

DESIGN, FABRICATION AND CHARACTERIZATION OF A VIBRATION DRIVEN ELECTROMAGNETIC ENERGY HARVESTER BASED ON MULTI-POLE MAGNET

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Abstract: This paper presents design, fabrication and characterization of a vibration driven electromagnetic energy harvester based on multi-pole magnet from where high voltage and power could be achievable for particular magnetic pole alignment. At first, ANSYS simulation for different alignment of magnetic pole array was done to observe the effects of enhanced flux density. Afterwards, the harvester design was addressed which comprises of copper coil, sintered NdFeB moving magnet and two fixed magnets at both end of the harvester with housing of Acrylic material. Finally, experimental results from a prototype three-magnet harvester demonstrates more than three times improvement of peak to peak voltage compared to single magnet harvester of same volume.

Keywords: electromagnetic, low frequency, multi-pole magnet, vibration source

INTRODUCTION

Renewable energy seems very interesting topics now-a-days because of limited amount of conventional resources like oil, coal, gas, fuel, kinetic movement of water etc. In addition to the scarcity, those resources require large power production facilities and they also pollute the environment. To overcome those limitations, alternative sources like solar, wind, thermal and ocean waves can be taken into consideration [1]. However, the production of power using those sources is costly, complex and large in scale. On the other hand, the use of various small-scale portable devices like mp3 players, mobile phones and wireless sensors has increased tremendously. To power those small portable devices, conventional resources and large-scale alternative sources do not seem suitable. Even though high-power batteries like alkaline (non-rechargeable), nickel metal hydride, lithium ion (rechargeable) etc. are available, such batteries need to be charged up regularly and has a limited life cycle after which they must be disposed of. Also those conventional batteries involve chemical reaction which pollutes the environment too. Considering all of these limitations, a vibration source seems quite suitable for powering small-scale portable devices because of its low cost, smaller scale and easy availability in the environment [2]. Various types of vibration-based energy harvesters like electromagnetic, piezoelectric and electrostatic have been investigated [3]. Among those, electromagnetic harvester seems appropriate because of their simple structure and low resonance frequency. Various electromagnetic energy harvesters using single magnet has been investigated [4]-[5]. However, power from those single magnet energy harvesters is very low and insufficient to power modern day's electronics devices. To solve this problem and to increase the efficiency of the harvester, multi-pole magnets were being used by some groups [5]-[8]. The output voltage and power was increased in those cases, but was accompanied by an undesirable

increase in harvester size.

Therefore, this study is focused on the design, fabrication and characterization of a multi-pole magnet energy harvester capable of producing ample voltage and power within a limited volume for a particular magnetic pole alignment.

ANSYS SIMULATION

Initially, an ANSYS simulation is performed to determine the magnetic flux densities of different magnet with different pole alignments of same volume from Fig. 1-3. Fig. 1 shows symmetrical pole alignment of the magnetic flux towards *Y-axis*, where each '*south pole*' of a magnet is attracted to the opposite '*north pole*' of another magnet. In those cases, a flux density of 0.262 T is observed for all magnets. Therefore, if this type of magnetic pole alignment is used in an energy harvester, multi-pole magnet will not increase the total efficiency.

Fig. 2 shows an un-symmetrical magnetic pole alignment towards *Y-axis* where each '*south pole*' of a magnet is attracted by the '*south pole*' of another magnet and vice versa for more magnet cases. As it is observed from the figure, the flux densities are 0.262 T, 0.3224 T, 0.3115 T and 0.3081 T for single, double, triple and quadruple-pole magnets respectively. The flux density of two pole magnets has increased compared to that of the single pole magnet. However for double, triple and quadruple-pole magnets, flux density are almost same. But the total flux line has increased with increase flux peak in those cases. So using this alignment in moving magnet the total efficiency of the harvester will increase. However, connecting same '*south*' to '*south*' and '*north*' to '*north*' pole does not seem realistic.

Fig. 3 shows the magnetic pole alignment towards *X-axis*, where it is very easy to connect different pole arrays. Fig. 3(a) shows a flux density of 0.1904 T for single magnet whereas Fig. 3(b) shows flux density of

0.3993 T for two magnet cases. Thus, it is clear that the flux density for two magnets has increased compare to that of a single magnet. However, for three and four magnet cases in Fig. 3(c) and 3(d), the flux densities are nearly same at 0.3948 T and 0.3917 T, respectively. Then the question arises is how multipole magnet increases the efficiency. The noticeable thing in Fig. 3(a)-3(d) is that, the total number of flux peaks and areas increases as more magnets are added in an array. It can be easily observed that, the number of flux peaks increases with two, three, four and five for single, double, triple and quadruple-pole magnets respectively. In this way, the total rate of change in flux increases, which makes the harvester more efficient. Fig. 3(a)-3(d) also shows that, the width of the flux density is reduced as the number of magnets increases. So to better utilize those flux peaks, the coil of the harvester should be positioned as close as possible to the magnet.

