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The CEHMS Chronicle

Technical Article: Energy Harvesting from Large Vibrations of Tensegrity Membranes

Special points of interest:

- Next **Energy Summit/IAB meeting / INAMM Symposium** will take place in Dallas, Texas from January 28—30.
- CEHMS proudly announces the upcoming "Energy Harvesting and Systems" (EHS) Journal. The firs tissue will be released in January 2014.

Inside this issue:

Energy Harvesting from Large Vibrations of Tensegrity Membranes

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Structures have been traditionally designed assuming that vibrations under environmental loads (e.g. wind, water, seismic waves) are disadvantageous. The energy imparted to a structure by the environment was considered *detrimental* and such structures were designed to be *stiff* and *heavily damped*, as showed in Fig. 1, for fast and *maximal* energy dissipation. In this project we propose a paradigm shift by taking the opposite view, that the environmental energy could be *beneficial* and can be harvested using structures that

are extremely *flexible* and *lightly damped* as showed in Fig. 2. These structures can easily oscillate under the kinetic energy of the environment with *minimal* internal energy dissipation.

Our proposed solutions are lightweight structures capable of large deformations, composed of tensegrity and membranes (Fig. 3). The fundamental difference compared to other energy harvesting concepts is in the methodology of capturing energy from *large* amplitude vibrations using these structures. Most current kinetic energy absorbers focus on the exploitation of *small* amplitude, generally fast vibrations. As a consequence, the energy harvested is small and much useful energy is lost through internal damping. By exploiting large amplitude vibrations of the new structures the magnitude of the harvested energy is expected to increase substantially. Due to the intrinsic flexibility of tensegrity and membranes these structures easily exhibit large amplitude vibrations. They also present a continuous rather than discrete spectrum of natural frequencies that can be exploited for energy harvesting.

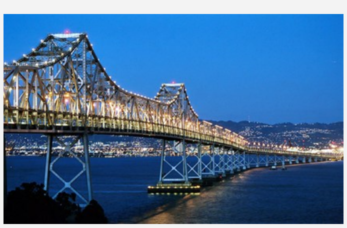

Fig. 1: Traditional structures—Heavily damped, stiff, static heavy

Fig. 2: Tensegrity structures—Lightly damped, flexible, dynamic, lightweight

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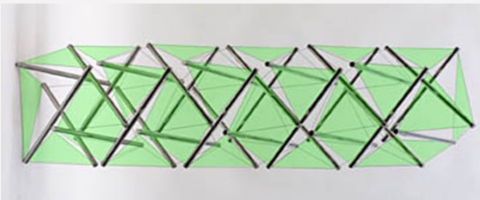

Fig. 3: A Tensegrity structure

The challenges associated with the analysis and design of such energy harvesting systems are numerous [1-3]. These challenges are dictated by a) the intrinsic *heterogeneity* of the entire system, which is composed of elements with very different characteristics (e.g. tensegrity structures, membranes, transducers), b) the desire to exploit *large* amplitude vibrations that require nonlinear modeling and analysis tools [4], and c) the necessity to estimate the electric current, which, at the minimum, calls for electro-mechanical modeling.

We initiated our studies in energy harvesting from tensegrity and membranes several years ago via a grant from ICTAS. Since then we have established a robust framework that can reliably be used to: a) model; b) analyze; c) optimally design tensegrity membranes for energy harvesting. Fig. 4 shows a prototype whose detailed analysis was recently presented in [5] and it is summarized next.

For the prototype depicted in Fig. 4 the feasibility of harvesting energy using Polyvinylidene Fluoride (PVDF) patches mounted on a vibrating prestressed membrane, itself attached to a tensegrity structure was investigated. Kinematics of the tensegrity structure and the attached membrane was analyzed and conditions for prestressed stable equilibrium derived. Nonlinear partial differential equations describing the dynamics of the structure under the action of a time dependent transverse pressure were derived using the principle of virtual work. These equations were next linearized and the modes of the structure obtained using the finite element method, implemented in Matlab. The first two modes obtained are shown in Figs. 5 to 6. The corresponding natural frequencies are 95.8 Hz, 124.69 Hz.

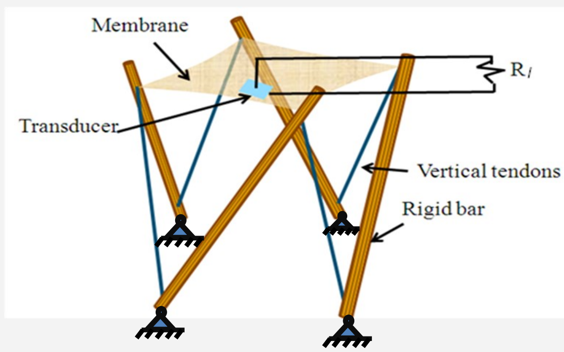

Fig. 4: Tensegrity membrane prototype for energy harvesting

The linearized modes were used as basis functions in a reduced -order model to obtain the response of the complete structure under the applied transverse dynamic pressure. The electrical current passing through the load resistance was calculated and the amount of energy available for harvesting was estimated. All analysis was implemented in Matlab and successfully validated using ABAQUS. Figure 7 shows a comparison between a Matlab based voltage estimation and the corresponding estimation from ABAQUS.

