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Structural Performance and Evaluation of PDMS-Based Planar Membrane for Electromagnetic Vibration Energy Harvester (EM-VEH)

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ABSTRACT

This paper discusses the performances of Polydimethylsiloxane (PDMS) membranes with the electromagnetic coils and magnetic arrangement as the supporting structure to generate electricity by capturing the energy from vibrating ambient source. The membrane attached to the permanent magnet moved according to the structure of the electromagnetic system. The study first designed the PDMS planar membrane to allow the vibration energy capturer to induce the coils efficiently. Membrane vibration from a loudspeaker with an operating frequency of 32 Hz was used as the vibration source. The generated energy stored in a storage circuit using a 220 µF/25 Volt capacitor, while a 1.5 Volt LED was used as a tested load in the system. The results showed that the moving membrane attached with a 10 mm diameter magnet revealed an open circuit output voltage of 500 mV on the EM coil. An experiment within a 20-minute flashing LED load test produced an output voltage of 2.2 Volts. This study would benefit the development of vibration energy harvester used to supply a low electrical power for microdevices in an isolated area.

Keywords: 3-5 Electromagnetic (EM), energy harvester, PDMS Membrane, vibration analysis

1. INTRODUCTION

The mechanical energy from vibrating ambient sources, such as oil pipelines, engines, bridges, high buildings, or earthquakes, can be captured and converted to electrical energy by moving electromagnetic fields onto electromagnetic coils. The energy harvester system can generate electrical power for isolated low-power electronic devices and systems, such as sensor nodes, implanted biomedical devices, etc. [1]

The Vibration energy harvester consists of a MEMS-based transducer, including a moving permanent magnet, a static electromagnetic coil, and a resonator to amplify the vibrator [2]. The main problems of this system are the low power output due to the low membrane flexibility and the large dimension of the current generators, which limit their implementation in an isolated area.

The Micro electro mechanical System (MEMS) has become an extraordinary technology in the last ten years. MEMS has led the industry to switch from bulky conventional systems to miniaturized devices and developed an environmentally sustainable and economically efficient technology [3-9].

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MEMS offers various methods for converting membrane movement into the generation of electric current. Two prevalent methods in this regard are piezoelectric systems and electrostatic energy converters [10]. However, these approaches come with inherent limitations.

One notable drawback is their inability to effectively capture a wide spectrum of vibration frequencies. Moreover, these systems often require a substantial power supply connection, which can compromise their reliability when deployed in a vibrating ambient. On the other hand, Electromagnetic Vibrational Energy Harvester (EM-VEH) has received significant attentions due to relatively simple construction and able to generates power at low frequencies.

Electromagnetic harvester use Faraday's law principle of induction that a magnet passing through a coil induces a current. Electromagnetic induction and inverse magnetostrictive effects are commonly adopted for electromagnetic energy conversions [11].

$$\varepsilon = -N \; \Delta\varphi/\Delta t \qquad (1)$$

in which ε is the voltage produced in terms of electromagnetic (EM), N is the number of loops of the coil, and φ is the magnetic flux. A negative sign arises due to Lenz's law. If the magnetic flux across a wire or circuit changes, an electric current will be induced in the circuit.

Several studies on the materials of MEMS based vibration energy harvesters have been done previously; commonly used flexible membrane materials, such as thin silicon, polyimide, and also PDMS [2], in this study, the PDMS was studied more comprehensively by experimenting its mixing composition. The comparison of mixing PDMS and its current agent is based on the elastic properties of the mixing material. [12][13].

This paper reports the development of Electromagnetic Vibrational Energy Harvesters (EM-VEH) with a planar membrane structure to transmit vibrations optimally and then be converted into new energy as an alternative energy-harvesting [14].

