Review And Scope Of Scavenging micro Energy using Piezoelectric materials

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Abstract

This paper reviews the energy harvesting for micro level devices such as mobile phones, low powered signal lights and energy storage batteries by using Lead Zirconite Titanite (PZT) with the help of vibration on cantilever beams and batteries. Recent advances on micro power portable devices require limitless battery life for improving performance. A lot of energy is being wasted which is around us and also research has been conducted to develop energy harvesting devices by using PZT materials. This paper gives innovative ideas to develop energy harvesting devices for future scientific community.

Introduction

The term energy harvester is defined as the generator device undergoing either vibrations or pressure due to a specific form of excitation or force. Energy harvesting from ambient waste energy for the purpose of running low powered electronics has emerged during the last decade as an enabling technology for wireless applications [1]. With recent advances in wireless technology the energy harvesting is highlighted as an alternative of conventional batteries. There are two types of energy harvesting. One is macro level energy harvesting and another one is micro level energy harvesting. Wind energy, solar energy and tidal energy comes under macro level energy harvesting because they produce power in KW or MW but whereas power will be generated with the help of PZT's is in mW or µW by using either by mechanical stress strain or vibrations therefore it is called micro level energy harvesting. In this paper the energy harvesting is limited to Micro level energy harvesting. Since piezoelectric material is used for converting mechanical energy into electrical energy it is great power source for developing micro level energy harvesting devices and wireless sensor network systems.

Piezo electricity is a form of coupling between the mechanical and the electrical behaviors of ceramics and crystals belonging to certain classes. These materials exhibit the piezoelectric effect, which is historically divided into two phenomena as the direct and the converse piezoelectric effects. When a piezoelectric material is mechanically strained, electric polarization that is proportional to the applied strain is produced. This is called the direct piezoelectric effect and it was discovered by the Curie brothers in 1880. When the same material is subjected to an electric polarization, it becomes strained and the amount of strain is proportional to the polarizing field. This is called the converse piezoelectric effect or inverse piezoelectric effect. The constitutive equations for a piezoelectric material are given by [2][3]. It can be seen that the first equation is the Hooke’s Law when electric field is zero and the second is Gauss’s law of Electricity when stress is zero.

\[ \delta = \frac{\sigma}{Y} + dE \]

\[ D = \varepsilon E + d\sigma \]

Where,

\( \delta \) - Mechanical strain
\( \sigma \) - Mechanical Stress
\( Y \) - Modulus of Elasticity (Young’s Modulus)
\( d \) - Piezoelectric strain coefficient
\( E \) - Is the electric field
\( D \) - Electric Charge Displacement
\( \varepsilon \) - Dielectric constant of piezoelectric material
Representative piezoelectric materials can be categorized into piezoceramics and piezopolymers. Piezoceramics have large electro-mechanical coupling constants and provide high energy conversion rate, but they are too brittle to use general shape energy transducer. On the other hand, piezopolymers have smaller electromechanical coupling constants compared to the piezoceramics, but they are very flexible. Based on direct piezoelectricity, many research works have been conducted for piezoelectric energy harvesting from mechanical vibration.

2. Energy harvesting with Piezo ceramics:
In this section energy harvesting with piezoceramics are reviewed. Priya.M [4] provided a review of a comprehensive coverage of the piezoelectric energy harvesting using low profile transducers and the results for various energy harvesting prototype devices. She also gave a brief discussion on selection of piezoelectric materials for on and off resonance applications. According to her theoretical calculation, the energy density of piezoelectric energy harvesting devices is 3-5 times higher than electrostatic and electromagnetic devices (Fig. 1).

Cristoper et al [5] proposed a parasitic power harvester from Heel strike system (piezo electric shoe) from a piezoceramic material. The Heel Strike System consists of two major pieces – the Heel Strike Generator and the power electronics circuit. The Heel Strike Generator is the device depicted in Fig. 2, where it has a mass of 0.455 kg and has approximate dimensions of 8.89 cm (L) by 7.94 cm (W) by 4.29 cm (H). The principle components of the Heel Strike Generator are four PZT-5A bimorph crystal stacks, lead screw, bearing and rotary cam [Fig.3]. The power electronics circuit is 5.2 cm² with a height of 1.7 cm and has a mass of 10 g. Its purpose is to convert unusable power from the Heel Strike Generator to usable power. The power electronics circuit is connected to the Heel Strike Generator to form the Heel Strike System.

