures, e.g. highway bridges, are still challenging because of many uncertainties associated with construction errors, environmental effects, various loading conditions, etc. In this paper, a probability-based bridge health monitoring strategy is provided considering temperature-varying condition. A probability model is set up on the SHM results of a truss bridge structure under temperature fluctuation using first order reliability method. The target SHM methods in this paper are modal flexibility method and stochastic damage locating vector method. A 6-year long-term monitoring data on an in-service highway bridge in Connecticut will be utilized to correlate the results of the analysis.

8348-80, Session 11

An impedance-based approach for detection and quantification of damage in cracked plates and loose bolts in bridge structures

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A low-power, low-cost, and modular sensor network for health and usage monitoring of safety-critical structures is presented in this paper. The proposed system utilizes a network of flexible sensor nodes connected to a communication node that transmits high-level health metrics to a base station. System intelligence is distributed among individual nodes to reduce the required communication bandwidth and allow system capabilities to be customized for various applications.

The development in this paper is focused on health assessment of Armored Vehicle Launched Bridges (AVLBs). Specifically, fatigue crack growth and damaged (loose) bolts were identified as the two key failure mechanisms of the AVLB to be monitored.

The applicability of Electro-Mechanical Impedance (EMI) approach to

damage detection, localization and quantification was investigated. In this approach, a single PZT transducer is used as both actuator and sensor; any change in the (local) mechanical impedance of the structure (e.g., due to structural damage) will be reflected in the electrical impedance measured at the sensor's terminals.

It was shown through experiment that bolt damage (defined here as different torque levels applied to bolts) can be detected, quantified and located using a network of PZT sensors distributed on the structure. It was also shown that cracks of various sizes can be detected and quantified using the EMI approach. The experiments were performed on laboratory specimens as well as full size bridge components that were built as part of this research.

The effects of various parameters on the performance of the proposed health assessment approach were also investigated. For instance, the performances of two different sensor types (Micro Fiber Composite (MFC) and circular PZT patches of different sizes) were compared. The results suggested that aside from the directionality of MFCs, both sensor types can reliably detect the damage. The effect of transient loading on the damage baseline, excitation frequency on the separability of damage states and the excitation voltage on detection region were also studied.

8348-81, Session 11

Flexibility-based damage detection for in-service highway bridge

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Highway bridges are the backbones of a country's road network infrastructure. In order to efficiently maintain these important structures, structural health monitoring (SHM) can be implemented to impart a more deterministic management procedure. To date, many damage detection strategies have been developed and implemented on lab-scale or simple bridge structures however, damage detection research has rarely been conducted taking full scale in-service structures into account with ambient vibration. Among the different approaches modal flexibility method is one of the sensitive tools for damage detection which has been widely used over the last two decades. This paper presents a damage detection based on the stochastic damage locating vector (SDLV) method for an in-service highway bridge using ambient vibration data from long-term SHM. The target bridge was equipped with a long-term SHM system as a part of a research project of the University of Connecticut. The ambient vibration data during 2001 and 2005 are used to identify the damage on the highway bridge. Finally, the potential damage locations are determined using the SDLV method with the limited number of sensors.

8348-82, Session 11

Evaluation of bridge span by recovered stiffness data obtained with moving vehicle loadings