2. MATERIAL AND METHODS

The study started by modeling a membrane that would capture vibrations and enable magnetic induction . The membrane design has four planar spring arms from 4 sides of the membrane core measuring 10 x 10 mm. The length of each arm is 10 mm, and the sleeve width is 1.5 mm. The thickness ranges from 10 to 100 µm. The structure and geometry list of which can be seen in Table 1. The design is made into 2 model parameters, namely membrane with membrane with spring arm at the center of the membrane (Design A) and spring arm at the edge of the membrane (Design B), as shown in Figures 1 and 2. The mechanical proiperty of the membrane will be analyzed using FE analysis. After integrating the membrane with the electromagnetic coil the system will be the measured to see the effect of the material composition on the voltage output. Finally, the output voltage will be measured based on the effect of the coil formation.

2.1 Membrane Design

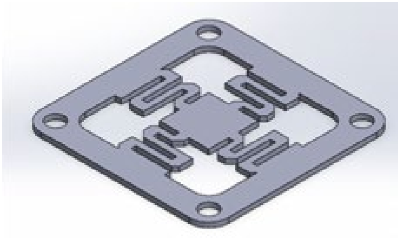


Figure 1. Design A: Spring arm membrane with a spring arm at the center of the membrane.

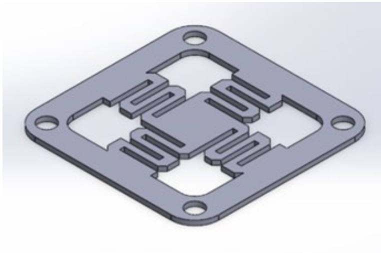


Figure 2. Design B: Membrane with a spring arm at the edge of the membrane.

Table 1 The size of the spring arm membrane

No	Geometry Of Spring Arm Memrane	Size (mm)
1	Length of membrane	10
2	Width of membrane	10
3	Length of the first spring arm	4
4	The length of the second and subsequent spring arms	8
5	The width of the second subsequent arms	1.9
6	The width of the second and subsequent spring arms	1.5
7	Thickness of spring arm	1.5, 2, 3

To obtain the optimal flexible properties of a membrane, the PDMS material was experimented with various curing agent mixture (PDMS : Curing agent) of 10:1, 10:3, and 10:5 with various thicknesses of 1.5 mm, 2 mm, and 3 mm, respectively. The PDMS mixture was then poured to a previously prepared master mold with size of 20 cm x 20 cm and left for 1x 24 hours for complete dryness. After that, the PDMS sheet was printed using the laser cutting method.

The comparison of spring arm thickness between the two membrane designs can be seen in the Figure 3. It is shown that thicker and sturdier membrane cannot result in good flexibility. Membrane of design A with thickness of 10 mm would have the deformation ability of about 2.2 mm.

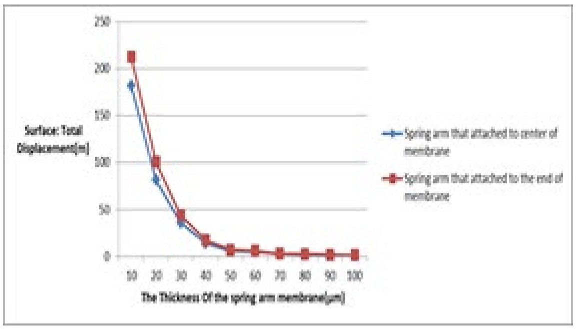


Figure 3. Effect of the membrane thickness on the mechanical deformation.

2.2. Electromagnetic System

After obtaining the best and optimal membrane, the membrane was applied to the electromagnetic system for integration with the Energy Harvesting Microgenerator (EH Micro generator). As shown in Figure 4, the system consists of the movable membrane (Yellow) attached with two magnets at the top and the bottom of the membrane and two electromagnetic coils (orange) sandwiched at the top and the bottom side of the system.

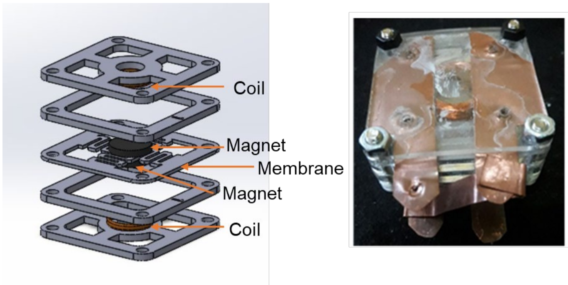


Figure 4 Energy harvester with PDMS Membrane, (a) the schematic of the structure, (right) the photograph of the EM-VEH device.

