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Vibration Energy Extraction

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Abstract- Now a day, the demand of renewable energy is dramatically increased. This paper presents a new vibration-based electromagnetic power generator which can convert ambient vibration energy into electric power. A low frequency driven electromagnetic energy harvester (EMEH) consists of a flexural spring, NdFeB permanent magnets, and a copper coil. As the device is excited by the vibration, the construction of the mechanism produces an oscillation of the magnetic circuit with permanent magnets against the fixed coil. Due to Faraday's law the oscillation movement of magnetic field induces voltage in the coil. The amplitude of the excited oscillation movement depends on level of the vibration and parameters of the mechanism design. Mathematical modeling and ANSYS finite element analysis (FEA) were used to theoretically investigate the mechanical properties of the spring mass system. The proposed EMEH generates a maximum power of 17.46 mW at a resonance frequency of 11 Hz.
Keywords- Vibration, Energy harvesting, Electromagnetic, Flexural bearing, Copper coil.

I. INTRODUCTION

Energy harvesting is an active field of research aimed at powering low power wireless systems, self-powered sensors and micro-systems and recharging existing batteries. Renewable energy can be harvested by generating electrical energy from solar, thermal or kinetic energy present within or around the system. Solar cells are excellent energy harvester under direct sunlight, but are limited in application under dim day light condition, in the night and where light has no access, such as in embedded systems. Thermal energy can be converted into electrical energy using see back effect, but this approach produces energy in the range of a few μW only. Kinetic energy harvester converts kinetic energy present in the environment into electrical energy. It has already been demonstrated by several groups that the ambient kinetic energy can be easily converted into electrical energy in the μW range. Kinetic energy is typically present in the form of vibration, random displacement of forces and is typically converted into electrical energy using electromagnetic, electrostatic and piezoelectric energy transduction method. [5]Low frequency Vibrations (5 - 25 Hz) are found in vehicles, blender casings, etc. Thus, these vibrations can be extracted using vibration energy harvesting device and use this energy to power different electronic devices. In this study, energy harvester is proposed to be built and studied for low vibration energy harvesting. In this paper, a novel method that generates electricity from mechanical energy by electromagnetic transduction is proposed. [8]

II. MATHEMATICAL MODELING

Resonant generators are essentially a second-order, spring-mass system. Fig. 1 shows a general example of such a system based on a seismic mass, m, on a spring of stiffness, k. Energy losses within the system are represented by the damping coefficient, c_t. These losses comprise parasitic losses c_p(e.g. air damping) and electrical energy extracted by the transduction mechanismc_e. These generators are intended to operate at their natural frequency, given by $\omega_n = \sqrt{\frac{k}{m}}$, and should be designed such that this coincides with the vibrations present in the intended application environment. The theory of inertial-based generators is well documented and will only be briefly covered here. Assuming the generator is driven by an external sinusoidal vibration of the form$y(t) = Y\sin(\omega t)$, it will move out of phase with the mass at resonance resulting in a net displacement, *z (t)*, between the mass and the frame.[3]

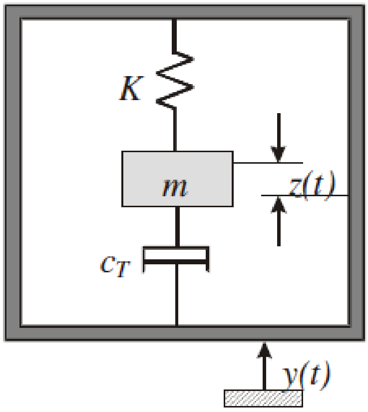

Fig. 1 Model of linear, inertial generator

Assuming that the mass of the vibration source is significantly greater than that of the seismic mass and therefore not affected by its presence, then the differential equation of motion is described as: The dynamic equation of the mass spring damper system can be written as

$$m\ddot{z}(t) + c\dot{z}(t) + kz(t) = -m\ddot{y}(t) \quad (2.1)$$

The power dissipated within the damper (i.e. extracted by the transduction mechanism and parasitic damping mechanisms) is given by:

$$P_d = \frac{m\xi_t Y^2 (\frac{\omega}{\omega_n})^3 \omega^3}{[1-(\frac{\omega}{\omega_n})^2]^2 + [2\xi_t(\frac{\omega}{\omega_n})]^2} \quad (2.2)$$

