2013 IEEE Student Conference on Research and Development (SCOReD), 16 -17 December 2013, Putrajaya, Malaysia

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

Mohd Fauzi. Ab Rahman[1], Swee Leong. Kok[2], Eliyana. Ruslan[3], Abdul Halim. Dahalan[4], Saifullah. Salam[5]
[1,3,4,5]Faculty of Engineering Technology, [2]Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[1]`mfauziar@utem.edu.my`
[2]`sweeleong@utem.edu.my`

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 would generate electrical energy. In this paper, a comparison study in terms of generated voltage output, induced current and generated electrical power output are presented. Experimental results show that, the new approach; four pole magnets type harvester is capable of generating greater electrical power as compared to the conventional approach; 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 particularly based on piezoelectric and electromagnetic transduction mechanisms are getting popular among others generally because of their better performance in terms of power density generation [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 was capable to generate considerably high power density. Later on, S. Beeby [8] demonstrated an 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 power output 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 cantilever proof mass in the harvester design also would influence the generated electrical energy. In this paper, we investigate the characteristics of the new approach; four poles magnets arrangement as compared to the conventional approach; two poles magnets arrangement as the cantilever beam proof mass in the hybrid harvester. The investigation comprises the comparison of generated voltage output, 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 its transduction mechanism.

In this paper, two harvesters are presented and analyzed. These two harvester used a brass reinforced piezoelectric cantilever purchased from Piezo Systems Inc. with dimension 63.5mm x 31.8 mm x 0.51mm. For the first harvester, four Neodymium magnets with dimension of 25 mm x 10 mm x 5 mm were arranged so that it made 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.

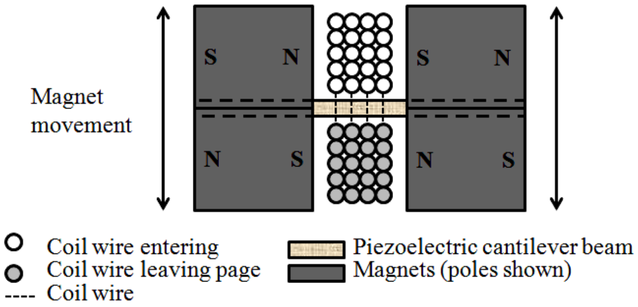

Fig. 1. Cross section view through the four poles magnets arrangement.

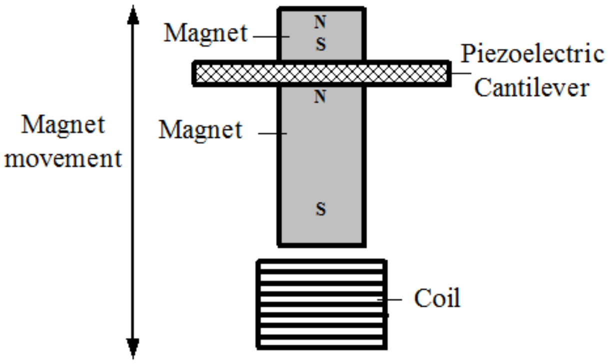

Fig. 2. Cross section view through the two poles magnets arrangement.

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 4 mm and thickness of 3 mm. These magnets were arranged so that its form a two poles magnets arrangement, with one pole located on the top while the other pole located at the bottom of the piezoelectric cantilever beam. The bottom pole magnet consists of three magnets that having same dimension as the top magnet, were stacked together as one unit to make a large bottom pole magnet. The same coil used in the first harvester was placed underneath the bottom magnet as shown in Fig. 2.

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 with respective 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 voltage output 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

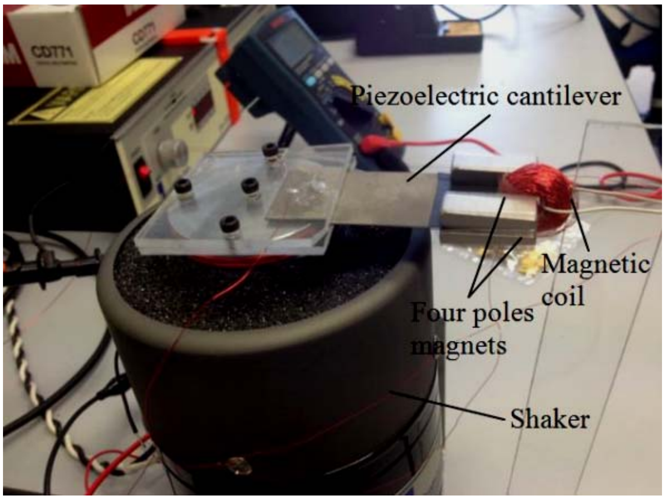

Fig. 4. Testing two poles magnets type harvester

Fig. 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.