The magnetic coil system having 1000 turns and the permanent magnet of 10 mm with variations in coil diameter, will then be measured. Three types of coils with varying diameters including, (Coil Type1) Core with a diameter of 3 mm, (Coil Type 2) air core with a diameter of 3 mm, and (Coil Type 3) air core with a diameter of 10 mm were applied, as shown in Figure 5

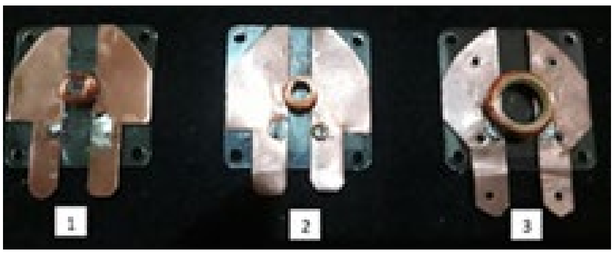


Figure 5. 3 Various coils formation (1), coil with air core (2), coil with large diameter (3).

The performance of the EM-VEH was then evaluated through experimental vibrations. The EM-VEH is installed on top of the harvesting loudspeaker energy device; electronic vibration input from the loudspeaker is around 0 -100 Hz, then captured by the EM-VEH and transmitted to the PDMS membrane. The PDMS membrane will continuously vibrate as long as the harmonic vibration from the loudspeaker is available. The energy in the voltage is measured using a Hantek portable oscilloscope. The EM-VEH experimental settings can be seen in Figure 6.

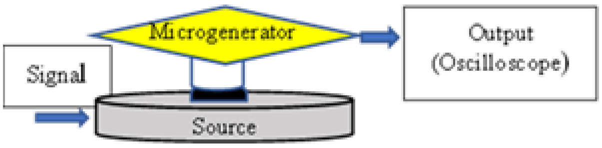


Figure 6. Experimental setup of the EV- EHmicrogenerator.

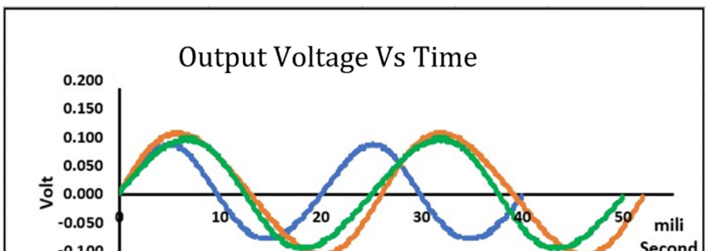
3. RESULTS AND DISCUSSION

The PDMS-based membrane composition is measured by forwarding electronic frequency vibrations from the sound system speakers within an operating frequency range of 0-100 Hz; the results can be seen in Table 2.

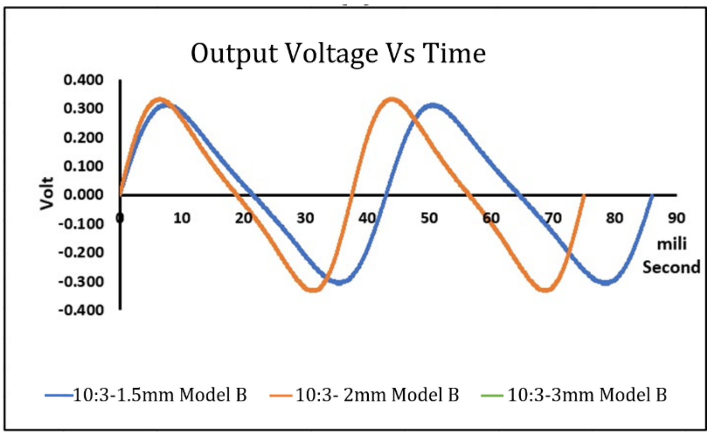
Table 2 The Experimental parameters of the PDMS-based membrane

