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Effect of Power Generation by the Piezoelectric Material by Changing the Tips Masses Weight and its Position: A Review

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Abstract

Piezoelectric energy harvesting is a promising technology for extracting the power from environmental vibrations. It generates the electrical power of few orders of amplitudes. Such vibration-based energy harvester generates the most energy when the generator is excited at its resonance frequency. When the external frequency shifts, the performance of the generator drastically reduces. This paper presents a review of effect of power generation by the piezoelectric material by changing the tip masses and its position. The purpose of this review paper is to summarize the important published papers on effect of power generation by piezoelectric material by changing the tip mass by many authors usage the most common masses.

Keywords: Mechanical vibration; energy harvesting; PZT; Power Output; frequency; Bimorph Beam.

Introduction

Energy harvesting from ambient vibrations by using various form of transduction has been recognized as a viable means for powering small electronic devices and remote sensors in order to eliminate their dependence on external power sources such as batteries or power grids. With such self-powered capabilities, these devices and sensors can operate in an uninterrupted fashion over prolonged periods of time. In recent years, interest in energy harvesting has increased rapidly, and harvesting vibration energy using piezoelectric materials has attracted a great deal of attention. Different types of piezoelectric transducer can be used to harvest vibration energy, including monomorph, bimorph, stack or membrane. Each configuration has its own advantages and limitations, and in general it is not possible for an energy harvester to perform well in all applications. For this reason, energy harvesters are normally designed for a specific application and a particular frequency range of operation.

Electromagnetic, electrostatic and piezoelectric transductions are the three basic Conversion mechanisms commonly used to convert the basic vibrations to electrical energy. Energy density of piezoelectric mechanism is three times higher compared to other means. Piezoelectric cantilever beams are widely used structures in energy harvesting applications due to their high flexibility and low natural frequency. Often a tip-mass is attached to the free end of the cantilever to reduce its natural frequency and increase its deflection. A symmetrical Piezoelectric layers when attached to the parent shim surface of the cantilever, it is known as a
Bimorph beam and bimorph beam give the double power as compared to unimorph beam.

Literature Review

The following literature review describes important research results regarding the power harvesting by the piezoelectric material using different proof mass and geometry configuration.

Huicong Liu, F.E.H. Tay, Chengkuo Lee et al. (2013) proposed a piezoelectric EH comprising a composite cantilever and a proof mass at the free end. The composite cantilever is formed by a piezoelectric bimorph and a polymer beam mechanically connected along the longitudinal direction. Comparing with the resonant frequency of 275 Hz of a standalone piezoelectric bimorph, the composite cantilever design enables the resonant frequency of the EH to be as low as 36 Hz. Moreover ,this kind of EH is demonstrated to be 3.12 times and 1.32 times (at 0.1 g) more efficient at output power generation than a standalone piezoelectric bimorph and piezoelectric bimorph with

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a proof mass at the free end, respectively. With the aid of spring hardening effect, the operating bandwidth (BW) can be increased from 5 Hz to 16.4 Hz. **[1]**

M.N. Fakhzan, Asan G.A.Muthalif (2012) investigated the voltage production of piezoelectric cantilever beam when subjected to base excitation, with and without attached proof masses. The beam is modeled using Euler–Bernoulli, also known as thin beam theory. As such, the model obtained here is applicable for micro- and nano-beams. The frequency response function (FRF) that relates the output voltage and transverse acceleration is identified for multi-mode vibration. These analytical predictions are then compared with experimental results and good agreement is obtained. **[2]**

Wahied G. Ali, Sutrisno W. Ibrahim (2012) investigated the necessary conditions to enhance the extracted AC electrical power from exciting 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. Different capacitive loads are tested to store the output energy. The experimental results validated the theoretical analysis **[3].**

