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KINETIC ENERGY HARVESTING USING PIEZO ELETRIC MATERIALS

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Anotation
Kinetic energy harvesting transducers is the most promising low power energy sources. Such technologies gives opportunity ensure lifetime power supply for low power systems i.e. networks of wireless sensors, wearable electronics and electronics for monitoring of physiological parameters. The most attractive kinetic energy harvesting technology is piezoelectric energy harvesting. Piezoelectric transducers are cheap, have simple construction and low operation costs in comparison with other kinetic energy harvesting technologies. This paper represents experimental investigation of bimorph with brass beam. Experimental investigations of the beam were performed in order to obtain electrical and electromechanical characteristics i.e. voltage versus resistance load, current versus resistance load characteristics. Moreover characteristics of beam angle inclination versus voltage were investigated. Analysis of the obtained data showed that proposed prototype could be employed as power supply of low power electronics.
KEY WORDS: Energy harvesting; piezo electrical materials; kinetic energy devices; low power devices.

Introduction

Energy harvesting from ambient has high potential to use kinetic energy for power supply. Kinetic energy sources can be anything that have periodic motion. For example vibrations of machines, motion of human walking, vibrations of buildings and etc. [1] Therefore, such technology gives opportunity obtain lifetime power supply for various low power electronics and devices with wireless data transfer. [2]

The most common transducers for kinetic energy harvesting is electromagnetic, electrostatic, triboelectric and piezoelectric transducers. In comparison with piezo electric transducers electromagnetic, electrostatic and triboelectric transducers has low power density and complex constructions. In addition to this electrostatic transducers should has external power source.[3,4] These, disadvantages has negative impact for practical applications, on the other hand piezoelectric energy harvesting transducers are more promising due to high power density, simple construction and low cost of producing.[5]

In general, piezoelectric kinetic energy harvesting device is cantilever beam with one or two piezoelectric layers. In most cases, cantilever beam is excited by host motions of and as a result strains are inducted in piezoelectric layers and generates an alternating voltage across electrodes placed on an active layers of the device [6]. Constructions of the bimorph and unimorph are given in Fig. 1

The main disadvantage of cantilever beams as energy harvesting systems is effective mechanical energy conversion possible only at specified excitation frequency. In line with this can be said that the most effective energy conversion will be archived only at resonance of natural frequency of the beam and host vibrations.[7]

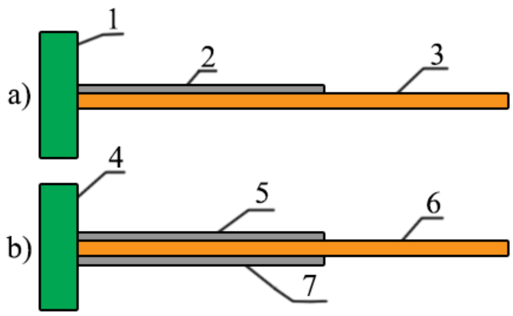

Fig. 1 Construction of the cantilever beams; a – unimotph; b – bimorph; 1, 4 - host structure; 3,6 – supporting beam; 2,5,7 – piezoceramic

Many authors investigated possibility wideband frequency energy harvesting by employing comb -type systems based on different cantilever beams. (Fig. 2) Such construction of the systems ensures possibility harvest kinetic energy with different frequencies of the motion.

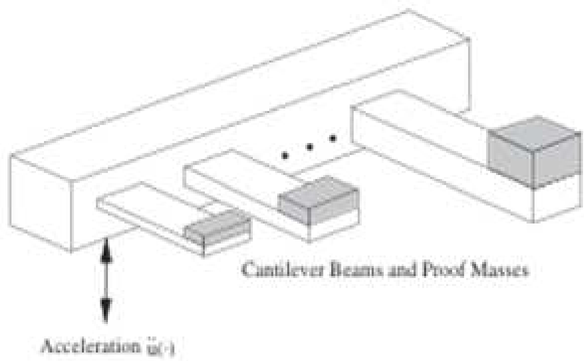

Fig. 2 Comb – type kinetic energy harvesting system for wideband excitation frequencies

This paper represent experimental investigation of the cantilever beam based on the bimorph. Goal of the investigation was indicate level of the electrical outputs generated by designed beam. Experimental investigation was carried out with two types of the electrical interfaces i.e. based on the general purpose diodes and Shottky diodes in order to indicate the best rectifier for generated voltage.

