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A Study of Vehicle Vibration-Driven Electromagnetic Energy Harvester (EMEH) Based on Magnetic Levitation

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Abstract: This paper proposes a kinetic energy harvester designed to be implanted in a vehicle, which works at a low frequency associated with the movement of the automobile. Since the average frequency for a moving vehicle is around 30 Hz, the proposed prototype is designed to work with this low frequency. The concept of magnetic-force-driven energy harvesting is utilized to this prototype considering the car movements during routine driving. Finite element method was used to evaluate the magnetic field for the levitation magnet within the harvester. The simulation results for the resonant frequency and the voltage induced in a coil were 30 Hz and 3.5 V respectively. A prototype of the energy harvester was fabricated and tested. Experimentally, maximum open circuit voltage of 3 V was obtained and the resonant frequency of 28 Hz was observed.

Keywords: *Electromagnetic, Vibration, Energy harvesters, Magnetic levitation, Simulation*

Introduction:

In the last decade, many researchers have been working on extracting energy from the environment focusing on kinetic energy (vibration) and using this energy to power small electronic devices[1,2]. Theoretically, any kind of vibration source can be transformed into electric power [1]. Obtaining power from mechanical vibration has drawn much attraction over the last few decades due to its plenty in nature and infinite lifetime [1,2] and can be employed as an energy source in the vehicle. Different vibration sources, such as human and machine motion [3,4], water and wind flow [5,6], rotary motion [7] etc. generate vibrations of different frequencies and amplitudes, but most vibrations are of low frequencies and large amplitudes with various cyclic movements in different directions. There are three basic techniques for this kind of conversion: piezoelectric transducers—energy is induced by the deformation of piezoelectric materials, like PZT ceramics, PVDF films and piezoelectric composite fibres [8]; spring-mass electromagnetic transducers—energy is generated between a moving magnet and a coil based on Faraday's law [9]; and electrostatic transducers—energy is generated by charging vibrating capacitor electrodes [10].

The purpose in using Vibration energy harvesters (VEHs) related to power electronic devices in vehicles and this will reduce the power requirement as well as the communication in an autonomous way and to the disposition of the monitor, the measure, and the process data in a hostile environment. On this concept, VEHs can be used in many fields such as environmental monitors, wireless sensors, medical implants [11–13] and vehicle [14]. Vibration from the environment can be qualified by a random distribution of frequency components, relatively low vibration frequency and high amplitude displacement. Usual vibration energy harvesters are based on resonant modes of mass-spring-damper systems and the maximum energy can be effectively scavenged when the resonant frequency of device attains ambient frequency.

Harvesting the kinetic energy through the electromagnetic mechanism have been presented recently [15–17]. The amount of energy that can be garnered depends on the amplitude of vehicle vibration and relative movement velocity between magnets and coils.

In electromagnetic energy harvesters (EMEHs), permanent magnet is usually applied to create a strong magnetic field and coil is employed as the conductor. Either the permanent magnet or the coil is fixed to the harvester's frame, whereas, the other is tied to the excitation source. In most of the improved devices, the coil is fixed while the magnet is moved as the micro-fabricated coil is fragile compared to the magnet. Moreover, the static coil can increase the lifetime of the device. Ambient vibration results in the relative motion between the permanent magnet and the coil, due to this relative motion the coil experience the change in magnetic flux density that results in electromotive force (emf) generated in the coil. According to the Faraday's Law, the induced voltage is relative to the intensity of the magnetic field, the velocity of the relative motion and the number of turns of the coil. In comparison to piezoelectric and electrostatic energy harvesters, electromagnetic energy harvesters produce high output current levels due to low internal impedance (coil resistance) [18]. Moreover, electromagnetic energy harvesters require no external voltage source for initial charging, as required in electrostatic energy harvesters [19], and no mechanical stoppers are needed.