C. Cheng, C. Yu, Y. Ke, K. Hsu, Chaoyang Univ. of Technology (Taiwan)

The damage assessment for bridge girders is frequently done by comparing the difference of modal or deflection curvature between the intact and the damage states. In field tests, the accurate curvature cannot be obtained using limited measurement points. The experimental data has to be fitted into the finite-element models for further evaluation. In present study, the stiffness of a bridge span is evaluated by the dynamic displacement response at single measuring point corresponding to the moving three-axle vehicle load. A quasi-displacement influence line is obtained by smoothing the dynamic responses with Parzen window and multiplied the time axis with the vehicle speed. In order to identify the difference between the quasi-influence line corresponding to multiple-axle vehicle loading and the analytical influence line corresponding to a point load, the theoretical dynamic displacement responses corresponding to a point moving load as well as the multiple axial loads were derived by the principle of modal superposition, and solved for in the time domain using the convolution integral. Both responses are smoothed by the same window. The second derivatives of both influence lines indicate discrepancies in curvature only occurred near both end of the beam. As a result, a general Modulus of Elasticity along the central portion of a span can be obtained by dividing the curvature distribution of three-axle loading to the ideal moment diagram obtained from the concentrate loading applied at the measuring point. A field study has been successfully performed to evaluate the stiffness of a bridge span with damaged girders using the microwave interferometer.

8348-83, Session 11

Dynamic assessment of steel-concrete composite structures using dynamic response sensitivity

X. Zhu, Univ. of Western Sydney (Australia)

In aging structures, the condition of shear connectors may not be acceptable due to corrosion and/or overloading. Damage or failure of shear connectors will deteriorate the composite action, and therefore reduce the bridge load-carrying capacity. Before retrofitting/strengthening these existing structures, one may be required to detect the integrity of the existing shear connectors. The inaccessibility of the connection system makes direct inspection difficult. In addition, the huge number of shear connectors prevents any local non-destructive testing methods to access the connectors one by one. It is of practical importance to develop a new destructive assessment technique to detect the integrity of shear connectors. In this study, model updating procedures based on dynamic response sensitivity has been developed to detect, assess and quantify the damage in the connection system between steel beam and concrete slab. The shear model of the connection is adopted and the damage in the connection is defined as the reduction of the shearing and the axial stiffness. Numerical and experimental results illustrated that the method used is effective and reliable to detect the damage in the connections system of steel-concrete composite structures.

8348-84, Session 11

Recovery of lost data for wireless sensor network used in structural health monitoring

Y. Bao, H. Li, X. Sun, Harbin Institute of Technology (China); J. Ou, Harbin Institute of Technology (China) and Dalian Univ. of Technology (China)

In the wireless sensor network (WSN) based structural health monitoring (SHM) system, the data loss often happened in the data transformation between wireless sensor nodes and base station, which will decrease the communication reliability of WSN in SHM applications. Otherwise, the error caused by the data loss will inevitably affect the data analysis of the structure. This paper proposed a method to recover the loss data of the wireless monitoring system based on the compressive sampling (CS) techniques. The main idea of the method is change the sent data x to y, where y is linear projection of x on a random matrix. The data vector y is allowed to loss part of data in wireless transmission between sensor nodes and base station. After the base station received the data, the original data vector x can be reconstructed with some error. The acceleration data collected from the vibration test of Shandong Harbin Sifangtai Bridge using wireless sensor is employed to illustrate the loss data recovery ability of the proposed method.

8348-85, Session 11

Visualization of active crack on bridge in use by mechanoluminescent sensor

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Recently there have been innovative mechanoluminescent (ML) particles made available, each of which emits light repeatedly in response to small stresses applied, such as deformation, friction, or impact. When dispersedly coated on a structure, each particle acts as a sensitive mechanical sensor, while the 2-dimentional emission pattern of the whole assembly reflects well the dynamical stress distribution inside the structure and mechanical information around crack and defect. This stress visualization technique provides a novel way of diagnosing the structural health, far more advantageous over the conventional point-by-point measurement method. Thus, we have applied the remarkable strong points of ML sensing technique to a bridge in use as a real social structure for the first time.

As the first ML monitoring test at bridge, we selected a relatively old bridge (established in 1954, 3-span continuous T-type RC bridge, length 24.4 m, width: 7.89 m). The ML sheet type sensors were put around the central area (700×400 mm) of the main girder, and ML images originated from load application via general traffic vehicles had recorded by using CCD under roughly dark condition.

