

Energy Harvesting through Electromechanical Transducers

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Abstract

Energy is an essential component in every aspect of human life. Within the scientific and engineering communities energy serves a critical role in our ability to observe, measure, analyze and control various systems in our physical world. Recent advances in low-power wireless sensors, electronics and microelectromechanical systems have fostered an increasing need for highly developed mobile power systems. The standard approach for powering such mobile or remotely-based systems is the use of conventional batteries for energy storage. While this approach is suitable for many applications, there are limitations due to finite lifespan and the need to recharge or replace spent battery cartridges. One alternative to the exclusive use of batteries is energy harvesting, a process which would serve to extend the operational lifetime and overall robustness of mobile power systems. In this manner the energy harvester would extract ambient or unwanted energy from a system's surroundings; storing this energy in batteries, capacitors, or directly using it to power necessary hardware.

Project Outline

The overall objective of this research project will be to compare the energy harvesting capabilities of two electromechanical transducers: the piezoelectric polymer Polyvinylidene Fluoride (PVDF) and the ionically conductive ionic polymer transducer (IPT). We will discuss the fundamental mechanisms behind each material's transduction properties and how they give rise to the respective polymer's intrinsic ability to convert energy between electrical and mechanical domains. The first material to be examined will be the piezoelectric polymer PVDF. This material will serve as the introductory phase of the project due to the wealth of information available in present literature [1-4]. The second material under consideration will be the ionically conductive polymer Nafion™ which is commonly used in the ionic polymer transducer (also known as the ionic polymer-metal composite - IPMC).

During the first weeks of this project our primary focus will be on the PVDF transducer, gaining an understanding of its electromechanical properties and how the piezoelectric constitutive models can be used to predict available power. These models will be coupled with physical models of the material to simulate internal strain within the material, which will then be used to model the energy generation for a dynamic mechanical load. Once a fundamental theoretical understanding of the PVDF transducer has been obtained, students will move into the lab where a series of tests will be conducted to (1.) characterize the physical and electromechanical coupling properties of the transducer and (2.) evaluate the energy harvesting abilities of a sample PVDF transducer. Tests will focus on the axial loading of the PVDF membrane, as shown in the experimental setup of Figure 1.

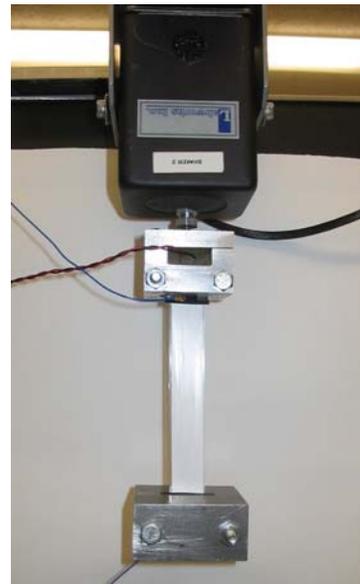


Figure 1: Experimental test fixture for axial loading of PVDF transducers.

The results of these tests will then be brought back into the analytical process to provide validation for the modeling approach.

As the students become comfortable with the modeling process for PVDF membranes, we will shift our focus toward the more compliant ionically conductive polymer. We will discuss the current modeling approaches discussed in literature, focusing the majority of our attention on the constitutive models of Newbury and Leo [5-6] which compare nicely to the commonly accepted models for piezoelectric materials. We will conduct a series of experimental studies to characterize the electromechanical properties of the ionic polymer transducer, incorporating these values into the modeling approach to predict the expected power levels from these materials under higher strains (1-5%). Following the theoretical development and material characterization, students will perform a series of experiments designed to quantify the energy harvesting abilities of the ionically conductive polymer. If time permits, we will investigate different circuit designs for storing the generated energy in super-capacitors and/or electrochemical batteries. Once the testing has been completed, students will begin compiling the accumulated data, tabulating the benefits and disadvantages of the piezoelectric and ionically conductive polymers for a vibration-based energy harvester.

Project Schedule

This project will focus on developing a comprehensive understanding of how ionically conductive materials can be used in harvesting electricity from ambient vibrations. This work will be conducted over an eight week period. The expected work is outlined in the following timeline.

Week 1:	Safety training and project introduction
Week 2:	Analytical study of piezoelectric polymer
Week 3:	Study the physical response of PVDF under axial loading
Week 4:	Shift modeling approach to ionic polymer transducers (IPTs)
Week 5:	Characterize electromechanical properties of IPT
Week 6:	Design and test harvesting circuitry for IPTs
Week 7:	Finish testing and begin preparing results
Week 8:	Present project findings

References/ Suggested Reading

1. Park, G., Farrar, C.R., Todd, M.D., Hodgkiss, W., Rosing, T., 2007, "Energy Harvesting for Structural Health Monitoring Sensor Networks," www.lanl.gov/projects/ei/pdf_files/LA-14314-MS.pdf
2. Sodano, H., Inman, D., Park, G., 2005, "Comparison of Piezoelectric Energy Harvesting Devices for Recharging Batteries." *JIMSS*, vol. 16, pp. 799-807.
3. Sodano, H., Park, G., Inman D.J., 2004, "A Review of Power Harvesting Using Piezoelectric Materials," *Shock and Vibration Digest*, vol. 36, no. 3, pp. 197-206.
4. Sodano, H., Granstrom, J., Feenstra, J., Farinholt, K., 2007, "Harvesting of Electrical Energy from a Backpack using Piezoelectric Shoulder Straps," *Proceedings of SPIE*, no. 6525-01.
5. Newbury, K., Leo, D. 2003 "Linear Electromechanical Model of Ionic Polymer transducers – Part I: Model Development," *JIMSS*, vol. 14, pp.333-342.
6. Newbury, K., Leo, D. 2003 "Linear Electromechanical Model of Ionic Polymer transducers – Part II: Experimental Validation," *JIMSS*, vol. 14, pp.343-357.

Equipment Requirements

PVDF and ionic polymer transducers will be needed for experimental studies. Basic breadboard components will be needed to assemble energy harvesting circuitry. An electromagnetic shaker will be needed to oscillate samples, and a suitable mass will be needed to provide loading. Tests will rely on a laser vibrometer or accelerometer to measure input motion and a standard Fourier analyzer to capture data.

Software Requirements

Standard mathematical software (MATLAB or Mathematica) will be required for simulations.