In this paper, a magnetic spring has been utilized to reach a compact energy harvester and this enables the spring constant to be set by varying magnet strength. We present design prototype of the energy harvester in vehicle, including a comprehensive simulation and observational outcomes. Such results will be a benchmark to develop a practical device.

Harvester design:

A prototype of the energy harvester with magnetic spring is presented in Figure 1. Two design challenges of the generator are the low frequency and large amplitudes associated with vehicle movements. Referable to the constrained volume of the space, the size of the prototype was designed to be 10 cm in length with a diameter of 1cm and the harvester is to be planted at the top of dashboard as shown in Figure 2.

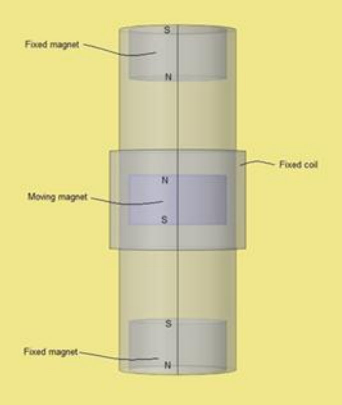

Figure 1: Schematic of magnetic spring harvester.

Figure 2: Location of device.

The design consists of two fixed magnets at the top and bottom of the tube and a moving magnet inside the tube. A Teflon tube was used in order to reduce the friction between moving mass and the inner surface of the tube.

Fabrication and Experimental arrangement:

Figure 3 shows the assembled harvester. Two 5mm diameter neodymium (NdFeB) cylindrical magnets were attached at top and bottom of the Teflon tube that has a coil wound from 50µm diameter Copper wire with 1700 coil turns. One magnet has been the moving mass and placed into the tube. After that, the harvester was hanged in the holder as shown in Figure 4 and tested on the shaker which was shaken in the vertical direction.

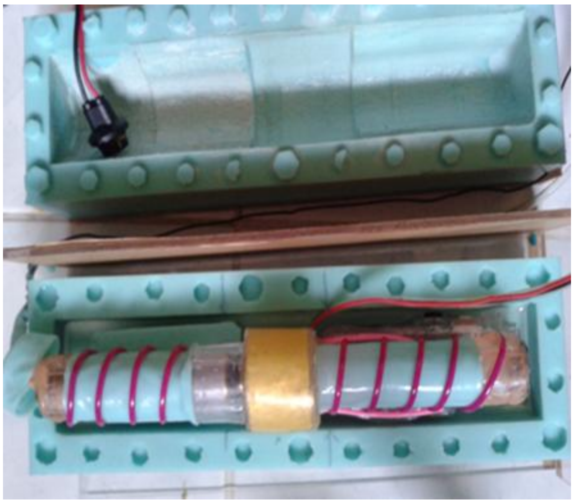

Figure 3: Fabricated energy harvester.

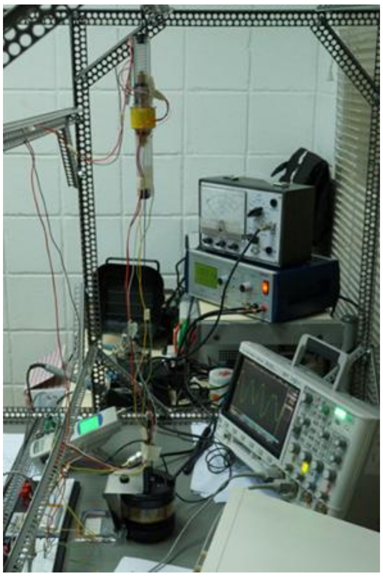

Figure 4: Experiment settings.

Results and discussion:

Static analysis. The proposed model was simulated in COMSOL to study magnetic flux variation, the resonant frequency of the harvester and the voltage induced in a coil. The magnetic flux density along the tube is shown in Figure 5.