As the result, we successfully detected intense ML patterns not only along visible crack but also at round normal part on the girder at a glance. In the view of characteristics of the ML sensor, however, it is quite natural to conclude the ML pattern as the existence of displacement or strain, and as the result of discussion with experts in maintenance field, we concluded the existence of invisible micro-crack.

8348-86, Session 12

Predictive simulation of nonlinear ultrasonics

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Structural health monitoring during the early stage of degradation and fracture is important for detecting micro cracks that may exist. Conventional linear elastic ultrasonic techniques are sensitive to gross defects but less sensitive to micro cracks. The nonlinear ultrasonic technique, which uses the nonlinear ultrasonic characteristics with distinctive higher harmonics or sub harmonics, proves itself as a promising approach to detect micro cracks.

Most of the nonlinear ultrasonic studies todate have been experimental, but few theoretical predictive studies exist. In this paper, predictive simulation of nonlinear ultrasonics is investigated analytically and with finite element simulation. A pitch-catch method is used to interrogate a beam with a “breathing crack”, which opens and closes under stretching and compression. Piezoelectric wafer active sensors used as the transmitter and receiver are modeled with coupled field elements. The “breathing crack” is simulated (a) analytically through a nonlinear stiffness model; and (b) by finite element simulation via (b1) “element birth and death” and (b2) contact elements. The acoustic wave generated by the transmitter propagates into the structure, interacting with the “breathing crack”, acquiring nonlinear features and is picked up by the receiver. For cases where waves are not strong enough to open and close the crack, an additional vibration excitation is introduced to achieve the nonlinear effect with ultrasonic wave propagating along the structure. The receiving signal is processed to show the nonlinear characteristics indicating the presence and severity of the damage. The paper finishes with summary, conclusions, and suggestions for future work.

8348-87, Session 12

Identification of nonlinearities for damage inspection of thin-walled structures

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Structures have inherent nonlinearities, damage introduces extra nonlinearities, and aging aggravates nonlinearities. Hence, nonlinearity identification is the major task in dynamics-based damage inspection, health monitoring, and control of structures, and industries, DOD agencies, and NASA centers are eager for advanced nonlinearity identification techniques. Unfortunately, nonlinearity identification is a challenging reverse engineering problem, nonlinear vibrations are often non-stationary, and popular frequency-domain methods for linear system identification cannot work for nonlinear systems. Hence, advanced time-frequency signal processing techniques and nonlinear dynamics characterization and identification methods need to be developed.

This paper is to use recent discoveries about time-varying characteristics of amplitudes and frequencies of nonlinear dynamical systems to further develop and experimentally validate a newly derived time-frequency analysis method for nonlinearity identification, damage detection, and health monitoring of advanced structural systems. We recently discovered that time-varying amplitudes and frequencies of vibrations can be used for accurate parametric and non-parametric identification of nonlinear dynamical systems, and we derived a time-frequency analysis method based on the empirical mode decomposition (EMD) and a time-domain-only conjugate-pair decomposition (CPD) method. Available results show that this time-frequency analysis method is more accurate and versatile than the Hilbert-Huang transform (HHT) for extracting time-varying frequencies and amplitudes of nonlinear non-stationary signals. In this paper we further develop and integrate the new discoveries about nonlinear vibration characteristics with the new time-frequency signal processing method. The accuracy of EMD is improved by developing signal conditioning techniques and pre- and post-processing methods. A pre-processing method based on curve-fitting for removing a signal’s moving average before EMD is developed, and CPD is improved for post-processing. A three-point version of CPD can be used for online frequency tracking without the edge effect that destroys HHT’s accuracy. Parametric identification techniques are developed based on characteristics of time-varying frequencies and amplitudes of different nonlinear systems. Second- and higher-order perturbation solutions of nonlinear systems subject to harmonic excitations are used to derive amplitude and frequency modulation characteristics of different nonlinear systems. Non-parametric identification techniques are developed by using maximum-displacement states and maximum-velocity states to extract spring and damping forces, respectively. The derived nonlinearity identification and damage detection techniques are experimentally verified on beams and plates with nonlinearities/cracks.