Piezoelectric phenomena and materials

There are two main types of synthetic piezoelectric materials i.e. piezo ceramics like Lead Zirconate Titanate (PZT) and piezopolymer like Polyvinylidene Fluoride (PVDF). The models of each material are given in Fig.3 and Fig.4, respectively.

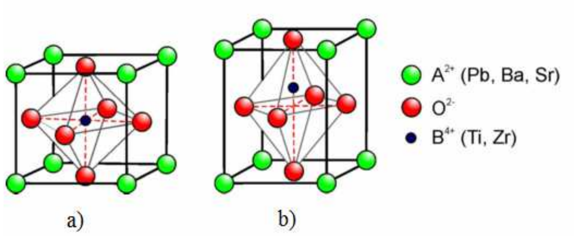

Fig. 3 Model of the PZT; a – above curie point; b – below Curie point.

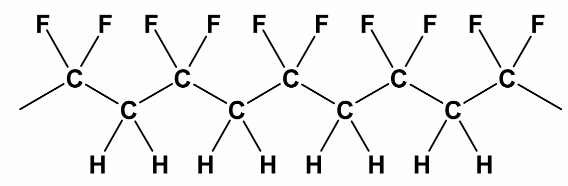

Fig. 4 Model of the PVDF

Piezo ceramics and piezo polymers are unique due to ability to convert mechanical energy to the electric charge, this means that by straining piezo ceramic material, electrical potential will be generated on the surface of the material. Moreover piezo material could act like two-sided transducer. i.e. convert strain to electrical potential as shown in Fig. 4, or convert electrical potential to strain as shown in Fig. 5.

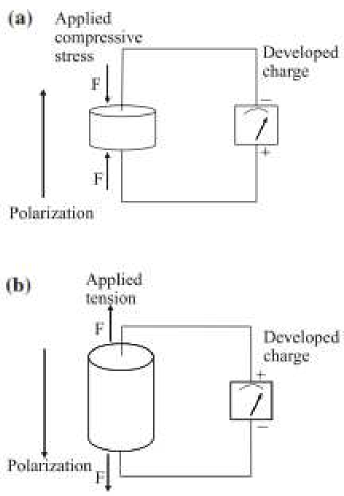

Fig. 5 Direct piezo-effect; a – at applied compressive stress; b – at applied tension

Direct piezoelectric effect is characterized by the charge which is accumulated on the surface of the piezoelectric materials when they are strained or stressed by mechanical forces.

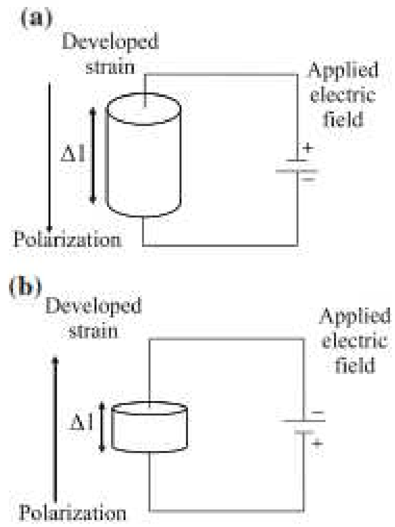

Fig. 6 Inverse piezo-effect at applied electrical field

Inverse piezoelectric effect is characterized by the inducted deformations of the material. These deformations is caused by applied electric field to piezoelectric material.

The mechanical and electrical behavior of the piezoelectric material can be modeled by strain-charge form equations as given below.

$$S = [s]_E \cdot T + [d]^t \cdot E \qquad (1)$$
$$D = d \cdot T + \varepsilon_T \cdot E$$

where S –is strain inducted in material; D – charge – density displacement; s_E – is compliance matrix of the material; T – is stress inducted in material; d^t - piezoelectric coefficients for the material; E – electric field; d is piezoelectric coupling terms; ε_T – permittivity of the material.

In summary of this chapter can be concluded that the generated electrical charge is directly related to strain applied to piezoelectric material. In line to this can be said that generated electrical outputs are directly linked to mechanical characteristics of the energy harvesting system. So, according to this can be said that strain should be improved at energy harvesting system in order to obtain higher energy conversion coefficient.

