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Self-made electromagnetic vibration energy harvester of different stroke length and number of coil turns

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Abstract. This paper presents the experimental work on a new tube-shape electromagnetic vibration energy harvester to obtain its optimum peak-to-peak voltage output based on different stroke length, number of coil turns and optimum frequency. The harvester is fabricated using Acrylonitrile Butadiene Styrene (ABS) material. It consists of housings with three different stroke lengths, top and bottom covers, Neodymium Iron Boron (NdFeB) magnets, spring and copper coil. The tested stroke lengths are 40 mm, 45 mm and 50 mm while the number of coil turns are 10, 20 and 30. A standard energy harvesting circuit which consists of full-wave bridge rectifier and a capacitor is designed and fabricated to conduct this experiment. The importance of this circuit is to convert alternating current (AC) to direct current (DC) as well as to enable harvesting and storing processes of electrical energy. The harvester is tested on external vertical vibrations generated by shaker with frequency ranged from 5 Hz to 50 Hz with interval of 5 Hz. The raw voltage readings have been extracted from Oscilloscope and are analysed using Microsoft Excel and Octave software. From the results obtained, the optimum peak-to-peak voltage harvested is 39.41 mV at resonant frequency of 5 Hz by 50 mm stroke length and 30 coil turns device. The higher the stroke length and number of coil turns, the higher the peak-to-peak voltage can be harvested.

1. Introduction

Energy harvesting is a process of converting energy from light, thermal, solar, wind and kinetic to electrical energy with the final goal of creating self-powered actuators, sensors and other low power consumption electronic devices. The idea of energy harvesting is not completely new, where conversion of solar energy to electrical energy is an example of one of the earliest methods being used [1]. Each of these sources of energy can be useful to be harvested and power up electronic devices, however, vibration-based energy harvesting is the one that have been emphasized by many researchers [2]. Vibrations are omnipresence in environment thus it is a reliable source for energy harvesting. This source can be found in environment such as vehicle motions, human movements, buildings and bridges that have different frequencies.

Over the past years, this concept of energy harvesting has received a huge consideration by research community due to non-stop decrease in the power usage of microelectronic devices and systems. For example, wireless sensors, network systems and smart dust are becoming so low in power consumption that energy stored in super-capacitor or capacitor by energy harvester is able to drive them [3]. The energy harvesting can be acquired by using an appropriate transduction mechanism capable of converting part of the energy related to mechanical vibrations into electrical energy. The harvesting device is usually in a very small scale. Electrostatic, piezoelectric and electromagnetic induction are most commonly used mechanisms by researcher [4]. However, in the present study, only the electromagnetic induction is focused.

In 2010, Sari *et al.* [5] produced a prototype that set forth "frequency upconverter" technology using cantilever design. This harvester is capable to convert the resonance frequency of the device from the external vibration frequency and improves the efficiency of the conversion of energy. The concept of magnetic was utilized in the study to produce the harvesting device. This device can overcome the problem when external vibration frequency was not matched with the resonance frequency of the device. Dallago *et al.* [3] developed a tube type electromagnetic energy harvester by using four NdFeB permanent magnets. It had an outstanding peak induced voltage of 2.25 V and maximum output power of 6 mW. The resonant frequency achieved by this harvester was 10.4 Hz. Another example of tube-shaped electromagnetic harvester to collect very low ambient vibration was designed by Oh *et al.* [6]. A cylinder magnet was utilized to generate some voltage, and the use of spring to assist in the movement of magnet when external vibrations was applied. Current in the coil was induced when it vibrated. With this device, collecting energy from vibration generated by human becomes possible as it was efficient in low frequency vibrations. However, the size was large and involved complex manufacturing process.

Several methods on electromagnetic energy harvester based on vibration were actively investigated including utilized cylindrically-shaped magnets as the springless proof mass [7-9], spring-mass-damping system concept [3,6] and spherically proof mass [10-11]. Each of the methods has their pros and cons. In designing the energy harvester based on electromagnetic, spring-mass system is commonly utilized by applying the external vibration to the device. The system transforms the relative motion generated by the coil and permanent magnet into electrical voltage. Although it has the advantage of good performance at resonance and simple design, it has the drawback of require high operation frequency [12]. Therefore, it becomes the initiation of the present study, which is to test the electromagnetic energy harvester on low frequency range by manipulating the amplitude motion based on the stoke length and number of coil turn.

In this study, a self-made electromagnetic energy harvester is presented based spring-mass-damping system on the vibration that generated by shaker. The aims of the present study is to produce a small size of electromagnetic harvester with reasonable harvesting outputs by varying the number of coil turns and the stroke lengths.

