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A Review of Vibration-Based Piezoelectric Energy Harvesters

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Abstract

Piezoelectric energy harvesting technology has received a great attention during the last decade to activate low power microelectronic devices. Piezoelectric cantilever beam energy harvesters are commonly used to convert ambient vibration into electrical energy. In this paper we reviewed the work carried out by researchers during the last ten years. The improvements in experimental results obtained in the vibration-based piezoelectric energy harvesters show very good scope for piezoelectric harvesters in the field of power in the near future.

Keywords: Vibration; Energy Harvesting; PZT; Voltage; Power Output; Frequency, Beam.

Introduction

We already know that the power requirement for the day to day work increase as technology use of human being increasing, in such condition the regenerative power sources requirement is very-very important topic to research the vibration energy harvesting is one of the important topic for as the regenerative power source. In this piezoelectric material is use as medium to develop power

The piezoelectric effect was discovered by J and P Curie in 1880. They found that if certain crystals were subjected to mechanical strain, they became electrically polarized and the degree of polarization was proportional to the applied strain. Conversely, these materials deform when exposed to an electric field. Piezoelectric materials are widely available in many forms including single crystal (e.g. quartz), piezoceramic (e.g. lead zirconate titanate or PZT), thin film (e.g. sputtered zinc oxide), screen printable thick-films based upon piezoceramic powders and polymeric materials such as polyvinylidenefluoride (PVDF).

Most of the vibration harvester operates at frequencies of more than 100 Hz with making them suited for harvesting energy from rotating machinery. The human motion generate vibration in the range of 1-30 Hz very low frequency in this condition to get power is quite difficult because more of the power damped as mechanical loss, instead of to transferred as electrical domains.

The flexibility associated with piezoelectric materials is very attractive for power harvesting. They possess more mechanical energy for conversion into electrical energy and can also withstand large amounts of strain. Many methods have been reported to improve the harvested power. One of the methods is by selecting a proper coupling mode of operation. This involves two modes of operation. The first mode called 31 mode, involves the excited vibration force being applied perpendicular to the poling direction (pending beam). And the other is called 33 mode, in which the force is applied on the same side as the poling direction. The two modes 33 mode and 31 mode are as shown in Fig. 1. Between the two modes, 31 mode is most commonly used. It produces a lower coupling coefficient 'k', when compared to the 33 mode. The second method for harvested power improvement is by changing the device configuration. This is accomplished by adding multiple pieces of piezoelectric materials to the harvester. The uni-morph cantilever beam configuration is as shown in Fig. 2c.

Two combinations of bimorph structures are possible:
(a) Series type.
(b) Parallel type.

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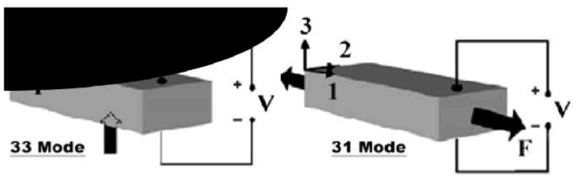

Fig.1 Piezoelectric coupling modes.

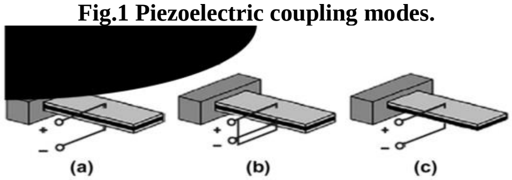

Fig. 2. (a) A series triple layer type cantilever. (b) A parallel triple layer type cantilever. (c) A uni-morph cantilever.

Cantilever geometrical structure also plays an important role in improving the harvester's efficiency. The rectangular shaped cantilever structures are most commonly used in piezoelectric harvesters. They are easy to implement and effective in harvesting energy from ambient vibrations. However the triangular shaped cantilever beam with a small free end can withstand higher strains and allows maximum deflections, resulting in higher power output when compared to a rectangular.

Literature Survey

1 Lei Gu(2010) they presented a low-frequency piezoelectric energy harvester based on impact vibration assembled with a compliant driving beam and two rigid generating beam. The advantage of this is to increase power density of harvester. This operate at low frequency around 1-30 Hz.