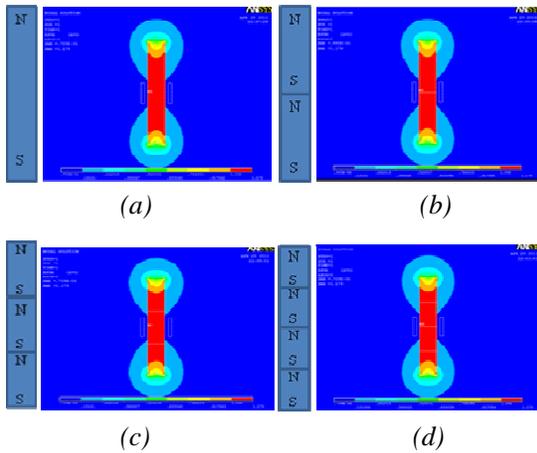


Fig. 1: ANSYS simulation of magnetic pole alignment towards Y-axis (Symmetrical) (a) 1-magnet 'B'=0.262 (T), (b) 2-magnet 'B'=0.262 (T), (c) 3-magnet 'B'=0.262 (T), (d) 4-magnet 'B'=0.262 (T)

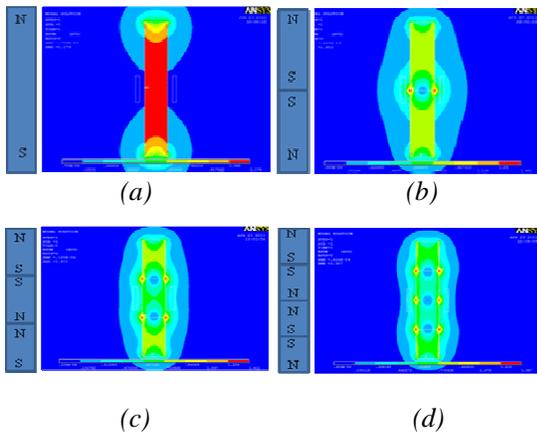


Fig. 2: ANSYS simulation of magnetic pole alignment towards Y-axis (Un-symmetrical) (a) 1-magnet 'B'=0.262 (T), (b) 2-magnet 'B'=0.3224 (T), (c) 3-magnet 'B'=0.3115(T), (d) 4-magnet 'B'=0.3081 (T)

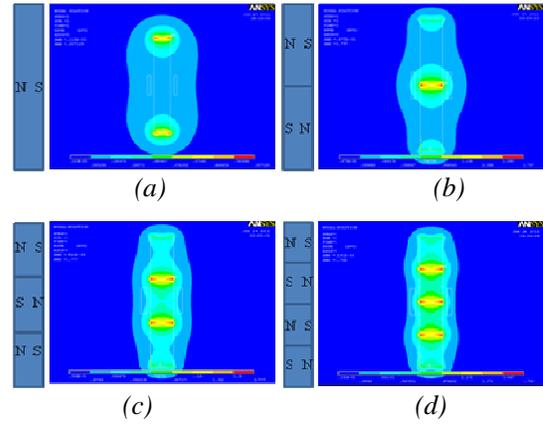


Fig. 3: ANSYS simulation of magnetic pole alignment towards X-axis (a) 1-magnet 'B'=0.1904 (T), (b) 2-magnet 'B'=0.3993 (T), (c) 3-magnet 'B'=0.3948 (T), (d) 4-magnet 'B'=0.3917 (T)

It is clear among those three designs that the third magnetic pole alignment is the best. Therefore, this third magnetic pole alignment has been proposed as a moving magnet for the harvester.

Harvester Design and fabrication

Fig. 4 shows a schematic diagram of an optimized vibration-driven electromagnetic energy harvester. The proposed structure is composed of a rectangular housing made of Acrylic glass with length of 12 mm, width of 7 mm and height of 120 mm, a copper induction coil and an active mass.