8348-88, Session 12

Sensor location analysis for nonlinear acoustics based damage detection in composite structures

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This paper investigates the piezo-based nonlinear vibro-acoustic modulation technique for impact damage detection in composite structures. The method is based on combined low-frequency modal excitation and high-frequency ultrasonic excitation that lead to vibro-acoustic modulations in damaged specimens. The work presented focuses on sensor location analysis. Low-profile, surface bonded piezoceramic transducers are used for ultrasonic and modal excitation.. Modulated responses are acquired using laser vibrometry. Various areas of monitored composite structures are investigated to establish positions exhibiting the largest intensities of vibro-acoustic modulations resulting from impact damage. The study demonstrates that sensor location in composite structures is important for efficient damage detection.

8348-89, Session 13

Dynamic fiber Bragg grating strain sensing with wavelength-locked tunable fiber ring laser

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The interrogation systems based on fiber-optic sensors are very attractive for practical applications in structural health monitoring (SHM) owing to a number of advantages of optical fiber elements over their electronic counterparts. Among the fiber-optic sensors, the fiber Bragg gratings (FBGs) have their own unique features to be widely used for detection of acoustic emission (AE) to predict the early failure in civil infrastructures. We have developed a dynamic strain sensing system for AE detection by using a tunable single longitudinal mode Erbium-doped fiber (EDF) ring laser to be locked to the middle-reflection wavelength of the FBG as a demodulation technique. A proportional-integral-derivative (PID) device continuously controls the laser wavelength that is kept at the FBG middle-reflection wavelength, thus stabilizing the operating point against quasi-static perturbation with low frequency, while the high frequency dynamic strain shifts the FBG reflection profile. The reflected power varies in proportion to the applied strain which can be derived directly from AC photocurrent of the reflected signal. We demonstrate a four-channel demodulator system for simultaneous high frequency dynamic strain sensing.

8348-90, Session 13

Dynamic characteristics of a wind turbine blade using 3D digital image correlation

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As a result of continued industrial development and population expansion, global demands for sustainable energy have steadily increased. Wind energy is known as a promising source of clean and renewable energy that helps to offset greenhouse gas emissions. Wind turbines have grown significantly in size as the need for more consumable energy increases and it is suspected that these machines will continue to grow in the decades to come. However, as the size of these machines scales to meet energy demands, wind turbines are subjected to a combination of increased static and dynamic loading that has an impact on their performance, efficiency, and reliability. Qualifying and certifying blades is an important part of the design process to verify structural integrity as well as fatigue life. Because of the added complexity, increased loading, and shear size, the need to accurately quantify the integrity of blades is even more critical.

Wind turbines are subjected to aerodynamic loads that cause fatigue failures in blades. A detailed modal analysis leading to the extraction of natural frequencies and mode shapes helps to validate and update models, which can reduce the risk of failures due to vibrations. For years, modal analysis has been performed using accelerometers; however accelerometers are only capable of measurements at a limited number of discrete points. Moreover, accelerometers can suffer from mass loading effects and require a considerable amount of instrumentation when the number of sensors used is high. Photogrammetry and digital image correlation (DIC) has become an alternative to using traditional data acquisition systems. The ability to capture full-field measurements along with its non-contacting features has led to the growing use of DIC. Within this paper, DIC techniques are used to identify the mode shapes of a wind turbine blade. A wind turbine blade containing a handful of optical targets is excited at different frequencies using a shaker and the response is recorded using two PHOTRON high speed cameras. Time domain data is transferred to the frequency domain to extract mode shapes and natural frequencies. A finite element model of the blade is also used to compare the mode shapes. Furthermore, an impact modal test is done using accelerometers. A comparison of mode shapes from the photogrammetric, finite element, and impact test approaches are presented to show the accuracy of the DIC techniques.

