Piezoelectric energy harvesting for powering low power electronics

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1 Introduction

Although wireless data transmission techniques are commonly used in electronic devices, they still suffer from wires for the power supply or from batteries which require charging, replacement and other maintenance. The vision for the portable electronics and industrial measurement systems of the future is that they are intelligent and independent on their energy supply. The major obstacle in this path is the energy source which enables all other functions and "smartness" of the systems as the computing power is also restricted by the available energy. The development of long-life energy harvesters would reduce the need for batteries and wires thus enabling cost-effective and environment friendlier solutions for various applications such as autonomous wireless sensor networks, powering of portable electronics and other maintenance-free systems.

One of the most promising techniques is mechanical energy harvesting e.g. by piezoelectric components where deformations produced by different means is directly converted to electrical charge via direct piezoelectric effect. (Liu et al.) Subsequently the electrical energy can be regulated or stored for further use. The total mechanical energy in vibration of machines can be very large and usually only a fraction of it can be transformed to electrical energy. Recently, piezoelectric vibration based energy harvesters have been developed widely for different energy consumption and application areas. As an example for low energy device an piezoelectric energy harvester based on impulse type excitations has been developed for active RFID identification (Takeuchi et al.). Moreover, piezoharvester with externally leveraged mechanism for force amplification was reported to be able to generate mean power of 0.4 mW from backpack movement (Feenstraa et al.). Significantly higher power levels are expected from larger scale testing in Israel, where piezoelectric material is embedded under active walking street, road, airport or railroad. The energy is harvested from human or vehicle traffic and used for e.g. road lightning. (Innowattech)

2 Objectives of the research

In direct piezoelectric effect stress or strain applied for the piezoelectric material generates a charge on the electroded faces of the component. In vibration based harvesters deformation is produced by vibrating mass of the piezoelement itself or external mass or directly transferring deformation of external system into piezoelectric material. The natural stiffness or Young's modulus of the piezoelectric material is relatively high (typically 50-70 GPa) and therefore vibration cannot normally generate required stresses for the material. In order to overcome this problem bending type structures are typically utilised in vibration based harvesters providing

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extremelly compact internal leverage mechanism for the force amplification. One of the commonly used structures is a unimorph type cantilever (in Figure 1 a) which was chosen for this research. The component consists of active PZT and passive steel layers where the steel can be substituted with different materials such as post-processed ceramics to enable e.g. embedded and encapsulated structures (Heinonen et al.). In this structure external mass is usually placed at the tip of the cantilever, as in Figure 1 (b), in order to tune the resonance frequency and to enhance the coupling of the vibration for the piezoelectric material (Lefeuvre et al.).

Schematics of the complete energy harvesting system is shown in Figure 1 (b) consisting the energy harvester components and required electronics. The electronics in its simplest form can be a one stage design with a rectifier and the storage capacitor or it can have several stages with switched mode regulators providing controlled output voltage and high voltage energy storage significantly improving efficiency of the harvesting. (Lefeuvre et al.)

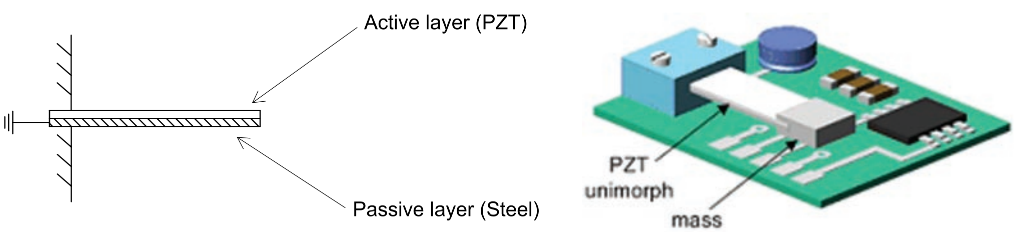

Figure 1 Schematics of (a) unimorph type piezo structure (b) energy harvester system with the harvester and accompanying electronics.

3 Measurements and results

Measured piezocomponents were 25.4 and 33.0 mm long unimorph type cantilevers. The width of the cantilevers varied from 5 mm to 9 mm and the thickness of the active layer was 250 μm. PZT-5H material (Morgan Electro Ceramics, UK) and steel were used for active and passive layers, respectively. The thickness of the passive layer was 100 μm and external mass was not used in these measurements.

3.1 Measurement setup

The measurement setup, shown in Figure 2 (a), consisted of a differential Doppler shift vibrometer (OFV-5000 , Polytec GmbH, Germany) for the displacement measurements of the energy harvester, a piezo stack actuator (Piezomechanik Pst 150/7/160 VS12) for generating the vibration and energy harvesting electronics based on one stage rectifier with a 1 μF capacitor. The voltage of the storage capacitor was measured with a multimeter with 10 MΩ input impedance.

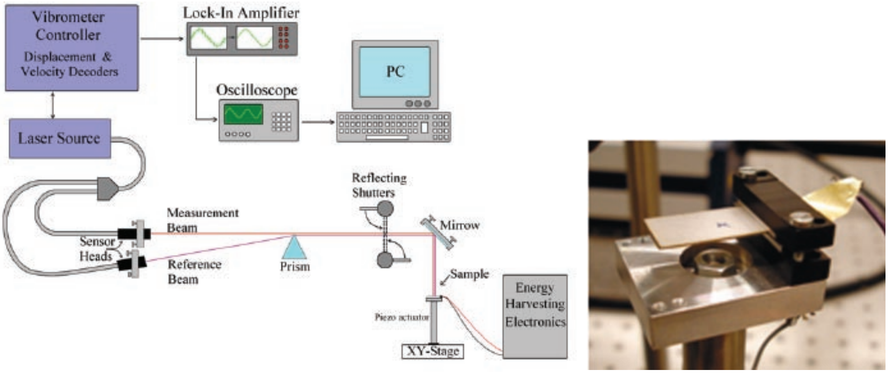

Figure 2 (a) Measurement setup (b) energy harvester attached to the vibrating bench.