Experimental investigation

Experimental investigation was performed in order to investigate electrical characteristics of the designed cantilever beam. For this purpose was made prototype of the beam. View of the prototype is given in Fig. 7.

Prototype of the kinetic energy harvesting system consist of seismic beam (Fig.7 – 1). Seismic beam acts as vibration amplitude amplifier. It is made of cooper tube with length 350 mm, piezoelectric buzzer with two piezo ceramic layers (Fig.7 – 2), diameter of it is 50 mm. Piezo ceramic layer has diameter 29mm, thickness 0.3mm of each layer. Clamping beam was made of cooper tube as seismic beam and has 10 mm length.

Fig. 7. Prototype of the kinetic energy harvesting system; 1 – seismic beam; 2 – piezoelectric buzzer; 3 – clamping beam

Experimental investigation was performed by employing experimental setup. Schematic is given in Fig. 8.

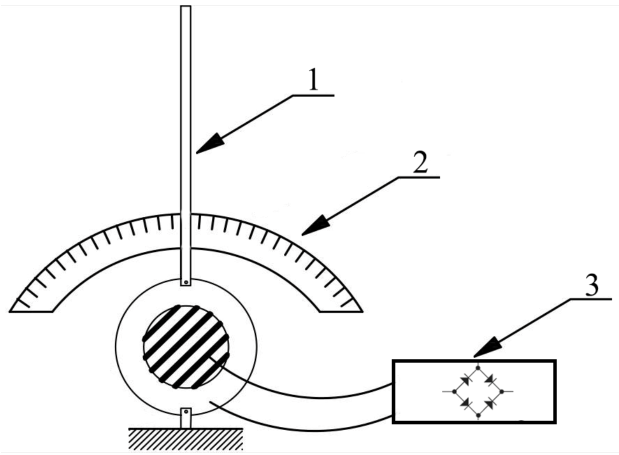

Fig. 8. Schematic of the experimental setup; 1 – energy harvesting system; 2 – protractor; 3 – electrical circuit

As shown in Fig. 8 experimental setup consist of protractor (Fig.8 – 2) who was used for measurement of the beam inclination angle. Electrical circuit (Fig. 8 – 3) was used for rectifying of the generated voltage and measurement of it.

Two types of the electrical circuits were used. First one was based on general purpose diodes 1N4007 as shown in Fig. 9 - a. Second one was based on Shottky diodes 1N5819G as shown in Fig. 9 – b.

In the proposed circuit diodes D1 – D4 acts as full bridge rectifier, capacitor C1 was employed as energy storage device and R1 acts as variable resistance load. Ammeter and voltmeter was used for measurements of the electrical characteristics.

Firstly voltage versus resistance load characteristics was investigated. Results of the investigation are given in Fig. 10.

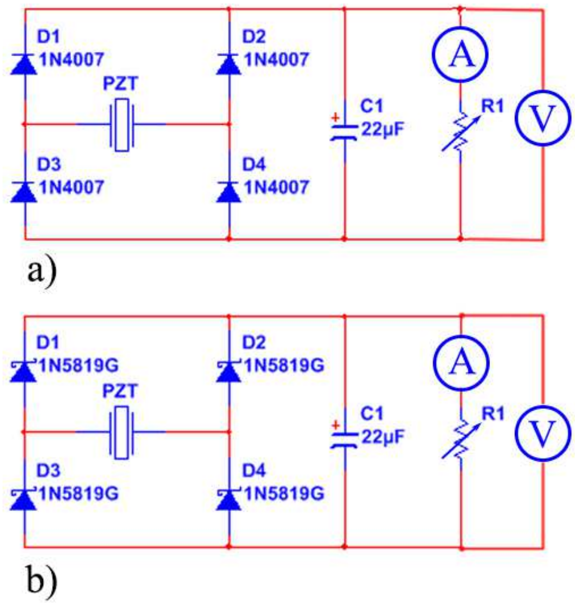

Fig. 9 Electrical circuits used for investigation; a - with general purpose diodes 1N4007; b – with Shottky diodes 1N5819.

