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DESIGN AND ANALYSES OF VIBRATION DRIVEN ELECTROMAGNETIC ENERGY HARVESTER USING MULTI-POLE MAGNET

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Abstract- *This paper investigates design and analyses of a vibration driven electromagnetic energy harvester using multi-pole magnet. Firstly, ANSYS simulations of various magnetic pole alignments were analyzed which effects the enhancement of flux density with voltage and power. It was found that, for particular type of magnetic pole alignment the magnetic flux density could be higher. Then, harvesters design was addressed which comprises magnetic spring, copper coil, NdFeB magnet with housing of Acrylic material. Finally, magnetic parameters like load resistance, coil resistance and magnetic field have been analyzed to obtain an optimized output power for the harvester through theoretical study.*

Keywords: Vibration power harvesting, multi-pole magnet, low frequency, simulation.

1. INTRODUCTION

Now-a-days the use of small scale portable devices like mp3 player, mobile phone and wireless sensors has tremendously gone up. For powering up of those devices, various type of conventional battery like Alkaline (non-rechargeable), Nickel Metal Hydride and Lithium Ion (rechargeable) is being used. But those conventional battery needs to be charged up regularly and also have a limited life cycle after which we have to dispose of those. Also those conventional batteries have chemical reaction which pollutes the environment very much. To overcome those limitations of battery we can consider of using alternative energy sources like solar, wind and thermal etc. [1-3]. But for portability and inside remote sensing those sources seems not suitable. Also they are complex and high in cost. On the other hand, vibration source seems very appropriate because of their easy working principle [4]. Various type of vibration based energy harvester was investigated like electromagnetic, piezo-electric and electrostatic [5]. But among them electromagnetic seems appropriates because of their simple structure and low resonance frequency. It just follows the Farads law of induction where one center magnet moves with respect to spring throughout coil and cut the magnetic flux of the magnet [6]. Thus creates rate of change of flux around the coil and produce voltage. Various electromagnetic energy harvester has been investigated which uses the single magnet [7-10]. But the power from those single magnet energy harvesters is very low for application. To solve the problem some groups tried to use more than one magnet i.e. multi-pole magnet instead of single magnet [11-15]. The output voltage and power was increased in those cases but the size also increased which is undesired.

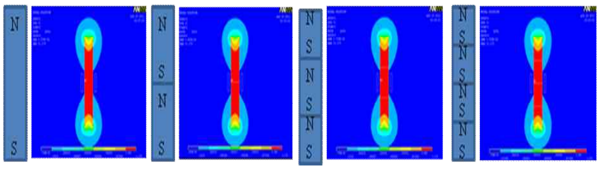
Therefor, this paper is focused on design and analyses of an energy harvester having more than one magnet i.e., multi-pole magnet which could have high voltage and power within same volume for particular magnetic pole alignment.

2. ANSYS SIMULATION

At first, ANSYS simulation was done to see the magnetic flux density for different magnetic pole alignment. Figure 1-3, shows different magnetic flux density for single, double, triple and four pole magnets maintaining same volume. Figure 1, Shows the ANSYS simulation for magnetic pole alignment towards *Y-axis* where the pole array is symmetrical i.e., each '*south pole*' is attracted by opposite '*north pole*' and vice versa for more magnets. For those cases it shows no change of flux density for single, double, triple and four pole magnets and the density is around 0.262 T. So, if we choose this type of magnetic pole alignment in energy harvester, multi-pole magnet will not increase the total efficiency. Figure 2, shows an un-symmetrical magnetic pole alignment towards *Y-axis* where each *'south pole'* is attracted by same *'south pole'* and vice versa for multi-pole cases. It is clear, flux density has increases for multi-pole magnet cases comparing to single pole magnet and it shows flux density of 0.262 T, 0.3224 T, 0.3115 T and 0.3081 T respectively. But connecting same *'south'* to *'south'* and *'north'* to *'north'* pole is very difficult. So this pole alignment seems no good at all.

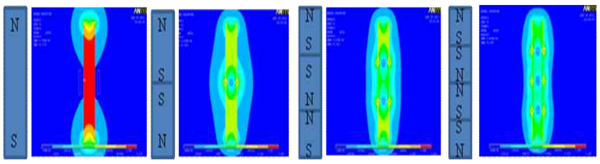
Next Fig. 3 shows ANSYS simulation for magnetic pole alignment towards *X-axis* where it is very easy to connect different pole array one with others. Figure 3(b) shows flux density of 0.3993 T for two magnet cases which has increased comparing to single magnet of

0.1904 T in Fig. 3(a). For three and four magnet cases in Fig. 3(c) and 3(d), it remains almost same. The question arises then how multi-pole magnet increases the efficiency? The noticeable thing is as more magnets add in an array the total number of flux peak also increases. It can be easily seen from Fig. 3(a)-3(d) that increase of flux peak of two, three, four and five for single, double, triple and four pole magnets respectively. So the rate of change in flux totally increases, which makes the harvester more efficient. But also from the fig. 3(a)-3(d), it can be seen that as the number of magnet increases, the area of flux density reduces.



