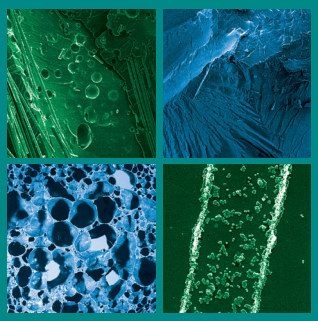


Smart Materials and Structures

Systems from nano- to macroscale

Highlights of 2009

IMPACT FACTOR
1.749*
*As listed in the 2009 ISI Journal Citation Reports®

Dear Colleague,

I am delighted to present a collection of abstracts from highlight articles published in 2009 in *Smart Materials and Structures* to showcase the exciting research we present across all areas of smart materials, structures and systems.

The articles were chosen based on their popularity with our readers, the editorial board and international press.

If you would like to find out more about *Smart Materials and Structures* and read the full text versions please go to **www.iopscience.org/sms**

Best wishes

Natasha Leeper
Publisher
Smart Materials and Structures

A feasibility study of self-heating concrete utilizing carbon nanofiber heating elements

Christiana Chang [1], Michelle Ho [2], Gangbing Song [1], Yi-Lung Mo [2] and Hui Li [3]

[1] Department of Mechanical Engineering, University of Houston (UH), Texas, N207 Engineering Building 1, Houston, TX 77204, USA
[2] Department of Civil Engineering, University of Houston, Texas, N207 Engineering Building 1, Houston, TX 77204, USA
[3] School of Civil Engineering, Harbin Institute of Technology (HIT), Harbin, People's Republic of China

Abstract

This paper presents the development of an electric, self-heating concrete system that uses embedded carbon nanofiber paper as electric resistance heating elements. The proposed system utilizes the conductive properties of carbon fiber materials to heat a surface overlay of concrete with various admixtures to improve the concrete's thermal conductivity. The development and laboratory scale testing of the system were conducted for the various compositions of concrete containing, separately, carbon fiber, fly ash, and steel shavings as admixtures. The heating performances of these concrete mixtures with the carbon fiber heating element were experimentally obtained in a sub-freezing ambient environment in order to explore the use of such a system for deicing of concrete roadways. Analysis of electric power consumption, heating rate, and obtainable concrete surface temperatures under typical power loads was performed to evaluate the viability of a large scale implementation of the proposed heating system for roadway deicing applications. A cost analysis is presented to provide a comparison with traditional deicing methods, such as salting, and other integrated concrete heating systems.

Christiana Chang *et al* 2009 *Smart Mater. Struct.* **18** 127001

Experimental study of a metal hydride driven braided artificial pneumatic muscle

Alexandra Vanderhoff and Kwang J Kim
Active Materials and Processing Laboratory, Mechanical Engineering Department, University of Nevada, Reno, Reno, NV 89557, USA

Abstract

This paper reports the experimental study of a new actuation system that couples a braided artificial pneumatic muscle (BAPM) with a metal hydride driven hydrogen compressor to create a compact, lightweight, noiseless system capable of high forces and smooth actuation. The results indicate that the metal hydride–BAPM system has relatively good second law efficiency average of 30% over the desorption cycle. The thermal efficiency is low, due mainly to the highly endothermic chemical reaction that releases the stored hydrogen gas from the metal hydride. The force to metal hydride weight is very high ($\sim$14 000 N_{Force}/kg_{MH}) considering that this system has not been optimized to use the minimum amount of metal hydride required for a full actuation stroke of the fluidic muscle. Also, a thermodynamic model for the complete system is developed. The analysis is restricted in some aspects concerning the complexity of the hydriding/dehydriding chemical process of the system and the three-dimensional geometry of the reactor, but it provides a useful comparison to other actuation devices and clearly reveals the parameters necessary for optimization of the actuation system in future work. The system shows comparable work output and has the benefits of biological muscle-like properties for potential use in robotic systems.

Alexandra Vanderhoff and Kwang J Kim 2009 *Smart Mater. Struct.* **18** 125014

A simple route to synthesize $ZnFe_2O_4$ hollow spheres and their magnetorheological characteristics

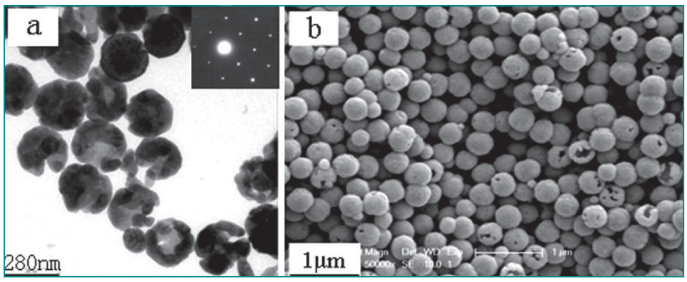
Wanquan Jiang [1], Zhen Cao [1], Rui Gu [2], Xingzhu Ye [2], Cuifeng Jiang [1] and Xinglong Gong [2]