Huicong Liu, Cho Jui Tay et al (2011) proposed a piezoelectric MEMS energy harvester (EH) with low resonant frequency and wide operation bandwidth was designed, micro fabricated, and characterized. The MEMS piezoelectric energy harvesting cantilever consists of a silicon beam integrated with piezoelectric thin film (PZT) elements parallel arranged on top and a silicon proof mass resulting in a low resonant frequency of 36 Hz. The whole chip was assembled onto a metal carrier with a limited spacer such that the operation frequency bandwidth can be widened to 17 Hz at the input acceleration of 1.0 g during frequency up-sweep. Load voltage and power generation for different numbers of PZT elements in series and in parallel connections were compared and discussed based on experimental and simulation results. Moreover, the EH device has a wideband and steadily increased power generation from 19.4 nW to 51.3 nW within the operation frequency bandwidth ranging from 30 Hz to 47 Hz at 1.0 g. Based on theoretical estimation, a potential output power of 0.53 μW could be harvested from low and irregular frequency vibrations by adjusting the PZT pattern and spacer thickness to achieve an optimal design. **[4]**

Bin Yang, Chengkuo Lee (2009) investigated a novel non-resonant energy harvester with wide band frequency is proposed for collecting energy from ambient vibration at low frequency. A free-standing magnet is packaged inside a sealed hole which is created by stacking 5 pieces of printed circuit board (PCB) substrate sn with multi-layer copper coils made on double-sides. When the energy harvester is shook from 10 to 300 Hz at 1.9g acceleration along longitudinal direction of hole, a 65 Hz flat-band-like output voltage of 4.5 mV at the case of only one side with drilled air holes on acrylic plate is generated within 35 to 100 Hz. The output power from the coils is measured as 0.1μW under matched loading resistance of 50 Ω within this flat band range under 1.9 g ambient vibration. **[5]**

Andrew Townley (2009) proposed utilizes AlN due to its ease in processing and potential for on-chip integration. By operating at a MEMS scale, the benefit is that arrays of piezo generators can be placed on the same die. With the process advantages of AlN, a long term goal of an integrated power-harvesting chip becomes feasible. Theoretical results of scaling predict that raw power output and even power per unit volume will decrease with scaling. **[6]**

Jae-yun Lee, Sanghwan Kim et al (2009) investigated optimal environments and specimens for an energy harvesting system using resonator. An important thing is the correlation of the resonant frequency of diaphragm and piezoelectric elements in experiments. Experimental results indicate a maximum peak to peak voltage of 46.2V and power of 1.84μW. Based on the experimental results, when piezoelectric materials (PVDF) are arranged regularly and resonant frequencies of a diaphragm and piezoelectric materials correspond to driving energy source, it will be expected to improve the efficiency. **[7]**

Huicong Liu, Chengkuo Lee, Takeshi Kobayashi.et al.(2012) This paper investigated the design, micro fabrication, modeling and characterization of a piezoelectric energy harvester (PEH) system with a wide operating bandwidth introduced by mechanical stoppers. The wideband frequency responses of the PEH system with stoppers on one side and two sides are investigated thoroughly. The experimental results show that the operating bandwidth is broadened to 18 Hz (30–48 Hz) and the corresponding optimal power ranges from 34 to 100 nW at the base acceleration of 0:6g and under top- and bottom-stopper distances of 0.75 mm and 1.1 mm, respectively. By adjusting the mechanical stopper distance, the output power and frequency bandwidth can be optimized. **[8]**

Bin Yang Chengkuo Lee et al (2010) a novel hybrid energy harvester integrated with piezoelectric and electromagnetic energy harvesting mechanisms is investigated. It contains a piezoelectric cantilever of multilayer piezoelectric transducer PZT ceramics, permanent magnets, and substrate of two-layer coils. The effect of the relative position of coils and magnets on the PZT cantilever end and the poling direction of magnets on the output voltage of the energy harvester is explored. When the poling direction of magnets is normal to the coils plane, the coils yield the maximum output voltage. The maximum output voltage and power from the PZT cantilever are 0.84 V and 176 W under the vibrations of 2.5-g acceleration at 310 Hz, respectively. And the maximum output voltage and power from the coils are 0.78 mV and 0.19 W under the same conditions. **[9]**

