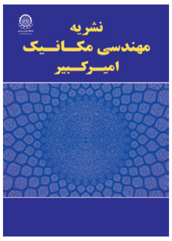

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Experimental and Numerical Investigation of Width Reduction Effect on the Output Power of Piezoelectric Energy Harvester Beam

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ABSTRACT: Considering that global energy resources are decreasing, energy harvesting from the environment has become more important. One of the most important methods of power scavenging from environmental vibrations is energy harvesting using piezoelectric materials, and researchers have recently focused on optimizing this type of energy harvesters. In this paper, the effect of decreasing beam width on the amount of harvested energy from an oscillating piezoelectric cantilever beam is investigated using experimental and numerical methods. In this study, one of the newest piezoelectric materials called electro active paper cellulose has been utilized. At first, a fixed-width beam was investigated, and then two beams with half-width of the initial beams were analyzed in series and parallel connections with the same boundary conditions, and in the next stage, the unit cantilever was divided into three equal parts and serial and parallel states of these beams have been investigated and the results are compared with laboratory data. It is seen that if the width of a beam is divided into several equal parts and some beams with fewer width and series connection are utilized, amount of harvested energy is significantly greater than the initial beam.

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1. INTRODUCTION

Energy harvesting is used to describe the scavenging of ambient energy in the environment that would otherwise be wasted [1]. For low powered electronic devices, harvesting energy from the ambient vibrations seems to be an ideal solution due to the definite life span and high cost for replacement of the traditional batteries [2]. During the past decade, energy harvesting from mechanical vibrations of ambient environments has attracted the attention of many researchers due to the ever-increasing desire to produce wireless and portable electronics with extended life. Three mechanisms are available for vibration energy harvesting, using electrostatic devices, electromagnetic field and utilizing piezoelectric based materials [3]. The performance of piezoelectric vibration energy harvesters is more often than other methods. Piezoelectric materials possess a large amount of mechanical energy that can be converted into electrical energy, and they can withstand large strain magnitude. Compared to other structural forms of beams, a cantilever beam can obtain the maximum deformation and strain under the same conditions. Therefore the vast majority of piezoelectric vibration energy harvesting devices use a cantilever beam structure [4]. Most of the previous research focused on designing a linear vibration resonator, in which the maximum system performance can be achieved when the energy harvester is tuned to match its resonance frequency with the external excitation frequency. Hence, much attention is required in the choice of piezoelectric material. Cellulose Electro-Active Paper (EAPap) is a novel smart material which its efficiency in energy harvesting applications has proven, recently. In this paper, cellulose EAPap-based piezoelectric energy harvester is used for the investigation. Up to three cellulose elements are connected in parallel and series, respectively. However, as yet no study has been conducted with cellulose in both series and parallel connections, in this investigation. The potential applications for both the series and parallel connections are discussed based on their harvested voltage, current and power output.

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2. METHODOLOGY

The EAPap piezoelectric energy harvester was fabricated in the form of a cantilever beam. Aluminum beam with a length of 200 mm, a width of 50 mm and thickness of 1 mm was used as the host structure for capturing the ambient vibration energy by bending of the structure. The beam's length is inclusive of 5 cm fixing part that has four holes for screw fastening, and the EAPap film with the dimensions of 80 mm length and 50 mm width attached 10 mm away from the fixing line (refer to Fig. 1). The EAPap film was attached near to its clamped base where the largest bending was found.

The EAPap piezoelectric energy harvester in the form of the cantilever beam (or simply EAPap piezo beam) was fixed on the bobbin of an electromagnetic shaker (Eliezer HEV-50) with tightening jig. The piezo beam was excited with 100 mV input voltage controlled using a function generator (Agilent 33220A) and amplifier (Eliezer EA157) in the frequency range of interest. This is corresponding to 2 mm of displacement input. An accelerometer was used to monitor the displacement input where the input voltage was adjusted whenever necessary to maintain the displacement.

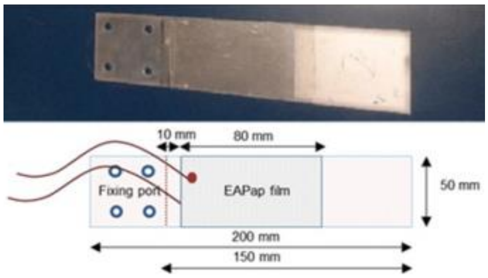

Fig. 1: Photograph and schematic diagram of the EAPap piezoelectric energy harvester [5]

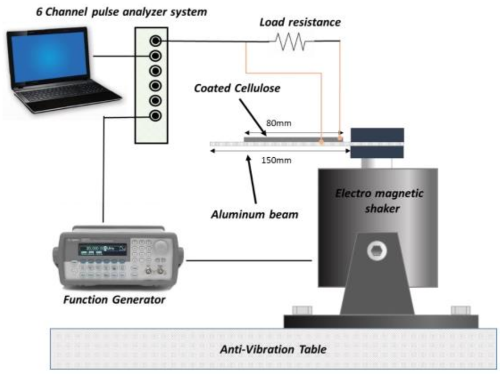

Fig. 2: Schematic of the experimental setup [5]

The experimental arrangement is shown in Fig. 2.