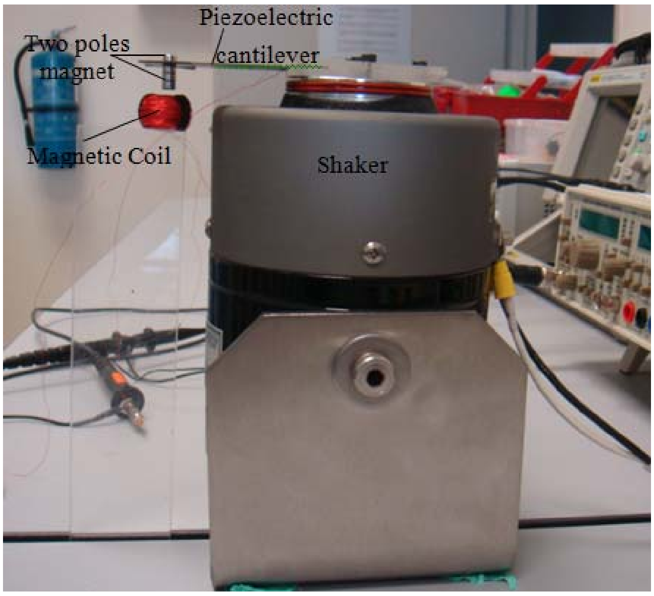

Fig. 3. Testing four poles magnets type harvester

III. ENERGY HARVESTERs RESULTS AND PERFORMANCE

In this study, we show the comparison in terms of voltage output, induced current and electrical power output generated from the hybrid energy harvester based on piezoelectric and electromagnetic transducers with two different magnet arrangements. 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 as the beam proof mass, with a wounded coil placed rigidly underneath the magnets arrangement. Although, these two harvesters were different in terms of 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 oscillates up and down as one unit. This movement resulted in either strain or stress in the piezoelectric cantilever beam that eventually produced an electrical energy. Furthermore, the effect of the movement also produced magnetic flux changes that induced an AC current in the wounded coil. This eventually would generate an electrical energy from the electromagnetic transducer as well.

The result of the measured voltage output for these two arrangements of magnets; two poles and four poles magnets are plotted and shown in Fig. 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.

