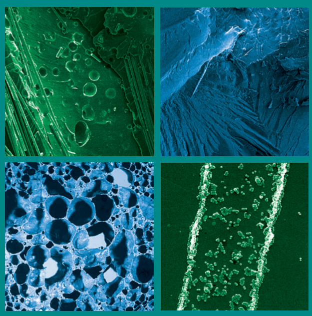

Smart Materials and Structures

Systems from nano- to macroscale

Highlights of 2010

Editor-in-Chief: Professor E Garcia, Cornell University, USA

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Best wishes

Natasha Leeper
Publisher
Smart Materials and Structures

Recent advances in the fabrication and adhesion testing of biomimetic dry adhesives

D Sameoto[1] and C Menon[2]

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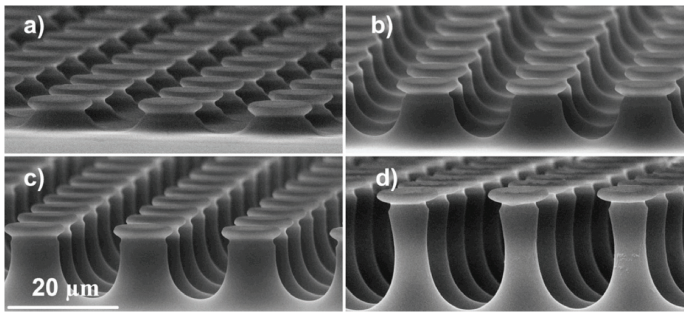
[2] MENRVA Group, School of Engineering Science, Simon Fraser University Burnaby, BC, V5A 1S6, Canada

Abstract
In the past two years, there have been a large number of publications on the topic of biomimetic dry adhesives from modeling, fabrication and testing perspectives. We review and compare the most recent advances in fabrication and testing of these materials. While there is increased convergence and consensus as to what makes a good dry adhesive, the fabrication of these materials is still challenging, particularly for anisotropic or hierarchal designs. Although qualitative comparisons between different adhesive designs can be made, quantifying the exact performance and rating each design is significantly hampered by the lack of standardized testing methods. Manufacturing dry adhesives, which can reliably adhere to rough surfaces, show directional and self-cleaning behavior and are relatively simple to manufacture, is still very challenging—great strides by multiple research groups have however made these goals appear achievable within the next few years.

2010 *Smart Mater. Struct.* **19** 103001



SEM images of ST-1060 polyurethane fibers cast from a negative silicone rubber mold produced by a commercial acrylic master mold. (a)–(c) are defined on a single mold with the same development time but with different exposure doses. (d) is formed with the same exposure dose as (c) but with an extra 50% development time.

A biologically inspired artificial fish using flexible matrix composite actuators: analysis and experiment

Zhiye Zhang[1], Michael Philen[2] and Wayne Neu[3]

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[3] Aerospace and Ocean Engineering, Virginia Polytechnic Institute and State University, 215B Randolph Hall, Blacksburg, VA 24061, USA

Abstract

A bio-inspired prototype fish using the flexible matrix composite (FMC) muscle technology for fin and body actuation is developed. FMC actuators are pressure driven muscle-like actuators capable of large displacements as well as large blocking forces. An analytical model of the artificial fish using FMC actuators is developed and analysis results are presented. An experimental prototype of the artificial fish having FMC artificial muscles has been completed and tested. Constant mean thrusts have been achieved in the laboratory for a stationary fish for different undulation frequencies around 1 Hz. The experimental results demonstrate that a nearly constant thrust can be achieved through tuning of excitation frequency for given body stiffness. Free swimming results show that the prototype can swim at approximately 0.3 m s^{-1}.

2010 *Smart Mater. Struct.* **19** 094017

A biologically inspired fish developed at Virginia Tech in collaboration with AVID, LLC. Names from left to right: Professor Wayne Neu (Virginia Tech), Richard Duelley (Virginia Tech), Professor Michael Philen (Virginia Tech), Etan Karni (AVID, LLC).

Open-loop position tracking control of a piezoceramic flexible beam using a dynamic hysteresis compensator

Phuong-Bac Nguyen and Seung-Bok Choi

Smart Structures and Systems Laboratory, Department of Mechanical Engineering, Inha University, Incheon 402-751, Korea

