Output Power Optimization of Energy Harvester, Employing Segmentation of Its Electrodes

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Abstract. This research suggests employing electrode segmentation in order to avoid charge cancellation in the piezoelectric layers of harvester, which occurs, if strain nodes of vibrating harvester are covered by continuous electrodes. For the experimental investigations two types of piezoelectric energy harvester prototypes were produced from piezoelectric T107-H4E-602 plate, epoxy bonded to stainless steel substrate. The first (reference) harvester prototype posses no electrode segmentation, while electrodes covering piezoelectric material of second harvester were segmented. Segmentation of the second harvester was configured for its operation at the second resonant frequency – i. e., performed so, that the electrodes of piezoelectric material are not covering strain node of the second vibration mode. Experimental results revealed that segmented harvester prototype posses efficiency advantage as compared to the non-segmented counterpart – adding voltages, generated at each segment would result from 8% to 52% increase of maximum generated voltage.

1. Introduction

Energy harvesting from environment for wireless sensor networks (WSNs) has been in intensive research for more that a decade, as exploitation of WSN nodes, currently powered by batteries, is very expensive due to complicated battery replacement, caused by inconvenient mounting and abundance of nodes. Thus, research community is aiming to develop self-powered WSN nodes which would eliminate the most costly issue of battery replacement [1].

This research concerns structural design optimization of the harvester, as it suggests employing segmentation of harvester electrodes in order to increase its output voltage. Classical vibration theory suggests that higher vibration modes of the cantilever beam have strain nodes, where the dynamic strain distribution changes sign. If these strain nodes are covered by continuous electrodes, cancellation of electric outputs occurs, resulting in overall harvested energy reduction [2]. Thus, developed harvester prototype possess electrode segmentation configured for the harvester operating at the second resonant frequency. Its electrical outputs are experimentally measured and compared to the performance of harvester prototype, which posses no electrode segmentation.

2. Determination of harvester strain nodes

To determine preliminary location of harvester strain nodes its Finite Element (FE) model was created employing COMSOL Multiphysics software [3]. Modeled piezoelectric energy harvester is a cantilever beam, comprised of substrate and PZT-5H layer bonded to it. Respective boundary conditions were set to represent electrodes on the piezoelectric material as well as clamping of the cantilever. FE model was subjected to eigenfrequency analysis and location of the strain nodes was determined employing Von Misses stress distribution plots (Fig. 1).

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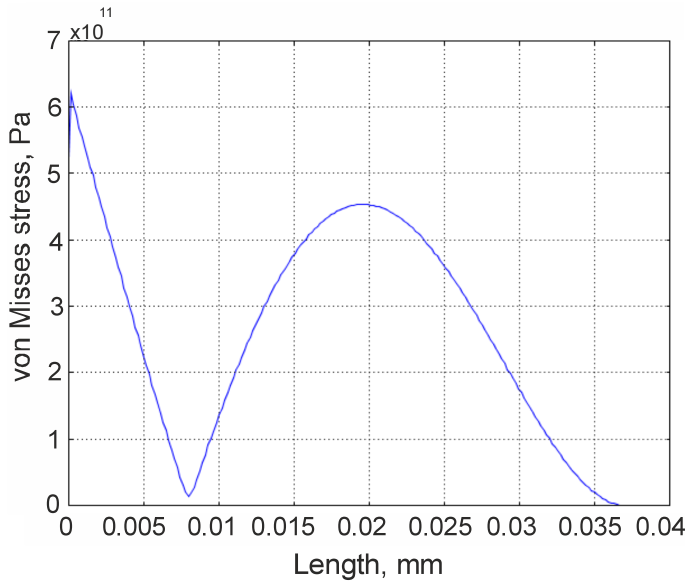

Figure 1. Von Misses stress distribution for the second vibration mode of the energy harvester.

3. Research Objects and Experimental Setup

For this study purposes two prototypes of piezoelectric energy harvesters were built. They were produced from Piezo systems, Inc. T107-H4E-602 plate covered with conductive layers, epoxy bonded to stainless steel substrate. The first harvester prototype (Fig. 2a) posses no electrode segmentation while the second harvester prototype (Fig. 2b) possess electrode segmentation configured for the harvester operating at the second resonant frequency, i. e., segmentation is performed so that the electrodes of piezoelectric material are not covering strain node of the second vibration mode.