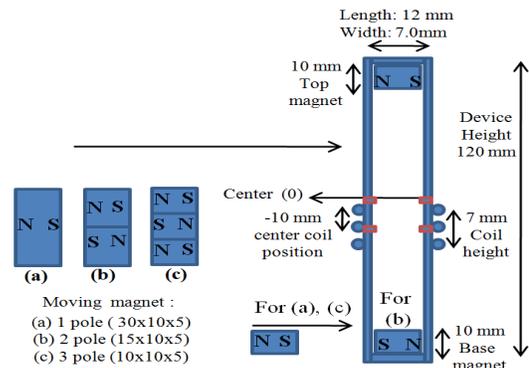


Fig. 4: Schematic diagram of an optimized Multi-pole energy harvester

As seen from the ANSYS simulation, third magnetic pole design by using rectangular *NdFeB* magnets are proposed for the active mass in the harvester. Also, two rectangular *NdFeB* magnets (10x10x5) mm each are proposed to be fixed at each end of the housing which also acts as magnetic springs for the moving magnet. As for using magnetic spring, harvester resonance frequency becomes very low.

When an external force $F(t)$, is applied, the center magnet starts to oscillate throughout the coil. According to Faraday's law of induction, the coil cut

the flux line of the magnet, thus produces voltage. According to the law, (assuming vibration is vertical)

$$V_{coil} = -N \frac{d\phi}{dt}, \quad (1)$$

Where N is the number of turns, $d\phi/dt$ is the rate of change in flux [9]. Fig. 5 shows the fabricated harvester with an experimental setup.

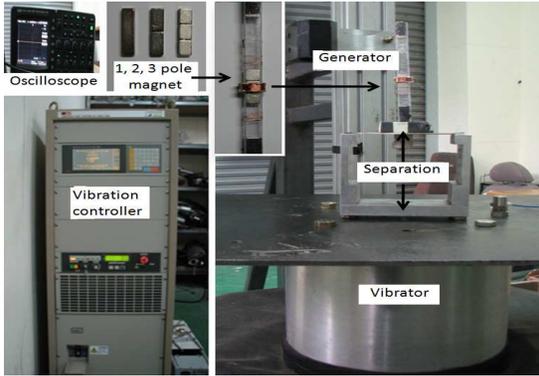


Fig. 5: Fabricated harvester with experimental setup

EXPERIMENTAL RESULTS

A mechanical vibration test system (CV-1000-080) with amplitude of 0.5 g has been used for the oscillation of the harvester. To eliminate the magnetic effects of the vibration system, a separation of 8 cm between the vibration system and harvester has been used.

At first the harvester height is varied from 90 mm to 135 mm to find out the harvester optimized height. The maximum no load voltage is found at the height of 120 mm including 10 mm of bottom and top fixed magnet. Fig. 6 shows the peak to peak voltage vs. height for the harvester.

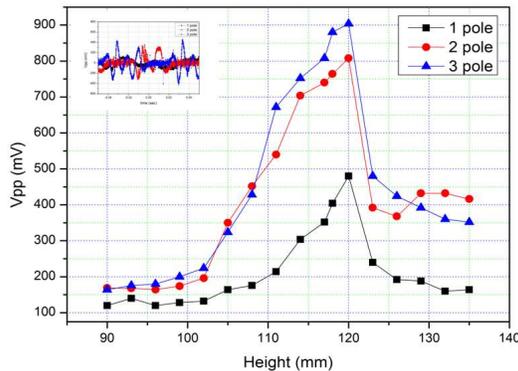


Fig. 6: No load peak to peak voltage versus height of three type magnets

After fixing the height of the harvester, frequency is varied from 3 Hz to 9 Hz. At 6 Hz of frequency, the entire three type magnet shows high vibrating oscillation then others. Fig. 7 shows the V_{pp} voltage of three type magnet versus the frequency. After words,

the coil position is varied from -25 mm to center (0 mm) of the housing and from center to +33 mm of the housing. At -10 mm from the center of the housing, maximum no load voltage is found for all three types of magnet. Because of the gravitational force, the moving magnets position is slightly lower from the center of the housing. That's why the coil is also slightly lower from its center of the housing. Fig. 8 shows the no load voltage versus coil position for the three types of magnet.