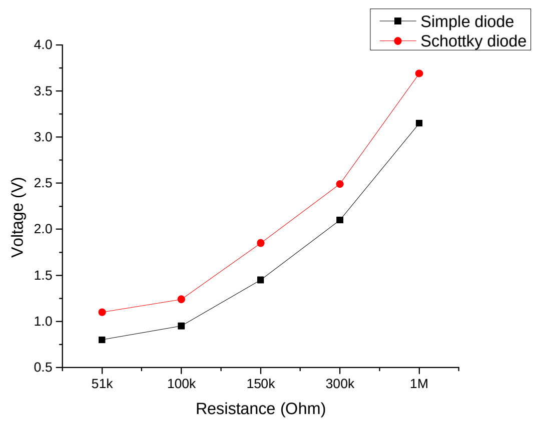

Fig. 10 Voltage versus resistance load characteristics

Analysis of the Fig. 10 showed that generated voltage has higher level with Shottky diodes based electrical circuit. This difference is caused by lower voltage losses in Shottky diodes in comparison with general purpose diodes. Difference in voltage level at each resistance load is approximately 0.3V. The highest voltage was obtained at resistance load 1MΩ and it was equal to 3.8V.

In this stage of the investigation can be concluded that Shottky diodes are more suitable for energy harvesting system due to lower voltage losses during voltage rectifying.

Next stage of the investigation was dedicated to Current versus resistance load characteristics. Results of the investigation are given in Fig. 11.

Analysis of the current - resistance load characteristic showed that general purpose diodes has positive impact to generated current. Current value is higher more than 2 times on the 51kΩ in comparison with Shottky diodes. Moreover was noticed that impedance marching of the power source and load was obtained on 300kΩ resistance load. Marching of the impedance revealed that Shottky

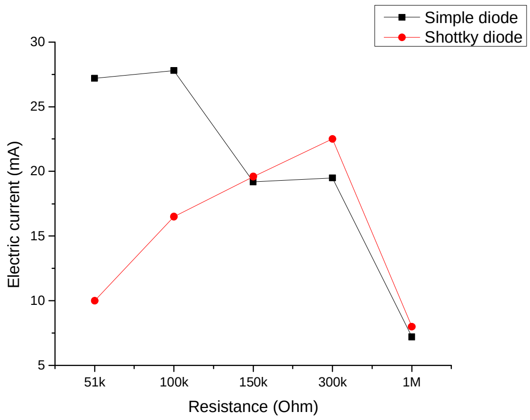

Fig. 11. Current versus resistance load characteristics

diodes has positive impact to generated current during impedance marching i.e. current was higher more than 8mA at such conditions.

In summary of this part of the investigation can be concluded that general purpose diodes are more suitable for energy harvesting when impedance of the power source and resistance load does not comply. On the other hand Shottky diodes are more effective when impedance is matched. In line with these conclusions circuit with Shottky diodes was chosen for further investigation.

Next stage of the investigation was dedicated to voltage - beam inclination characteristics. Investigation was performed with three different beam inclination values i.e. 15°, 25° and 30°. For beam inclination measurements protractor was used as shown in Fig.8. For voltage rectifying was chosen electrical circuit based on Shottky and general purpose diodes, resistance load was set to 300kΩ. These characteristics of the circuit was made with strict respect to previous investigations. For each case were performed five experiments. Results of the investigation are given in Fig. 12

Analysis of the obtained characteristics revealed that voltage generated by energy harvesting system has direct link to inclination angle. It is caused by liner behavior of the piezo electric materials and it can be noticed from equation 1. Results of the maximum voltage values analysis are given in Fig. 12.