Abstract

This paper proposes a novel hysteresis compensator to enhance control accuracy in open-loop position tracking control of a piezoceramic flexible beam. The proposed hysteresis compensator consists of two components: a rate-independent hysteresis compensator and a nonlinear filter. The compensator is formulated based on the inverse Preisach model, while the weight coefficients of the filter are identified adaptively using a recursive least square (RLS) algorithm. In this work, two dynamic hysteresis compensators (or rate-independent hysteresis compensators) are developed by adopting two different nonlinear filters: Volterra and bilinear filters. In order to demonstrate the improved control accuracy of the proposed dynamic compensators, a flexible beam associated with the piezoceramic actuator is modeled using the finite element method (FEM) and Euler–Bernoulli beam theory. The beam model is then integrated with the proposed hysteresis model to achieve accurate position tracking control at the tip of the beam. An experimental investigation on the tip position tracking control is undertaken by realizing three different hysteresis compensators: a rate-independent hysteresis compensator, a rate-dependent hysteresis compensator with a Volterra nonlinear filter and a rate-independent hysteresis compensator with a bilinear nonlinear filter. It is shown that the proposed dynamic hysteresis compensators can provide much better tracking control accuracy than conventional rate-independent hysteresis compensators.

2010 *Smart Mater. Struct.* **19** 125008

Artificial muscles with adjustable stiffness

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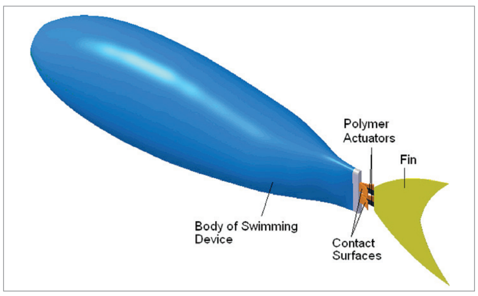
[2] ARC Centre of Excellence for Electromaterials Science, University of Wollongong, NSW 2522, Australia

Abstract

This paper reports on a stiffness enhancement methodology based on using a suitably designed contact surface with which cantilevered-type conducting polymer bending actuators are in contact during operation. The contact surface constrains the bending behaviour of the actuators. Depending on the topology of the contact surface, the resistance of the polymer actuators to deformation, i.e. stiffness, is varied. As opposed to their predecessors, these polymer actuators operate in air. Finite element analysis and modelling are used to quantify the effect of the contact surface on the effective stiffness of a trilayer cantilevered beam, which represents a one-end-free, the-other-end-fixed polypyrrole (PPy) conducting polymer actuator under a uniformly distributed load. After demonstrating the feasibility of the adjustable stiffness concept, experiments were conducted to determine the stiffness of bending-type conducting polymer actuators in contact with a range (20–40 mm in radius) of circular contact surfaces. The numerical and experimental results presented demonstrate that the stiffness of the actuators can be varied using a suitably profiled contact surface. The larger the radius of the contact surface is, the higher is the stiffness of the polymer actuators. The outcomes of this study suggest that, although the stiffness of the artificial muscles considered in this study is constant for a given geometric size, and electrical and chemical operation conditions, it can be changed in a nonlinear fashion to suit the stiffness requirement of a considered application. The stiffness enhancement methodology can be extended to other ionic-type conducting polymer actuators.

2010 *Smart Mater. Struct.* **19** 045004



Schematic representation of a suitably shaped contact surface for a swimming device propelled with a caudal fin.

Assessment of damage in composite laminates through dynamic, full-spectral interrogation of fiber Bragg grating sensors

A Propst[1], K Peters[1], M A Zikry[1], S Schultz[2], W Kunzler[2], Z Zhu[2], M Wirthlin[2] and R Selfridge[2]

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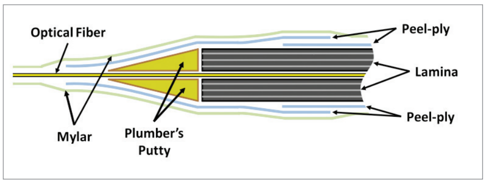
[2] Department of Electrical Engineering, Brigham Young University, 459 Clyde Building, Provo, UT, USA

Abstract

In this study, we demonstrate the full-spectral interrogation of a fiber Bragg grating (FBG) sensor at 535 Hz. The sensor is embedded in a woven, graphite fiber–epoxy composite laminate subjected to multiple low-velocity impacts. The measurement of unique, time dependent spectral features from the FBG sensor permits classification of the laminate lifetime into five regimes. These damage regimes compare well with previous analysis of the same material system using combined global and local FBG sensor information. Observed transient spectral features include peak splitting, wide spectral broadening and a strong single peak at the end of the impact event. Such features could not be measured through peak wavelength interrogation of the FBG sensor. Cross-correlation of the measured spectra with the original embedded FBG spectrum permitted rapid visualization of average strains and the presence of transverse compressive strain on the optical fiber, but smeared out the details of the spectral profile.

2010 *Smart Mater. Struct.* **19** 015016



Layup assembly of laminate with embedded optical fiber for vacuuming bagging and hot-press curing.

