DESIGN, SIMULATION AND CHARACTERIZATION OF A VIBRATION BASED AA SIZE ENERGY HARVESTER USING MAGNETIC SPRING

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Abstract*-This paper describes the design, analysis and characteristics of AA size electromagnetic energy harvester which capable of converting environmental vibration into electrical energy. Magnetic spring technique is used to scavenge energy from low frequency external vibration. The characterization of generator is done by using ANSYS 2D finite element analysis. The generator is optimized in terms of moving mass, fixed magnet size, coil width and load resistance. The optimized energy harvester can generate maximum 53.5 mW power at 8.1 Hz resonance frequency with a displacement of 0.5 mm.*

Keywords: Energy harvester, vibration, AA size, magnetic spring, low frequency

1. INTRODUCTION

Nowadays, wireless sensors are becoming very popular because of its wide range of applications in remote and physically inaccessible locations. These sensors require a compact, low cost, long operating life and light weight energy source [1-3]. Usually, fixed energy alternatives, such as, batteries and fuel cells are used as power source for those sensors. However, recharging or replacement of batteries are impractical for those applications, that requires sensor to be installed for long duration or in inaccessible locations, such as, biomedical implants and structure embedded micro sensors [4-7]. Batteries also have the limitations of environmental hazards and sometimes bulky in compare with MEMS device. Energy harvesting from ambient energy sources is a possible alternative to batteries. There are several environmental energy sources, such as- thermal, solar, acoustic noise, wind and vibration [8-11]. Vibration is more attractive, since it is inherent in nature [6, 12].

In this study, we focused on designing an AA size electromagnetic energy harvester. Several studies have already reported related to AA size transducers. For example, in [13-14], the authors proposed an AA size energy harvester by using spring mass system, which are capable of producing maximum 120 μW and 830 μW power at 70.5 Hz and 100 Hz resonance frequency. Recently, S. Korla et al. proposed same size generator using piezoelectric transduction technique, which can generate 625 μW of power at 50 Hz resonance frequency [15]. However, the resonance frequency of those harvesters is very high. On the other hand, ambient vibration frequency is very low (1-10 Hz) [16]. Some researches have been also conducted to reduce the operating frequency of harvesters. For example, using frequency up conversion technique, it is possible to operate the transducer at 25 Hz resonance frequency [17]. However, it can generate only 3.79 μW maximum power.

Therefore, this paper presents, design and analysis of an electromagnetic energy harvester by using magnetic spring. Magnetic spring type generator has the advantages of low resonance frequency, simple construction process and easy vibration under off resonance conditions [18-19].

2. DESIGN

2.1 Generator structure

A schematic diagram of a magnetic spring generator is shown in Fig. 1. A moving magnet inserted into a hollow plastic straw. Then, two opposite pole fixed magnets has

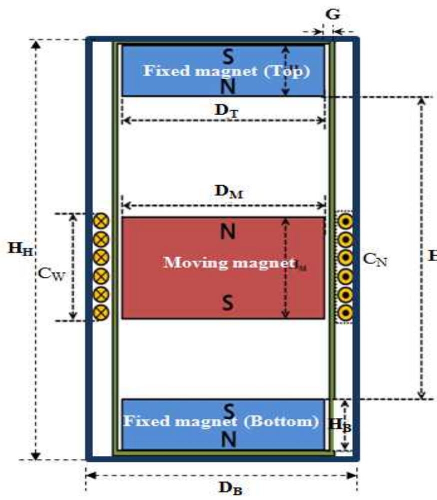

Fig. 1: Schematic diagram of the magnetic spring transducer

been placed vertically in such a way that, all the facing surface of magnets have same pole. A coil of enamel coated copper wire is wrapped horizontally around the outer casing of plastic straw. When an external force applied to the structure, the middle magnet start to oscillate due to magnetic repulsion of two fixed magnets and hence AC voltage will be induced in the coil.

2.2 Modeling of the generator

The proposed energy harvester can be described by a spring mass system. Assume that, a sinusoidal force F is applied to the system. By applying Newton's second law to the moving magnet, we can write:

$$m\frac{d^2x}{d^2t} = P + F_{damping} + F_{spring} + F \qquad (1)$$

Where, m is the moving magnet mass, x is the relative displacement between moving magnet and generator housing, and P is the gravitational force.

Equation (1) can be written as:

$$m\frac{d^2x}{d^2t} = -mg - (D_p + D_e)\frac{dx}{dt} - kx + F \qquad (2)$$

$$m\frac{d^2x}{d^2t} + (D_p + D_e)\frac{dx}{dt} + kx = F - mg \qquad (3)$$

Where, D_p and D_e are the parasitic damping coefficient and electromagnetic damping coefficient respectively. k is the spring constant with the following form:

$$k = \frac{F}{x} = \frac{F_T - F_B}{x} \qquad (4)$$

Where, F_T is the force between top and moving magnet and F_B is the force between bottom and moving magnet. Therefore, the solution of displacement of Eq. (3) [20]

$$x(t) = \frac{F_0 - mg}{\sqrt{(k - mw^2) + (D_p + De)^2 w^2}} \qquad (5)$$

The average generated power at resonance (i.e., $w=w_n=\sqrt{(k/m)}$) can be written as:

$$P_{res} = \frac{D_e(F - mg)^2}{2(D_p + D_e)} \qquad (6)$$

3. RESULT AND DISCUSSION

The generator structure is modeled by using ANSYS 2D axi-symmetric finite element analysis as shown in Fig. 2. The simulation parameters are given in Table 1.