[1] Department of Chemistry, USTC, Hefei 230026, People's Republic of China

[2] CAS Key Laboratory of Mechanical Behavior and Design of Materials, Department of Modern Mechanics, USTC, Hefei 230027, People's Republic of China

Abstract

In this paper, a simple route to synthesize hollow spheres of $ZnFe_2O_4$ without the assistance of a template is reported. The crystal structure and morphology of these particles were characterized by x-ray diffraction (XRD), transmission electron microscopy (TEM), and field emission scanning electron microscopy (FE-SEM). It was found that the final products were hollow spheres with perfect morphology, and their size and the thickness of their shells decreased with the increase of urea precursor. Ferromagnetism was observed from the magnetic hysteresis loops of the $ZnFe_2O_4$ hollow spheres at room temperature. The possible formation mechanism of the hollow spheres is discussed. In addition, $ZnFe_2O_4$ magnetorheological (MR) fluids were prepared and then their MR effect was investigated on a rotational rheometer equipped with a magnetic field generator.



TEM (left) and SEM (right) images of nanoparticles prepared with processed urea under the reaction time of 24 h, the inset is the ED of a hollow sphere.

Wanquan Jiang *et al* 2009 *Smart Mater. Struct.* **18** 125013

On thermoelectric and pyroelectric energy harvesting

Gael Sebald [1], Daniel Guyomar [1] and Amen Agbossou [2]

[1] Université de Lyon, INSA de Lyon, LGEF, 8 rue de la physique, 69621 Villeurbanne cedex, France

[2] Université de Savoie, LOCIE—CNRS FRE 3220, Campus scientifique—Savoie Technolac, 73376 Le Bourget du Lac Cedex, France

Abstract

This paper deals with small-power energy harvesting from heat. It can be achieved using both thermoelectric and pyroelectric effects. In the first case, temperature gradients are necessary. The main difficulty of thermoelectric energy harvesting is imposing a large temperature gradient. This requires huge heat flows because of the limited surface heat exchanges and the large heat conductivity of thermoelectric materials. This results in a drastic decrease of power and the efficiency of conversion. In case of pyroelectric energy harvesting, a time varying temperature is necessary. Although such a temperature time profile is hard to find, the overall optimization is easier than the thermoelectric strategy. Indeed, it depends much less on heat exchange between the sample and the outer medium, than on heat capacity that dimensions optimization may easily compensate. As a consequence, it is shown that the efficiency and output power may be much larger using pyroelectric energy harvesting than thermoelectric methods. For instance, using a limited temperature gradient due to the limited heat exchange, a maximum efficiency of 1.7% of Carnot efficiency can be expected using a thermoelectric module. On the contrary, a pyroelectric device may reach an efficiency up to 50% of Carnot efficiency. Finally, an illustration shows an estimation of the output power that could be expected from natural time variations of temperature of a wearable device. Power peaks up to 0.2 mW cm^{-3} were found and a mean power of 1 μW cm^{-3} on average was determined within 24 h testing.

Gael Sebald *et al* 2009 *Smart Mater. Struct.* **18** 125006

Design analysis of a piezoelectrically driven synthetic jet actuator

An-Shik Yang

Department of Energy and Refrigerating Air-Conditioning Engineering, National Taipei University of Technology, 1, Section 3, Chung-Hsiao E Road, Taipei 106, Taiwan, Republic of China

Abstract

Technological advancement is being realized by using piezoelectric synthetic jet actuators to generate managing forces and moments with zero-net-mass-flux oscillatory jets for various air flow control applications. This paper firstly explores the synthetic jet flow behavior for a dual-diaphragm piezoelectrically driven synthetic jet actuator. In the experimental study, a flow visualization system was utilized to acquire the particle streak images scattered from red fluorescent spheres for examining the synthetic jet flow. The centerline velocity of the jet was measured with a hot-wire anemometer. For exploring the formation progression of synthetic jets, the numerical analysis implemented unsteady three-dimensional conservation equations of mass and momentum with a standard k–ε two-equation turbulent model adopted for turbulence closure. The moving boundary was also treated to represent the motion of the piezo diaphragm under actuation. For a complete sinusoidal actuation cycle at an operating frequency of 648 Hz, the synthetic jet flow pattern was simulated and compared with the visualized image and measured centerline velocity distribution to validate the computer software. In general, the far-field flow structure was fairly similar to a common continuous turbulent air jet; whereas, the predicted time-recurring formation of a vortex pair was observed in the near field. The surrounding air close to the slot was also drawn into the cavity of the actuator when vortex pairs advected sufficiently downstream. Numerical experiments were then extended to assess the performance of synthetic jet actuators by systematically varying the driving voltage, relative phase delay of frequency, width of the slot and depth of the actuator cavity.