8348-91, Session 13

In-situ acousto-ultrasonic monitoring of crack propagation in Al2024 alloy

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A data fusion technique implementing the principles of acoustic emission (AE), ultrasonic testing and digital image correlation (DIC) was employed to monitor real time crack propagation in a Al 2024 alloy compact tension (CT) specimen. The specimen was designed according to ASTM E647-08 and was pre-cracked under fatigue loading to ensure stable crack growth. Tensile loads were applied according to ASTM E1290-08 while simultaneously recording the AE activity and full-field surface strains using DIC. Additionally, ultrasonic pulses centered at three different frequencies were periodically generated. Upon post-analysis, waveform features sensitive to crack propagation were extracted and depicted visible trends as a function of estimated crack length providing a viable technique for online crack monitoring. Furthermore, real-time 2D source location and surface strain contour plots were computed during the experiment and demonstrated the evolution of both AE and mechanical activity. The DIC results confirmed the stable crack propagation during loading. This test constitutes a preliminary study that reveals the potential of the proposed data fusion technique in structural health monitoring.

8348-92, Session 13

Metal detector using a polymeric fiberoptic magnetostriction sensor

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Metal detector systems are widely using in current daily life. Nowadays, metal detectors operate on three basic technologies: very low frequency (VLF), pulse induction (PI), and beat-frequency oscillation (BFO). They are commonplace in libraries, airports, military camp, prisons, stores and shops. However, these devices share the common disadvantages of not being able to detect the profile of metal object and bulky in size. To overcomes these problems, we recently developed a compact metal detector capable of differentiate metal of different shapes and geometry using a fiber-optic magnetostriction sensor. This polymeric magnetostrictive metal detector system has many advantages, such as it is easy to fabricate and also resistant to RF interference (which is common in typical electromagnetic type metal detectors). The metal detector system utilizes a simple DC magnetic field detection scheme that integrated in magnetostriction material and interferometer to create the metal detection system. The basic concept of the metal detection is based on monitoring strain-induced optical path length change in the interferometer stems from the magnetic field induces magnetostriction effect on the ferromagnetic material which is coated on optic-fiber. The magnetostrictive device can produce polarized magnetic fields when applied magnetic field on the metal sensor, similarly generated from walk-through metal detectors system. Metal detection is made possible by disrupting the magnetic flux density present on the magnetostrictive sensor. In this paper, we will present our latest 3-D metal detection results. Several designs and their metal detection performance will be discussed and compared.

8348-93, Session 14

Sensor and measurement statistics in ultrasonic assessment of aerospace structures

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Recent developments in aerospace structures continue to emphasize the need for real-time condition assessment and structural health monitoring (SHM). To date, a variety of sensing approaches have been developed including SHM methods utilizing piezoelectric and magneto-elastic active sensors. Most popular methodologies consider wave propagation (pitch-catch or pulse-echo) and standing wave (vibration or impedance) techniques with damage detection capabilities dependant upon structural geometry, material characteristic, distance to damage and damage size/ orientation. In contrast to a broad spectrum of recent studies focusing on cumulative damage detection statistics and classification, this study explores the contribution of sensor parameters and their associated variability into the damage detection scheme. Piezoelectric and magneto-elastic active sensors (PWAS and MEAS) are considered for ultrasonic signal generation and reception. Response of the sensors is investigated under a variety of inputs to infer characteristic dependencies governing signal transmission and reception. Uncertainties inherent in popular SHM methodologies are explored and their contribution into overall statistics is studied. Examples of several damage detection experiments are presented. In particular, ultrasonic damage detection in aluminum structures is considered and magneto-mechanical impedance assessment is studied. The importance of sensor statistics is discussed and its contribution into the overall detection scheme is explored.