Figure 6 shows the effect of frequency to the output based on different of the coil turn number. From the graph, minimum 3 volt can be collected at frequency 30 Hz and the number of coil turn is at least 1700 turns. Figure 7 shows the effect of frequency to the output based on different magnet size. From the graph, minimum of 3 volts can be collected at frequency 30 Hz and the minimum size of the coil is 5x7.5 (diameter x high). Figure 8 shows the effect of distance between magnet and coil to the output based on magnet size. From the graph, minimum 3 volt can be collected at gap 5 mm (maximum). It is due to the decrement of magnetic flux in long distance.

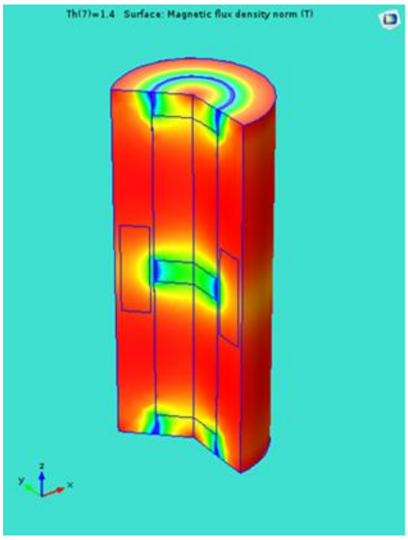

Figure 5: The simulation results of magnetic flux density along the tube.

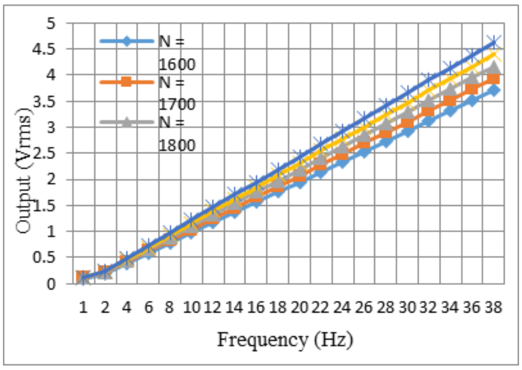

Figure 6: Voltage (Vrms) versus Frequency (Hz) with different of coil turn number.

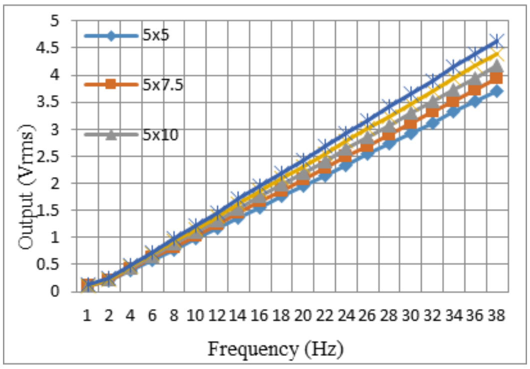

Figure 7: Voltage (Vrms) versus Frequency (Hz) with different of magnetic core size.

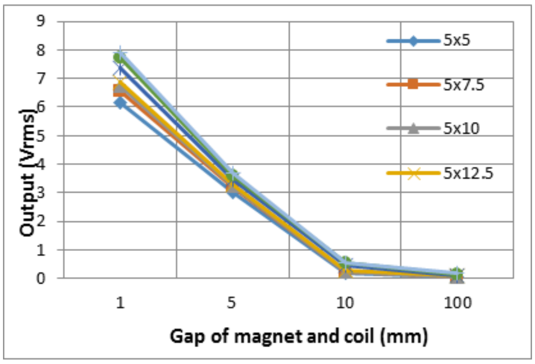

Figure 8: Voltage (Vrms) versus Gap (mm) between the magnet and coil.

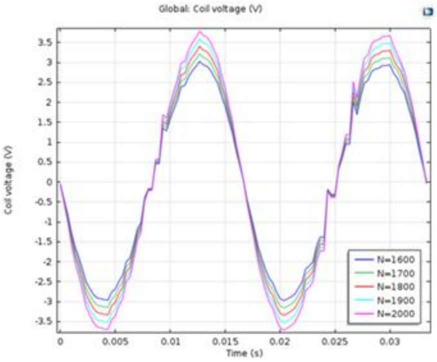

Figure 9: Coil voltage output for different number of turns.