An-Shik Yang 2009 *Smart Mater. Struct.* **18** 125004

A novel multi-axis force sensor for microrobotics applications

R J Wood [1], K-J Cho [2] and K Hoffman [1]

[1] School of Engineering and Applied Sciences, Harvard University, USA

[2] School of Mechanical and Aerospace Engineering/IAMD, Seoul National University, Korea

Abstract

High performance force sensors often encounter the conflicting requirements of fine sensitivity and wide bandwidth. While there is an intrinsic tradeoff between these two metrics that cannot be physically avoided for any force transducer, through proper optimization the product of these two can be maximized. Similarly, the requirements of multiple sensing axes and overall compactness are also often at odds. This paper describes a novel design, simple method of fabrication, and thorough analysis of a high performance two-axis force sensor. We conclude with an example application: measuring the lift and drag forces from a flapping-wing robotic insect.

R J Wood *et al* 2009 *Smart Mater. Struct.* **18** 125002

Symmetry breaking, snap-through and pull-in instabilities under dynamic loading of microelectromechanical shallow arches

K Das and R C Batra
Department of Engineering Science and Mechanics, M/C 0219, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA

Abstract
Arch-shaped microelectromechanical systems (MEMS) have been used as mechanical memories, micro-relays, micro-valves, optical switches and digital micro-mirrors. A bi-stable structure, such as an arch, is characterized by a multivalued load deflection curve. Here we study the symmetry breaking, the snap-through instability and the pull-in instability of a bi-stable arch-shaped MEMS under static and dynamic electric loads. Unlike a mechanical load, the electric load is a nonlinear function of the a *priori* unknown deformed shape of the arch. The nonlinear partial differential equation governing transient deformations of the arch is solved numerically using the Galerkin method and a time integration scheme that adaptively adjusts the time step to compute the solution within the prescribed tolerance. For the static problem, the displacement control and the pseudo-arc-length continuation methods are used to obtain the bifurcation curve of the arch's displacement versus a load parameter. The displacement control method fails to compute the arch's asymmetric deformations that are found by the pseudo-arc-length continuation method. For the dynamic problem, two distinct mechanisms of the snap-through instability are found. It is shown that critical loads and geometric parameters for instabilities of an arch under an electric load with and without consideration of mechanical inertia effects are quite different. A phase diagram between a critical load parameter and the arch height is constructed to delineate different regions of instabilities. We compare results from the present model with those from a continuum mechanics based approach, and with results of other models and experiments available in the literature.

K Das and R C Batra 2009 *Smart Mater. Struct.* **18** 115008

Piezoelectric energy harvesting from broadband random vibrations

S Adhikari [1], M I Friswell [1] and D J Inman [2,3]
[1] School of Engineering, Swansea University, Singleton Park, Swansea SA2 8PP, UK
[2] CIMSS, Department of Mechanical Engineering, Virginia Tech, Blacksburg, VA 24061, USA
[3] University of Bristol, Bristol BS8 1TR, UK

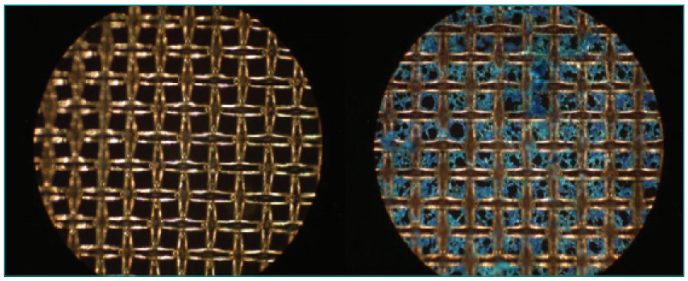
Abstract
Energy harvesting for the purpose of powering low power electronic sensor systems has received explosive attention in the last few years. Most works using deterministic approaches focusing on using the piezoelectric effect to harvest ambient vibration energy have concentrated on cantilever beams at resonance using harmonic excitation. Here, using a stochastic approach, we focus on using a stack configuration and harvesting broadband vibration energy, a more practically available ambient source. It is assumed that the ambient base excitation is stationary Gaussian white noise, which has a constant power-spectral density across the frequency range considered. The mean power acquired from a piezoelectric vibration-based energy harvester subjected to random base excitation is derived using the theory of random vibrations. Two cases, namely the harvesting circuit with and without an inductor, have been considered. Exact closed-form expressions involving non-dimensional parameters of the electromechanical system have been given and illustrated using numerical examples.

S Adhikari *et al* 2009 *Smart Mater. Struct.* **18** 115005

Bioinspired living skins for fouling mitigation

Rahul Ganguli [1], Vivek Mehrotra [1] and Bruce Dunn [2]
[1] Teledyne Scientific Company, 1049 Camino Dos Rios, Thousand Oaks, CA 91360, USA
[2] Department of Materials Science and Engineering, University of California, Los Angeles, CA 90095-1595, USA

Abstract
A biomimetic method to mitigate marine biofouling using a pilot-whale-inspired sacrificial skin concept has been developed. We developed a method to form conformal, protective skins in situ underwater using a circulatory system. In addition, the materials chemistry was tuned such that the skin dissolves after a tunable stable period, removing any foulants that may have collected on it. Skin formation, stability and dissolution have been studied by forming skins on 6 inch square flat substrates and curved surfaces. Several different materials and material combinations were tested for their skin-forming ability. Rheology studies were conducted to determine the changes in viscosity of the materials upon exposure to seawater. The materials' microstructure and composition were probed before and after seawater exposure. These experiments helped explain the mechanisms by which skin formation and dissolution occurs. Biofouling experiments consisted of culturing and growing the bacteria Pseudoalteromonas carrageenovora, a strain known to cause biofouling in marine environments. Efforts focused on determining experimental conditions necessary to achieve high levels of biofouling growth in the shortest amount of time. A large reduction in biofouling was demonstrated for surfaces protected by the sacrificial skin compared to identical unprotected surfaces, when high fouling pressure was generated using bacteria in artificial seawater.



