Comparison of an Electromagnetic Energy Harvester 
Performance using Wound Coil Wire and PCB Coil

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Abstract. This paper presents the performance of two types of electromagnetic energy harvester, one using manually wound coil wire (EH-EC) and the other one using printed circuit board (PCB) coil (EH-EP). The objective of the study is to measure the corresponding output voltage and power by varying the number of coils and the position of the magnet. The experiment was conducted at a fix 50 Hz of frequency and at 0.25g of acceleration. The EH-EP was found to be more effective than the 350 turns of the wound coil wire, with maximum power of 26 µW. Overall, the performance of the EH-EC showed better result with maximum power of 125 µW for 1050 turns when compared to the EH-EP.

1. Introduction
Recently, due to small electronics devices, there is a high demand of low power applications using energy harvesters. [1]. Energy harvesting can be useful in many areas of application such as biomedical, building monitoring, health and remote sensing. The harvested energy can be generated from many sources such as from vibration, light, heat [2]. There has been many research focusing on vibration based energy harvester since it is a promising technology to produce high energy output when the source of vibration is available [3-5].

There are three types of harvester that researcher work to harvest energy from the vibration to convert vibration energy to the electrical energy which are electrostatic, electromagnetic and piezoelectric energy harvester. Electromagnetic energy harvester is one of the efficient harvester to convert the mechanical energy to electrical energy [6, 7]. For this study, two types of electromagnetic energy harvester to harvest energy from the vibration and will be described in the next following section below.

2. Mathematical model
The basic equation of the electromagnetic energy harvester based on the Faraday’s law of electromagnetic induction as per equation (1):

\[ V_{emf} = -\frac{d\phi}{dt} \]  

(1)

Where \( V_{emf} \) is the voltage induced in the conductor proportional to the time rate of change of the magnetic flux \( \phi \) of the circuit. For the practical of the electromagnetic energy harvester with the fix
and permanent magnet, the \( V_{\text{emf}} \) generated of the coil with \( N \) turns and the average flux \( \phi \), the equation is expressed:

\[
V_{\text{emf}} = -N \frac{d\phi}{dt}
\]  

(2)

For vibration based electromagnetic harvester, the relation of the motion between coil and permanent magnet in the direction of \( x \)-direction, the voltage \( V_{\text{emf}} \) can be expressed as a product of a flux linkage gradient and the velocity of movement. The equation can be expressed in equation:

\[
V_{\text{emf}} = -N \frac{d\phi}{dx} \frac{dx}{dt}
\]  

(3)

To measure the power generated by the electromagnetic energy harvester is by connecting load resistance \( R_L \) to the harvester. In the frequency domain, the power generated by the harvester can express as in given by [8]:

\[
Q(\omega) = \frac{K_m m \omega^3 Y_0}{(R_L + R_e + jL\omega)\left(\omega_0^2 - \omega^2 + j\omega \zeta + K\right)}
\]  

(4)

The open circuit voltage \( V_{OC} \) of the power output \( P_{opt} \) of the electromagnetic generator as can be expressed as follow:

\[
V_{OC} = \frac{K_m m \omega^3 Y_0}{\sqrt{\left(\omega_0^2 - \omega^2\right) + \left(2\zeta_m \omega_0\omega\right)^2}}
\]  

\[
P_{opt} = \frac{R_L (K_m m \omega Y_0)^2}{2\left(\left(R_L + R_e\right)^2 + (L\omega)^2\left(\omega_0^2 - \omega^2\right) + (2(\zeta_m + \zeta_m)\omega_0\omega)^2\right)}
\]  

(6)

3. Design and experiment

There are 2 types of electromagnetic energy harvester in this paper. The first one is labelled as EH-EC as shown in figure 1, where the electromagnetic energy harvester is generated by using coil wire at the free end of cantilever beam and NdFeB magnet is located near to the cantilever beam. For EH-EC, the magnet is fixed while the cantilever beam is vibrating. The second type, labelled as EH-EP as shown in figure 2, where electromagnetic energy harvesters is generated by using coils from printed circuit board (PCB). For EH-EP, the NdFeB magnet is attached at the free end of the cantilever beam and the coil from PCB is fixed.