Structural shape reconstruction with consideration of the reliability of distributed strain data from a Brillouin-scattering-based optical fiber sensor

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[2] Fraunhofer Institute for Non-Destructive Testing, Maria-Reiche-Strasse 2, D-01109 Dresden, Germany

Abstract

In this paper, we constructed a shape reconstruction algorithm using a finite element (FE) model of the target structure, taking advantage of characteristics of the distributed strain data, which was acquired from a Brillouin-scattering-based optical fiber sensor. The remarkable point is that, using not only raw strain data but also information of the non-uniformity of strain distribution profiles, the algorithm appropriately considers the data reliability for accurate shape reconstructions. The constructed algorithm was applied to the reconstruction of the deflection of a composite laminate specimen, in which an optical fiber network was embedded. The results indicated that reconstruction accuracy was greatly improved by using weight values determined from the non-uniformity index of the strain distribution profile for each data point. Moreover, we demonstrated that the prior information of identification parameters, which were the node-displacements of the FE model, could be provided for accurate shape reconstructions of complex deformations using the non-uniformity index.

2010 *Smart Mater. Struct.* **19** 035011

Design and characterization of an electromagnetic energy harvester for vehicle suspensions

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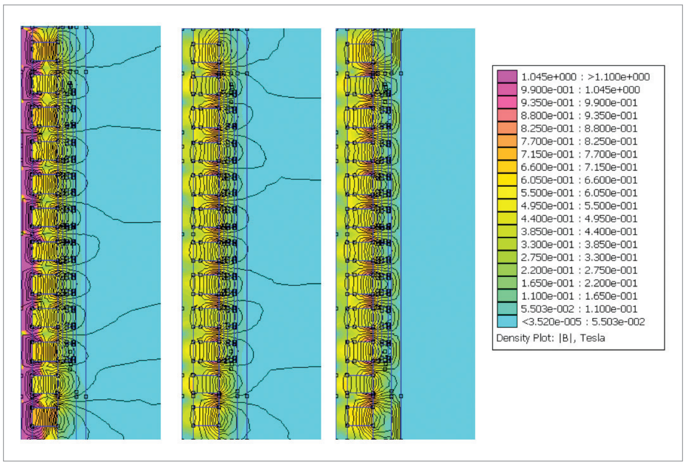
Abstract

During the everyday usage of an automobile, only 10–16% of the fuel energy is used to drive the car—to overcome the resistance from road friction and air drag. One important loss is the dissipation of vibration energy by shock absorbers in the vehicle suspension under the excitation of road irregularity and vehicle acceleration or deceleration. In this paper we design, characterize and test a retrofit regenerative shock absorber which can efficiently recover the vibration energy in a compact space. Rare-earth permanent magnets and high permeable magnetic loops are used to configure a four-phase linear generator with increased efficiency and reduced weight. The finite element method is used to analyze the magnetic field and guide the design optimization. A theoretical model is created to analytically characterize the waveforms and regenerated power of the harvester at various vibration amplitudes, frequencies, equilibrium positions and design parameters. It was found that the waveform and RMS voltage of the individual coils will depend on the equilibrium position but the total energy will not. Experimental studies of a 1:2 scale prototype are conducted and the results agree very well with the theoretical predictions. Such a regenerative shock absorber will be able to harvest 16–64 W power at 0.25–0.5 m s^{-1} RMS suspension velocity.

2010 *Smart Mater. Struct.* **19** 045003



The magnetic flux intensity of the original and improved designs calculated with the finite element method. Steel center rod and no outer cylinder (left), aluminum center rod and no outer cylinder (center), aluminum center rod and steel outer cylinder (right).

Wavelet-based blind identification of the UCLA Factor building using ambient and earthquake responses

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Abstract
Blind source separation using second-order blind identification (SOBI) has been successfully applied to the problem of output-only identification, popularly known as ambient system identification. In this paper, the basic principles of SOBI for the static mixtures case is extended using the stationary wavelet transform (SWT) in order to improve the separability of sources, thereby improving the quality of identification. Whereas SOBI operates on the covariance matrices constructed directly from measurements, the method presented in this paper, known as the wavelet-based modified cross-correlation method, operates on multiple covariance matrices constructed from the correlation of the responses. The SWT is selected because of its time-invariance property, which means that the transform of a time-shifted signal can be obtained as a shifted version of the transform of the original signal. This important property is exploited in the construction of several time-lagged covariance matrices. The issue of non-stationary sources is addressed through the formation of several time-shifted, windowed covariance matrices. Modal identification results are presented for the UCLA Factor building using ambient vibration data and for recorded responses from the Parkfield earthquake, and compared with published results for this building. Additionally, the effect of sensor density on the identification results is also investigated.

