IEEE Student Conference on Research & Development 2013

Comparison Study between Four Poles and Two Poles Magnets Structure in the Hybrid Vibration Energy Harvester

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Abstract— Vibration energy harvester is receiving considerably amount of interest for the past decade. Many improvements such as making it tunable, broadband based and hybrid harvester have been demonstrated in the literature, generally to exploit more electrical energy from the ambient. In this paper, we study the arrangements of the magnets that referred to as cantilever beam proof mass, as means for generating greater electrical power output. The harvesters consist of piezoelectric cantilever beam with two different arrangements of magnets; two poles magnets and four poles magnets attached to its free end tip. A coil is placed underneath the magnets arrangement, so that when the harvester is being excited by external vibration, both piezoelectric and electromagnetic transducer will generate electrical energy. In this paper, a comparison study in terms of generated output voltage, induced current and generated electrical power output are presented. Experimental results show that, four pole magnets type harvester is capable of generating greater electrical power as compared the two pole magnets type harvester when exposed to its resonant frequency at 1g acceleration (1g = 9.8 ms^{-2}) . This implies that by incorporating a proper magnets arrangement, the harvester is capable of producing greater power output.

***Index Terms*— Four poles magnets, hybrid, vibration energy harvester, piezoelectric, electromagnetic**.

I. Introduction

In the past decade, research in the field of energy harvesting has shown an increasing trend in terms of publications and prototype demonstrations [1-7]. Vibration energy harvesting specially from piezoelectric and electromagnetic transduction mechanisms are getting popular among others generally because of their better performance in terms of power density [4, 8-9].

Earlier Roundy [4] had shown that his prototype which consist of bimorph piezoelectric cantilever with a tungsten alloy as the proof mass attached to the cantilever beam free end tip capable to generate considerably high power density. Later on, S Beeby [8] demonstrated his electromagnetic harvester using a silicon wafer as the cantilever beam with a stationary coil representing proof mass attached to its free end tip. Four magnets constituting a four poles magnet arrangement were fixed firmly in between the coil. The prototype was capable of generating significantly high output power over its size.

Aforementioned harvesters used single element of transducer to generate electrical energy either piezoelectric or electromagnetic element. Combining and integrating these two elements of transducer in a single unit called hybrid energy harvester would produce greater electrical energy [10]. Different arrangements of magnets used as proof mass in the harvester design also would give different electrical energy. In this paper, we study the characteristics of the four poles and two poles magnets arrangement used as the proof mass in the hybrid harvester based on piezoelectric and electromagnetic to generate electrical energy. The study comprises the comparison of generated output voltage, induced current and generated electrical power output when these harvesters are vibrated at acceleration level of 1g and its resonant frequency.

II. ENERGY HARVESTER CONFIGURATION AND SET-UP

A. Energy Harvester Configuration

The harvesters used in the experiment consist of piezoelectric cantilever beam with a proof mass made from arrangement of few magnets, attached to its free end tip, while the other end tip is fixed rigidly to a base. A coil is placed securely underneath the cantilever proof mass, so that when the cantilever moved up and down due to external vibration, both piezoelectric and electromagnetic able to generate electrical energy based on the transduction mechanism.

In this paper, two harvesters are presented and analyzed. The first harvester used a brass reinforced piezoelectric cantilever purchased from Piezo Systems Inc. with dimension 63.5mm x 31.8 mm x 0.51mm with four Neodymium magnets having size of 25 mm x 10 mm x 5 mm were arranged accordingly, to make a four poles magnets arrangement at the cantilever free end tip. A coil with 1200 number of turns, made from 0.02sq mm BELDEN 8057 USA magnet wire was placed in between of the magnets arrangement as shown in Fig. 1.

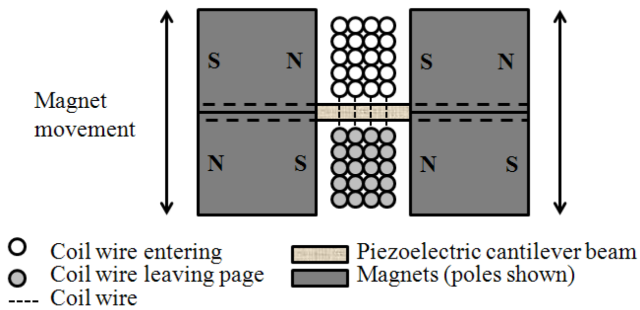

Fig. 1. Cross section view through the four poles magnets arrangement.