2. The Methodology

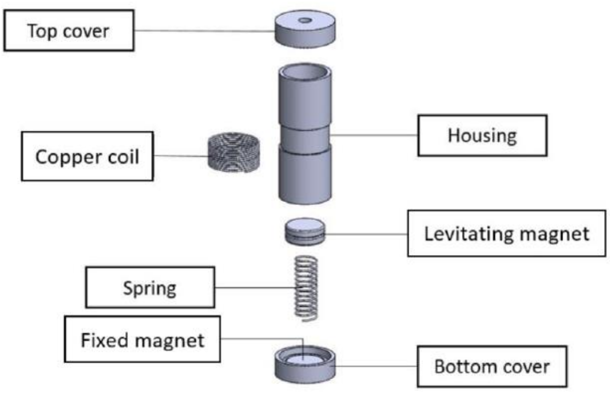
2.1. Design of the magnetic harvester

The design of the magnetic harvester is shown in Figure 1(a). It is comprised of copper coil, spring, fix magnet, levitating magnet, housing and its covers. The levitating magnet and the fix magnet located at the bottom of the cover are in opposite polarity so that vertical vibration can be generated when external excitation is applied. Table 1 shows the parameters for the design while the stroke length is illustrated in Figure 1(b).

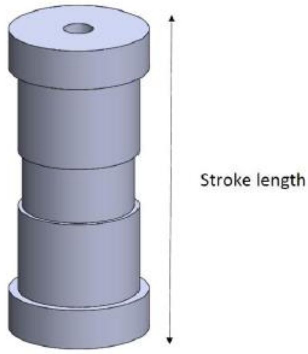
Table 1:Variables of the harvesting device

Parameter	Value
Number of coil turn	10, 20, 30
Stroke length (mm)	40, 45, 50

There are several magnet types available. However, neodymium magnet is chosen for this project because it has the highest magnetic field strength. The diameter of the magnet is 15mm and has a thickness of 3mm. The size is relatively small in order to minimize the overall volume of the electromagnetic energy harvester. The dimensions that are chosen for the inner and outer diameter of the housing are 17 mm and 20 mm respectively. A tolerance between the inner diameter of the housing and the magnet is required so that the magnet can move freely in vertical direction. ABS is chosen for the material of these components as it is light-weight, has high toughness and can withstand high temperature up to 80°C. The material of the coil is one of the most important aspect to consider for this harvester as the electrical current will flow through the coil. Copper coil is chosen because it has the lowest electrical resistance where the current can flow through it easily. The chosen diameter of the coil is 0.5 mm.



(a)



(b)

Figure 1. (a) concept of electromagnetic energy harvester; (b) The stroke length of the device

2.2. Energy harvesting circuit

In order to harvest the energy from electromagnetic energy harvester, a simple and functional circuit is required. The circuit is designed to ensure the output voltage can be stored and measured during the experimental work. It consists of full-wave bridge rectifier and a 100 μF capacitor connected in parallel. Full-wave bridge rectifier is made of four 1N4002 diodes that have a constant forward-biased voltage drop. The purpose of this component is to convert alternating current (AC) to direct current (DC). This is because the electromagnetic energy harvester can only generate alternating current that alternates from positive to negative and it is not practical. Thus, a direct current and a stable output voltage is required.

2.3. Experimental setup

Figure 2 shows the overall setup of the experiment. The harvester is glued to the Shaker using double sided tape. This is to ensure that the harvester can be removed in order to change the variable. The two ends of the coil are connected to harvesting circuit which are then connected to oscilloscope to measure the voltage output. Personal computer equipped with Siemen Simcenter Testlab Structures Acquisition software is used to connect with Simcenter SCADAS Mobile via Ethernet cable. This software is to give input to the Simcenter SCADAS Mobile and then control the frequency of shaker. For each variable,

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the data time recorded on oscilloscope is 5 seconds and the frequency range is between 5 Hz to 50 Hz with an interval of 5 Hz.

3. Results and Discussions

3.1. Optimum harvested voltage identification

The raw data is collected using oscilloscope and further analysed using Microsoft Excel and Octave software. To obtain the accurate peak-to-peak voltage, Octave software is used to find the root-mean-square voltage ($Vrms$) from the raw data. The value is then converted to peak-to-peak voltage (Vpp) by using equation 1.

$$V_{pp} = V_{rms} x 2\sqrt{2} \quad (1)$$

Figure 3(a), 3(b) and 3(c) show the results of peak-to-peak voltage value at different stroke length. Based on these graphs, the peak-to-peak output voltages illustrate a similar increasing trend as the number of coil turns is increasing. It is proved by equation (2) that the value of voltage induced is directly proportional with the number of coil turns.

$$e = -N\frac{d\emptyset}{dt}\ (Volt) \quad (2)$$

Where e is the voltage or electromotive force (V), N is number of coil turns, $\emptyset$ represents the magnetic flux (Weber, Wb) and t is time (s). It is observed that as the stroke length increases, the peak-to-peak value increases too. This is because the maximum vertical stroke is increased and enabled the magnet to vibrate at maximum amplitude.

