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Electrical Power Generation Using Piezoelectric Crystal

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Abstract- The usefulness of most high technology devices such as cell phones, computers, and sensors is limited by the storage capacity of batteries. In the future, these limitations will become more pronounced as the demand for wireless power outpaces battery development which is already nearly optimized. Thus, new power generation techniques are required for the next generation of wearable computers, wireless sensors, and autonomous systems to be feasible. Piezoelectric materials are excellent power generation devices because of their ability to couple mechanical and electrical properties. For example, when an electric field is applied to piezoelectric a strain is generated and the material is deformed. Consequently, when a piezoelectric is strained it produces an electric field; therefore, piezoelectric materials can convert ambient vibration into electrical power. Piezoelectric materials have long been used as sensors and actuators; however their use as electrical generators is less established. A piezoelectric power generator has great potential for some remote applications such as in vivo sensors, embedded MEMS devices, and distributed networking. Developing piezoelectric generators is challenging because of their poor source characteristics (high voltage, low current, high impedance) and relatively low power output. This paper presents a theoretical analysis to increase the piezoelectric power generation that is verified with experimental results.

Index Terms-Piezoelectric materials, piezoelectricity, power generation, PZT ceramics.

1 Introduction

Mechanical stresses applied to piezoelectric materials distort internal dipole moments and generate electrical potentials (voltages) in direct proportion to the applied forces. These same crystalline materials also lengthen or shorten in direct proportion to the magnitude and polarity of applied electric fields.

Because of these properties, these materials have long been used as sensors and actuators. One of the earliest practical applications of piezoelectric materials was the development of the first SONAR system in 1917 by Langevin who used quartz to transmit and receive ultrasonic waves [1]. In 1921, Cady first proposed the use of quartz to control the resonant frequency of oscillators. Today, piezoelectric sensors (e.g., force, pressure, acceleration) and actuators (e.g., ultrasonic, micro positioning) are widely available.

The same properties that make these materials useful for sensors can also be utilized to generate electricity. Such materials are capable of converting the mechanical energy of compression into electrical energy, but developing piezoelectric generators is challenging because of their poor source characteristics (high voltage, low current, high impedance). This is especially true at low frequencies and relatively low power output.

These challenges have limited the use of such generators primarily because the relatively small amount of available regulated electrical power has not been useful. The recent advent of extremely low power electrical and mechanical devices (e.g., micro electromechanical systems or MEMS) makes such generators attractive in several applications where remote power is required. Such applications are sometimes referred to as power scavenging and include *in vivo* sensors, embedded MEMS devices, and distributed networking.

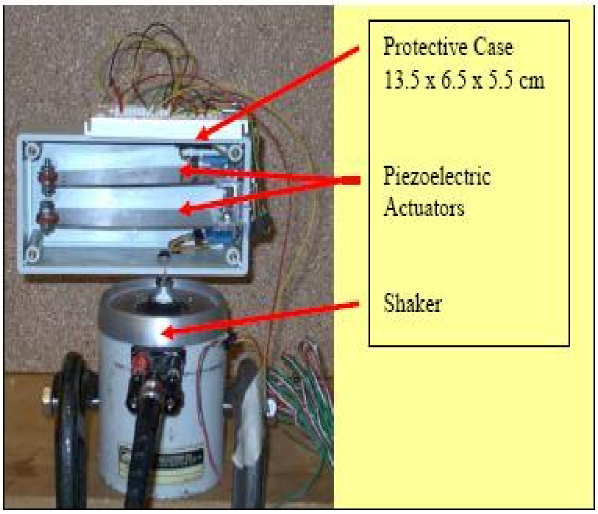
Several recent studies have investigated piezoelectric power generation. One study used lead zirconate titanate (PZT) wafers and flexible, multilayer polyvinylidene fluoride (PVDF) films inside shoes to convert mechanical walking energy into usable electrical energy [2], [3]. This system has been proposed for mobile computing and was ultimately able to provide continuously 1.3 mW at 3 V when walking at a rate of 0.8 Hz.

Other projects have used piezoelectric films to extract electrical energy from mechanical vibration in machines to power MEMS devices [4]. This work extracted a very small amount of power (<5uW) from the vibration and no attempt was made to condition or store the energy. Similar work has extracted slightly more energy (70uW) from machine and building vibrations [5].