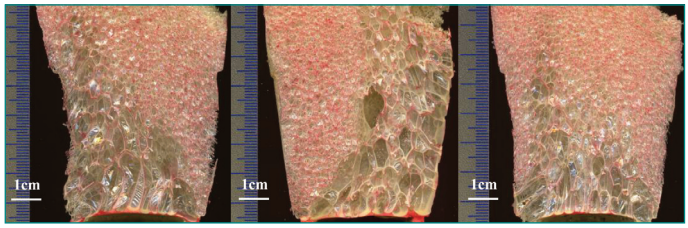
Diffuser protected with skin (left) showed significantly reduced accumulation of biofouling compared to the unprotected diffuser (right).

Rahul Ganguli *et al* 2009 *Smart Mater. Struct.* **18** 104027

Porosity tailoring mechanisms in sonicated polymeric foams

C Torres-Sanchez and J R Corney
Department of Design, Manufacture and Engineering Management, University of Strathclyde, James Weir Building, Glasgow G1 1XJ, UK

Abstract
Functionally graded cellular microstructures whose porosity (i.e. volume fraction of void to solid) is engineered to meet specific requirements are increasingly demanded by bio-engineers, who wish to exploit their synergistic mechanical, chemical and thermal properties. Because traditionally polymeric foams have been manufactured with *homogeneous* porosity, established processes cannot control the distribution of porosity throughout the resulting matrix. Motivated by the creation of a flexible process for engineering *heterogeneous* foams, this paper reports how the manufacture of polymeric foams with a variable porosity distribution can be achieved by ultrasound irradiation during the 'sensitive' stages of the polymerization reaction. This paper reports how for each of the five distinctive stages of polymerization (i.e. cream, rising, packing, gelation and solidification) the energy and mass balances were studied in order to determine the underlying mechanisms that ultrasound employs to affect the reaction. It was concluded that controlled ultrasonic irradiation affects convective mass transfer during foaming, especially during 'rising' and 'packing' stages, and enhances the diffusion of the blowing agent (i.e. $CO_2(g)$) from bubble to bubble in the 'packing' and 'gelation' stages. The mechanical work put into the system by ultrasound assists both the convection and diffusion by increasing the rate of mass flux. The paper concludes with some experimental results that support the above hypotheses.



Cross-section of foams sonicated at 20 kHz, same value of acoustic pressure but different positions in the acoustic field (irradiating probe was located on the left in the three cases).

C Torres-Sanchez and J R Corney 2009 *Smart Mater. Struct.* **18** 104001

A new magnetorheological fluid–elastomer mount: phenomenological modeling and experimental study

Xiaojie Wang and Faramarz Gordaninejad
Composite and Intelligent Materials Laboratory, Mechanical Engineering Department, University of Nevada, Reno, NV 89557, USA

Abstract
A new magnetorheological (MR) mount consisting of an MR fluid encapsulated in a polymeric solid is presented. The mechanical properties of the proposed mount are controllable through an externally applied magnetic field. The dynamic behavior of this system under various magnetic fields has been investigated by means of oscillatory compression cycles over a frequency range of 0.1–10 Hz for various deformations (less than 1 mm). The energy dissipation in the material is analyzed as related to strain amplitude, strain frequency and magnetic field strength. The field induced damping mechanism is discussed in terms of the damping exponent. A phenomenological model is presented to account for the dynamic behavior of the MR fluid–elastomer mount's vibration isolators under oscillatory compressive deformations. This model is a two-element system comprised of a variable friction damper and a nonlinear spring. The parameters of the model have been identified by a series of harmonic loading tests. The theoretical and experimental results are in excellent agreement. Both experimental and theoretical results have demonstrated that the proposed MR fluid–elastomer mounts show promise in applications where tuning vibration characteristics of a system are desired, such as altering natural frequencies, mode shapes, and damping properties.

