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POWER HARVESTING APPLICATION

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ABSTRACT

This work presents techniques of power harvesting of low voltage through the use of piezoelectric materials used in systems to absorb mechanical vibrations, converting this absorbed energy into electric energy destined to self powered systems, such as systems for structural health monitoring.

Keywords: harvesting, piezoelectricity, mechanical vibration.

INTRODUCTION

Due to the increase of the demand in relation to the mobility of electronic devices, the field research in relation to the alternative forms of low voltage power generation has increased in the last years. The use of batteries can not only increase the size and weight of MEMS (microelectromechanical systems) but also suffer from the limitations of a brief service life and the need for constant replacement, which is not acceptable or even possible for many practical applications (Shu and Lien, 2006); which may cause, many times, a infeasible cost due to maintenance of load of the electrochemical batteries. It has motivated many research efforts focused on harvesting electrical energy from various ambient sources through the use of electromechanical transducers. These include solar power, thermal gradients and vibration (Roundy, Steingart, Frechette, Wright and Rabaey, 2004). This technique is called Power Harvesting, where the problem concerning an effective power source was associated with the necessity of utilization of energy generated from the vibration energy drains when using piezoelectric ceramics converting mechanical vibration energy into electric energy.

Among the mechanisms used in Power Harvesting, stands out the one based on the conversion of mechanical energy of vibration into electrical energy through the piezoelectric effect.

ENERGY SOURCES

The types of existing energy sources can be divided into two groups: the sources of fixed energy density (eg batteries) and the sources of fixed power (power generation by the environment). The sources of fixed density have limitations on the amount of available energy, because after the available energy is exhausted, the source must be replaced or recharged. In another way, the sources of fixed power have the advantage of being free, besides, the conversion mechanisms are not polluting.

The sources of fixed power have a potentially infinite life cycle and are particularly useful in applications where power generation devices feed remote systems. There are those that provide good amount of energy, but are not very used in certain applications due to the amount of energy that must be generated to supply the load be greater than that delivered, being necessary to seek other sources, eg, the solar energy, which has the capability of providing power density of 15000 μW/cm^3, two orders of magnitude higher than other sources. However, solar energy is not an attractive source of energy for indoor environments

as the power density drops down to as low as 10-20 μW/cm^3. There for, a source more attractive would be mechanical vibration (300 μW/cm^3), which is abundant and accessible through MEMS to being converted into electric energy through piezoelectric, electromagnetic and capacitive transducers.

BASIC MECHANISM OF POWER HARVESTING

A piezoelectric energy harvester is often modeled as a mechanism composed by the following components:

mass + spring + damper + piezoelectric element

Furthermore, an energy storage system is connected to this mechanism. Fig. 1 shows schematically the complete arrangement.

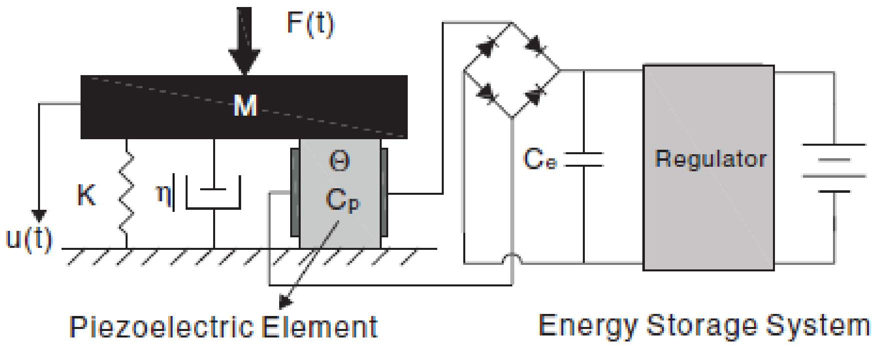

Fig. 1 - An equivalent model for a piezoelectric vibration energy harvesting system (Shu and Lien, 2006)

Vibration of a rigid body can be caused by several factors such as unbalanced mass in a system, tear and wear of materials and can occur in almost all dynamical systems. The characteristic behavior is unique to each system and can be simply described by two parameters: damping constant (ζ) and natural frequency (ω_n). Most commonly, a single degree of freedom lumped spring mass system is utilized to study the dynamic characteristics of a vibrating body associated with energy harvesting (Laura et al. 1974). The single degree of freedom helps to study unidirectional response of the system. Cantilever structure with tip mass is the most widely used configuration for piezoelectric energy harvesting device (Priya and Inman, 2009). Fig. 2 presents the scheme of this structure where, in (a), a cantilever with a tip mass is shown; in (b), multilayer piezoelectric plates fixed to the cantilever are presented (the source of vibration is shown with an arrow at the base of the contact point); and in (c), it's observed an equivalent lumped spring mass with external excitation as an representation of the dynamic characteristics of the mechanism. The stiffness of the structure depends on the loading condition, material, and cross-sectional area perpendicular to the direction of vibration (Priya and Inman, 2009).

