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DESIGN, FABRICATION AND CHARACTERISTICS OF A VIBRATION DRIVEN ELECTROMAGNETIC GENERATOR BASED ON FR-4

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Abstract*-This paper describes the design, fabrication and characteristics of a vibration driven electromagnetic micro generator based on FR-4 material for spring which converts mechanical energy to electrical power by Faraday's law of induction. The fabricated generator consists of a vertically polarized NdFeB permanent magnet attached to the center of a planar spring and a copper coil. ANSYS modal analysis and MATLAB software were used to determine the resonant frequency and output of the generator. The output voltages are shown with different coil turns and input frequencies. The generator is capable of producing up to 550 mV peak-to-peak under 7 Hz, which has a maximum power of 95.5 μW with load resistance of 580 Ω.*

Keywords: Energy harvesting, Vibration, Electromagnetic, FR-4

1. INTRODUCTION

With the fast development of low-power wireless sensor networks and MEMS, how to supply the power for them efficiently is becoming an important engineering problem. Batteries have been widely used to power those systems up to now, but those have many disadvantages as a short lifetime, contains a finite amount of chemical energy, difficult to replace and recharge and cause the environmental pollution. Therefore, a renewable power supply must be found to substitute batteries.

Energy harvesting from ambient vibration energy has become possible during the last decades [1-3], and electro-dynamical transduction is a popular electro-mechanical power conversion scheme for its high-power density [3]. Various magnetic energy harvesting devices have been investigated for applications that require long-lasting portable power sources [4-8]. The vibration energy sources are available in various forms, such as, machine vibrations [8], ocean waves [9], human motions [5-7], and so on.

In the literature, a majority of the power scavengers are the moving magnet type electromagnetic generators [10-14], whereas moving coil type generators are also investigated [15, 16]. Electromagnetic, piezoelectric, and other types of generators are reviewed in detail in [17-22]. Energy harvester generates maximum power when environmental frequency matches the resonant frequency of the mechanical structure, but since the environmental vibrations are typically below 100 Hz and broadband characteristics, there is a need for energy scavengers that operate at low and broadband frequencies. Even though all of the reported electromagnetic generators operate in the high level of frequencies, the fabricated generator using FR-4 is worked at low frequencies because of low young's modulus of FR-4 materials, and it is possible to make easily and cheaply than Si and Cu materials.

This paper presents the simulation, fabrication process and experimental results of the vibration driven electromagnetic energy harvester based on FR-4.

2. DESIGN

The schematic design of vibration based electromagnetic energy harvester is shown in Fig. 1. The structure is composed of a cylindrical housing, a planar type induction coil, and an electromagnetically active mass spring. The mass spring consists of a vertically polarized NdFeB permanent magnet attached to the center of a FR-4 planar spring which has two spring beams and a platform.

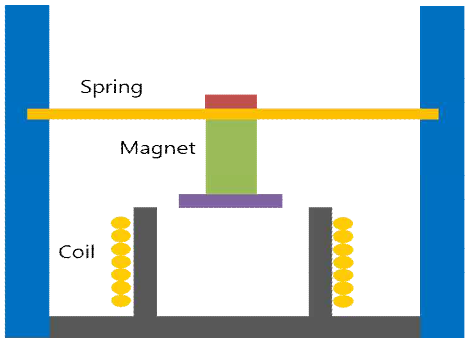


Fig. 1: Schematic structure of the fabricated energy harvester

When the external force is applied magnet will vibrate and move towards the coil and caused the change of the magnetic flux across the coil. As a result, voltage will be induced in the coil according to the Faraday's law of induction [23].

The spring has longer beam length, which can produce small spring constant and bigger amplitude of vibration and the corner of the spring beam is circular which can decrease the stress intensity of the spring. The spring beam is 1 mm in width and 200 um in thickness. The volumes of the permanent magnet are $4\Phi\times2T$ (upper), $4\Phi\times10T$ (middle), and $8\Phi\times2T$ (bottom) respectively. A copper wire of 0.1 mm diameter was used for coil with different number of coil turns (400, 800 and 1200).

3. ANALYSIS

ANSYS modal analysis was used to predict the resonant frequency of the generator as shown in Fig. 2 and 3. Figure 2 shows the resonant frequencies of spring mass with different spring materials. FR-4 has the lowest resonant frequency compare with Si and Cu.