Whereξ_t is the total damping ratio given by:

$$\xi_t = \frac{c_t}{2m\omega_n} \quad (2.3)$$

Maximum power occurs when the device is operated at ω_n and in this case the theoretical maximum power stored in the system is given by:

$$P = \frac{mY^2\omega_n^3}{4\xi_t} \quad (2.4)$$

Equation 2.4 demonstrates that the power delivered varies linearly with the mass. Also, for a constant excitation amplitude, power increases with the cube of the frequency, and for a constant frequency power increases with the square of the base amplitude. It should be noted that since acceleration A=$\omega^2 Y_0$ both of these conditions must be associated with increasing acceleration in the environmental vibrations. Incorporating the parasitic and electrical damping gives the power delivered to the electrical load.

$$P_L = \frac{m\xi_e Y^2 \omega_n^3}{4(\xi_p + \xi_e)^2} \quad (2.5)$$

Maximum power is delivered when $\xi_p = \xi_e$.

III. FLEXURE BEARINGS

Bearing permits relative motion between two surfaces (magnet and coil).Flexure suspension system forms an important part of the electromagnetic device. Design of the flexure suspension system will ensure a wear free, friction less movement of the magnet and coil. Therefore, flexure bearings play crucial role in the long life and maintenance free operation of the electromagnetic device. Generally, Beryllium Copper or Stainless steel is used for manufacturing the flexure bearing. The bearing must satisfy the following requirements:

- It should be able to rotate/oscillate in one complete revolution. It should have sufficient strength and fatigue life for a sustained period of time.
- It should possess linear / rotational motion accuracy at the nanometer level or better.
- It should be compact to fit into the limited spaces in various micro-machines and devices.

3.1 Variation Of Stiffness

Stiffness of spring can be varied by varying Thickness of the Spring,Spiral angle ,Width of cut ,Starting radius ,Ending radius .

Table 1 Effect of thickness on stiffness of spring

Sr.No.	Thickness (mm)	Stiffness (N/m)	Equivalent stress (MPa)
1	0.3	49.07	723.58
2	0.4	114.90	416.57
3	0.5	221.58	257.52
4	0.6	378.31	178.08
5	0.7	592.88	129.99

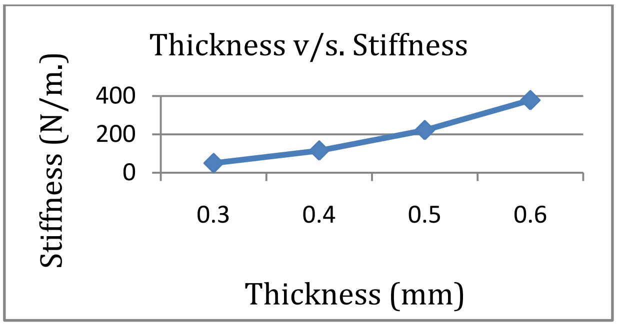

Fig. 2 Graph of thickness V/s Stiffness

As thickness increases stiffness increases rapidly. As angle of groove increases stiffness decreases rapidly .Change in width of groove gives slight variation in stiffness of spring.

IV. NEODYMIUM MAGNET

The three Neodymium magnets were used in the practical part of this paper work. Neodymium is the strongest strength of the magnetic field magnet in the rare earth family because of the Neodymium, Iron and Boron.