Zhongsheng Chen, Yongmin Yang et al (2012) in this paper is the widening of the resonant bandwidth of a piezoelectric harvester based on phononic band gaps, which is called one-dimensional phononic piezoelectric cantilever beams (PPCBs). Broadband characteristics of one-dimensional PPCBs are analyzed deeply and the vibration band gap can be calculated. The effects of different parameters on the vibration band gap are presented by both numerical and finite element simulations. Finally experimental tests are conducted to validate the proposed method. It can be concluded that it is feasible to use the PPCB for broadband vibration energy harvesting and there should be a compromise among related parameters for low-frequency vibrations **[10].**

S Roundy and P K Wright (2004) the focused of this paper is to discuss the modeling, design, and optimization of a piezoelectric generator based on a two-layer bending element. An analytical model of the generator has been developed and validated. In addition to providing intuitive design insight, the model has been used as the basis for design optimization. Designs of 1 cm3 in size generated using the models have demonstrated a power output of 375 μW from a vibration source of 2.5 m s−2 at 120 Hz **[11].**

Shad Roundy, Paul K. Wright, Jan Rabaey (2003). Different conversion mechanisms are investigated and evaluated leading to specific optimized designs for both capacitive MicroElectroMechanical Systems (MEMS) and piezoelectric converters. Simulations show that the potential power density from piezoelectric conversion is significantly higher. Experiments using an off-the-shelf PZT piezoelectric bimorph verify the accuracy of the models for piezoelectric converters. A power density of 70 mW/cm3 has been demonstrated with the PZT bimorph. Simulations show that an optimized design would be capable of 250 mW/cm3 from a vibration source with acceleration amplitude of 2.5 m/s2 at 120 Hz [**12].**

Daisuke Koyama , Kentaro Nakamura(2010) An energy harvesting device with a polyurea thin film formed through vapor deposition polymerization with 4,40-diphenylmethane diisocyanete (MDI) and 4,40-diamino diphenyl ether (ODA). The conversion efficiency from mechanical to electrical energy was calculated using finite elemental analysis (FEA) of the cantilever configuration. Higher conversion efficiency was obtained using a thinner and shorter cantilever configuration with increased resonance frequency of the device. Experiments were conducted using an electric power generation device with a 3 lm thick polyurea thin film attached to a 0.1-mm-thick, 18-mm-long beryllium copper cantilever **[13].**

A. T. Mineto, M.P. Souza Braun, H. A. Navarro, P. S. Varoto (2010) this paper to predict the power generated from a cantilever steel beam with harmonic oscillations using PZT-PIC 255. A parametric study is also performed to optimize the energy generation of piezoelectric-beam system **[14].**

N.H. Diyana, Asan G.A. Muthalif, M.N. Fakhzan, A.N.Nordin (2012) in this paper unimorph piezoelectric energy harvester is chosen to harvest wideband mechanical energy. The derivation of the mathematical modelling is based on the Euler-Bernoulli beam theory. MATLAB and COMSOL Multiphysics software are used to study the influence of the structure in generating output voltage due to base excitations. Finally, the results of the frequency response are displayed in the form of voltage within frequency range of 0 to 3500 Hz, at which the comb-shaped piezoelectric beam structure shows better performance as there exist more natural frequencies in the specified range of frequency **[15].**

Conclusions

1. A new PEH-S configuration with high power output has been proposed for low-frequency piezoelectric energy harvesting. The power output of PEH-S increases by 32% at 0.1 g while the resonant frequency is decreased by a factor of 3.47, as compared to PEH-M **[1].**

2. The effect of using different proof masses which is attached at the end of the cantilever beam is also discussed. It is found that for heavier proof mass, the value of natural Frequency decreases and the value difference between its subsequent natural frequencies is smaller. The energy harvester operates effectively at low working bandwidth <1 kHz, therefore an appropriate proof mass is needed to tune the natural frequency so that it falls within this bandwidth range **[2].**