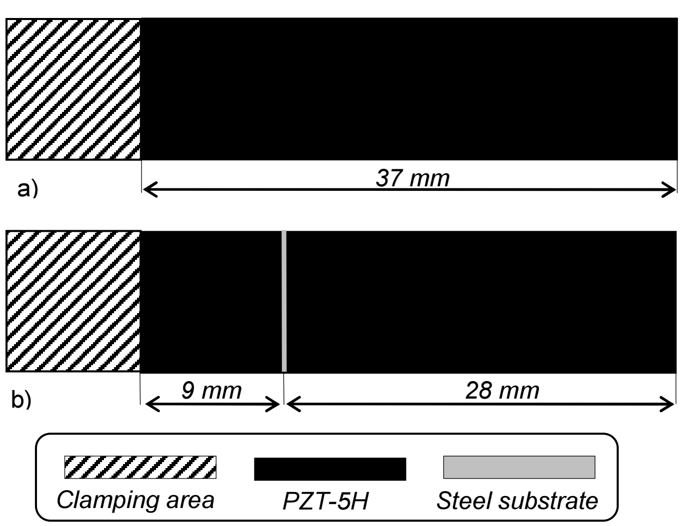

Figure 2. Schemes of produced harvester prototypes:
a) non-segmented;
b) segmented – intended for operation in 2nd vibration mode.

Experimental setup consists of a piezoelectric harvester and three main systems – excitation, measurement and data acquisition. The main part of the excitation system is an electromagnetic shaker, which is employed to excite piezoelectric harvester that is fixed in the custom-built clamp made of acrylic glass. Function generator AGILENT 33220A and voltage amplifier KROHN-HITE 7500 are used to control harmonic excitation signal transmitted to the electromagnetic shaker. Single-axis miniature piezoelectric charge-mode accelerometer METRA KS-93 is attached at the top of the clamp for acceleration measurements at the base of the harvester. Doppler vibrometry system, consisting of differential laser interferometer POLYTEC OFV-512 and vibrometer controller POLYTEC OFV-5000, is used to measure tip displacement (or velocity) of the harvester in the transverse direction. Data acquisition system consists of a 4-channel USB oscilloscope (analog-to-digital converter) PICO 3424 that collects signals from the function generator, laser vibrometer, base accelerometer and piezoelectric energy harvester through connected resistive load. Signals from the oscilloscope are forwarded to the computer with data management software (PicoLog 5®, Picoscope 6®).

4. Experimental Results

Measured frequency responce of output voltage of the second sector of energy harvester is presented in the Fig. 3. It was determined, that first resonant frequency is 235Hz, and second is 1469Hz.

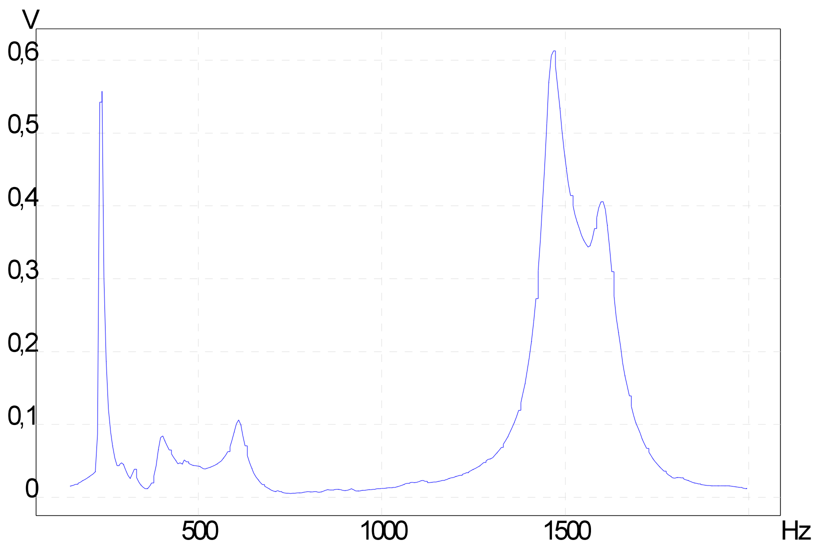

Figure 3. Measured frequency responce of output voltage of the second sector of energy harvester.