Design A			
PDMS Composition	1,5mm	2mm	3 mm
10: 1	-	-	-
10 : 3	0.0314 Volt	0.0784 Volt	0.0408 Volt
10: 5	0.0784 Volt	0.1537 Volt	0.0627 Volt
Design B			
10: 1	0.0953 Volt	0.1250 Volt	0.1084 Volt
10 : 3	0.2039 Volt	0.3729 Volt	-
10: 5	0.0825 Volt	0.1100 Volt	0.0806 Volt

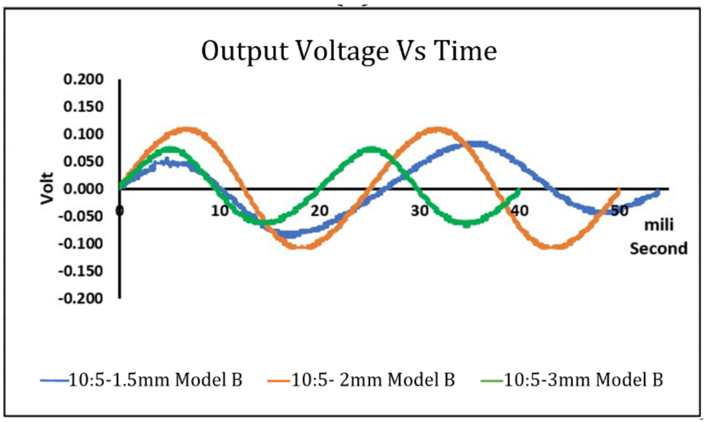
From Table 2, the PDMS membrane with a thickness of 2 mm in Design B obtained a potential output of 0.3729 volts. The membrane experiments show that the mixing and thickness of the results obtained are more optimal in design B with a PDMS mixture ratio of 10 : 3 ml with the current agent. The resulting voltage output composition graph can be seen in Figure 7.



(a)



(b)



(c)

Figure 7. Output voltage characteristics of EH system with various membrane Compositon (a) Compositon 10 : 1 , (b) Compositon 10 : 3 and (c) Compositon 10 : 5.

Figure 7 shows the output voltage generated by the EM-VEH system. It is shown that thicker and sturdier membrane does not result in higher voltage. This experiment concludes that the EM-VEH Model B with PDMS membrane composition of 10:3 would generate the highest output voltage compared to other type.

To further examine the performance of the EM-VEH, 3 models of the device were tested. Table 3 shows the specification of the model. The EM- VEH uses two magnets with a diameter of 10 mm and two coils for one EM-VEH system with three coil models.

Tabel 3 Specification of the measured electromagnetic system

No	The Measured Part of Electromagnetic System	Specification
1	Nd-Fe-B permanent magnet diameter	10 mm
2	Magnetic Induction (Br)	1900 Gauss
3	Wire Coil diameter	0.05 mm
4	Number of loops in the Coil	1000 Tuns
5	Diameter Coil	2 – 12 mm

Model 1, which has a diameter of 3 mm and a coil core, gets a voltage input of 0.3 Volt, as seen in the oscilloscope simulation in Figure 8. The Energy harverste system two NdfedBmagnets with a diameter of 10 mm and two coils for one EH Micro Generator system with three coil models. Model 1, which has a diameter of 3 mm and an acrylic coil core, gets a maximum result of 0.28 Volt, as seen in the oscilloscope simulation in Figure 8.