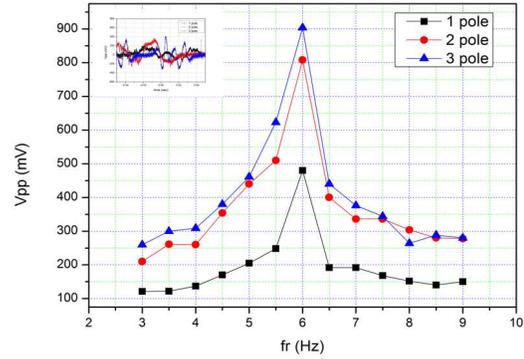


Fig. 7: No load peak to peak voltage versus resonance frequency of three type magnets

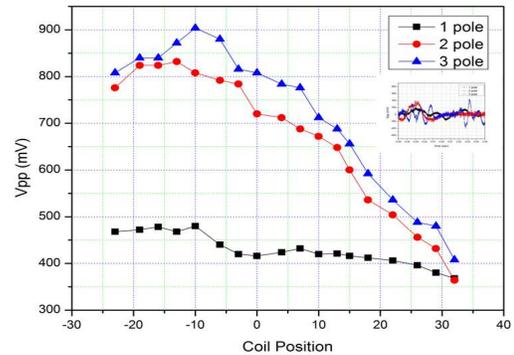


Fig. 8: No load voltage versus optimized coil position

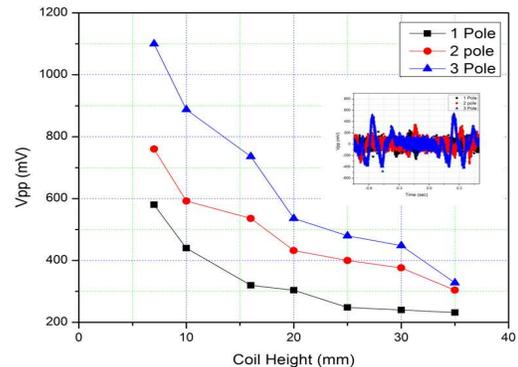


Fig. 9: No load voltage versus optimized coil height

Moreover, optimum coil height is examined by varying the height from 7 mm to 35 mm. As it is observed, smaller coil height (7mm) gives more output voltage than the larger one. When the coil height is larger, flux lines get totally enclosed by the coil, thus do not contribute any resulting output voltage whereas

for smaller height, the rates of change in flux is more, thus contributes more resulting output voltage. Fig. 9 shows the no load voltage versus coil height for the entire three pole magnets.

Fig. 10 shows peak to peak voltage with different turn numbers. At 900 numbers of turns, a maximum V_{pp} of 1.42 V is achievable for three pole magnets whereas for single and two pole magnets, the voltage is 480 V and 800 V, respectively.

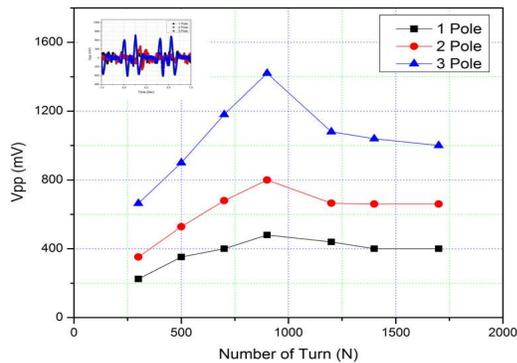


Fig. 10: No load voltage versus coil number of turns

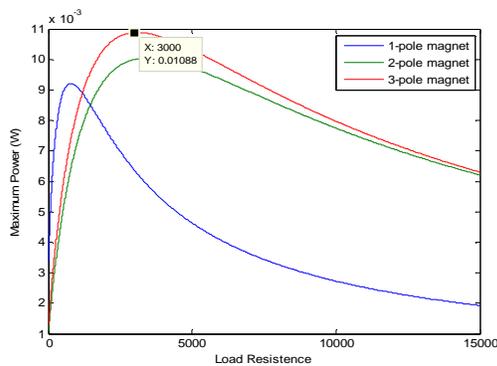


Fig. 11: Maximum power vs. load resistance

Fig. 11 shows calculated power vs. load resistance using MATLAB program. The output power reaches its maximum value of 10.88 mW at load resistance of 3.0 k Ω for 3 pole magnets [10].

CONCLUSION

In this work, a new vibration-driven electromagnetic energy harvester using a multi-pole magnet was designed, fabricated and analyzed. An ANSYS simulation has been used to study the different pole alignments of the magnet. In the experiment section, different parameters were evaluated to have an optimized multi-pole harvester. The final optimized harvester shows, a maximum of 10.88 mW of power with a load resistance of 3.0 k Ω for 3 pole magnets with 900 coil turns. Therefore it is clear, for same volume multi-pole energy harvester have high voltage and power for particular magnetic pole alignment.

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