When moving magnet height is less than coil width, the response (i.e., flux density vs. distance) shows some nonlinearity towards the ends [18]. The nonlinearity can be reduced by increasing moving magnet height, since; increase of moving magnet mass reduces linear stiffness.

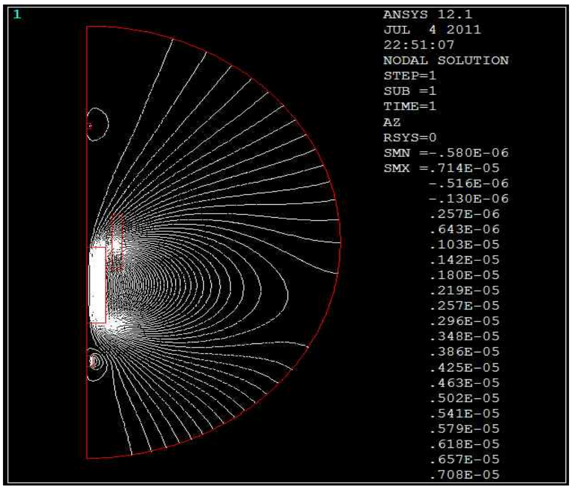

Fig. 2: Axi-symmetric finite element simulation showing flux lines

Table 1: Generator materials and simulation parameters

Parameter	Value/material
Dimension of housing (D_H x H_H)	14x48 mm^2
Inner cylinder's material	Plastic straw
Inner cylinder's dimension	7x46 mm^2
Magnet's material	NdFeB (N35)
Coil's material	Copper
Coil position	0 (Center)
Coil width (C_W)	10 mm
Coil thickness	0.1 mm
Coil resistance	96.502 Ω
Coil-magnet gap (G)	1 mm
Distance between fixed magnets (H_C)	42 mm
Displacement (y)	0.5 mm

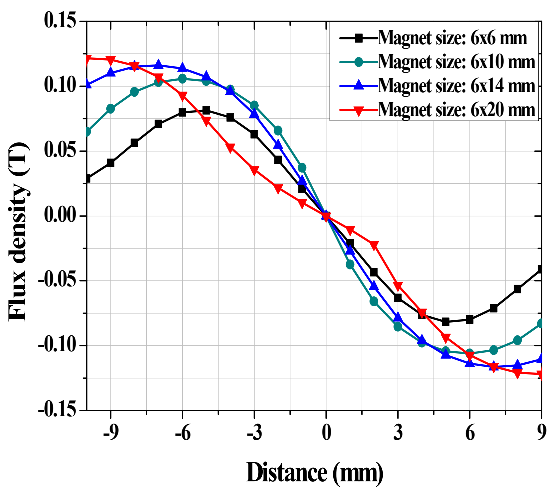

Fig. 4: Flux density across coil surface vs. position of moving magnet

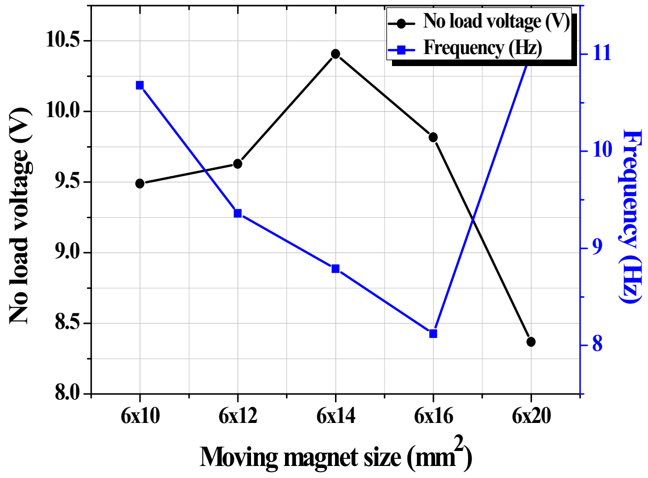

Fig. 4: No load voltage vs. resonance frequency for different moving magnet size

coefficient. As observed from Fig. 3, the response shows more linearity with the increase of moving magnet size.

If moving magnet size increases, flux density across the coil also increases, however, displacement speed of moving magnet will decreases [16, 19]. Therefore, to optimize the output voltage, a trade off is required between flux density and moving magnet displacement speed. As it is shown in Fig. 4, a maximum voltage of 10.4 V obtained for 6x14 mm moving magnet size with a resonance frequency of 8.8 Hz.