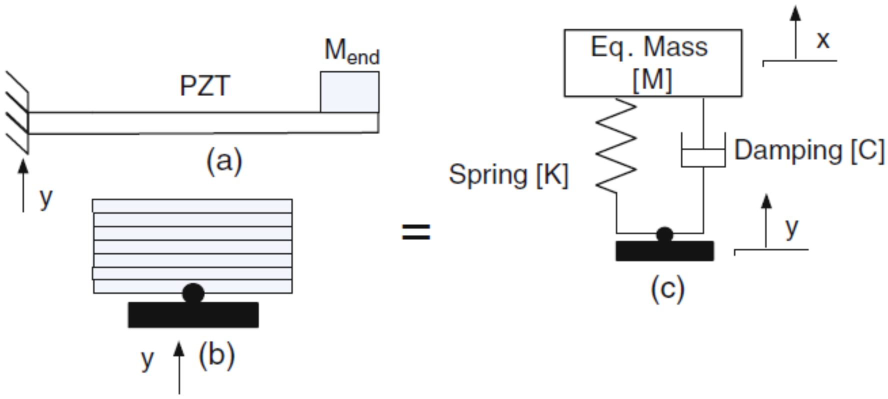

Fig. 2 - (a) Cantilever beam with tip mass, (b) multilayer PZT subjected to transverse vibration excited at the base, and (c) equivalent lumped spring mass system of a vibrating rigid body (Priya and Inman, 2009)

SOME APPLICATIONS

There are several interesting applications of power harvesting generators. Rome et al. (2005) from who Feenstra et al. (2007) have taken the example, have developed the "suspended-load" backpack, which generated up to 7.4 watts, or a 300-fold increase over previous shoe devices (20 milliwatts) by converting the mechanical energy from the vertical movement of carried loads (weighing 20 to 38 kilograms) to electricity during normal walking (Galhardi, Guilherme and Lopes Junior, 2008).

Mateu and Moll (2005) worked to obtain an optimized configuration of bending beams in shoes. Their research involved examining the combination of materials used to create the piezoelectric harvester as well as the coupling mode and shape of the harvester. In an effort to develop a micro-scale power harvester, Ammar *et al* (2005) designed a 1 μm thick piezoelectric cantilever beam with a seismic mass attached to its end. This micro-power harvester was to be used as the energy source for a compact wireless sensor node. In addition to designing the cantilever, an adaptive energy harvesting circuit was also developed to help optimize the mechanical to electrical energy conversion process (Anton and Sodano, 2007).

Studies have been conducted to explore the possibility of using piezoelectric power harvesting devices to provide energy to various types of sensors. Roundy and Wright (2004) developed a small piezoelectric cantilever generator that was used to power a custom radio transmitter. The generator was designed with a 1 cm3 total volume, taking into consideration the size of most wireless sensor nodes. The radio transmitter consumed 10 mA of current at 1.2 V and was capable of transmitting a 1.9 GHz signal a distance of 10 m (Anton and Sodano, 2007).

Two other applications for power harvesting are shown below:

BORDER SECURITY SENSORS

Border intrusion monitoring requires sensors to be powered continuously for a long period of time. This puts limit on the usage of microbatteries until they can be frequently recharged using environmental resources such as sunlight and wind. The sensors dispersed in rough terrainsmay be constantly under shade or covered requiring an alternative to photovoltaic's. In these circumstances, wind flow becomes an attractive source for generating small magnitudes of electrical energy and recharging the batteries (Priya 2005). Fig. 3 shows the schematic representation of the mini-windmill integrated with a section of the sensor nodes through control circuits (Priya and Inman, 2009).

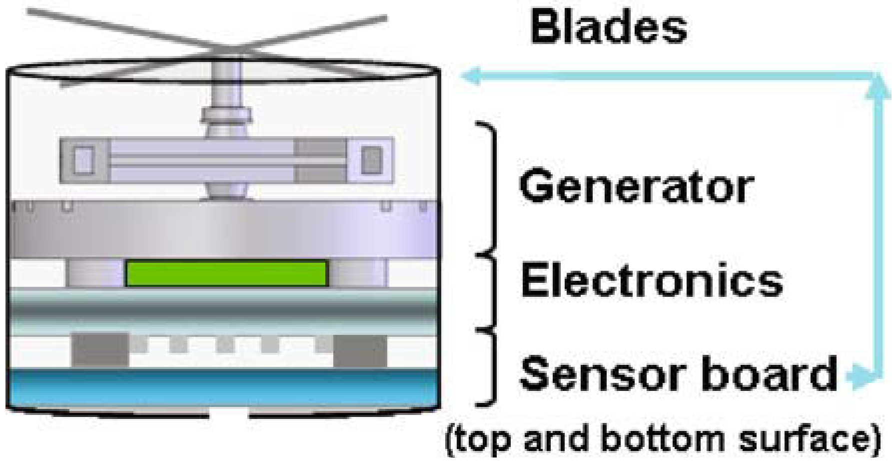

Fig. 3 - Schematic diagram of miniature Piezoelectric Windmill® with integrated electronics and sensor nodes (Priya and Inman, 2009)