Xiaojie Wang and Faramarz Gordaninejad 2009 *Smart Mater. Struct.* **18** 095045

A practical multilayered conducting polymer actuator with scalable work output

Kimiya Ikushima , Stephen John , Kazuo Yokoyama and Sachio Nagamitsu
Panasonic Corporation, 3-4 Hikaridai, Seika-cho, Soraku-gun, Kyoto 619-0237, Japan

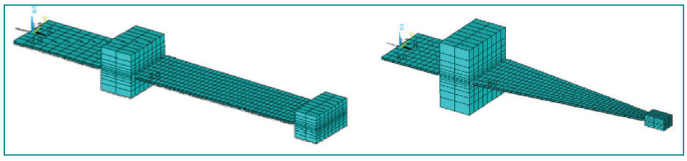
Abstract
Household assistance robots are expected to become more prominent in the future and will require inherently safe design. Conducting polymer-based artificial muscle actuators are one potential option for achieving this safety, as they are flexible, lightweight and can be driven using low input voltages, unlike electromagnetic motors; however, practical implementation also requires a scalable structure and stability in air. In this paper we propose and practically implement a multilayer conducting polymer actuator which could achieve these targets using polypyrrole film and ionic liquid-soaked separators. The practical work density of a nine-layer multilayer actuator was 1.4 kJ m^{-3} at 0.5 Hz, when the volumes of the electrolyte and counter electrodes were included, which approaches the performance of mammalian muscle. To achieve air stability, we analyzed the effect of air-stable ionic liquid gels on actuator displacement using finite element simulation and it was found that the majority of strain could be retained when the elastic modulus of the gel was kept below 3 kPa. As a result of this work, we have shown that multilayered conducting polymer actuators are a feasible idea for household robotics, as they provide a substantial practical work density in a compact structure and can be easily scaled as required.

Kimiya Ikushima *et al* 2009 *Smart Mater. Struct.* **18** 095022

Robust segment-type energy harvester and its application to a wireless sensor

Soobum Lee, Byeng D Youn and Byung C Jung
Department of Mechanical Engineering, University of Maryland, College Park, MD 20742, USA

Abstract
This paper presents an innovative design platform of a piezoelectric energy harvester (EH), called a segment-type EH, and its application to a wireless sensor. Energy harvesting technology is motivated to minimize battery replacement cost for wireless sensors, which aims at developing self-powered sensors by utilizing ambient energy sources. Vibration energy is one of the widely available ambient energy sources which can be converted into electrical energy using piezoelectric material. The current state-of-the-art in piezoelectric EH technology mainly utilizes a single natural frequency, which is less effective when utilizing a random ambient vibration with multi-modal frequencies. This research thus proposes a segment-type harvester to generate electric power efficiently which utilizes multiple modes by separating the piezoelectric material. In order to reflect the random nature of ambient vibration energy, a stochastic design optimization is solved to determine the optimal configuration in terms of energy efficiency and durability. A prototype is manufactured and mounted on a heating, ventilation, air conditioning (HVAC) system to operate a temperature wireless sensor. It shows its excellent performance to generate sufficient power for real-time temperature monitoring for building automation.



Initial (left) and optimal (right) design.

Soobum Lee *et al* 2009 *Smart Mater. Struct.* **18** 095021

A high speed magnetostrictive mirror deflector

R Angara , L Si and M Anjanappa
Department of Mechanical Engineering, University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA

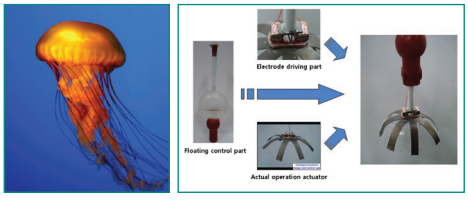
Abstract
This paper discusses the development of a high speed magnetostrictive mirror deflector that is compact, power efficient, and requires only low voltage for excitation. The magnetostrictive mirror deflector was designed and fabricated, and its performance tested. Three kinds of experiments were conducted to evaluate the performance, namely, identification of resonance frequencies, measurement of the angle of deflection, and study of the stability of the actuator under continuous use. The measurements were made using a high speed charge coupled device camera integrated with a PC using a custom made data acquisition and analysis program. The deflector was able to produce more than 6.1 mrad at 5.28 kHz with a minimal power of 0.8 W. Experiments conducted to test the repeatability of the measurements made have shown that the device is suitable for continuous duty operation. The results obtained in this study showed that the magnetostrictive mirror deflector is a good candidate for lidar and rapidly tunable laser system use.

R Angara *et al* 2009 *Smart Mater. Struct.* **18** 095015

A biomimetic jellyfish robot based on ionic polymer metal composite actuators

Sung-Weon Yeom and Il-Kwon Oh
School of Mechanical Systems Engineering, Chonnam National University, 300 Yongbong-dong, Buk-gu, Gwang-Ju 500-757, Republic of Korea

Abstract
A biomimetic jellyfish robot based on ionic polymer metal composite actuators was fabricated and activated to mimic real locomotive behavior with pulse and recovery processes. To imitate the curved shape of the jellyfish, a thermal treatment was applied to obtain a permanent initial deformation of a hemispherical form. The bio-inspired input signal was generated for mimicking real locomotion of the jellyfish. The vertical floating displacement and the thrust force of the biomimetic jellyfish robot under various input signals were measured and compared. The present results show that the bio-inspired electrical input signal with pulse-recovery process generates much higher floating velocity of the biomimetic jellyfish robot in comparison with pure sinusoidal excitations. The curved shape of the IPMC actuator through thermal treatments can be successfully applied to mimic the real biomimetic robots with smooth curves.