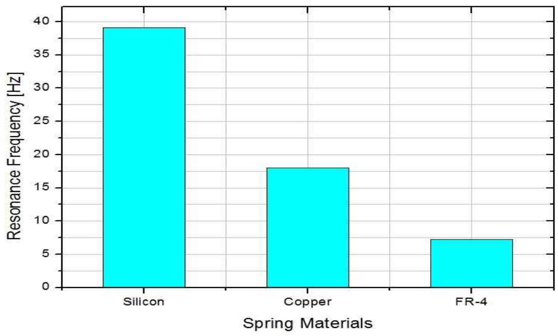
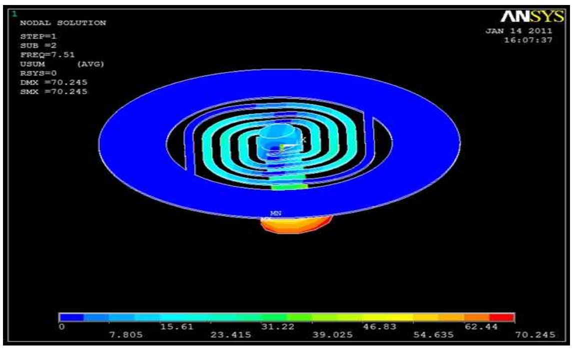
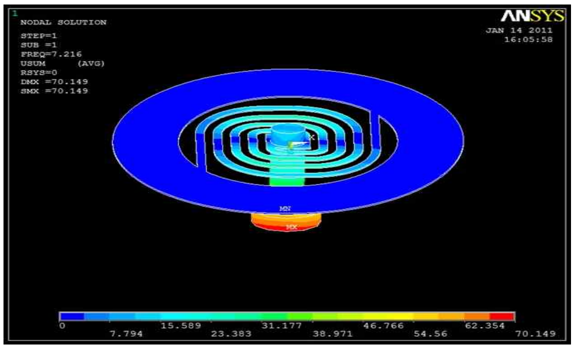


Fig. 2: Resonance frequency variations according to the spring materials

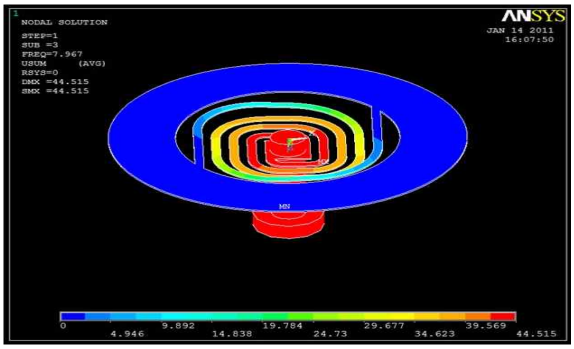
The three different modes of vibration are shown in Fig. 3 (a) to (c). Figures 3 (a) and (b) shows that the magnet rotates about an axis parallel to the plane of the spring in the first and the second modes and resonant frequency is (a) 7.510 Hz and (b) 7.216 Hz respectively. Figure 3 (c) is about the third mode in which the spring and magnet vibrate in vertical direction and also has 7.967 Hz of resonant frequency [23]. The maximum deflection of spring is the third mode and the maximum output voltage is generated at that time.



(a)



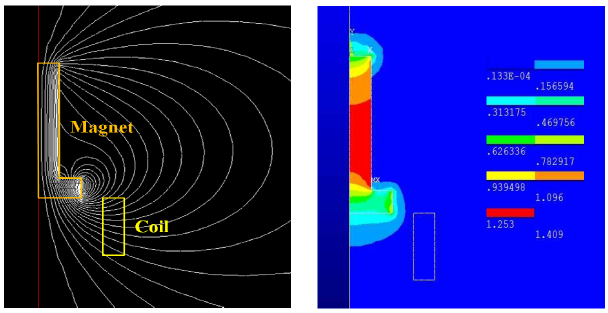
(b)



(c)

Fig. 3: Simulated results of modal analysis: (a) first-mode shape, (b) second-mode shape and (c) third-mode shape

Figure 4 shows the results of axi-symmetric finite element simulation of the corresponding generator structure of Fig. 1. The flux lines and magnetic flux density distribution around the magnet in the simulation are shown in Figs. 4 (a) and (b). The bottom magnet has a direct influence on a coil.

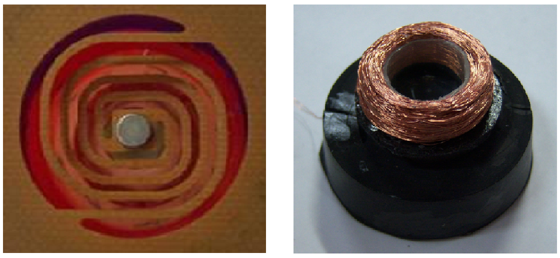


(a) (b)

Fig. 4: 2D FEA simulations of (a) flux lines and (b) magnetic flux density in the model

4. FABRICATION

The fabricated FR-4 spring and Cu coil is shown in Fig. 5. FR-4 is most commonly used as an electrical insulator possessing considerable mechanical strength and copper has the high electrical conductivity of the commercial metals. The spring pattern is 1 mm in width, 200 µm in thickness and 1 mm gap is used between consecutive spring beam and vertically polarized permanent magnet is attached to the center of spring. The coil consists of various turns (400, 800 and 1200) with the diameter of 0.1 mm.