The second harvester used the same piezoelectric cantilever beam and coil. The only differences were their magnets arrangement and the position of the coil. The magnets used in this harvester were Neodymium magnets, having diameter of 4mm and thickness of 3mm. These magnets were arranged so that its form a two poles magnets arrangement. The same coil that used in the first harvester was placed underneath the bottom magnet as shown in Figure 2.

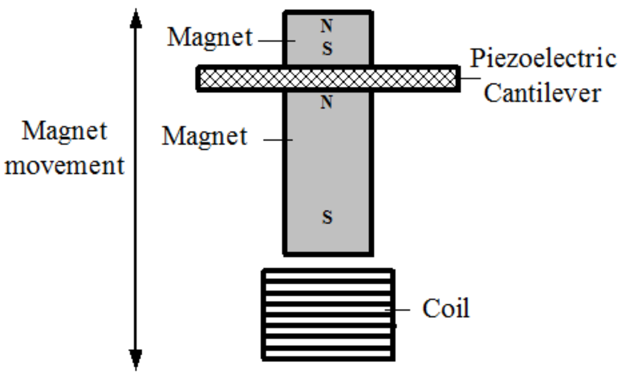

Fig. 2. Cross section view through the two poles magnets arrangement.

B. Experiment Set-up

Testing of the harvesters was conducted using a shaker unit with accelerometer feedback and tunable decade resistance. The accelerometer used in this experiment was connected to Digital Multimeter, to find the value of the voltage that correspond to the desired acceleration level in g. Function generator, power amplifier and shaker unit were used to simulate the ambient vibration that would be exerted into the harvester. The output voltage generated from each of the transducer in the hybrid harvester, piezoelectric and electromagnetic were taken by observing the voltage waveforms displayed on the oscilloscope. Detail of the apparatus used in the experiment is shown in Table 1.

Table 1. Experiment equipments

ADXL 335; Zout, Sensitivity 300mV/g, Vcc :3V
Oscilloscope RIGOL DS 5152CA 2 channels
Decade Resistance
Shaker Labworks Inc. ET-126HF
Power Amplifier Labworks Inc. pa-138
Function Generator ED-4770
Digital Multimeter SANWA CD771

Figure 3 and 4 show the photographs of experiment set-up for both harvesters analyzed in the experiment; four poles magnets type harvester and two poles magnets type harvester.

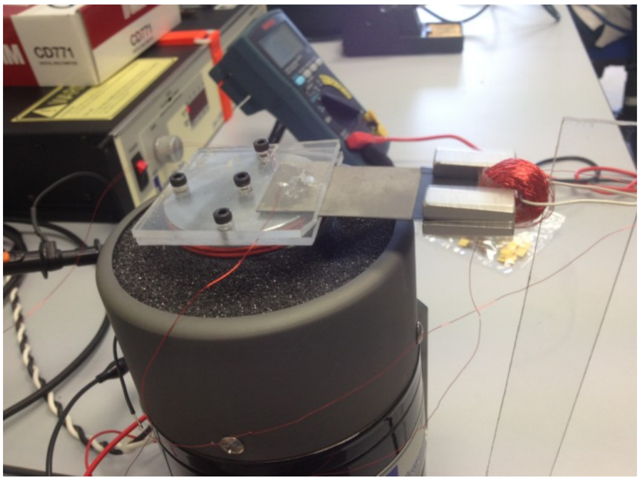

Figure 3. Testing four poles magnets type harvester

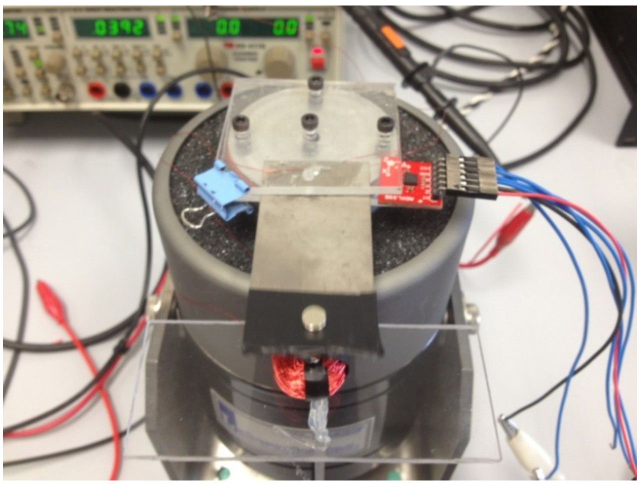

Figure 4. Testing two poles magnets type harvester

III. ENERGY HARVESTERs RESULTS AND PERFORMANCE

The result of the measured output voltage for these two arrangements of magnets; two poles and four poles magnets are plotted and shown in Figure 5. In this study, the harvester was excited at 1g acceleration and at its resonant frequency, in which the two poles magnets type harvester having resonant frequency of 49 Hz while the four poles magnets type harvester having resonant frequency of 15 Hz. This excitation condition applies to all analysis presented in this paper.