Real jellyfish (left). Components of jellyfish robot (right).

Sung-Weon Yeom and Il-Kwon Oh 2009 *Smart Mater. Struct.* **18** 085002

A carbon nanotube/cement composite with piezoresistive properties

Xun Yu [1] and Eil Kwon [2]
[1] Department of Mechanical and Industrial Engineering, University of Minnesota Duluth, MN 55812, USA
[2] Department of Civil Engineering, University of Minnesota Duluth, MN 55812, USA

Abstract
This paper studies the piezoresistive property of the CNT/cement composite to explore its feasibility as an embedded stress sensor for civil structures such as roadways, levees and bridges. The experimental results show that the electrical resistance of the CNT/cement composite changes with the compressive stress level, indicating the potential of using the CNT/cement composite as a stress sensor for civil structures. The piezoresistive responses of the composite with different fabrication methods and CNT doping levels were also studied. It is found that dispersion-assistant surfactants could block the contacts among carbon nanotubes, thus impairing the piezoresistive response of the composite, while a higher CNT doping level could improve the sensitivity of the composite stress response.

Xun Yu and Eil Kwon 2009 *Smart Mater. Struct.* **18** 055010

Wireless impedance sensor nodes for functions of structural damage identification and sensor self-diagnosis

Seunghee Park [1], Hyun-Ho Shin [2] and Chung-Bang Yun [1]
[1] Department of Civil and Environmental Engineering, Sungkyunkwan University, 300 Cheoncheon-dong, Jangan-gu, Suwon, Gyeonggi-do 440-746, Korea
[2] Department of Civil and Environmental Engineering, KAIST, 373-1 Guseong-dong, Yuseong-gu, Daejeon 305-701, Korea

Abstract
Economic and reliable online health monitoring strategies are very essential for safe operation of civil, mechanical and aerospace structures. This study presents online structural health monitoring (SHM) techniques using wireless impedance sensor nodes equipped with both functions of structural damage identification and sensor self-diagnosis. The wireless impedance sensor node incorporating a miniaturized impedance measuring chip, a microcontroller and radio-frequency (RF) telemetry is equipped with the capabilities for temperature sensing, multiplexing of several sensors, and local data analysis. The feasibility of the sensor node for structural damage identification is firstly investigated through a series of experimental studies inspecting loosened bolt damage and cut damage cases. Additionally, a temperature effects-free sensor self-diagnosis algorithm is embedded into the sensor node and its feasibility is examined from the experiments monitoring the integrity of each piezoelectric sensor on a wireless sensor network.

Seunghee Park *et al* 2009 *Smart Mater. Struct.* **18** 055001

Health monitoring of reinforced concrete shear walls using smart aggregates

Shi Yan [1], Wei Sun [1,2], Gangbing Song [3], Haichang Gu [3], Lin-Sheng Huo [2], Bo Liu [1] and Yue-Guo Zhang [1]

[1] School of Civil and Hydraulic Engineering, Dalian University of Technology, Dalian Liaoning 116024, People's Republic of China

[2] School of Civil Engineering, Shenyang Jianzhu University, Shenyang Liaoning 110168, People's Republic of China

[3] Department of Mechanical Engineering, University of Houston, Houston, TX 77204, USA

Abstract

In this paper, a smart aggregate-based approach is proposed for the structural health monitoring of a concrete shear wall structure. The piezoceramic-based smart aggregates were distributed in predetermined locations prior to the casting of the concrete structure to form an active-sensing system for the health monitoring purpose. To evaluate the damage in different areas, the concrete shear wall was sectioned into sub-domains and a wavelet-packet-based damage index matrix is proposed to evaluate the health status in these sections. A cyclic loading procedure was applied to gradually fail the concrete shear wall and the proposed structural health monitoring approach was used to perform structural health monitoring during this loading procedure. The experimental results have shown that the proposed smart aggregate-based approach effectively evaluated the damage status in different areas and detected the precautionary point to predict the structural failure. The proposed approach has the potential to be applied to the structural health monitoring of large-scale concrete shear wall structures.

Shi Yan *et al* 2009 *Smart Mater. Struct.* **18** 047001

Capacitive Coulter counting: detection of metal wear particles in lubricant using a microfluidic device

Srinidhi Murali [1], Xingao Xia [2], Ashish V Jagtiani [1], Joan Carletta [2] and Jiang Zhe [1]

[1] Department of Mechanical Engineering, University of Akron, 302 Buchtel Common, Akron, OH 44325, USA

[2] Department of Electrical and Computer Engineering, University of Akron, 302 Buchtel Common, Akron, OH 44325, USA

Abstract

A microfluidic device based on the capacitance Coulter counting principle to detect metal debris particles in lubricant oil is presented. The device scans each individual metal debris particle as they pass through a microfluidic channel by monitoring the capacitance change. We first proved the feasibility of using the capacitance Coulter counting principle for detecting metal particles in a fluidic channel. Next, we tested the microfluidic device with aluminum abrasive particles ranging from 10 to 25 μm; the testing results show the microfluidic device is capable of detecting metal wear particles in low-conductive lubricant oil. The design concept demonstrated here can be extended to a device with multiple microchannels for rapid detection of metal wear particles in a large volume of lubricant oil.