On the other hand, it is found that the harvested voltage to be less effective at larger value of frequency. The smaller the frequency, the higher the peak-to-peak voltage based on Figure 3(a), 3(b) and 3(c). At larger frequency range, the collected peak-to-peak voltage is found to be almost constant for small coil turns regardless to the value of the frequency. The optimum working frequency in the present study is to found to be 5 Hz as the highest peak-to-peak voltage is obtained at 5 Hz for all of the cases.

Figure 3(d) illustrates optimum peak-to-peak voltage based on the number of coil turns and stroke length. The optimum peak-to-peak voltage harvested is 39.41 mV by 50 mm stroke length device with 30 coil turns at 5 Hz. The largest stroke length and the biggest number of coil turns produced the highest voltage output.

3.2. Voltage Stored in Rechargeable Battery

The identified optimum voltage output and optimum frequency is used to conduct the experiment in storing the energy inside a 3.3 V rechargeable battery. The voltage reading of the battery is measured using ammeter before and after conducting the experiment. The harvesting device used is 50 mm stroke length with 30 coil turns and frequency is set at 5 Hz. The battery is connected at the output of the harvester circuit. The voltage stored in 5 minutes is 0.028 V. At this rate, it is required approximate of 9 hours and 48 minutes to fully charge the battery. More improvements are required to repair the efficiency of this device. For real application, it is useful to be applied in human-motion-induced-vibration, which is in low frequency, large amplitude motion and occurred randomly.

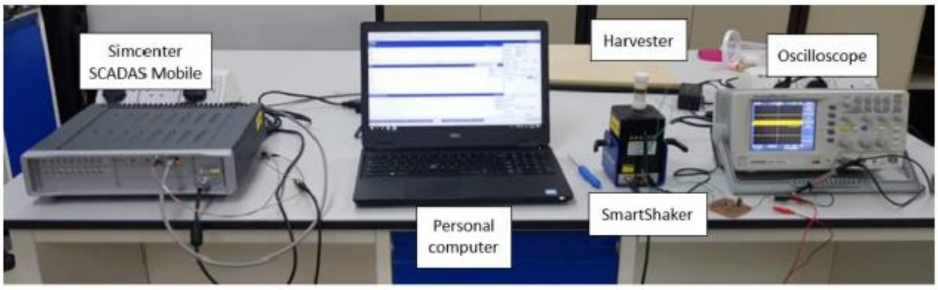
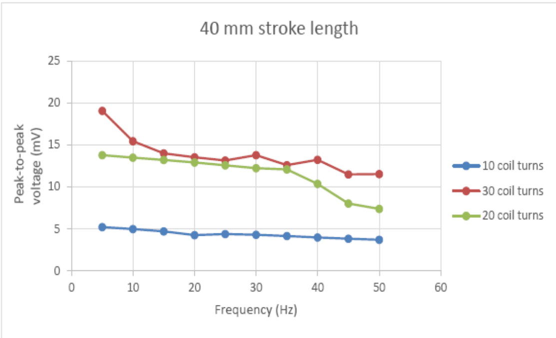
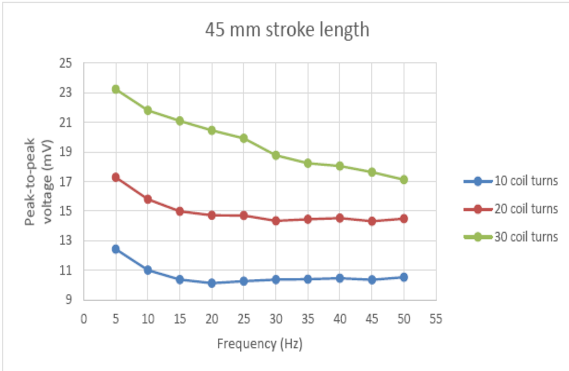


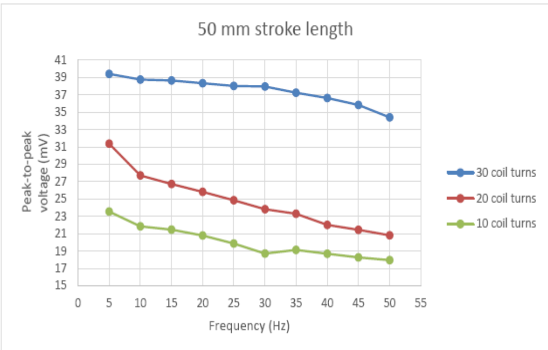
Figure 2. The experimental setup



(a)



(b)