In Figure 5, apparently, we can see that the four poles magnets type of harvester produces greater output voltages against the load resistance for both transducers; piezoelectric and electromagnetic as compared to the two poles magnets type of harvester. By taking resistive load of 100MΩ for comparison purpose, result shows that the four poles magnets type harvester produce 14.1V from piezoelectric and 0.8V from electromagnetic respectively. Meanwhile for two poles magnets type of harvester, both piezoelectric and electromagnetic produce relatively lower output voltage with each of them generated 9.5 V and 0.3V respectively.

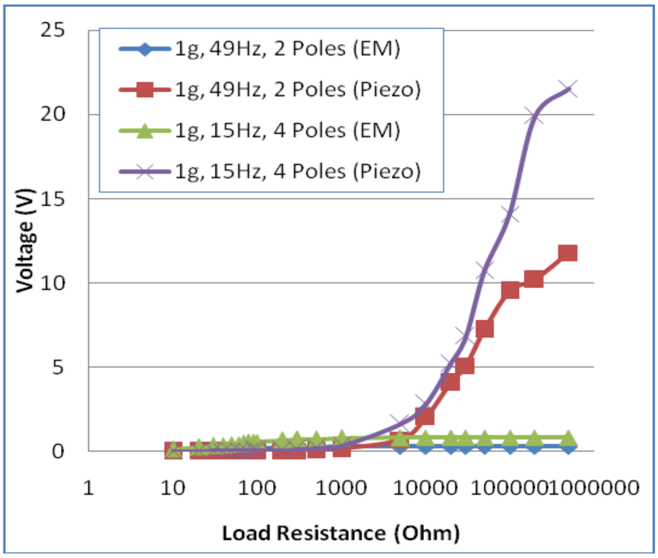

Figure 5. Output voltage against load resistance

In Figure 6, the results of the current induced in both piezoelectric and electromagnetic for two poles and four poles magnets type of harvester are plotted and shown for comparison purpose. From the figure, we can see that four poles magnets arrangement type of hybrid harvester induced more current against the load resistance as compared to the two poles magnets type harvester. Taking resistive load of 10 Ω for analysis purpose, output current of 0.6 mA and 14.5 mA are induced in each of the transducer elements, piezoelectric and electromagnetic for the four poles magnets type of harvester. Meanwhile, for the two poles magnets type of harvester, relatively smaller amount of output currents are produced with 0.8 mA induced in piezoelectric while 5.7 mA induced in electromagnetic.