Srinidhi Murali *et al* 2009 *Smart Mater. Struct.* **18** 037001

Active wing design with integrated flight control using piezoelectric macro fiber composites

Rolf Paradies [1,2] and Paolo Ciresa [1,3]

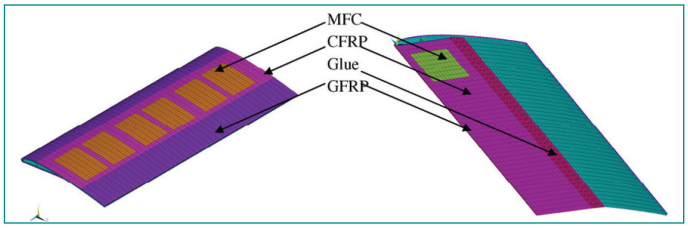
[1] Empa-Materials Science and Technology, Laboratory for Mechanical Systems Engineering, Überlandstrasse 129, CH-8600 Dübendorf, Switzerland

[2] Present address: Prose AG, Zürcherstrasse 41, CH-8400 Winterthur, Switzerland

[3] Present address: Bombardier Transportation AG, Engineering, Zürcherstrasse 39, CH-8401 Winterthur, Switzerland

Abstract

Piezoelectric macro fiber composites (MFCs) have been implemented as actuators into an active composite wing. The goal of the project was the design of a wing for an unmanned aerial vehicle (UAV) with a thin profile and integrated roll control with piezoelectric elements. The design and its optimization were based on a fully coupled structural fluid dynamics model that implemented constraints from available materials and manufacturing. A scaled prototype wing was manufactured. The design model was validated with static and preliminary dynamic tests of the prototype wing. The qualitative agreement between the numerical model and experiments was good. Dynamic tests were also performed on a sandwich wing of the same size with conventional aileron control for comparison. Even though the roll moment generated by the active wing was lower, it proved sufficient for the intended roll control of the UAV. The active wing with piezoelectric flight control constitutes one of the first examples where such a design has been optimized and the numerical model has been validated in experiments.



Finite element model of the active composite wing with six MFC patches on top and one MFC on the bottom surface. The colors indicate different material sections within the model.

Rolf Paradies and Paolo Ciresa 2009 *Smart Mater. Struct.* **18** 035010

Harvesting energy from the motion of human limbs: the design and analysis of an impact-based piezoelectric generator

Michael Renaud [1], Paolo Fiorini [1], Rob van Schaijk [2] and Chris van Hoof [1,3]

[1] Interuniversity Microelectronics Center (IMEC), Kapeldreef 75, 3001 Heverlee, Belgium

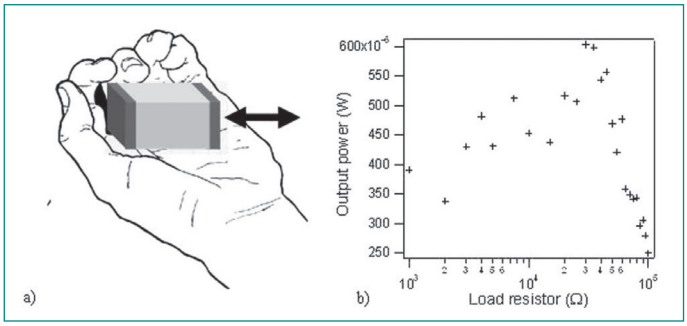
[2] Holst Centre, High Tech Campus 31, 5656 AE Eindhoven, The Netherlands

[3] Katholieke University Leuven (KUL), 3000 Leuven, Belgium

Abstract

Vibration energy harvesters can replace batteries and serve as clean and renewable energy sources in low-consumption wireless applications. Harvesters delivering sufficient power for sensors operating in an industrial environment have been developed, but difficulties are encountered when the devices to be powered are located on the human body. In this case, classical harvester designs (resonant systems) are not adapted to the low-frequency and high-amplitude characteristics of the motion. For this reason, we propose in this paper an alternative design based on the impact of a moving mass on piezoelectric bending structures. A model of the system is presented and analysed in order to determine the parameters influencing the device performances in terms of energy harvesting. A prototype of the impact harvester is experimentally characterized: for a generator occupying approximately 25

cm^3 and weighing 60 g, an output power of 47 μW was measured across a resistive load when the device was rotated by 180° each second. 600 μW were obtained for a 10 Hz frequency and 10 cm amplitude linear motion. Further optimization of the piezoelectric transducer is possible, allowing a large increase in these values, bringing the power density for the two cases respectively to 10 and 120 μW cm^{-3}.