(a) (b)

Fig. 5: Fabricated (a) FR-4 spring and (b) Cu coil

5. RESULTS AND DISCUSSION

Figures 6 and 7 shows the calculated output voltages with different coil turns at resonant frequencies and waveform at the maximum output voltage. We used various magnet mass in order to make the different resonant frequencies. Figure 6 also shows that the output voltage is proportional to the number of coil, so the turns should be as many as possible within the field of magnetic. To get a higher output voltage, increasing the number of coil turns is not always effective. As the number of coil turns increases, the internal resistance of the coil also increases; therefore, it is important to compromise between number of turns and internal resistance of coil to get an optimum number of coil turns for the design [24]. The obtained maximum voltage is 550 mV peak to peak voltages when the coil turns are 1200.

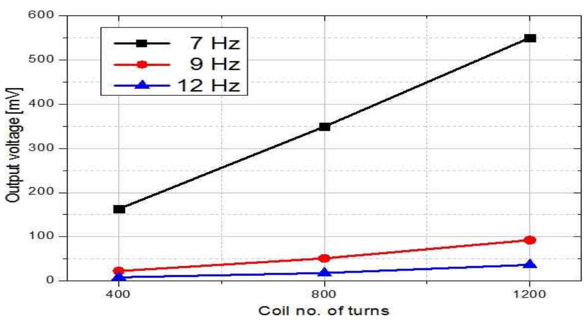


Fig. 6: Measured voltage vs. coil turns with different resonance

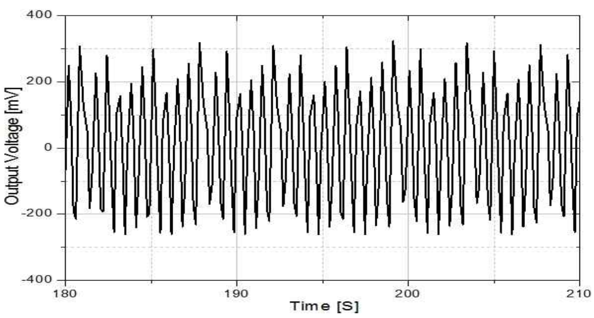


Fig. 7: Measured voltage waveform on 7 Hz resonant frequency

Figure 8 shows the calculated power output with respect to load resistance. The output power reaches its maximum value of 95.5 μW at a load resistance of 580 Ω.

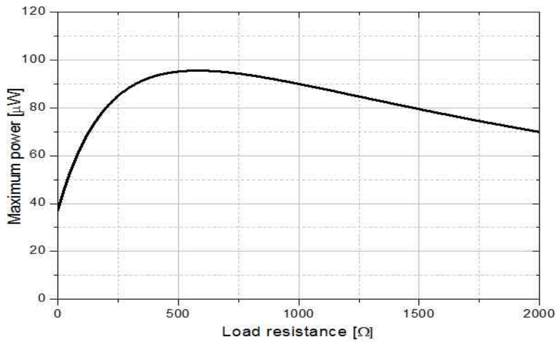


Fig. 8: Variations Calculated power vs. load resistance

Figure 9 shows the block diagram of the experimental setup. A power amplifier incorporated with a signal generator is used to vibrate the energy harvester and to regulate vibration strength. The generator is glued on the top of the vibration generator. An oscilloscope is connected with the coil of generator to measure the open-circuit voltage of the generator. When the frequency of the input vibration is equal to the natural frequency of the resonant structure, the spring-mass system will operate at resonance, meanwhile, the permanent magnet has the maximum of the amplitude and the coil will produce the maximum voltage [25].

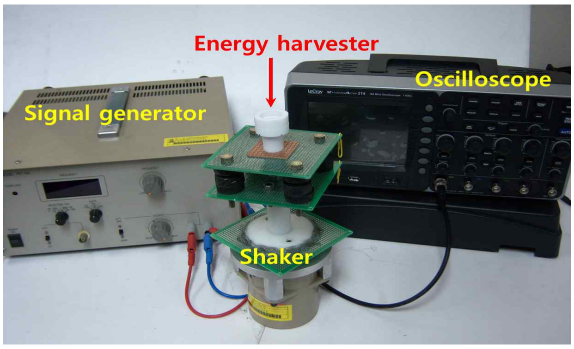


Fig. 9: Block diagram of the experimental setup

6. CONLUSIONS

In this work, we have presented the design, fabrication and characteristics of a vibration driven electromagnetic micro generator based on FR-4 which can convert mechanical vibration energy into electrical energy. The proposed generator consists of a vertically polarized NdFeB permanent magnet attached to the center of a planar spring and a planar type copper coil. The obtained maximum voltage is 550 mV peak to peak when the coil turns are 1200 and the output power reaches its maximum value of 95.5 uW at a load resistance of 580 Ω.

Compared with reported electromagnetic generator, our prototype has these advantages as a simple fabrication technique, low cost and level vibration. In addition, the output voltage of our prototype also arrived at a relative good level.

7. ACKOWLEDGEMENTS

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