8348-94, Session 14

Semi Monte Carlo sampling approach for data normalization in statistical time-series-based damage identification

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Damage identification based on auto-regressive (AR) modeling of time series has become a popular research trend during the past decade. Damage-sensitive features extracted from this model are either AR coefficients or their residual errors which become inputs for numerous statistical classification algorithms such as statistical process control techniques or machine learning methods to identify damage. Amongst various pairs of such features and methods, the use of AR vectors and the classification model based on Mahalanobis squared distance (MSD) has been often found to be more successful. The merits of this couple are that the MSD-based model is rather simple and requires low computation efforts whilst AR parameters are highly sensitive to damage. Besides the high performance of this pair for detecting genuine damage, false-positive indications have still been reported in recent studies. One possible reason for this symptom is the insufficiency of the data normalization process, leading to erroneous estimation of the MSD-based model threshold. This paper first aims to investigate possible errors occurring when implementing the MSD algorithm and the corresponding causes. A so-called semi Monte Carlo sampling approach is then proposed based on the controlling of the covariance matrix of the training data. By improving the covariance matrix condition, this approach helps to increase accuracy of threshold computation and overcome false-positive damage identification. More precise thresholds can therefore be used for automated identification processes. The effectiveness of this approach is demonstrated via applications on standard data sets from the Los Alamos Nation Laboratory, USA.

8348-95, Session 14

Detection and monitoring of axial cracks on cylindrical structures using torsional wave generated by piezoelectric macro-fiber composite

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In cylindrical structures such as pipelines and pressure vessels, cracks are most likely to occur along the longitudinal (axial) direction and they can be fatal to the serviceability of the structures. Unfortunately, the conventional ultrasonic crack detection techniques, which usually use longitudinal wave, are not very sensitive to this type of cracks. This paper focuses on the detection and monitoring of axial cracks on cylindrical structures using torsional wave generated by piezoelectric macro-fiber composite (MFC). The first order torsional wave is a kind of non-dispersive pure shear wave which propagates at a fixed wave speed. The torsional wave is utilized in this work because, intuitively, it is more sensitive to the axial cracks than the family of longitudinal waves. Numerical simulation has been performed using ANSYS to show the effectiveness of torsional wave in detecting and monitoring axial cracks. The time of flight (TOF) of the waves is used to determine the crack position, while the crack propagation is monitored by measuring the variation in the crack induced disturbances.

Experiments are also conducted to investigate the feasibility of the proposed method. MFC transducers oriented at 45° against the axis of the specimen are used to generate and receive torsional waves. Mode separation techniques are used to separate the useful information of torsional wave pack from the acquired signals. The conformity among the experimental results, the numerical results as well as the theoretical results shows that the existence and propagation of the axial cracks in cylindrical structures can be well monitored with the presented approach using tortional wave.

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Adaptive lossless image compression of oil pipelines

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Structural health monitoring (SHM) means to give, a diagnosis of the “state” of the materials. Small leaks along entire lengths of pipelines are detected and located by monitoring. This paper is focused on visual and photographic observation system as leakage detection to monitor the long range pipeline. In this system some cameras with overlap view locate along entire lengths of pipelines. One of the important issues related to image processing is how to store and also transmit this information via wireless sensor network to the base station. Hence, we require using small storage and yet a lossless image compression scheme to transfer data to the base station.

As regards in digital oil pipeline images, there is a correlation between neighboring pixels. Therefore, it is obvious that some information in rows or column related to images is redundant. For removing this extra data we can use a lossless image compression with lesser complex method such as Differential Pulse Code Modulation (DPCM). DPCM is a simple and efficient method for transforming images in a manner for hardware implementation. Favored application in neural network lead to use this method in image compression, especially in our proposed method, adaptive lossless compression neural network as a prediction to find out the best coefficients of DPCM to predict in real-time the pixels from neighboring pixels of original image to minimize error between original image and its predictive image which is used for storage and transmission. As shown in the experimental results in this method it has a good improvement in characteristics of image compression such as entropy and Signal to Noise Ratio (SNR). The results represent that entropy of pipeline images has a significant decrement and also lossless image compression which is appropriate for SHM system