The piezo cantilever was clamped to an aluminum base which was then in turn attached to the piezo stackactuator (Figure 2 b).

3.2 Measurement results

Energy harvesters were subjected to a 5.8 μm peak to peak vibration with varying frequency and their frequency responses are shown in Figure 3. As can be seen the longer cantilevers exhibit lower resonance frequency as compared to the shorter ones due to their lower stiffness derived from decreased area moment of inertia. However, it is notable that the collected energy increases with the resonance frequency of the cantilever which is due to increase in vibration energy as the force acting on the cantilever has a square relation with the vibration frequency.

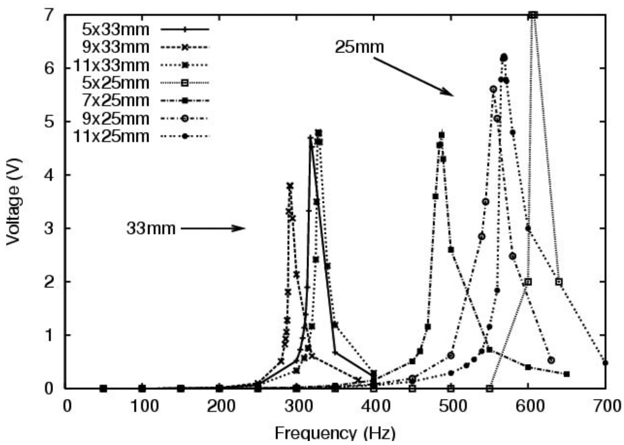

Figure 3 Frequency responses of the energy harvesters.

Rise time for the energy harvester was measured with a 1 MΩ load (the input impedance of the oscilloscope) and the vibration source was set to vibrate at the resonance frequency of the cantilever. The current output of the energy harvester was measured at the resonance frequency with a 1 kΩ load. Finally the power density was calculated based on the resonance frequency measurements and the dimensions of the cantilever. The power density was scaled to 1 g of acceleration. The summary of the measurements are shown in Table 1.

Table 1 Summary of the measurements

Cantilever	Resonance frequency [Hz]	Rise time 10–90 %, 1 MΩ load [ms]	Current into 1 kΩ [μA]	Power density [μW/cm3/g]
5 x 33 mm^2	318	250	63	74
9 x 33 mm2	291	179	88	96
11 x 33 mm^2	328	178	128	130
5 x 25.4 mm^2	605	100	164	196
7 x 25.4 mm^2	488	122	100	80
9 x 25.4 mm^2	555	83	200	192
11 x 25.4 mm^2	569	70	287	308

4 Relevance of the research

The measurement results provide valuable guidelines for designing and optimisation of the piezoelectric energy harvesting systems. Results indicate that by maximising the area of the cantilever, power density increases while resonance frequency remains fairly constant. It should be noted that very little power is harvested outside of the resonance frequency and therefore the optimal frequency of the harvester has to be tuned according to the vibration frequency by some novel desings or adaptive structures. However, the obtained results prove that piezoelectric energy harvesters are a viable option when powering low power electronics in vibrating environments. The existing prototypes would already harvest 7 Joules of electrical energy in a day which is enough for continuous temperature or ~88 acceleration measurements or up to four minutes of wireless ZigBee transmission time (Ahola et al.). Furthermore, applying external mass, scaling the structures according to application specific requirements, deploying new structures and more efficient materials will multiply the harvested energy.

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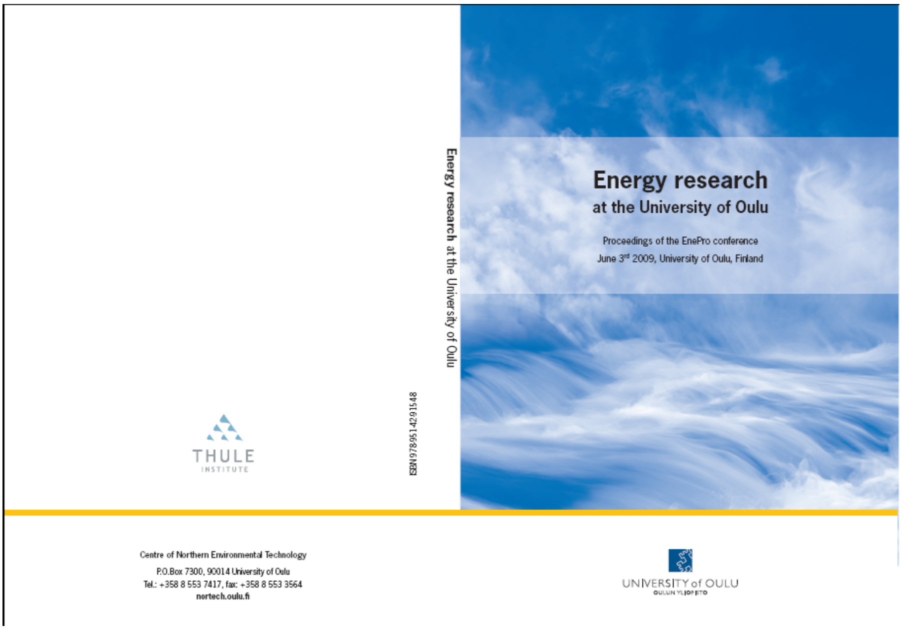

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