2010 *Smart Mater. Struct.* **19** 025005

A bio-inspired shape memory alloy composite (BISMAC) actuator

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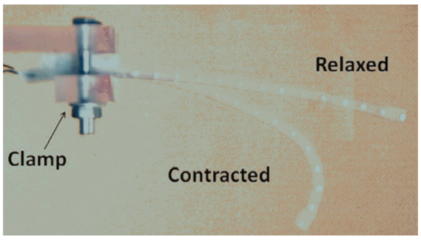
[2] Naval Undersea Warfare Center, Newport, RI 02481-1708, USA

Abstract
A beam-shape composite actuator using shape memory alloy (SMA) wires as the active component, termed a Bio-Inspired Shape Memory Alloy Composite (BISMAC), was designed to provide a large deformation profile. The BISMAC design was inspired by contraction of a jellyfish bell, utilizing the rowing mechanism for locomotion. Characterization of maximum deformation in underwater conditions was performed for different actuator configurations to analyze the effect of different design parameters, including silicone thickness, flexible steel thickness and distance between the SMA and flexible steel. A constant cross-section (CC)-BISMAC of length 16 cm was found to achieve deformation with a radius of curvature of 3.5 cm. Under equilibrium conditions, the CC-BISMAC was found to achieve 80% of maximum deformation, consuming 7.9 J/cycle driven at 16.2 V/0.98 A and a frequency of 0.25 Hz. A detailed analytical model was developed using the transfer matrix method and a 1D finite beam element (FE) model to simulate the behavior of the BISMAC incorporating gravity, buoyancy and SMA parameters. The FE and transfer matrix models had a maximum deformation error norm of 1.505 and 1.917 cm in comparison with experimentally observed beam deformation in the CC-BISMAC. The mean curvatures predicted by the FE and transfer matrix methods were 0.292 cm^{-1} and 0.295 cm^{-1} compared to a mean experimental curvature of 0.294 cm^{-1}, a percentage error of −5.4% and 2.77%, respectively. Using the developed analytical model, an actuator design was fabricated mimicking the maximum deformation profile of jellyfish of the species *Aurelia aurita* (AA). The designed AA-BISMAC achieved a maximum curvature of 0.428 cm^{-1} as compared to 0.438 cm^{-1} for *A. aurita* with an average square root error of 0.043 cm^{-1}, 10.2% of maximum *A. aurita* curvature.

2010 *Smart Mater. Struct.* **19** 025013



Picture of the AA-BISMAC in the relaxed and contracted configuration.

Guided wave structural health monitoring using CLoVER transducers in composite materials

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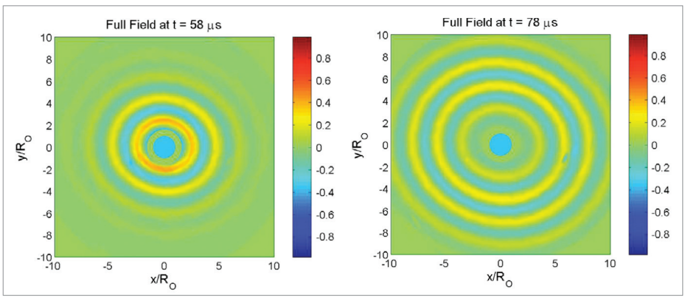
Abstract
The guided wave (GW) field excited by piezoelectric wafers and piezocomposite transducers in carbon-fiber composite materials is experimentally investigated with applications to structural health monitoring. This investigation supports the characterization of the composite long-range variable-length emitting radar (CLoVER) transducer introduced by the authors. A systematic approach is followed where composite configurations with different levels of anisotropy are analyzed. In particular, unidirectional, cross-ply $[0/90]_{3S}$ and quasi-isotropic $[0/45/-45/90]_{2S}$ IM7-based composite plates are employed. A combination of laser vibrometry and finite element analysis is used to determine the in-plane wave speed and peak-to-peak amplitude distribution in each substrate considered. The results illustrate the effect of the material anisotropy on GW propagation through the steering effect where the wavepackets do not generally travel along the direction in which they are launched. After characterizing the effect of substrate anisotropy on the GW field, the performance of the CLoVER transducer to detect damage in various composite configurations is explored. It is found that the directionality and geometry of the device is effective in detecting the presence and identifying the location of simulated defects in different composite layups.

2010 *Smart Mater. Struct.* **19** 015014



Full field visualization of guided wave excited by a circular piezoelectric wafer in a quasi-isotropic $[0/45/-45/90]_{2S}$ plate at 58 μs (left) and 78 μs (right) as measured using laser vibrometry; the fiber direction is parallel to the horizontal axis.