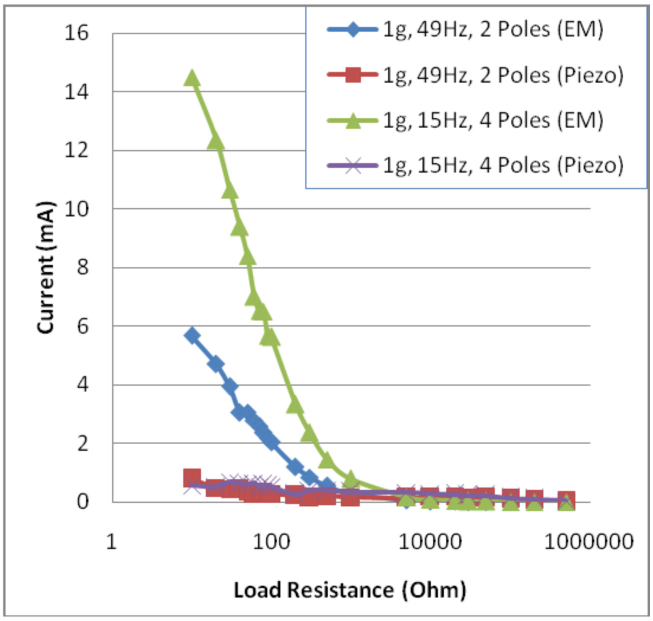

Figure 6. Induced current against load resistance

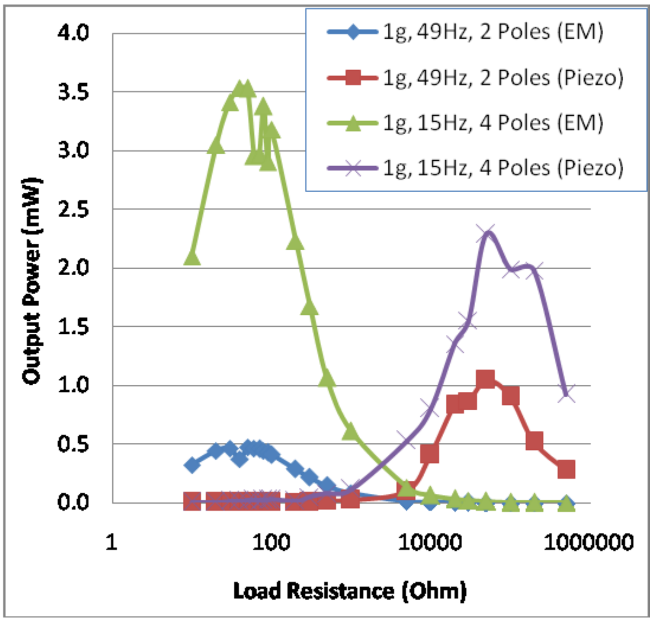

Figure 7. Electrical power output against load resistance

Figure 7 shows the comparison of generated output power from both piezoelectric and electromagnetic for the two harvesters. It shows that, greater electrical output power was generated from the four poles magnets type of harvester as compared to the two poles magnets type harvester. In detail, result shows that optimum power output of 2.3 mW (resistive load= 40Ω) and 3.5 mW (resistive load =50mΩ) were generated from each piezoelectric and electromagnetic transducer of the four poles type harvester, in which electromagnetic transducer generating comparatively higher electrical power as compared to piezoelectric. However for the two poles magnets type of harvester, electromagnetic transducer generated smaller amount of optimum electrical power output, 0.5mW (resistive load =50Ω) as compared to piezoelectric transducer with 1 mW (resistive load 50MΩ).

IV. CONCLUSIONS

This paper presented the comparison study in terms of output voltage, induced current and electrical power output generated from the hybrid energy harvester based on piezoelectric and electromagnetic transducers with two different magnets arrangement were studied. The first one using four poles magnets arrangement, while the second one using two poles magnets arrangement. These magnets were attached securely on the piezoelectric cantilever beam end tip, referred to as the cantilever beam proof mass, with a wounded coil placed rigidly underneath the magnets arrangement. Although, these two harvesters were different in terms of the magnets arrangement, however, they shared similarity in terms of transduction mechanism. When the harvesters were excited by an external vibration (1g acceleration at resonant frequency) the piezoelectric cantilever beam together with the magnets will oscillates up and down as one unit. This movement would result in either strain or stress in the piezoelectric cantilever beam, that eventually will produce electrical energy. On the other hand, the effect of the movement also would produce magnetic flux changes that would induce an AC current in the wounded coil. This eventually would generate an electrical energy from the electromagnetic transducer as well.

Experimental results show that, four poles magnets type harvester was able to generate greater output voltage, induced current and electrical power output from both piezoelectric and electromagnetic transducer as compared to the two poles magnets type harvester. Taking electrical power output as an example, optimum power output of 2.3 mW (resistive load= 40Ω) and 3.5 mW (resistive load =50mΩ) were capable to be generated from each piezoelectric and electromagnetic transducer in the four poles magnets type harvester as compared to the two poles magnet type harvester with only 0.5mW (resistive load =50Ω) and 1 mW (resistive load 50MΩ) power output that able to be generated from each electromagnetic and piezoelectric transducers.

This implies that, with proper magnets arrangement used for the cantilever beam proof mass, greater electrical power is capable to be generated, in which the four poles magnets arrangement is referred in this study.

V. ACKNOWLEDGMENT

The authors thank Ministry of Higher Education for the research grant, PRGS/2011/FKEKK/TK02/1 – T00001 as well as University Teknikal Malaysia Melaka for the Short Term Grant Research Scheme PJP/2012/FTK(36A)/S01040.

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