Lastly, several optimization problems were solved using genetic algorithm based optimization to maximize the harvested energy over various sets of optimization parameters, such as PVDF patch locations, tendon rest lengths, and rest dimensions of the membrane. Significant improvement in the energy that can be harvested (i.e. 10 times compared to the energy that corresponds to an initial guess in the design variables) was obtained when both discrete and continuous variables were used in the optimization process. This prompted the conclusion that, for further improvement, studies should focus on large scale discrete-continuous optimization in which the number of patches, their size and locations, as well as other structural parameters are involved as design variables.

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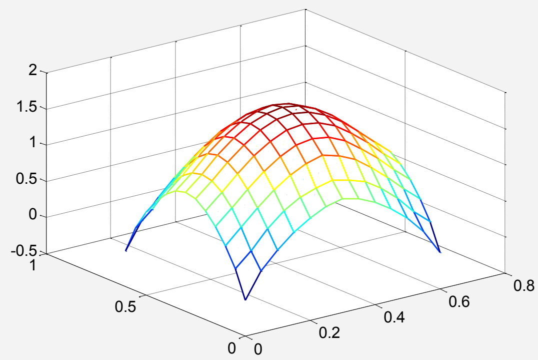

Fig. 5: **First mode of the prestressed membrane**

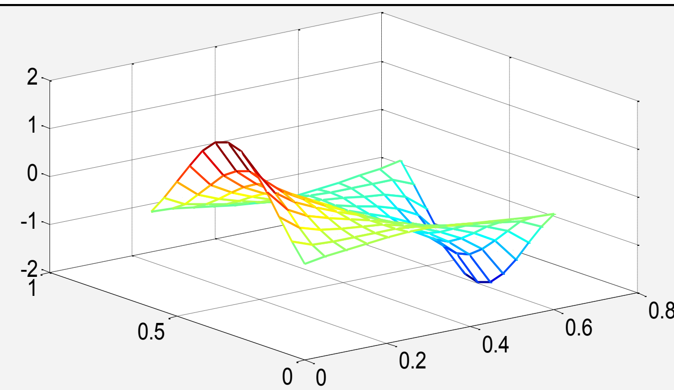

Fig. 6: **Second mode of the prestressed membrane**

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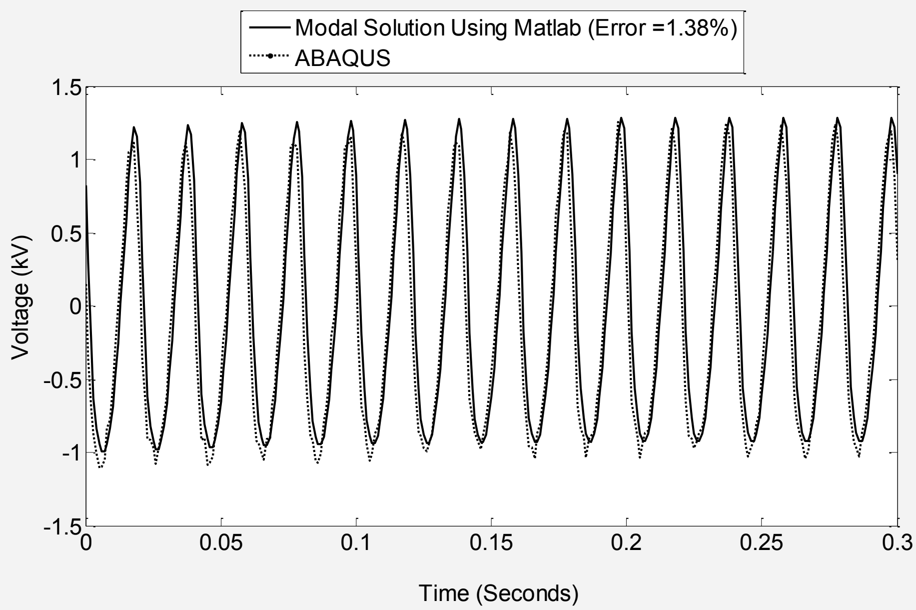

Fig. 7: Variation of voltage across the two ends of the patch

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International Relations: Indian Institute of Science Bangalore

Indian Institute of Science (IISc) is a prestigious public institution for scientific and technological research located in Bangalore. It was conceived as a "research institute" by Jamsetji Nusserwanji Tata (J N Tata) in 1909. The history of the Institute is a fascinating story. The accidental meeting between J N Tata and Swami Vivekananda during their voyage to the United States in 1893 laid the first step towards the initial conception of the Institute.

Tata, who was inspired by Swami Vivekananda's views on Science and Leadership abilities sought, his guidance in laying the foundation for the Institute. Vivekananda became enthusiastic about the project and Tata, with the aim of advancing the scientific abilities of the country, prepared a plan for setting up the institute for scientific research.