2 Huicong Liu, Chengkuo Lee, Takeshi Kobayashi, Cho Jui Tay, Chenggen Quan(2012) They proposed a FUC cantilever stopper for converting random and low-frequency external vibration to self-oscillation of a FUC stopper at high resonant frequency. This is broadens the frequency range and increases the output voltage and power.

3 Huicong Liu, Chengkuo Lee, Takeshi Kobayashi, Cho Jui Tay and Chenggen Quan They have analytically and experimentally investigated the wideband frequency response of a PEH system with stoppers on one side and two sides. The key parameters for the frequency response, including base accelerations, damping ratios, frequency characteristics and stopper distances, have been studied based on their mathematical model.

4 Huicong Liu ,Cho Jui Tay , Chenggen Quan ,Takeshi Kobayashi ,Chengkuo Lee They have investigated energy harvesting from the aspects of widening the operating frequency range and frequency up-conversion. The unique impact mechanism including scrape-through and release between the two piezoelectric cantilevers is presented.

5 Lokesh Dhakara, Huicong Liu, F.E.H. Tay, Chengkuo Lee. (2013) they have made the polymer piezoelectric bimorph beam (made of polyethylene terephthalate) which they called soft spring that is mechanically connected to longitudinal direction

6 Henry A. Sodano, Gyuhae Park, Donald J. Leo and Daniel J. Inman(2003) they develop the model of piezoelectric power harvester beam for getting accurate estimate of power generation. And simplify the design procedure necessary for determining the appropriate size and vibration levels necessary for sufficient energy to be produced and supplied to the electronic devices. An experimental verification of the model is also performed to ensure its accuracy.

7 F. Stoppel, C. Schröder, F. Senger, B. Wagner, W. Benecke (2011) they presented a resonant micro power generator based on the transverse piezoelectric. The generator consists of large silicon mass attached to a polysilicon cantilever covered with an AlN thinfilm as piezoelectric material. To maximize the power density of the generator, a parametric study by means of analytical modeling and FEM simulation has been performed. Different optimized generators with resonance frequencies in the range from 100 Hz up to 1 kHz have been designed and fabricated.

8 M.F. Lumentut, I.M. Howard (2011) They presents an analytical method for modeling and electromechanical piezoelectric bimorph beam with tip mass under two input base transverse and longitudinal excitations. The Euler– Bernoulli beam equations were used to model the piezoelectric bimorph beam

9 Huicong Liu , Chengkuo Lee ,Takeshi Kobayashi , Cho Jui Tay , Chenggen Quan(2012) In this paper, a new S-shaped piezoelectric PZT canti-lever was successfully micro fabricated with small device size and extremely low resonant frequency. An S-shaped PZT cantilever is designed for achieving an extremely low resonance of 27.4 Hz. It would be more applicable to ambient vibrations at low frequency and low accelerations.

10 Huicong Liu, Chenggen Quan, Cho Jui Tay, Takeshi Kobayashi , and Chengkuo Lee (2011) This paper describes the design, microfabrication and measurement of such device for harvesting energy from low frequency environmental vibrations. Instead of deposition of PZT bulk film, ten

PZT thin film patterns (PZT patterns) are parallel arrayed and electrically isolated on the supporting beam of the cantilever. The performance of output voltage and power of PZT patterns in series and in parallel connections are studied based on the experimental and simulation results.

11Einar Halvorsen and Tao Dong (2008) they have developed closed form equations for piezoelectric unimorph energy harvesters with a tapered beam and an extended proof mass, i.e. not a point mass. They find that there are a number of solutions that give the same resonance frequency and therefore could be considered.

12Simon Paquin and Yves St-Amant(2009) They have made a semi- analytical model that takes both the dynamic and the electromechanical behavior of the harvester into account was first described. Using this model, it has been shown that the energy harvested can be increased by 69% when the thickness of the beam is varied (0.3 degree slope angle). It also leads to a more uniform strain distribution and thus increases the amount of energy that can be harvested. The main objective of this paper was to demonstrate that the efficiency of a cantilever beam vibration energy harvester can be increased by using a variable thickness.