Similarly, for the optimization of fixed magnet at top and bottom end of the tube, a trade off is required between flux density and mass displacement [21-22]. As observed from Fig. 5, when 1x1 mm size magnet is used at top and bottom, the device operates at lowest resonance frequency (7.8 Hz). However, at this time, output voltage is low (9.67 V). An optimum voltage of 11.4 V is obtained, when 1x1 mm and 2x2 mm size magnet is used at top and bottom respectively.

Figure 6 shows, no load voltage for different coil widths. As it is observed, smaller coil width (5mm) is giving more output voltage (13.88 V), thus, there is less possibility of flux enclosing than a larger coil width. The flux lines totally enclosed by the coil do not have any

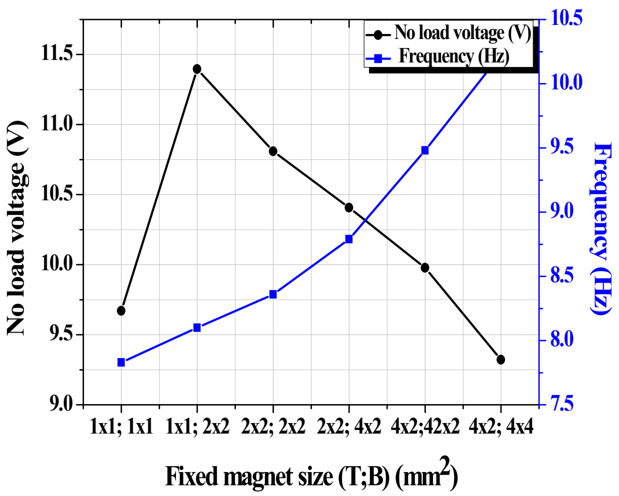

Fig. 5: No load voltage and frequency vs. top (T) and bottom (B) magnet size

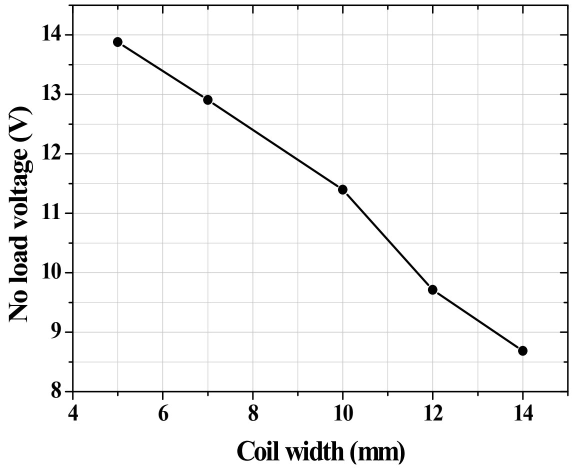

Fig. 4: No load voltage vs. coil width

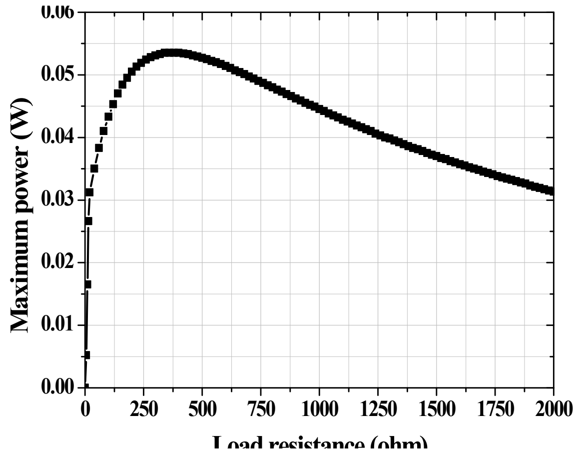

Fig. 4: Measured output power vs. load resistance at resonance condition

contribution in the resultant output voltage, because, total flux linkage for those flux lines with the coil is constant [23].

PSpice simulation software is used to find out the maximum power at optimum load condition. A full wave rectifier is made by using HITACHI HRP22 Silicon Schottky barrier diodes (V_f= 0.35 V). Three 1000 µF, 10 V SAMWAH SG series capacitors are used in parallel with the load resistance to reduce the ripple in the output. As it is observed from Fig. 4, a maximum power of 53.5 mW is obtained at 360 Ω load resistance. The optimized parameters of the proposed AA size electromagnetic energy harvester are given Table 2.

Table 2: Optimized parameters of generator

Parameter	Dimension
Moving magnet size (mm^2)	6x14
Top magnets size (mm^2)	1x1
Bottom magnets size (mm^2)	2x2
Coil width (mm)	5
Load resistance (Ω)	360
Maximum power (mW)	53.5

5. CONCLUSION

This paper has demonstrated an AA size electromagnetic transducer by optimizing moving magnet size, fixed magnets size and coil width. Moreover, the nonlinear behavior of the generator has been reduced by increasing moving magnet height in comparison with coil width. The optimized energy harvester can produce 53.5 mW power at 360 Ω load resistance. The main advantages of the proposed magnetic spring type energy harvester are simple operation, lower cost and long operating life. Furthermore, the generator can operate at 8.1 Hz resonance frequency. Therefore, proposed generator is very useful for supplying power for health care and environmental monitoring sensor systems.

6. ACKOWLEDGEMENTS

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