3. The maximum (mechanical/electrical) power transfer depends on piezoelectric material properties and other matching operating conditions. Resonant frequency of the harvester can be identified experimentally by tracking the maximum extracted electrical power. Increasing tip mass decreases the resonant frequency. Output power increases as the value of tip mass in-creases that means; the Q-factor is also increased. After certain limit; increasing tip mass decreases the Q-factor due to the increasing of the damping effect **[3].**

4. Due to the wideband effect, the voltage and power generations show a steadily increased and wideband range once the critical input acceleration of 0.2 g is exceeded. It is found that, under the same input acceleration, the optimal power remains the same no matter what the connection type are **[4].**

5. A free-standing magnet oscillates within this hole in response to ambient vibrations. It is first demonstrated experimental data that a miniature device can provide flat-band like output voltage of 4.5 mV in an operation frequency range of 65 Hz for harvesting energy from ambient vibrations of less than 100 Hz. The average output power of 0.1μW can be harvested within this wide 65 Hz range under ambient vibration and shock with 1.9g acceleration **[5].**

6. The current device structure does not have scaling advantages in power per unit area or volume. It is difficult to produce sufficient displacement at small scales to generate a considerable voltage. At the microscale, resonance frequencies are too low to effectively convert ambient frequencies as found in nature **[6].**

7. The cantilever type of PVDF generates higher voltage than the circular type of one. The more The number of PVDF arrays on diaphragm, the more the voltage generates in PVDF. A maximum voltage is 46 Vp-p, when resonant frequency is 400 Hz and the number of PVDF is two. If array of PVDF is changed, the voltage can be more generated **[7].**

8. 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 our mathematical model **[8].**

9. The number of magnets, i.e., different value of added mass, the relative position of coils and magnets, and the poling direction of placed magnets are critical to the output voltage and power of energy harvester. The output voltages of PZT cantilever with four magnets and coils obtain the maximum level of 0.66 V and 0.75 mV under the vibration of 2.5-g acceleration **[9].**

10. i) center frequency of vibration band gap of a one-dimensional PPCB increases exponentially with mass(m), and near- linearly with the thickness of piezoelectric patches and the elastic modulus . The width of the vibration band gap increases with the mass (m).

ii) Vibration energy is mainly localized at the first several cells in a one-dimensional PPCB, where higher voltage output will be generated. We can improve the efficiency of broad VEH by sticking some PZT patches on those cells **[10].**

11. The system should be designed to resonate at the dominant driving frequency of the target vibrations if possible. (2) Power output is proportional to the proof mass attached to the system. Therefore, the proof mass should be maximized while maintaining other constraints such as resonance frequency and strain limits. (3) Power output is inversely related to the driving and resonance frequency **[11].**

12. Piezoelectric converters will be capable of converting more power per unit volume than capacitive converters. Piezoelectric converters are also favorable because they require no separate voltage source, and because the output voltage for the vibration sources under consideration is in the range of 3–10 V. While capacitive converters require a separate voltage source, and are not capable of converting as much power per unit volume **[12].**

13. Higher conversion efficiency was achieved using a shorter cantilever with the higher resonance frequency, and the maximum efficiency was estimated to be 0.233% **[13].**

14. A parametric study is performed to optimize (location of the applied force, PZT position and PZT length) the power generation of piezoelectric-beam system. The maximum power was obtained for the applied force in the free-end beam; the PZT located close to clamped end; and PZT length about the half of the beam, but sometimes this is not viable **[14].**

15. The simulation studies of single and comb-shaped piezoelectric beam structure for energy harvesting. The derivations of the mathematical equations are based on Euler-Bernoulli Beam theory. The harvester is assumed to experience lateral vibration from its base excitation. The presence of tip mass is considered in mathematical derivation. It is seen that comb structure can be used to harvest broadband vibration energy **[15].**

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