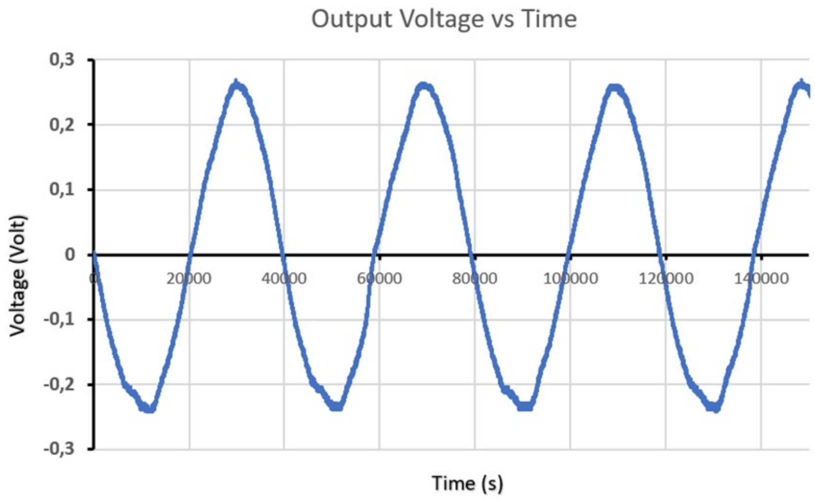


Figure 8. Output voltage signal Coil Model 1.

The coil model 2, with a diameter of 3 mm, had an empty coil core and got an output voltage that was not symmetrical (0.36 Volt), as seen in Figure 9.

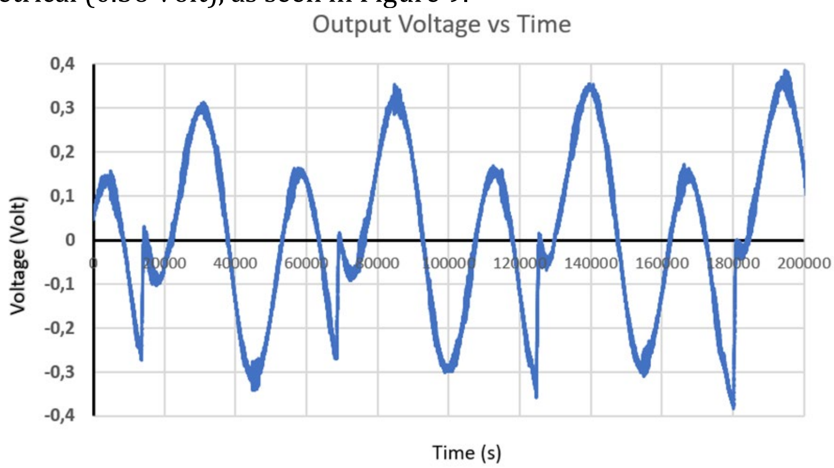


Figure 9. Output voltage signal Coil Model 2.

Model 3, with a diameter of 10 mm, was designed to allow the magnet to enter the coil core if there is vibration on the membrane so that an output voltage value of 0.4 Volts, as seen in Figure 10, can be obtained.

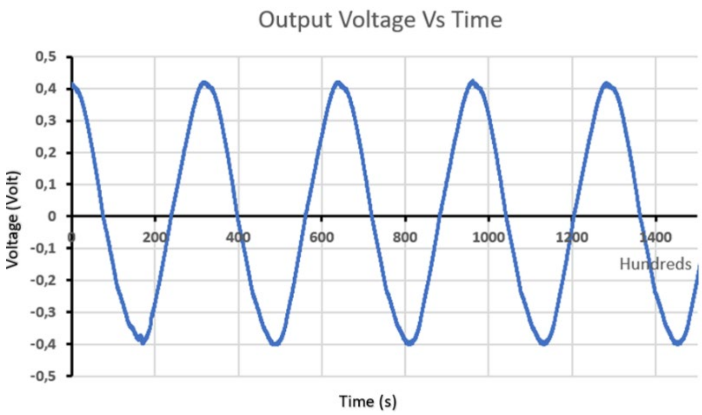


Figure 10. Output voltage signal Coil Model 3.