2.1 Cantilever type:
A cantilever type vibration energy harvesting has very simple structure and can produce a large deformation under vibration. SrikanthKorla et al[6] proposed an effect of cross-section of a piezoelectric cantilever beam by attaching PZT’s on dynamic magnifier and proved the effect of the use of magnifier has a very prominent effect on the beam frequencies. The resonance occurs at lower frequencies for all the modes (Fig: 4).
Modal analysis of cantilever beams with different cross-sections such as rectangular, trapezoidal and triangular (Fig. 5) were carried out and the first six natural frequencies were plotted by considering number of nodes on X-axis and frequency values on Y-axis (Fig. 6a, 6b, 6c).

Figure 5: Beam with different Cross-Sections

Initially the modal analysis was carried out on a regular cantilever beam with different cross-section. After that the analysis was carried out for cantilever beam with a magnifier. And also he carried out the modal analysis of a cantilever beam with trapezoidal cross-sectional area and thickness varying uniformly throughout its length (Fig 7).

Figure 7: Cantilever beam with trapezoidal cross-section and uniformly varying thickness.

Elvin et al. [7] proposed a theoretical model by using a beam element and performed experiment to harvest power from PZT material. They showed that a simple beam bending can provide the self-power source of the strain energy sensor. Wright et al. [8] presented a series of vibration energy harvesting devices. First, they indicated low-level vibrations occurring in common household and office environments as a potential power source and investigated both capacitive MEMS and piezoelectric converters. The simulated results showed that power harvesting using piezoelectric conversion is significantly higher. They optimized a two-layer cantilever piezoelectric generator and validated by theoretical analysis (Fig. 8).

Figure 8: A two layered cantilevered beam with mass at free end

3. Compact energy harvester:
Srikanthkorla et al. [9] designed a compact size self contained energy harvesters were built by considering typical space available for AA size batteries. Each of the harvesters contains a rectifier circuit with four diodes and a capacitor. A series of
piezoelectric energy harvesters with circular and square cross-sections were built and tested at different frequency and amplitude levels. On a 1 MΩ impedance digital oscilloscope, it was observed that the voltages reached 16 V (round cross-section) and 25 V (square cross-section) at 50 Hz frequency. The highest power output accomplished was 625 mW. The outputs of both types of the harvesters were very similar at low amplitudes. However, the square cross-section facilitates better attachment of the piezoelectric elements with the harvester shell and worked efficiently at higher amplitudes without immediate failure [fig. 9, 10].

Marco et al. [10] proposed an energy harvesting circuit [fig 11] which includes two parts. The first one includes the piezoelectric element, the switch S1, the inductor L1, the diode bridge rectifier (D1–D4), and the intermediate capacitor Cint. The part corresponds to the interface circuit of the series SSHI proposed by Taylor et al. and described in [11, 12]. The second part consists of the switch S2, the inductor L2 and the diode D5, which is a buck-boost static converter.

Conclusion

Piezoelectric energy harvesting technologies were reviewed in this paper. Principles of piezoelectric energy harvesting, various types of piezoelectric harvesting devices and piezoelectric materials were investigated. Vibration energy harvesting technology is highlighted as a permanent power source of portable electronic devices and wireless sensor network. There have been many novel ideas for piezoelectric energy harvesters.

Future scope:

However, real applications of the vibration-based energy harvesters are not still limited. There are three issues that limit the broad technological impact of the vibration-based piezoelectric energy harvesters. Firstly, development of high coupling coefficient piezoelectric materials is essential to improve the performance of piezoelectric energy harvesters. Proportional to the coupling coefficient, the energy conversion efficiency will be improved therefore increasing the coupling coefficient for the PZT material is quintessential. Thus, the advent of new piezoelectric materials with high coupling coefficient will bring a new era of piezoelectric energy harvesters. Secondly, the energy harvesters should be able to sustain under impact loads, random vibrations and shocks. Thus, development of flexible and resilient piezoelectric materials is necessary. Thirdly, development of efficient electronic circuitry for energy harvesters is necessary. Since the obtained electrical energy from vibration is small, rectification and energy storing circuits should be able to activate in such a low power condition. Vibrations are available everywhere therefore vibration-based energy harvesters should come to the real life of the world population.

References