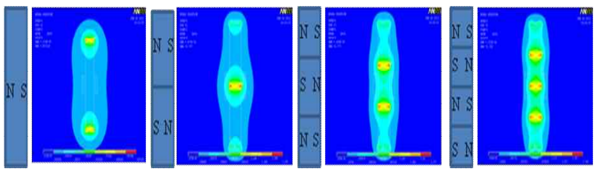
(a) (b) (c) (d)

Fig. 1: ANSYS simulation for 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)



(a) (b) (c) (d)

Fig. 2: ANSYS simulation for 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)



(a) (b) (c) (d)

Fig. 3: ANSYS simulation for 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)

So, to make more utilization of those flux peaks, the coil of the harvester has to put close as much as possible to magnet. It is clear among those three designs that, the 3rd magnetic pole alignment is best. The design of the harvester will be explained in details on next section using the 3rd magnetic pole alignment.

2.1 Design of the harvester

Figure 4 shows schematic diagram of the vibration driven electromagnetic energy harvester. The proposed structure is composed of a rectangular housing made of Acrylic glass, copper induction coil and an active mass. As seen from the ANSYS simulation in Fig. 3, magnetic pole towards *X-axis* of single, double, triple and four pole rectangular magnets is proposed for the active mass in the harvester. Also two rectangular type magnets are proposed to fix at both end of the housing. Both active magnet and fixed magnet is proposed of *NdFeB* because of their high flux density [19].

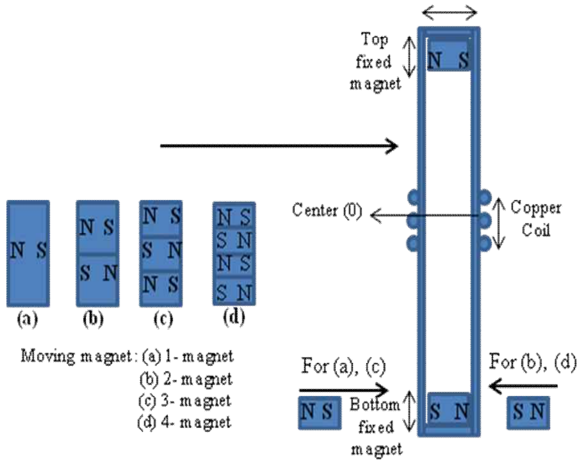


Fig. 4: Schematic diagram of multi-pole energy harvester

The top and bottom fixed magnet will act as a magnetic spring for the moving magnet. As for using magnetic spring, the harvester resonance frequency will be very low which is very suitable for human body sensor applications [16]. When the harvester stars to vibrate by external forces, the center magnet will start to oscillate throughout the coil. According to the Faraday's law of induction the coil will cut the flux line of the magnet, thus will produces voltage. According to the law, voltage induced in the coil (assumed vibration is vertical) is,

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

Where, N is the number of turn. By varying N the induced voltages can be varied. $d\phi/dt$ is the rate of change of flux. By increasing $d\phi/dt$, the total induced voltage can be increased [16].

2.2 Analytical study

In order to predict practical performance of the devices, analytical study including damping and other parameter has been studied. Damping includes parasitic and electromagnetic ones. The parasitic damping represents loss mechanism such as air damping, friction between housing and moving mass etc. The electromagnetic damping represents the mechanism by which the electrical power is being extracted from the system [17]. In a system, maximum efficiency can be occurred by decreasing parasitic and increasing electromagnetic damping.

The important fact for analytical study is the amount of power that the generator will produce. Equation (2) shows the optimized power which is,

$$P_{avg} = (y^2 w^2 s^2) / (8 z_t^{\,2} (R_l + R_c)) \qquad (2)$$

Where, $z_t = z_e + z_m$

Here, *Ze* is the electromagnetic damping which is

$$z_e = s^2 / 2mw(R_l + R_c), \text{ and } s = NBl$$

Where, N is the number of turns in the coil, l is the length of coil, B is the magnetic flux density and *Rc, Rl* is the coil resistance and load resistance respectively. Using Eq. (2) various parameters has been analyzed from Fig. 5-8 [18]. Figure 5 shows calculated power vs. coil number of turn. As it is observed from Fig. 5, optimum power of 28.24 mW could be obtained at 1400 number of coil turns.