Furthermore, coil model 3 will be selected for the Energy Harvesting Micro generator prototype to find the optimal mechanical vibration based on the requirement of the EH Generator.
The electric power generation test results showed that an output voltage of 0.4 Volts produced by the PDMS membrane with PDMS membrane vibrations of 40 Hz is transmitted to the 220 μF/25V capacitor circuit, and for the LED load, a constant load voltage of 2 Volts is measured during the 190-minute test.

4. CONCLUSION

The research studied the PDMS-based membrane and its implementation as the energy harvester. The structure was attached with an electromagnetic coil and permanent magnets to create a Micro-generator system. Membrane with the finger arm at the edge of the membrane would have better deformation capability. The experimental test results show that a high voltage output of 0.4 Volt volts is achieved when the membrane with a coil of diameter 10 mm vibrates at a frequency of 40 Hz. The output voltage is 25% higher than the output voltage of a coil with a diameter of 3 mm.

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REFERENCES

[1] Kumar, A.; & Anjankar, S. C. (2016). Electromagnetic Energy Harvester for Low-Frequency Vibrations using MEMS, Procedia Computer Science, 79.

[2] Yunas, J., Nur Indah, (2020). Mechanical Characterization Of MEMS Vibration Membrane With Planar Spring Design For Energy Harvester, JESTEC.

[3] S. Menninger, J. O. Mur-Miranda, R. Amirtharajah, A. P. Chandrakasan, & J. H. Lang, “Vibration-to-electric energy conversion,” in Proc. Int. Symp. Low Power Electron. Design, Aug. 1999, pp. 48–53.

[4] Peralta, P.; Ruiz, R.O.; & Meruane, V. (2019). Experimental study of the variations in the electromechanical properties of piezoelectric energy harvesters and their impact on the frequency response function. Mechanical Systems and Signal Processing, 115, 469-482.

[5] Pawinanto, R. E.; Yunas, J.; Majlis, B. Y.; & Hamzah, A. A. (2016). Design and fabrication of compact MEMS electromagnetic micro-actuator with planar micro-coil based on PCB. TELKOMNIKA, 14(3), 856-866.

[6] Tian, Y.; Li, G.; Yi, Z.; Liu, J.; and Yang, B. (2018). A low-frequency MEMS piezoelectric energy harvester with a rectangular hole based on bulk PZT film. Journal of Physics and Chemistry of Solids, 117, 21-27.

[7] Tian, Y.; Li, G.; Yi, Z.; Liu, J.; and Yang, B. (2018). A low-frequency MEMS piezoelectric energy harvester with a rectangular hole based on bulk PZT film. Journal of Physics and Chemistry of Solids, 117, 21-27.

[8] Rojas, R. A.; and Carcaterra, A. (2018). An approach to optimal semi-active control of vibration energy harvesting based on MEMS. Mechanical Systems and Signal Processing, 107, 291-316.

[9] Kanda, K.; Hirai, S.; Fujita, T.; and Maenaka, K. (2018). Piezoelectric MEMS with multi-layered Pb(Zr,Ti)O3 thin films for energy harvesting. Sensors and Actuators A: Physical, 281, 229-235.

[10] I. Hamidah, R. E. Pawinanto, B. Mulyanti, J. Yunas, A bibliometric analysis of micro electro mechanical system energy harvester research, Heliyon 7 (2021) e06406.

[11] Andrew Muscat, Soham Bhattacharya, and Yong Zhu Electromagnetic Vibrational Energy Harvesters: A Review, Sensors 2022, 22, 5555. https://doi.org/10.3390/s22155555. MDPI.

[12] 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,” Proc. IEEE, vol. 96, no. 9, pp. 1457–1486, Sep. 2008.

[13] E. Harvorsen, “Energy harvesters driven by broadband random vibrations,” J. Microelectromech. Syst., vol. 17, no. 5, pp. 1061–1071, Oct. 2008.

[14] M H Khairuzzaman, Nur Indah, Badaria Bais, Jumril Yunas (2022), Study on Mechanical Characteristics of Flexible Membrane for Electromagnetic Energy Harvesting. AIP Conference Proceedings 2561, 020001 (2022). https://doi.org/10.1063/5.0114285.