Multifunctional self-charging structures using piezoceramics and thin-film batteries

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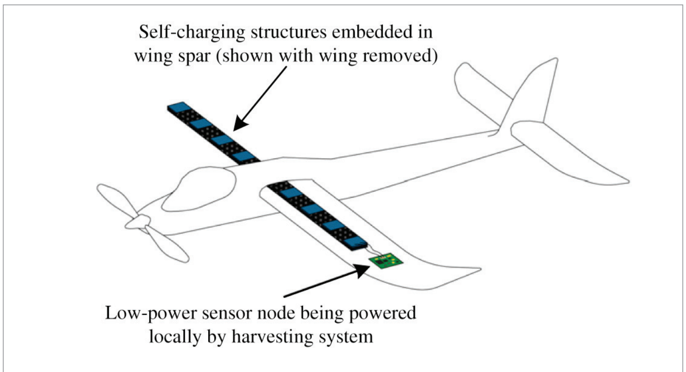
Abstract
Multifunctional material systems combine multiple functionalities in a single device in order to increase performance while limiting mass and volume. Conventional energy harvesting systems are designed to be added to a host structure in order to harvest ambient energy surrounding the system, but often cause undesirable mass loading effects and consume valuable space. Energy harvesting systems can benefit from the introduction of multifunctionality as a means of improving overall system efficiency. This paper presents the investigation of a novel multifunctional piezoelectric energy harvesting system consisting of energy generation, energy storage, and load bearing ability in a single device. The proposed self-charging structures contain piezoelectric layers for power generation, thin-film battery layers for energy storage, and a central metallic substrate layer, arranged in a bimorph configuration. Several aspects of the development and evaluation of the self-charging structure concept are reviewed. Details are provided on the fabrication of a piezoelectric self-charging structure. An electromechanical model is employed to predict the response of the harvester under harmonic base excitation. Experimentation is performed to confirm the ability of the device to simultaneously harvest and store electrical energy. Finally, both static and dynamic strength analyses are performed to determine the load bearing ability of the structure.

2010 *Smart Mater. Struct.* **19** 115021



Potential use of self-charging structures: schematic of small UAV with embedded self-charging structures in wing spar used to provide local power for low-power sensor node.

Multiscale modelling of a composite electroactive polymer structure

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[2] Danfoss PolyPower A/S, Nordborgvej 81, DK-6430 Nordborg, Denmark

Abstract
Danfoss PolyPower has developed a tubular actuator comprising a dielectric elastomer sheet with specially shaped compliant electrodes rolled into a tube. This paper is concerned with the modelling of this kind of tubular actuator. This is a challenging task due to the system's multiscale nature which is caused by the orders of magnitude difference between the length and thickness of the sheets as well as the thickness of the electrodes and the elastomer in the sheets. A further complication is the presence of passive parts at both ends of the actuator, i.e. areas without electrodes which are needed in order to avoid short circuits between negative and positively charged electrodes on the two sides of the sheet. Due to the complexities in shape and size it is necessary to introduce some simplifying assumptions. This paper presents a set of models where the three-dimensional problem has been reduced to two-dimensional problems, ensuring that the resulting models can be handled numerically within the framework of the finite element method. These models have been derived by expressing Navier's equation in elliptical cylindrical coordinates in order to take full advantage of the special shape of these actuators. Emphasis is placed on studying the passive parts of the actuator, as these degrade the effectiveness of the actuator. Two approaches are used here to model the passive parts: a spring-stiffness analogy model and a longitudinal section model of the actuator. The models have been compared with experimental results for the force–elongation characteristics of the commercially available PolyPower 'InLastor push' actuator. The comparison shows good agreement between model and experiments for the case where the passive parts were taken into account. One of the models developed is subsequently used to study geometric effects—specifically the effect of changing the ellipticity of the tubular actuator on the actuator's performance is investigated.

2010 *Smart Mater. Struct.* **19** 124008

A self-healing 3D woven fabric reinforced shape memory polymer composite for impact mitigation

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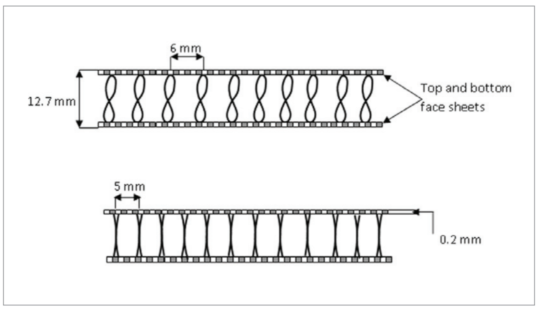
Abstract
In this paper, a three-dimensional (3D) woven fabric reinforced shape memory polymer composite for impact mitigation was proposed, fabricated, programmed using a three-step strain-controlled thermomechanical cycle at a pre-strain level of 5% and machined to two groups of specimens (G1 and G2) with dimensions 152.4 mm × 101.6 mm × 12.7 mm. The specimens were impact tested, transversely, centrally and repeatedly with 32 and 42 J of energy. G1 specimens were healed after each impact until perforation occurred. G2 specimens were not healed after each impact and served as controls. At 32 J impact energy, G2 specimens were perforated at the 9th impact while G1 specimens lasted until the 15th impact; at 42 J impact energy, G2 specimens were perforated at the 5th impact while G1 specimens were perforated at the 7th impact. Visual inspection, C-scan, and scanning electron microscopy techniques were used to evaluate damage, failure modes, and healing efficiency.