Piezoelectric materials have also been studied to generate electricity from pressure variations in micro hydraulic systems [6]. The power would presumably be used for MEMS but this work is still in the conceptual phase. Other work has used piezoelectric materials to convert kinetic energy into a spark to detonate an explosive projectile on impact [7]. Still other work has proposed using flexible piezoelectric polymers for energy conversion in windmills [8], and to convert flowin oceans and rivers into electric power [9].A recent medical application has proposed the use of piezoelectric materials to generate electricity to promote bone growth [10]. This work uses an implanted bone prosthesis containing a piezoelectric generator configured to deliver electric current to specific locations around the implant. This device uses unregulated (high voltage) energy and it is not clear if the technique has advanced beyond the conceptual phase. The

above studies have all had some success in extracting electrical power from piezoelectric elements. However, many issues such as efficiency, conditioning and storage have not been fully addressed.
This paper presents the idea to increase the power generation by the piezoelectric. A few researchers have used single off the-shelf piezoelectric devices to harvest electrical power, yet little has been done to overcome the main weaknesses associated with piezoelectric power harvesting. This research seeks to systematically overcome the weaknesses associated with cantilever-mounted piezoelectric used for mobile power harvesting to maximize the power from a piezoelectric device the load impedance must match the impedance of device. This is problematic for frequencies between 10-100 Hz because a single piezoelectric may have impedance in the range of several hundred thousand ohms to ten million ohms. Thus, little current can be produced, and battery charging is diminished due to low current production. To reduce the impedance and increase electrical current, two off-the-shelf actuators (8 piezoelectric totals) are connected electrically in parallel and tuned to resonate in the frequency range of an ambient vibration similar to that produced by a person walking. A picture of the experimental setup may be seen in Figure 1.

Figure 1: The mobile power harvester attached to a shaker for experimental testing



To demonstrate the power harvesting advantage, 40 and 80 mAhr Nickel Metal Hydride batteries are recharged with each individual actuator then charged with both actuators connected in parallel. For a 1.4 Hz frequency (a brisk walking pace), the parallel combination charges two 40 mAhr batteries in 3.09 hours, and two 80 mAhr batteries in 5.64 hours. The individual actuators require 16.1 hours to charge a 40 mAhr battery, and 22.7 hours to charge an 80 mAhr battery. Clearly, the parallel combination of multiple off-the-shelf piezoelectric actuators increases battery charge times, and adding more parallel devices could increase power production so long as the total voltage exceeds the charged voltage of the battery. Since most production piezoelectric devices are designed as actuators, research is being conducted to optimize piezoelectric for power harvesting. Specifically, the locations of each piezoelectric on the cantilevered structure is being studied and designs that reduce electrical cancellation due to out of phase motions are ongoing.
On october 6, 2009 the Hefer intersection along the old coastal road of Route 4 in Israel was the place where a piezoelectric generator was put to the test and generated some 2,000 watt-hours of electricity. The setup consists of a ten-meter strip of asphalt, with generators lying underneath, and batteries in the road's proximity. Being the first practical test of the system, the researchers still expect energetic and feasibility results. Technion was helped by Innowattech, a company from Israel to finish the pilot project The project manager, Dr. Lucy Edery-Azulay, explained that the generators developed by Innowattech are embedded about five centimeters beneath the upper layer of asphalt. "The technology is based on piezoelectric materials that enable the conversion of mechanical energy exerted by the weight of passing vehicles into electrical energy. As far as the drivers are concerned, the road is the same," she says Edery-Azulay added that expanding the project to a length of one kilometer along a single lane would produce 200 KWh, while a four-lane highway could produce about a MWh sufficient electricity to provide for the average consumption in 2,500 households.

CONCLUSION

As the results shows that by using double actuators in parallel we can reduce the charging time of the battery and increase the power generated by the piezoelectric device.In second research where a piezoelectric generator was put to the test and generated some 2,000 watt-hours of electricity. The setup consists of a ten-meter strip of asphalt, with generators lying underneath, and batteries in the road's proximity. So that it is clear by using parallel combination we can overcome the problems like of impedance matching and low power generation. The results clearly show that piezoelectric materials are the future of electric power generation.

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