Fig. 4 shows the picture of small-scale Piezoelectric Windmill® which uses three fan blades to enhance the AC stress and effectively capture the wind flow (American Windmills, Diamond Springs, CA). The inner structure of the windmill consists of a vertical shaft connected to a lever arm that converts the rotational motion into translation motion. All three fans are connected into the single vertical shaft through an adjustable gear ratio. The windmill consists of two rows of piezoelectric bimorphs, mentioned here as front and back rows, where each row has nine bimorphs. The number of the bimorphs was selected from the force-displacement load line curve where the optimum point approximately corresponds to 50% reduction in available force. The operating frequency of the windmill can be easily adjusted by changing the gear ratio. The translation distance of the bimorphs can be adjusted by swapping the crank at the end of the piezoelectric pulling arm. This windmill was able to provide continuous power of 5-6mW when the wind speeds are in the range of 9-12 mph (Priya and Inman, 2009).

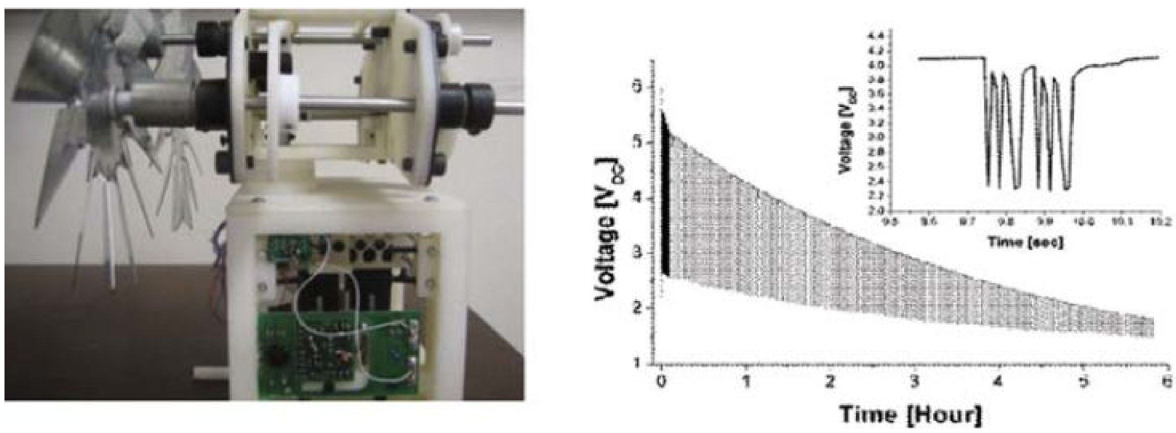

Fig. 4 - Picture of the windmill and real time transmission of the sensor data (Priya and Inma, 2009)

BIOMEDICAL APPLICATIONS

The design of human body-based vibration energy scavenging device incorporates mechanism that can respond to high acceleration and low frequency. The acceleration magnitude from human motion is in the range of ~100m/s² (~10 g) at a frequency of 2Hz while jogging (Mathuna et al. 2008). This frequency range is very low for implementing piezoelectric transduction mechanism without gears. However, incorporating complex gear boxes comes at the cost of comfort in motion and defeats the goal of harvesting. Most of the research on harvesting mechanical energy available during human motion has been on modifying the shoe structure. MIT Media lab has reported results on two different heel inserts, one made from PVDF (polyvinylidone fluoride) and the other from PZT. Power levels of up to 9.7mW were obtained from these shoe inserts (Paradiso and Starner, 2005).

CONCLUSION

Power harvesting is a relatively new technique which has been increasingly addressed. It is useful in various applications, eg, for a new generation of sensors will be self powered, avoiding wiring, battery replacement and providing weight reduction. It came as a solution for circuits that require low power and can be located in remote environments, where periodic maintenance in a short time would be impractical. Furthermore, the power harvesting takes all environmental resources available for electric power generation at a given location without damage to the environment.

Vibrational energy is available in various environments as an alternative form of waste energy. The modeling treatment required to predict the coupled dynamics of a piezoelectric energy harvester changes dramatically depending on the application and the form of the excitation. A model in which the piezoelectric is applied is constituted by a structure which is in vibration and a piezoelectric material attached to this, which together with the structure will undergo deformation by generating an electric voltage that can be used directly or stored in batteries or capacitors. These mechanisms can be implemented in environments or equipments subject to vibration, such as machinery, factories, vehicles, engines, generators, etc.; and their applications range from power biomedical devices (pacemakers, etc.) to structural health monitoring systems located in remote environments and wireless sensors.

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