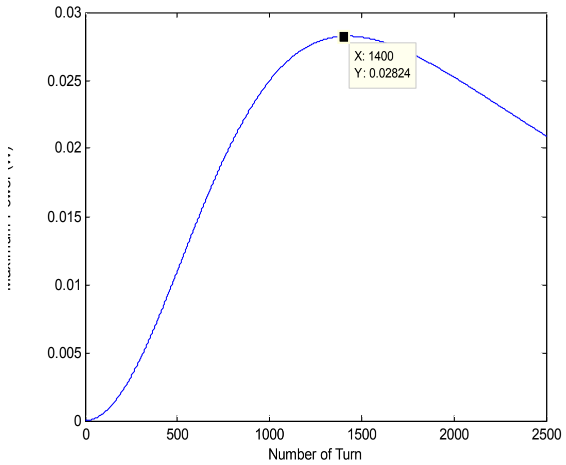


Fig.5: Maximum power vs. coil number of turn

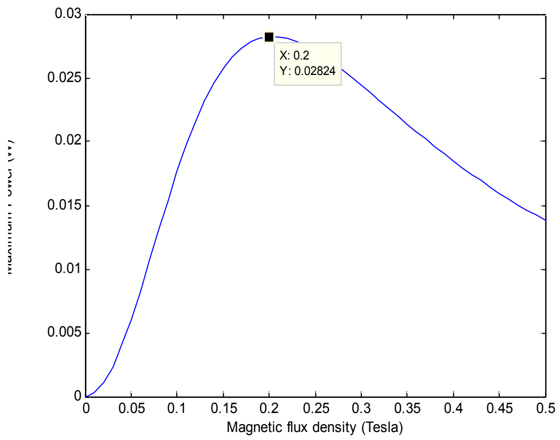


Fig.6: Maximum power vs. magnetic field 'B'

Figure 6 shows calculated power vs. magnetic field. As the magnetic field increase, corresponding power increases too. But high magnetic field needs big magnet. At that time, harvesters housing size will increase which could make the harvester less efficient. So increasing the size of the magnet should be avoided if it's not necessary.

Figure 7 shows calculated power vs. load resistance. The output power reaches its maximum value of 28.24 mW at load resistance of 1.7 kΩ [18].

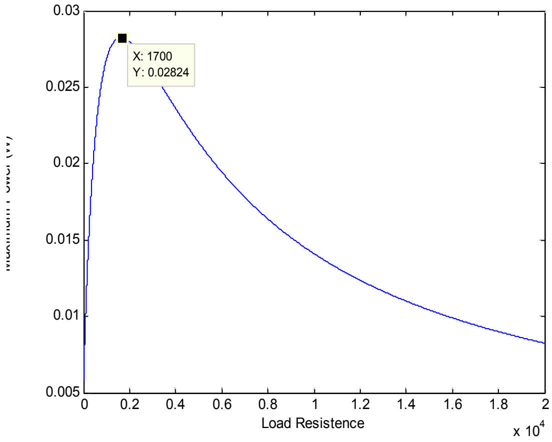


Fig.7: Maximum power vs. load resistance

Figure 8 shows calculated power vs. coil resistance. The analysis shows that, power are maximum when the coil resistance is minimum.

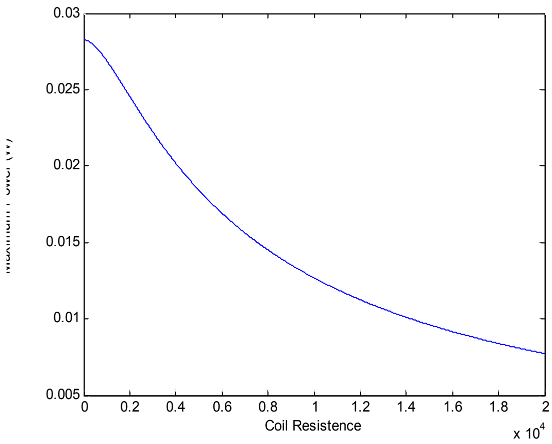


Fig.8: Maximum power vs. coil resistance

3. CONCLUSION

In this paper, a new vibration driven electromagnetic energy harvester using multi-pole magnet has been designed and analyzed. ANSYS simulation has been used to see different pole alignment of the magnet. In the analytical section damping and power was demonstrated using various parameters in MATLAB. The analysis shows that, maximum 28.24 mW of power could be achievable with a load resistance of 1.7 kΩ for 1400 number of coil turns.

4. ACKOWLEDGEMENTS

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