V. EXPERIMENTAL TEST SETUP

In order to measure the output characteristics of the Electromagnetic energy harvester, a vibration testing system is employed. A schematic drawing of the experimental setup for EMH system is shown in Figure .It consists of a vibration exciter, power amplifier, dSpace software or an oscilloscope, LVDT and DC power supply, electromagnetic device. The vibration signal is generated from the signal generator, amplified via the power amplifier and finally utilized to control the vibration amplitude and frequency of the shaker. Electromagnetic energy harvester device is mounted on the shaker by using end plate. Accordingly, the electromagnetic device will undergo excitations and generate output voltage signal which is recorded by the oscilloscope or DSpace software. Displacement signals will be measured by LVDT and then displayed on the monitor of computer.

Table 2 Dimensions and parameters of the EMEH prototype.

Description	Value
Magnet (NdFeB)	3000 Gauss (0.3 T)
Magnet dimensions	28 mm dia. x 12.5 mm thick x 10 mm dia. hole
Mass of each magnet	50grams
Resistivity of copper	1.7x10^{-8} Ωm
Gap between magnet and coil	1.25mm
No. of turns of coil	3420

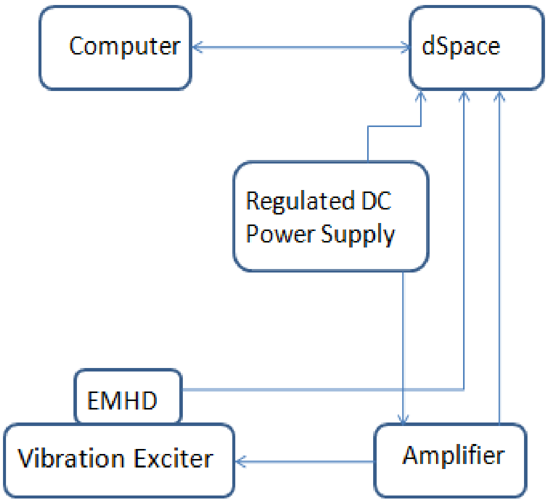

Fig 3: Schematic diagram of set up

Fig 4: Photo of set up

RESULT AND DISCUSSION

The experimental readings obtained by keeping input voltage 0.5V, 0.75V, 1V and 1.25 V and varying the frequencies from 1Hz to 25 Hz are plotted using MATLAB program.
From Graphs it can be seen that maximum output voltage and maximum displacement occurs at resonance frequency. Also, experimental results show that Maximum Output Voltage occurs at resonance frequency and thereafter even on increasing the frequency, drop in voltage output is recorded.