2010 *Smart Mater. Struct.* **19** 035007



A schematic of 3D woven fabric.

A mobile sensing system for structural health monitoring: design and validation

Dapeng Zhu[1], Xiaohua Yi[1], Yang Wang[1], Kok-Meng Lee[2] and Jiajie Guo[2]

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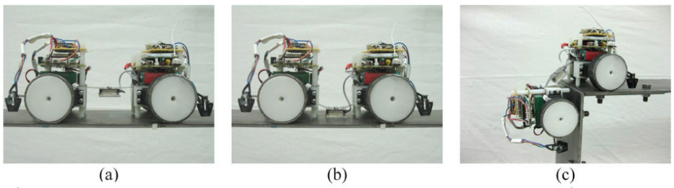
Abstract
This paper describes a new approach using mobile sensor networks for structural health monitoring. Compared with static sensors, mobile sensor networks offer flexible system architectures with adaptive spatial resolutions. The paper first describes the design of a mobile sensing node that is capable of maneuvering on structures built with ferromagnetic materials. The mobile sensing node can also attach/detach an accelerometer onto/from the structural surface. The performance of the prototype mobile sensor network has been validated through laboratory experiments. Two mobile sensing nodes are adopted for navigating on a steel portal frame and providing dense acceleration measurements. Transmissibility function analysis is conducted to identify structural damage using data collected by the mobile sensing nodes. This preliminary work is expected to spawn transformative changes in the use of mobile sensors for future structural health monitoring.

2010 *Smart Mater. Struct.* **19** 055011



Side view of the magnet-wheeled mobile sensing node: (a) sensor attachment; (b) sensor detachment; (c) transition over a right angle.

Improving the performance of a piezoelectric energy harvester using a variable thickness beam

Simon Paquin and Yves St-Amant

LSMI, Mechanical Engineering Department, Université Laval, Québec, QC, Canada

Abstract
In recent years, researchers have shown a growing interest in the possibility of harvesting mechanical energy from vibrating structures. A common way to proceed consists of using the direct piezoelectric effect of a bimorph cantilever beam with integrated piezoelectric elements. Several studies focused on the development of analytical models describing the electromechanical coupling. Historically, most of these models have been limited to simple structures such as a constant cross-section cantilever beam harvester. This paper studies the effect of a variable thickness beam harvester on its electromechanical performance. A semi-analytical mechanical model was developed using Rayleigh–Ritz approximations with a trigonometric functions set. The model was next validated by a finite element (FE) modeling. Numerical simulations were then performed for different beam slope angles in order to find the optimum for a given maximal strain across the piezoelectric elements. For the case under study, it is shown that tapered beams lead to a more uniform strain distribution across the piezoelectric material and increase the harvesting performance by a factor of 3.6.

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Tuning a resonant energy harvester using a generalized electrical load

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[1] Department of Aerospace Engineering, University of Bristol, Bristol BS8 1TR, UK

[2] Department of Engineering Mathematics, University of Bristol, Bristol BS8 1TR, UK

Abstract
A fundamental drawback of vibration-based energy harvesters is that they typically feature a resonant mass/spring mechanical system to amplify the small source vibrations; the limited bandwidth of the mechanical amplifier restricts the effectiveness of the energy harvester considerably. By extending the range of input frequencies over which a vibration energy harvester can generate useful power, e.g. through adaptive tuning, it is not only possible to open up a wider range of applications, such as those where the source frequency changes over time, but also possible to relax the requirements for precision manufacture or the need for mechanical adjustment *in situ*. In this paper, a vibration-based energy harvester connected to a generalized electrical load (containing both real and reactive impedance) is presented. It is demonstrated that the reactive component of the electrical load can be used to tune the harvester system to significantly increase the output power away from the resonant peak of the device. An analytical model of the system is developed, which includes non-ideal components arising from the physical implementation, and the results are confirmed by experiment. The −3 dB (half-power) bandwidth of the prototype energy harvester is shown to be over three times greater when presented with an optimized load impedance compared to that for the same harvester presented with an optimized resistive only load.