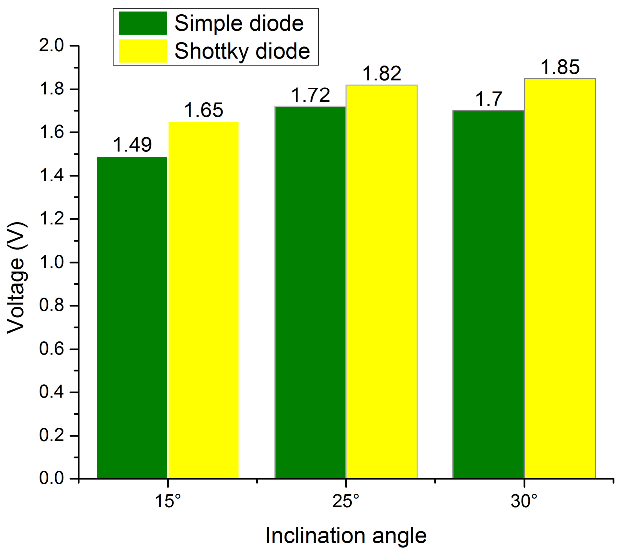

Fig. 12 Results of the maximum voltage analysis

Obtained maximum voltage values showed that the mots optimal inclination angle for designed energy harvesting system is 25°. Difference in generated voltage values at 25° and 30° is slight.

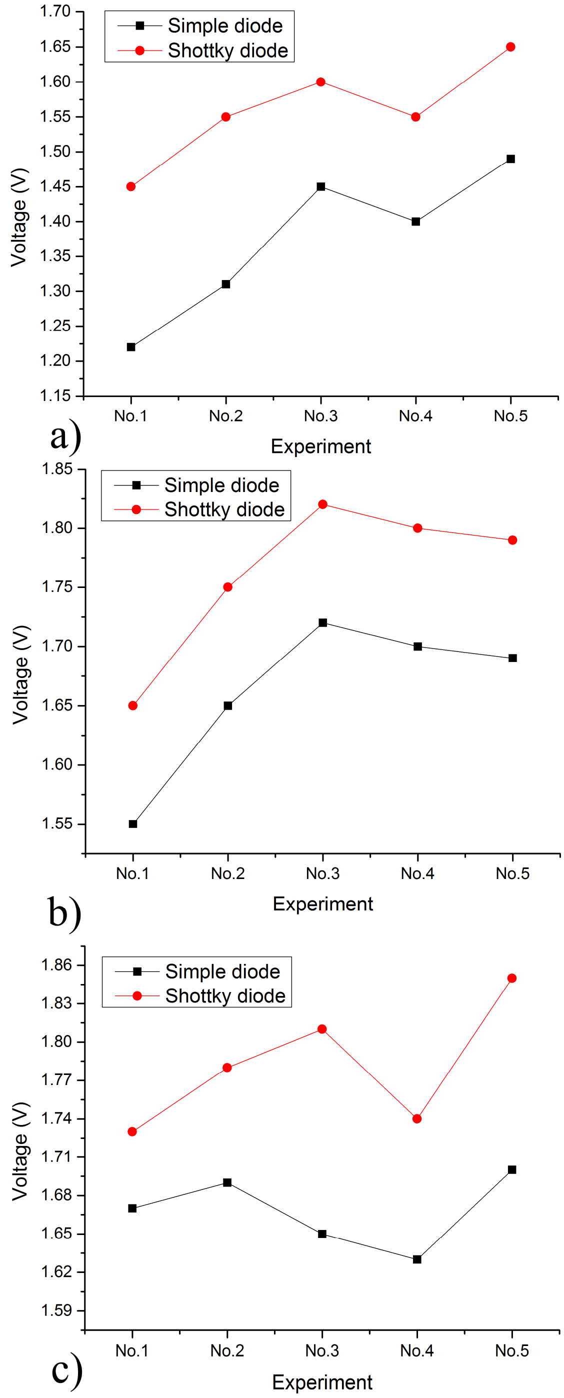

Fig. 12 Voltage - beam inclination characteristics; a – beam inclination 15°; b – beam inclination 25°; c – beam inclination 30°

Conclusions

Experimental investigation of the piezoelectric kinetic energy harvesting system based on the buzzer was performed. Study revealed that there is direct link between strain level at the piezo ceramic and electrical outputs. Experimental investigation showed that an altering voltage rectifying is more effective by employing Shottky diodes i.e. loses are less by 0.15 – 0.2V in comparison with general purpose diodes. Analysis of the voltage - beam inclination characteristics showed that optimal inclination angle for proposed system is 25°.In the end can be concluded that obtained voltage levels are suitable for low power electronics and devices with wireless data transfer, therefore so it can be summarized that proposed kinetic energy harvesting system can be used as power supply for various low power devices.

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