A potentiometer was used as resistive external load, added in series to the EAPap film for the measurement of power output. A picoammeter (Keithley 6485) was used to measure the electric current in the circuit, and a pulse analyzer (Bruel & Kjaer 35360B-030) was used to monitor voltage output. The impedance of EAPap film was measured using LCR meter (HP 4282A) and with respect to the frequency changes.

The energy harvesting from piezoelectric materials is an electromechanical phenomenon and both mechanical and electrical equations must be considered in numerical analysis. Comsol multiphysics considers electrical and mechanical equations for numerical analysis of energy harvesting from piezoelectric materials. The numerical solution consists of three sections: solid mechanics, electrostatic and the electrical circuit. In the numerical investigation, solid mechanics section covers the vibration analysis of cantilever beam, electrostatic is related to piezoelectric analysis and the electrical circuit is related to the analysis of the designed circuits.

3. RESULTS AND DISCUSSION

By decreasing the width of the beam, the natural frequency remains constant. The effect of reducing the width of the beam on the natural frequency in the experiment and numerical solution (Finite Element Method (FEM)) is shown in Table 1.

Piezoelectric harmonic movement leads to the generation of harmonic output voltage and current. The empirical values of voltage, current and maximum power are shown in Tables 2, 3 and 4, respectively. Each column of these tables corresponds to one step of the experiment (S: Series and P: Parallel).

Table 1: Natural frequency results in the experimental and numerical solutions

width(mm)	50	25	16.6
Experimental(Hz)	36.5	35.2	35.8
FEM(Hz)	36.64	36.5	36.45

Table 2: Numerical and experimental results of V_{p-p} for partially covered cellulose-based piezoelectric energy harvester

width(mm)	50	25		16.6	
Voltage(mV)		S	P	S	P
Experimental	256	40	173	65	185
Numerical	248	39	168	60	166

Table 3: Numerical and experimental results of I_{p-p} for partially covered cellulose-based piezoelectric energy harvester

width(mm)	50	25		16.6	
Current(nA)		S	P	S	P
Experimental	284	133	231	90	302
Numerical	274	131	224	83	280

Table 4: numerical and experimental results of P_{mean} for partially covered cellulose-based piezoelectric energy harvester

width(mm)	50	25		16.6	
Power (nW)		S	P	S	P
Experimental	0.91	1.28	1.00	1.4	1.4
Numerical	0.92	1.31	1.03	1.1	1.3

4. CONCLUSIONS

The analytically obtained expressions are used in a parametric case study with a novel piezoelectric material that has started to receive much attention due to its huge potential for various piezoelectric energy harvesters and is called EAPap. Width reduction is an applied method that can lead to maintaining the fundamental natural frequency of the beam at a constant value and increase the output harvested power. The width-split method is a practical way for increasing the electromechanical coupling and therefore the electrical outputs of the harvester. Future works will consider design optimization of the cellulose EAPap-based energy harvesters by the width-split method will be investigated to achieve the optimal geometry.

REFERENCES

[1] R. Hosseini, M.J.I.J.o.A.D. Hamedi, M. Technology, Study of the resonant frequency of unimorph triangular V-shaped piezoelectric cantilever energy harvester, 8(4) (2015).

[2] R. Hosseini, M.J.J.o.M. Hamedi, Microengineering, Improvements in energy harvesting capabilities by using different shapes of piezoelectric bimorphs, 25(12) (2015) 125008.

[3] R. Hosseini, M. Hamedi, An investigation into resonant frequency of triangular V-shaped cantilever piezoelectric vibration energy harvester, (2016).

[4] R. Hosseini, M.J.J.o.C. Hamedi, A.R.i.M. Engineering, Resonant frequency of bimorph triangular V-shaped piezoelectric cantilever energy harvester, 6(1) (2016) 65-73.

[5] R. Hosseini, M. Hamedi, J. Im, J. Kim, J.J.I.J.o.P.E. Dayou, Manufacturing, Analytical and experimental investigation of partially covered piezoelectric cantilever energy harvester, 18(3) (2017) 415-424.