A draft proposal was submitted to Lord Curzon, the Viceroy of India by the provisional committee on December 31, 1898 for the establishment of the Institute. Sir William Ramsay, a Nobel Laureate, who was approached for selecting a suitable place for such an institute, suggested Bangalore as the best location.

Unfortunately, J N Tata died in 1904 unaware that his dreams would be realized a few years later. The British government finally signed the vesting order on May 27, 1909 to establish an unmatched research institution and IISc was born.

IISc occupies nearly 400 acres of prime land in Bangalore including some generously donated by H.H.Sir Krishnaraja Wodiyar IV, the Maharaja of Mysore (the princely state now called the state of Karnataka). Tata himself gave several buildings towards the creation of IISc. The Maharaja of Mysore laid the foundation stone of IISc on the July 24, 1911.

The name Indian Institute of Science was chosen as Tata did not wish his name to be associated with the Institute. His dream was to create an institution that contributes to the development of the country. But, visitors to Bangalore who seek out IISc ask local residents the directions to "Tata Institute" a clear recognition that remains in public memory despite the passage of a century.

IISc began with two departments: General and Applied Chemistry under Norman Rudolf and Electro technology under Alfred Hay. Within two months, the Department of Organic Chemistry opened.

Morris W Traver, the first director of IISc, began the construction of the Main building which is one of the landmarks in Bangalore today. Sir C V Raman established the Physics department and became the Institute's first Indian Director. Since its inception, IISc has grown to become India's premiere centre for research and postgraduate education. In 2009, the Institute celebrated a century of existence.

Many of India's most distinguished scientists have been associated with IISc; notable among them are G N Ramachandran, Harish Chandra, S Ramaseshan, A Ramachandran, C N R Rao and R Narasimha. Alumni of the Institute are at the head of many major organizations in India and abroad.

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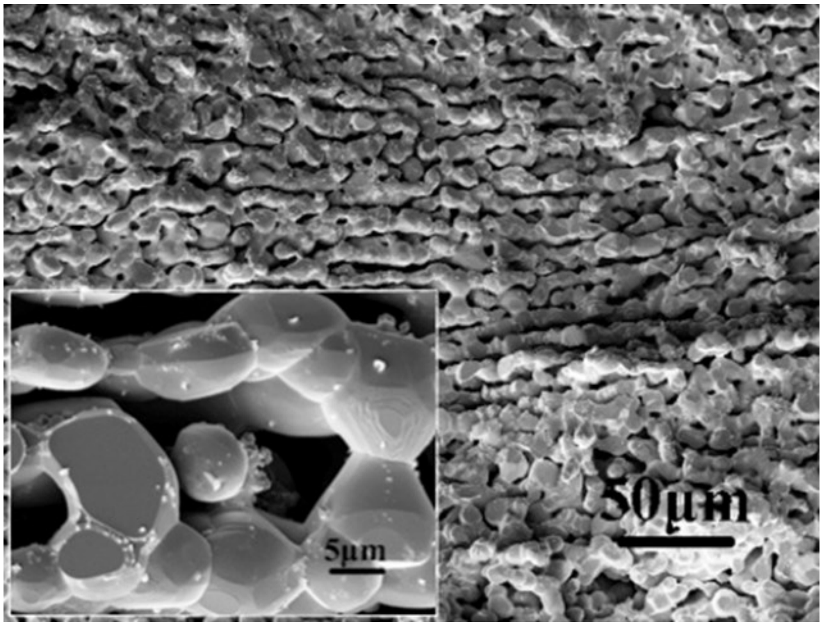
Laboratory Highlight: Nanoscale Energy Transport Laboratory

The Nanoscale Energy Transport Laboratory in the Center for Energy Harvesting Materials and Systems at Virginia Tech, under the direction of Professor Scott Huxtable, examines thermal transport in a variety of materials, structures, and devices and develops thermoelectric energy harvesting systems. On the fundamental side, we are interested in heat transport in nanostructured materials and through solid-solid and solid-liquid interfaces. For example, we use a time-domain thermoreflectance (TDTR) system to measure thermal transport in porous dielectric materials used in the semiconductor industry, bulk metallic glasses, nanostructured thermoelectric materials, superalloys, optoelectronic materials, nanoparticle suspensions, etc., and across solid-liquid interfaces where the solid has been modified with a variety of functional groups. We then translate this fundamental work into improving the performance of systems where thermal transport is critical (e.g. power electronics, thermal barrier coatings, thermoelectrics, etc.).



Nanostructured ZnO thermoelectric material grown by PhD candidate Yu Zhao. The layered structure reduces thermal conductivity and improves efficiency for thermoelectric energy harvesting.

On the device side, we design and fabricate thermoelectric systems for energy harvesting for a variety of applications ranging from powering small wireless sensors to converting waste heat in automobile exhaust into electrical power. We also work on developing thermoelectric heat flux sensors, and collaborate on the design, fabrication, and evaluation of gas and liquid heat exchangers. We are always interested in collaborating with industrial partners, so please feel free to contact Dr. Huxtable at huxtable@vt.edu.

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