2010 *Smart Mater. Struct.* **19** 055003

Design of micro-scale highly expandable networks of polymer-based substrates for macro-scale applications

G Lanzara, J Feng and F-K Chang

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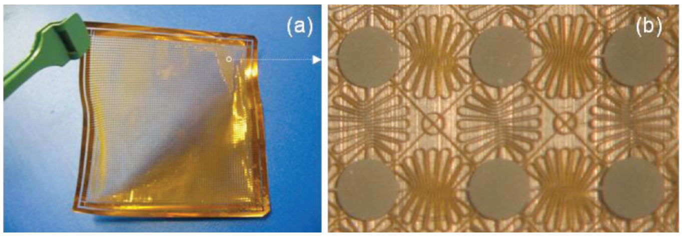
Abstract
An investigation was performed to design a network of nodes interconnected by conductive microwires in polymer-based substrates, which can be expanded to cover an area which is several orders of magnitude larger for macro-scale integration. The substrates can be potentially designed to host nano/micro-sensors/actuators and electronics to create a functional network for various applications. The major focus of the research is to develop a process to ensure that the network transition from a micro-scale fabrication to a macro-scale deployment is controllable, reliable and stable without failure. The key concept of the proposed design is to remove microscopically unnecessary materials from the substrate to create a network of infrastructures that can be stretched and expanded to a macro-scale size of several orders of magnitude. Material reduction is achieved by engineering a network of thousands of micronodes

interconnected by extendable microwires, which are the key element to perform uniform expansions of the network in all directions, to allow precise location of the nodes, to maximize the polymer expansion per unit area and to allow translation only of the nodes. The number of nodes, the bidimensional stretching ratio of the network and the material reduction are linked to the processable substrate size, to the final area coverage upon full expansion and to the in-plane area of the nodes and wires. In this paper we demonstrate that an expandable network with 200 μm diameter nodes and 4 μm wide wires is characterized by a 99.7% material reduction and a 25 600% bidimensional stretching ratio. A 5041 micronode network was built on a 100 mm diameter wafer and was expanded to a final area of 1 m^2 at low strain levels. The expanded node network is integrated into materials of different rigidities and is proven to resist under bending and twisting of the hosting material. The proposed flexible, expandable polymer design is a cost-effective approach that has the potential to build a bridge between the engineering of the nano/microscopic devices and their exploitation on the macroscopic scale. In particular, this approach can be used for wired or wireless sensor network applications as well as for the realization of innovative materials.

2010 *Smart Mater. Struct.* **19** 045013



5041 nodes reinforced sensor network. (a) Network on its Kapton side. (b) Optical microscope image of the network.

Magnetomechanical characterization and unified energy model for the quasistatic behavior of ferromagnetic shape memory Ni–Mn–Ga

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Abstract

This paper presents an overview of the characterization and modeling of single crystal ferromagnetic shape memory Ni–Mn–Ga. A continuum thermodynamics model is presented which describes the magnetomechanical characterization of single crystal Ni–Mn–Ga for the following behavior: (i) sensing effect; (ii) actuation effect; (iii) blocked force (stress generation). The thermodynamic potentials, namely the magnetic Gibbs energy and the Gibbs energy, are obtained from the Helmholtz energy in order to arrive at the set of required independent and dependent variables; the potentials include magnetic energy consisting of Zeeman, magnetostatic and anisotropy components, and mechanical energy consisting of elastic and twinning components. Mechanical dissipation and the microstructure of Ni–Mn–Ga are incorporated in the continuum model through the internal state variables volume fraction, domain fraction, and magnetization rotation angle. The constitutive response of the material is obtained by restricting the process through the second law of thermodynamics. The model requires only seven parameters identified from two simple experiments. Several interesting characteristics of Ni–Mn–Ga are examined in concert with the magnetomechanical characterization.

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Downscaling of proof mass electrodynamic actuators for decentralized velocity feedback control on a panel

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Abstract

This paper presents a simulation study on the downscaling of multiple electrodynamic proof mass actuators for the implementation of decentralized velocity feedback control loops on a thin panel. The system is conceived to reduce the panel response and sound radiation at low resonance frequencies. In the first part of the paper, the principal downscaling laws of a single proof mass actuator are revisited. In particular, the scaling laws are given for: (a) the fundamental natural frequency, (b) the damping factor, (c) the static displacement, (d) the maximum current that can be fed back to the actuator, (e) the maximum stroke of the proof mass and (f) the maximum control force that can be produced by the actuator. The second part of the paper presents a numerical study concerning the control performance produced by decentralized control systems with an increasing number of control units, which are scaled down in such a way as to keep the total base surface occupied by the actuators constant. This study shows that the control performance tends to rise as the number of control units is increased. However, this trend is reversed for large arrays of small scale actuators since the gain margin of the feedback loops tends to decrease with downscaling and incrementation of the actuators density.