The effect of number of coil turns on the performance of the EH-EC energy harvester was evaluated. The performance indicator was the output voltage and power. Three different number of coil turns were proposed, 350 turns (A), 700 turns (B) and 1050 turns (C). Meanwhile, for the EH-EP, the performance of the energy harvester was compared to the location of the NdFeB magnet at the free end of the cantilever.
The experimental setup for the electromagnetic energy harvester for EH-EC and EH-EP is shown in figure 3. The objective of the experiment is to measure the output voltage and power generated of the EH-EC and EH-EP at the frequency 50 Hz and 0.25g of acceleration. The function generator was set to produce the frequency at 50 Hz and connected to the amplifier before start to vibrate the shaker. The computer was installed with the Labview software and equipped with the vibration analysis to monitor the current value of the frequency and acceleration of the vibration of the shaker. The data of vibration is sent by DAQ card and connected to the laser vibrometer and pointed on the electromagnetic energy harvester EH-EC and EH-EP. The value of the open circuit voltage was measured by connecting the output terminal to the digital multimeter and for the power output; the magnitude voltage was measured by using digital multimeter at the load resistance.

4. Result and discussion

4.1. EH-EC energy harvester

The summary of the result for EH-EC is shown in Table 1. In this experiment, the load resistance is fixed at 50 KΩ, 70 KΩ and 100 KΩ. The open circuit voltage and power output is increased when the number of turns for coil is increased. The EH-EC for the 1030 turns showed the highest value of the open circuit voltage and power output. When the number of turns is increased, the weight at the free end of the cantilever beam increased and as a result, it increased the value of velocity of movement.

| Frequency (Hz) | 350 turns (A) | 700 turns (B) | 1050 turns (C) |
|---------------|--------------|--------------|---------------|
| $R_c$ (KΩ)    | 50           | 70           | 100           |
| $V_{OC}$ (V)  | 1.5          | 3.1          | 5             |
| $P_{opt}$ (µW)| 22.5         | 68.6         | 125           |
4.2. EH-EP energy harvester

Table 2 shows the summary of the measured value for EH-EP electromagnetic energy harvester. The open circuit voltage and output power was measured based on the 4 different position of the magnet at the free end of cantilever beam as shown in figure 2. The EH-EP is fixed but the magnet is moving with the same position of the motion of the cantilever beam. The different of the position will produce for the different value of the flux magnet generated and give different result of the value for open circuit voltage and power generated by EH-EP electromagnetic energy harvester.

| Table 2. The measure output of the EH-EP electromagnetic energy harvester at different position |
|-----------------------------------------------|
| Frequency (Hz) | A   | B   | C   | D   |
| R_\text{L} (K\Omega) | 50  | 50  | 50  | 50  |
| V_{\text{OC}} (V)   | 1.5 | 5.1 | 4.95| 0.8 |
| P_{\text{opt}} (\mu W) | 22  | 26  | 24.5| 6.4 |

5. Conclusion

The effect of using two types of coil for an electromagnetic energy harvester were presented in this paper. The first type was manually wound coil wire (EH-EC) and the second type was PCB board coil (EH-EP). The EH-EC showed increasing number of turns for coil affected the output power and produce high velocity of motion. The highest value of power was 125 \( \mu \text{W} \) for 1050 turns. In the EH-EP arrangement, the position of the magnet at the free end of the cantilever beam affected the output power. More power generated when more area of magnet exposed to the surface of EH-EP. The EH-EP was found to be more effective than the 350 turns of the wound coil wire, with 26 \( \mu \text{W} \) at position B. However, overall the EH-EC showed better result compared to the EH-EP.

6. References

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