(a) Illustration of the motion applied to the impact energy harvester. (b) Measured output power.

Michael Renaud *et al* 2009 *Smart Mater. Struct.* **18** 035001

An experimentally validated bimorph cantilever model for piezoelectric energy harvesting from base excitations

A Erturk [1] and D J Inman [2]

[1] Center for Intelligent Material Systems and Structures, Department of Engineering Science and Mechanics, Virginia Tech, Blacksburg, VA 24061, USA

[2] Center for Intelligent Material Systems and Structures, Department of Mechanical Engineering, Virginia Tech, Blacksburg, VA 24061, USA

Abstract

Piezoelectric transduction has received great attention for vibration-to-electric energy conversion over the last five years. A typical piezoelectric energy harvester is a unimorph or a bimorph cantilever located on a vibrating host structure, to generate electrical energy from base excitations. Several authors have investigated modeling of cantilevered piezoelectric energy harvesters under base excitation. The existing mathematical modeling approaches range from elementary single-degree-of-freedom models to approximate distributed parameter solutions in the sense of Rayleigh–Ritz discretization as well as analytical solution attempts with certain simplifications. Recently, the authors have presented the closed-form analytical solution for a unimorph cantilever under base excitation based on the Euler–Bernoulli beam assumptions. In this paper, the analytical solution is applied to bimorph cantilever configurations with series and parallel connections of piezoceramic layers. The base excitation is assumed to be translation in the transverse direction with a superimposed small rotation. The closed-form steady state response expressions are obtained for harmonic excitations at arbitrary frequencies, which are then reduced to simple but accurate single-mode expressions for modal excitations. The electromechanical frequency response functions (FRFs) that relate the voltage output and vibration response to translational and rotational base accelerations are identified from the multi-mode and single-mode solutions. Experimental validation of the single-mode coupled voltage output and vibration response expressions is presented for a bimorph cantilever with a tip mass. It is observed that the closed-form single-mode FRFs obtained from the analytical solution can successfully predict the coupled system dynamics for a wide range of electrical load resistance. The performance of the bimorph device is analyzed extensively for the short circuit and open circuit resonance frequency excitations and the accuracy of the model is shown in all cases.

A Erturk and D J Inman 2009 *Smart Mater. Struct.* **18** 025009

Conducting polymer actuator based on chemically deposited polypyrrole and polyurethane-based solid polymer electrolyte working in air

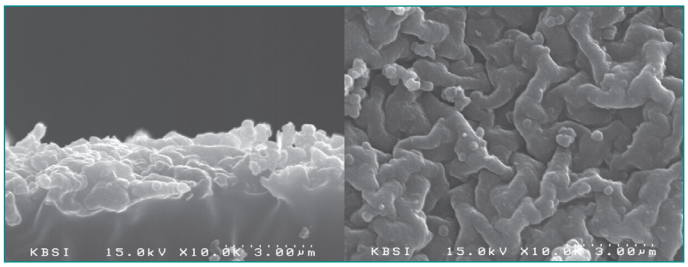
Hwa-Jeong Choi [1], Young-Min Song [1], Ildoo Chung [1], Kwang-Sun Ryu [2] and Nam-Ju Jo [1]

[1] Department of Polymer Science and Engineering, Pusan National University, Jangjeon-dong, Geumjeong-gu, Busan 609-735, Korea

[2] Department of Chemistry, University of Ulsan, Muger-Dong, Nam-gu, Ulsan 680-749, Korea

Abstract

Conducting polymers (CPs), such as polypyrrole, polythiophene, and polyaniline, are unique in that they have switchable properties due to their two or more mechanically stable oxidation states. Thus, their films or coatings can be easily switched by the application of a small voltage and current to change their volume during electrochemical redox processes. In particular, polypyrrole (PPy) has been studied most extensively because of its high electrical conductivity and good environmental stability under ambient conditions. In this work, we have studied a new CP actuator, fully polymeric, assembled with two PPy film electrodes and a solid polymer electrolyte (SPE), polyurethane/$Mg(ClO_4)_2$. Polyurethanes (PUs) were synthesized from 4,4'-diphenylmethane diisocyanate (MDI), 1,4-butanediol (1,4-BD) and three types of polyol: poly(ethylene glycol) (PEG), poly(propylene glycol) (PPG), and PPG-block-PEG-block-PPG (PPG-co-PEG). The chemical polymerization of PPy by immersion in Py monomer aqueous solution and oxidant aqueous solution is an adequate method to prepare PU/PPy composite film as an actuator. To find the proper thickness of the PPy coating layer for actuation, we measured the displacements of the actuators according to the thickness of the PPy coating layer. The displacement of all actuators is discussed in connection with the properties of the SPE and PPy. All the results obtained in this work show the feasibility of electrochemomechanical devices based on PPy and SPE film being able to work in air.



SEM image of the cross section (left); and the surface (right) of polypyrrole (PPy)

Hwa-Jeong Choi *et al* 2009 *Smart Mater. Struct.* **18** 024006