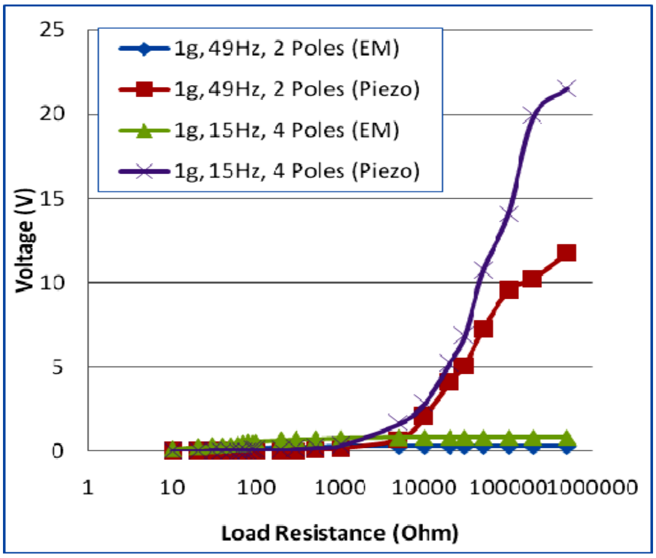

Fig. 5. Voltage output against load resistance

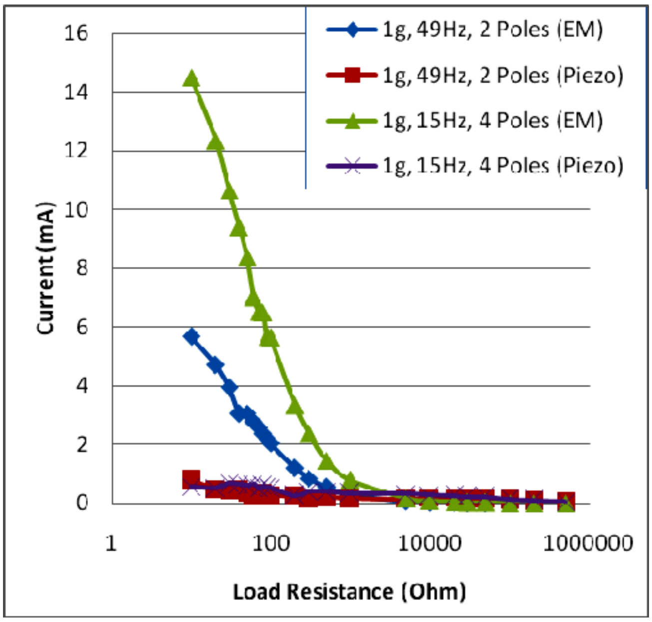

Fig. 6. Induced current against load resistance

In Fig. 5, apparently, we could see that the four poles magnets type of harvester produces greater voltage outputs 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

100 MΩ for comparison purpose, result shows that the four poles magnets type harvester produce 14.1 V from piezoelectric and 0.8 V from electromagnetic respectively. Meanwhile, for two poles magnets type of harvester, both piezoelectric and electromagnetic produce relatively lower voltage output with each of them generated 9.5 V and 0.3 V respectively.

In Fig. 6, the results of the induced current in both piezoelectric and electromagnetic for two poles and four poles magnets type of harvester are plotted and shown for comparison purpose. From the Fig., we could 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 as 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.

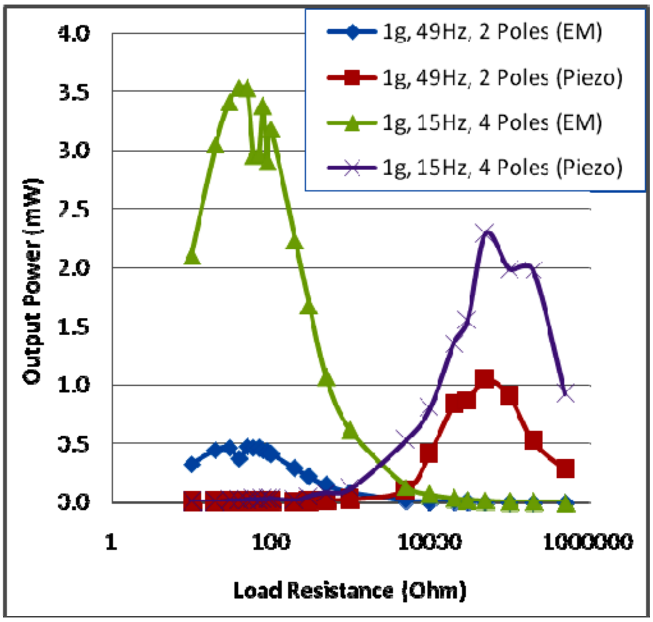

Fig. 7. Electrical power output against load resistance

Fig. 7 shows the comparison of generated power output from both piezoelectric and electromagnetic for the two harvesters. It shows that, greater electrical power output 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 = 40 Ω) and 3.5 mW (resistive load = 50 mΩ) 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, 0.5 mW (resistive load = 50Ω) as compared to piezoelectric transducer with 1 mW (resistive load 50 MΩ).

Based on aforementioned results, four poles magnet type harvester is able to produce greater amount of voltage output, induced current and electrical power output against the resistive load as compared to the two poles magnet type harvester. This is because of the voltage output and induced current depend very much on the produced magnetic field strength and flux gradient created by the magnets. By properly locating four poles magnet with each of them facing each other in opposite polarity on the cantilever beam as shown in Fig. 1, more flux gradient could be created. The existing of four poles magnets in the design, would give higher magnetic field strength and this magnetic fields would be concentrated surrounding the coil by the magnets arrangement. When the harvester is excited by an external vibration, greater flux gradient is produced, thus generating greater induced voltage in the coil.