13Wahied G. Ali, Sutrisno W. Ibrahim (2012) they find the necessary conditions to enhance the extracted AC electrical power from vibrations energy using piezoelectric materials. The effect of tip masses and their mounting positions are investigated to enhance the system performance. The optimal resistive load is estimated to maximize the power output.

14Dong-Gun Kim, So-Nam Yun, Young-Bog Ham, Jung-Ho Park(2010) they made the arrangement of vibration energy harvester which is using input like vibration or wind. The geared motor method depicts the windmill system and the vibrator is representive vibration source such as buildings, factories, vehicles and human body. The equivalent speed of the geared motor by windmill speed was controlled by controller and the output energy from the piezoelectric element with a cantilever was measured by data acquisition system.

15Kuok H. Mak, Stewart McWilliam n, Atanas A. Popov, Colin H.J. *Fox***(2011)** A theoretical model has been developed to analyse the performance of a piezoelectric cantilever energy harvester impacting a bump stop. The model estimates the contact force and predicts the dynamical and electrical responses of the harvester. Experiments have been carried out to validate the theoretical model of a piezoelectric energy harvester with and without the bump stop.

Conclusions

Various designs of harvesters and their experimentally obtained results in the last ten years have been summarized in this review .Basically these all paper work have centered to power develop the vibration energy harvester increase by changing design of beam, structure, material, method to develop equations etc. The low-frequency impact harvester cannot only demonstrate a high power density but also be especially suitable for the implementation with MEMS processes. By the frequency up-conversion, the reduced mechanical damping contributed to the efficiency of the energy transfer as high as 69.6% [1]. FUC cantilever stopper for converting random and low-frequency external vibrations to self-oscillation of a FUC stopper at high resonant frequency. The main advantage of it broadens the operation frequency range and increases the out-put voltage and power [2]. The key parameters for the frequency response, including base accelerations, damping ratios, frequency characteristics and stopper distances, have been studied based on mathematical model. The experimental results show a qualitative match to the modeling results. The performance can be further improved by optimizing the stopper distances, overlapping tip distance, beam stiffness and damping characteristics. [3]. with the low frequency the power output is high can be get [5, 7, 9, 10]. The amount of power capable of being generated through the vibration of a cantilever beam with piezoelectric elements can be calculated by the experimental modal which gives significant result [6]. The experimental findings show that the maximum tip absolute displacement tended to give the lowest and highest electrical voltage for resistance values approaching the short and open circuit conditions, respectively. Conversely, the maximum tip absolute displacement tended to give the highest and lowest electrical current approaching the short and open circuit conditions, the maximum dynamic displacement does not necessarily result in the highest current or voltage [8]. there are a number of solutions that give the same resonance frequency and therefore could be considered. The solutions fall in two sets: one with short beams, and another with long beams. Neither optimum value sets correlated with the homogeneity of stress in the beam. Within each set, output power was to a good approximation independent on tapering of the beam so this can be considered an additional design degree of freedom [11]. The efficiency of a cantilever beam vibration energy harvester can be increased by using a variable thickness. A semi- analytical model that takes both the dynamic and the electromechanical behavior of the harvester into account has been worked that the energy harvested can be increased by 69% when the thickness of the beam is varied (0.3 °slope angle). It also leads to a more uniform strain distribution and thus increases the amount of energy that can be harvested [12]. For a fixed level of excitation, the output power is inversely proportional to the natural frequency of a harvesting structure and hence it is preferable to operate at the first harmonic or the fundamental frequency of the vibrating structure, Maximum power transfer occurs when harvester's internal impedance matches the resistive load [13]. There are many energy sources such as vibration, wind power and wave power. Also, these can be used to the energy harvesting system [14]. Moving the bump stop location along the beam affected the electrical output of the energy harvester because the maximum displacement allowed is to be altered. The maximum beam displacement is the key factor that governs the electrical output and maximum bending stress. Reducing the maximum bending stress inevitably means reducing the maximum beam displacement, suppressing the electrical output [15].

Future Work

Future work is to design and fabricate the piezoelectric taper cantilever beam. It leads to a more uniform strain distribution and thus increases the amount of energy that can be harvested, this is expected taper beam may increase the voltage output and also give the simple design of vibration energy harvester.

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