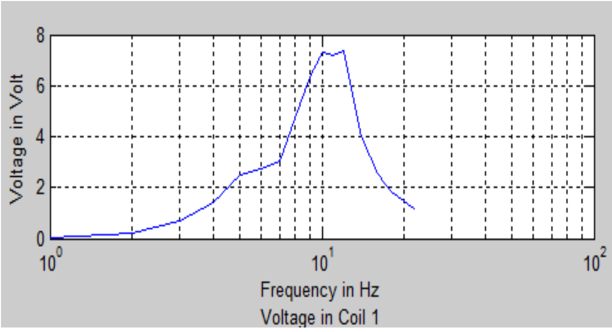

Fig 5: Graph of frequency V/s Voltage in coil 1

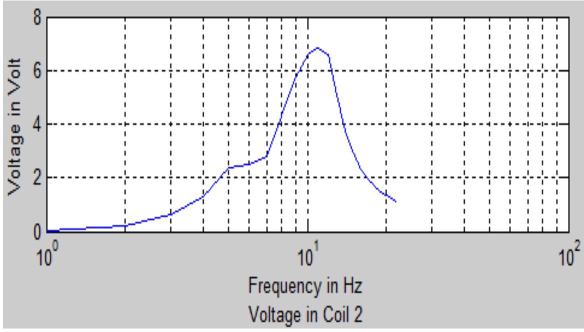

Fig 6: Graph of frequency V/s Voltage in coil 2

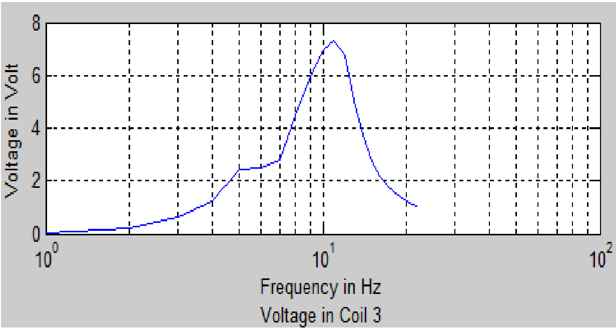

Fig 7: Graph of frequency V/s Voltage in coil 3

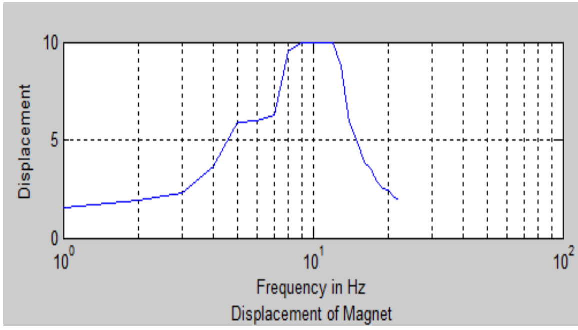

Fig 8: Graph of frequency V/s Displacement

CONCLUSIONS

A Novel EMEH using the flexural spring system was manufactured and experiments were carried out in low frequency range 1 to 25 Hz. Maximum Output Voltage occurs at input voltage 1.25 V and resonance frequency 11 Hz. The output voltage from 1 coil of EMEH is 7.3 Volt and Power Output from 1 coil of EMEH is 17.46 mW. Therefore the Total Power Output is 68 mW. From experimental results, it can be concluded that the proposed EMEH is suitable to harvest power at a low frequency level.

REFERENCES

[1] C. B. Williams and R. B. Yates, Analysis of a micro-electric generator for microsystems, the 8th International Conference on Solid-State Sensors and Actuators, 1995.

[2] S. Roundy, Energy scavenging for wireless sensor nodes with a focus on vibration to electricity conversion, University of California, Berkeley, 2003.

[3] Williams C.B. and Yates R.B, Analysis of a micro electric generator for Microsystems. Source: Sensors and Actuators A: Physical, Vol 52, no. 1, pp. 8-11, March 1996.

[4] J. R. Amirtharajah and A. P. Chandrakasan, Self-powered signal processing using vibration-based power generation, IEEE Journal of Solid-State Circuits, vol. 33, pp.687 – 695, May 1998

[5] P. Glynne-Jones, M.J. Tudor, and N. M. W. S.P. Beeby, An electromagnetic, vibration-powered generator for intelligent sensor systems, Source: Sensors and Actuators A: Physical, vol. 110, pp. 344–349, 2004.

[6] El-Hami M, Glynne-Jones P, James E, Beeby S P, White N M, Brown A D, Ross J N and Hill M, Design and fabrication of a new vibration-based electromechanical power generator Sensors Actuators A **92** 335–42, 2001.

[7] S P Beeby, M J Tudor and N M White, Energy harvesting vibration sources for Microsystems applications School of Electronics and Computer Science, University of Southampton, Southampton SO17 1BJ, UK

[8] Byung-Chul Lee and Gwiy-Sang Chung, Design and Fabrication of Low Frequency Driven Energy Harvester Using Electromagnetic Conversion, Source: Transactions on Electrical and Electronic Materials Vol. 14, No. 3, Pp.143-147, June 25, 2013
[9] S. Rathinamala and Dr. S. Manoharan**,** Vibration Powered Generators and Power Processing Circuits for Energy Harvesting: A Survey, International Journal of Advanced Research in Electrical, Electronics and
[10] Instrumentation Engineering (An ISO 3297: 2007 Certified Organization) Vol. 3, Issue 5, May 2014
[11] Stephen P Beeby and Terence O'Donnell, Electromagnetic Energy Harvesting.