Furthermore, the arrangement of the magnets also plays very important role in determining the rate of flux change. In the four poles magnet type harvester, four magnets were arranged nicely onto the piezoelectric cantilever beam forming a four poles magnet structure. In between of them, a gap is left just enough to slot in the magnetic coil. This arrangement is critical because the closer the distance of the coil to the magnets, greater magnetic flux gradient would be experienced by the coil, thus greater voltage output and induced current could be generated. When these two components, voltage output and induced current have greater value, more electrical power output could be generated as $P = VI$.

IV. CONCLUSIONS

This paper presented the comparison study in terms of voltage output, induced current and electrical power output generated from the hybrid energy harvester based on piezoelectric and electromagnetic transducers with two different magnets arrangement. The first one using four poles magnets arrangement, that being located in a specific place and arranged nicely on the cantilever beam, to give greater flux generation and flux concentration onto the coil, while the second one using two poles magnets arrangement, which is a conventional way of putting the magnets.

Experimental results show that, four poles magnets type harvester able to generate greater voltage output, 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 = 40 Ω) and 3.5 mW (resistive load = 50 mΩ) 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 0.5 mW (resistive load = 50 Ω) and 1 mW (resistive load 50 MΩ) power output that able to be generated from each electromagnetic and piezoelectric transducers.

This implies that, with the right magnet arrangement employed onto the cantilever beam, greater electrical power output is capable to be generated, in which the four poles magnets arrangement is referred in this study.

V. ACKNOWLEDGMENT

The authors thank University Teknikal Malaysia Melaka for the Short Term Grant Research Scheme PJP/2012/FTK(36A)/S01040 and ASECs research group for their ideas and technical supports.

VI. REFERENCES

[1] S. P. Beeby, M. J. Tudor, and N. R. Harris, "A credit card sized self powered smart sensor node," *Sensors & Actuators A: Physical,* vol. 169, p. 9p, 2011.

[2] M. F. Bin Ab Rahman and K. Swee Leong, "Investigation of useful ambient vibration sources for the application of energy harvesting," in *Research and Development (SCOReD), 2011 IEEE Student Conference on*, 2011, pp. 391-396.

[3] S. Ibrahim, B. Tuna, and K. Haluk, "An electromagnetic micro energy harvester based on an array of parylene cantilevers," *Journal of Micromechanics and Microengineering,* vol. 19, p. 105023, 2009.

[4] S. Roundy, P. K. Wright, and J. Rabaey, "A study of low level vibrations as a power source for wireless sensor nodes," *Computer Communications,* vol. 26, pp. 1131-1144, 2003.

[5] R. Torah, P. Glynne-Jones, M. Tudor, T. O. Donnell, S. Roy, and S. Beeby, "Self-powered autonomous wireless sensor node using vibration energy harvesting," *Measurement Science and Technology,* vol. 19, p. 125202, 2008.

[6] C. B. Wouldiams, R. C. Woods, and R. B. Yates, "Feasibility study of a vibration powered micro-electric generator," in *Compact Power Sources (Digest No. 96/107), IEE Colloquium on*, 1996, pp. 7/1-7/3.

[7] C. B. Wouldiams and R. B. Yates, "Analysis Of A Micro-electric Generator For Microsystems," in *Solid-State Sensors and Actuators, 1995 and Eurosensors IX.. Transducers '95. The 8th International Conference on*, 1995, pp. 369-372.

[8] S. P. Beeby, R. N. Torah, M. J. Tudor, P. Glynne-Jones, T. O. Donnell, C. R. Saha, and S. Roy, "A micro electromagnetic generator for vibration energy harvesting," *Journal of Micromechanics and Microengineering,* vol. 17, p. 1257, 2007.

[9] P. D. Mitcheson, E. M. Yeatman, G. K. Rao, A. S. Holmes, and T. C. Green, "Energy Harvesting From Human and Machine Motion for Wireless Electronic Devices," *Proceedings of the IEEE,* vol. 96, pp. 1457-1486, 2008.

[10] S. Yingjun, H. Xueliang, L. Hexiang, and J. Ping, "A Vibration-Based Hybrid Energy Harvester for Wireless Sensor Systems," *Magnetics, IEEE Transactions on,* vol. 48, pp. 4495-4498, 2012.