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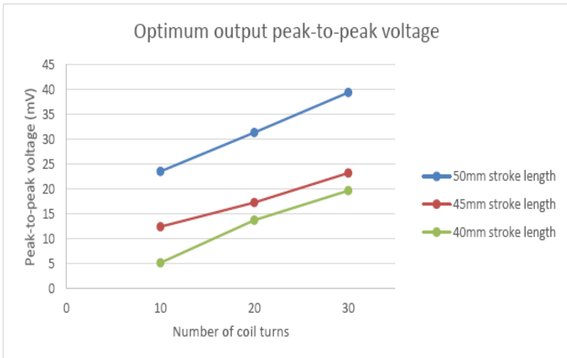

(d)

Figure 3. peak-to-peak voltage versus frequency for (a) 40 mm stroke length; (b) 45 mm stroke length; (c) 50 mm stroke length; (d): the optimum peak-to-peak voltage based on number of coil turn and stroke length

4. Conclusion

In this paper, a tube-shaped electromagnetic vibration energy harvester has been successfully fabricated to analyse the optimum voltage output that can be harvested based on different stroke length and number of coil turns. It consists of a standard energy harvesting circuit which is required to ensure the output voltage can be stored and measured during the experimental work. The experiment is conducted at different frequencies of vertical vibrations excites by Shaker ranged from 5 Hz to 50 Hz. The raw voltage readings have been extracted from Oscilloscope and are analysed using Microsoft Excel and Octave software. The aims of this research has been successfully attained. This study shows that the self-fabricated electromagnetic energy harvester can generate electrical energy by harvesting vertical vibrations. The results show that the higher the number of coil turns and stroke length, the higher the

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output voltage. The optimum peak-to-peak voltage harvested is 39.41 mV by 50 mm stroke length with 30 coil turns at 5 Hz. The harvested voltage is less effective at larger value of frequency. Approximate 9 hours and 48 minutes is required to fully charge a 3.3 V rechargeable battery by using the optimum condition of the harvester.

Acknowledgement

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References

[1] Sojan, S., Kulkarni, R.K. (2016). A Comprehensive Review of Energy Harvesting Techniques and its Potential Applications. *International Journal of Computer Applications, 139*, 14-19. Another reference.

[2] A.Abdelkefi. (2015). Aeroelastic energy harvesting : A review. *International Journal of Engineering Science, 100*, 112-135.

[3] Dallago, E., Marchesi, M., Venchi, G. (2010). Analytical Model of a Vibrating Electromagnetic Harvester Considering Nonlinear Effects. *IEEE Transaction on Power Electronics, 25*, 1989-1997.

[4] Caruso, G., Chirianni G., Vairo, G. (2016). Energy harvesting from wind-induced bridge vibrations via electromagnetic transduction. *Engineering Structures, 115*, 118-128.

[5] Sari, I., Balkan, T., Kulah, H. (2010). An Electromagnetic Micro Power Generator for Low-Frequency Environmental Vibrations Based on the Frequency Upconversion Technique. *Journal of Microelectromechanical Systems, 19*, 14-27.

[6] Oh, J.S., Kim, J.S., Jeong, U.C., Kim, Y.D., Kim, Y.C., Lee, H., Oh, J.E. (2016). Optimization and performance improvement of an electromagnetic-type energy harvester with consideration of human walking vibration. *Journal of the Korean Physical Society, 68*, 431-442.

[7] Rao Y., Cheng S., Arnold D.P. (2013). An energy harvesting system for passively generating power from human activities. J. Micromech. Microeng. 23, 114012. doi: 10.1088/0960-1317/23/11/114012.

[8] Ju S., Chae S.H., Choi Y., Lee S., Lee H.W., Ji C.H. (2013). A low frequency vibration energy harvester using magnetoelectric laminate composite. Smart Mater. Struct. 22,115037. doi: 10.1088/0964-1726/22/11/115037.

[9] Pillatsch P., Yeatman E.M., Holmes A.S. (2013). Real world testing of a piezoelectric rotational energy harvester for human motion. J. Phys. Conf. Ser. 476:012010. doi: 10.1088/1742-6596/476/1/012010.

[10] Bowers B.J., Arnold D.P. (2009). Spherical, rolling magnet generators for passive energy harvesting from human motion. J. Micromech. Microeng. 19,094008. doi: 10.1088/0960-1317/19/9/094008.

[11] Ju S., Chae S.H., Choi Y., Ji C.H. (2015). Macro fiber composite-based low frequency vibration energy harvester. Sens. Actuators A Phys. 226, pp126–136. doi: 10.1016/j.sna.2015.02.025.

[12] Chae, S.H., Ju, S., Choi, Y.H., Chi, Y.E., Ji, C.H., 2017. Electromagnetic Linear Vibration Energy Harvester Using Sliding Permanent Magnet Array and Ferrofluid as a Lubricant. Micromachines (Basel) 8(10), 288. doi: 10.3390/mi8100288