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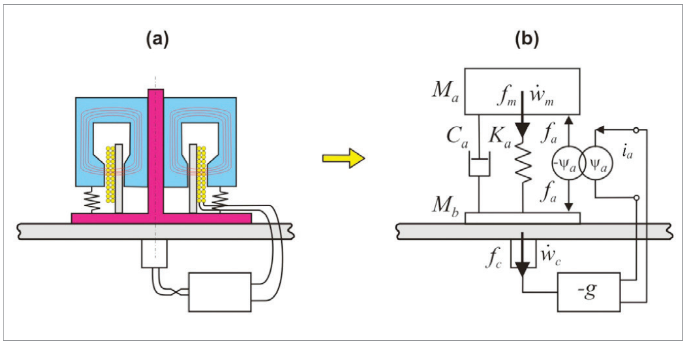

(a) Velocity feedback loop with the proof mass electrodynamic actuator. (b) Equivalent electrodynamic impedance/mobility schematic.

The magnetic coupling of a piezoelectric cantilever for enhanced energy harvesting efficiency

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Abstract
It is shown that the energy harvesting capabilities of a piezoelectric cantilever can be enhanced through coupling to a static magnetic field. A permanent magnet is fixed to the end of a piezoelectric cantilever, causing it to experience a non-linear force as it moves with respect to a stationary magnet. The magnetically coupled cantilever responds to vibration over a much broader frequency range than a standard cantilever, and exhibits non-periodic or chaotic motion. While the off-resonance response is substantially increased compared to that of a standard cantilever, no reduction in the response at the resonant frequency is observed, as long as a symmetric magnetic force is applied. The magnetically coupled cantilever motion is analyzed using a simple driven harmonic oscillator model with a non-linear magnetic force term. The results show that magnetic coupling can be used to increase the amount of power scavenged from environments containing multi-mode, or random vibration sources.

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Investigation of the durability of anisotropic magnetorheological elastomers based on mixed rubber

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Abstract
Magnetorheological elastomer (MREs)-based devices often operate at cyclic loading and high temperature conditions, which may cause fatigue and aging problems of MRE materials. This paper investigates the durability properties of MRE materials based on a mixed matrix: cis-polybutadiene rubber (BR) and natural rubber (NR). Six MREs samples were fabricated and their mechanical properties under cyclic loading with a constant strain amplitude of 50% and different aging temperatures were measured. The absolute MR effect, storage modulus (G') and loss modulus (G'') of MRE samples after cyclic loading and aging were evaluated by a modified dynamic mechanical analyzer (DMA). The results revealed that the MR effect, G' and G'' of all samples depended on the number of loading cycles, but samples which contained different ratios of two rubbers showed distinct properties. G' and G'' of all samples which contained only BR change little, but G' and G'' of samples which contained NR was large and decreased with the increment of the cycle number. Meanwhile, all their MR effects increased after cyclic loading. The results also revealed that the MR effect, G' and G'' of all samples were dependent on the time of aging at different aging temperatures. G' and G'' of all samples increased with the increment of aging time, but the properties of samples which contained more NR had better durability properties because their MR effect was higher and decreased more slowly than that of samples which contained more BR. The relationship between the durability properties, and cyclic loading and aging conditions were also analyzed.

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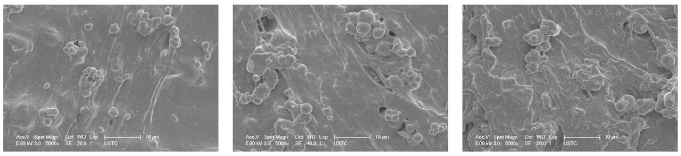

SEM images of the samples with different mass ratios of BR/NR. (left) 100:0, (center) 60:40 and (right) 0:100

Energy harvesting from base excitation of ionic polymer metal composites in fluid environments

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Abstract
In this paper, we analytically and experimentally study the energy harvesting capability of submerged ionic polymer metal composites (IPMCs). We consider base excitation of an IPMC strip that is shunted with an electric impedance and immersed in a fluid environment. We develop a modeling framework to predict the energy scavenged from the IPMC vibration as a function of the excitation frequency range, the constitutive and geometric properties of the IPMC, and the electric shunting load. The mechanical vibration of the IPMC strip is modeled through Kirchhoff–Love plate theory. The effect of the encompassing fluid on the IPMC vibration is described by using a linearized solution of the Navier–Stokes equations, that is traditionally considered in modeling atomic force microscope cantilevers. The dynamic chemo-electric response of the IPMC is described through the Poisson–Nernst–Planck model, in which the effect of mechanical deformations of the backbone polymer is accounted for. We present a closed-form solution for the current flowing through the IPMC strip as a function of the voltage across its electrodes and its deformation. We use modal analysis to establish a handleable expression for the power harvested from the vibrating IPMC and to optimize the shunting impedance for maximum energy harvesting. We validate theoretical findings through experiments conducted on IPMC strips vibrating in aqueous environments.

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