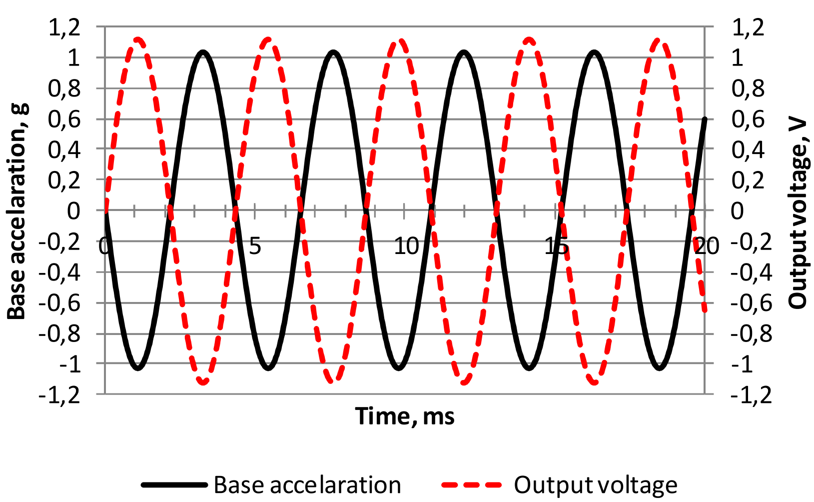

Figure 4. Measured time response of the base acceleration and output voltage of the non-segmented energy harvester.

Maximum output voltage of the non-segmented energy harvester observed at the first resonant frequency is about 1.12V (Fig. 4). However when it is excited at the second resonant frequency generated voltage decreases to 0.5V (Fig. 5, total voltage). Therefore top electrode of the energy harvester was divided to two parts in the place of the strain node as it is show in the Fig. 2.

Measured output voltage of the first sector is 0.54V and generated by second is 0.76V, while energy harvester was excited by 3g force at 1469Hz frequency. When energy harvester vibrates at the second resonant frequency the total generated energy is smaller, since generated alternate voltage by these two sectors has 2.44 radians phase shift. Summarizing it could be stated, that maximum output voltage generated separately by first or second sector is from 8% to 52% higher than maximum voltage generated by non-segmented energy harvester.

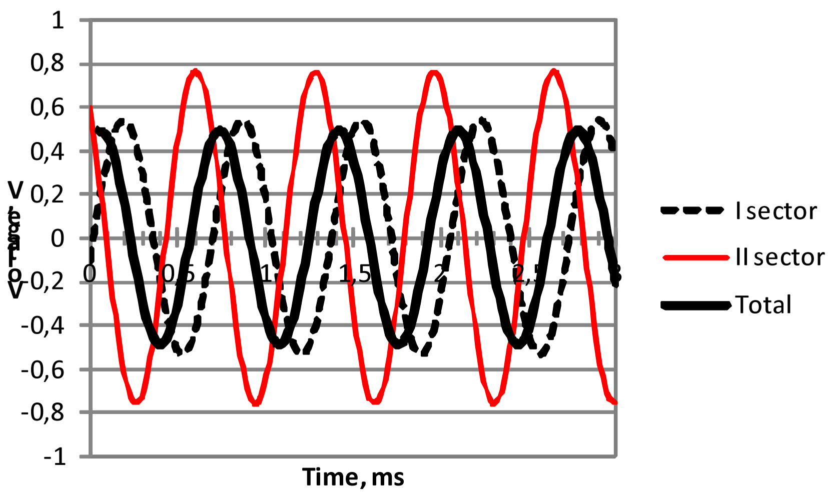

Figure 5. Measured time response of the first, second and total output voltage generated by segmented energy harvester.

5. Conclusions

It is highly important to predict location of strain nodes for different configurations of piezoelectric energy harvesters in order to avoid undesired cancellation effects and harvester efficiency reduction, which occur, if strain nodes are covered with continuous electrodes.

Experimental results show that maximum output voltage generated by first or second sector of the segmented harvester prototype is from 8% to 52 % higher as compared to the maximum output voltage generated by non-segmented energy harvester.

Acknowledgements

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References

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[3] Comsol Multiphysics http://www.comsol.com/products/multiphysics/