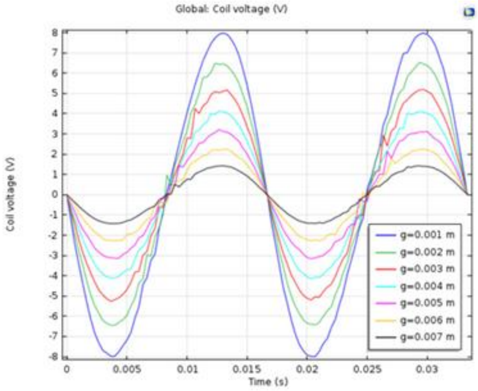

Figure 10: Coil voltage output for different distance between moving magnet and coil.

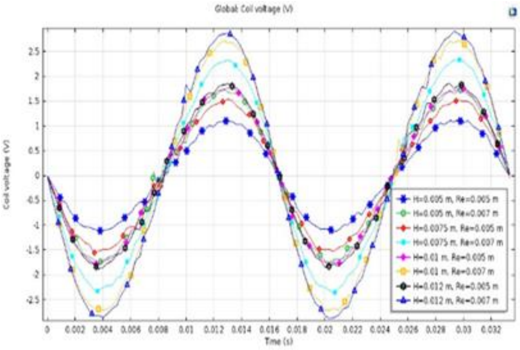

Figure 11: Coil voltage output for different sizes of moving magnet.

Time-dependent analysis. This type of analysis solves for the transient solution of different coil turns, different frequencies, the gap between magnet and coil and magnet size as functions of time. The purpose of this analysis is to find the optimum parameters of the EH model from a harmonic load during the first period. Since the magnetic flux of the electromagnetic energy harvester would be changed due to the magnet movement inside coil, the number of coil turns neck would be swept from 1600 turns to 2000 turns by 100 turns step size at the frequency 30 Hz to confirm the maximum output voltage in the simulation as shown in Figure 9. Also, Figure 10 and Figure 11 show the simulation results of the parametric sweep for different gabs and magnet sizes. Figure 12 shows the calculated voltage of 3 V at 30 Hz with 1700 coil turns and 5 mm distance between magnet and coil.

Conclusion:

We established a vibration-driven EMEH based on magnetic levitation. The optimized harvester presents a maximum 3.5 V of potential voltage for 1700 coil turns with 5mm x 7.5mm size of the magnet. The suggested harvester has a low resonance frequency (30 Hz) which is also convenient for charging the batteries in electric and hybrid vehicles and to power small-wired sensor networks that deliver important information to the vehicle has wired network backbone. Future works are being conducted to increase the bandwidth of the system, reduce the harvester size and give a better coil geometry for extracting more an efficient energy.

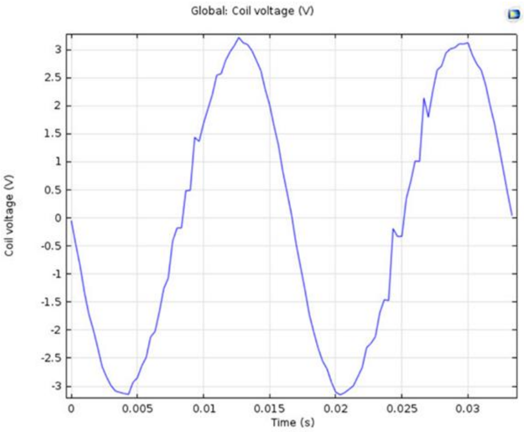

Figure 12: shows the induced voltage along the coil in which has 1700 turns at 30Hz with magnet size 5mm X 7.5mm (diameter X height).

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