Design and Development of an Electromagnetic Energy Harvester

A thesis submitted in partial fulfilment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

by

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MAY 2020

THESIS CERTIFICATE

This is to certify that the thesis entitled "**Design and Development of Electromagnetic Energy Harvester**" submitted by **PULICHERU THIRUPATHI** to the Department of Electrical Engineering, Indian Institute of Technology Madras for the award of the degree of **Master of Technology**, is a bonafide record of the research work carried by him under my supervision. The research work was carried out at the Indian Institute of Technology, Madras.

The content of this thesis, in full or in parts, have not been submitted to any other institute or university for the award of any other degree or diploma.

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Date: 16/06/2020

ACKNOWLEDGEMENTS

I sincerely express my profound gratitude to my project guide, Dr. Boby George, for his esteemed guidance and encouragement throughout the course of this project work. I am thankful to him for his most valuable guidance and his suggestions had been the source of inspiration for me during the conduct of this project and keep me on the right track which contributed immensely to the completion of this project.

I would like to thank the Department of Electrical Engineering, Indian Institute of Technology Madras, to who gave me an opportunity to undergo project work in their esteemed institution.

I would also like to extend my gratitude to all the Research Scholars for their guidance and support.

Finally, most importantly, I wish to express my heartfelt thanks to my family and friends, for being my source of energy.

Pulicheru Thirupathi

ABSTRACT

Energy harvesting is the process by which energy is derived from external sources e.g., solar power, thermal energy, wind energy, salinity gradients, and kinetic energy, also known as ambient energy, captured, and stored for small, wireless autonomous devices, like those used in wearable electronics and wireless sensor networks.

This project focuses on the use of electromagnetic transducers for the harvesting of kinetic (vibration) energy. It is introducing the fundamental principles of electromagnetism and describes how the voltage is linked to the product of the flux linkage gradient and the velocity. The flux linkage gradient is largely dependent on the magnets used to produce the field, the arrangement of these magnets, and the area and number of turns for the coil. The scaling of electromagnetic energy harvesters and the design limitations imposed by micro-fabrication processes are discussed in detail. Finally, the concludes with a 48milli Watt output power of electromagnetic harvester presented.

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CHAPTER-1

INTRODUCTION

1.1 Background of Energy Harvester

In the recent years, the importance of wireless connected system is more important because of the advancement in technology such as wireless sensor networks (WSNs), micro-electromechanical systems (MEMS), and Internet of Things (IoT) the utilization of mobile energy sources is more essential. Wire connectivity, nondegenerate energy sources, Battery connectivity etc, can solve these problems.

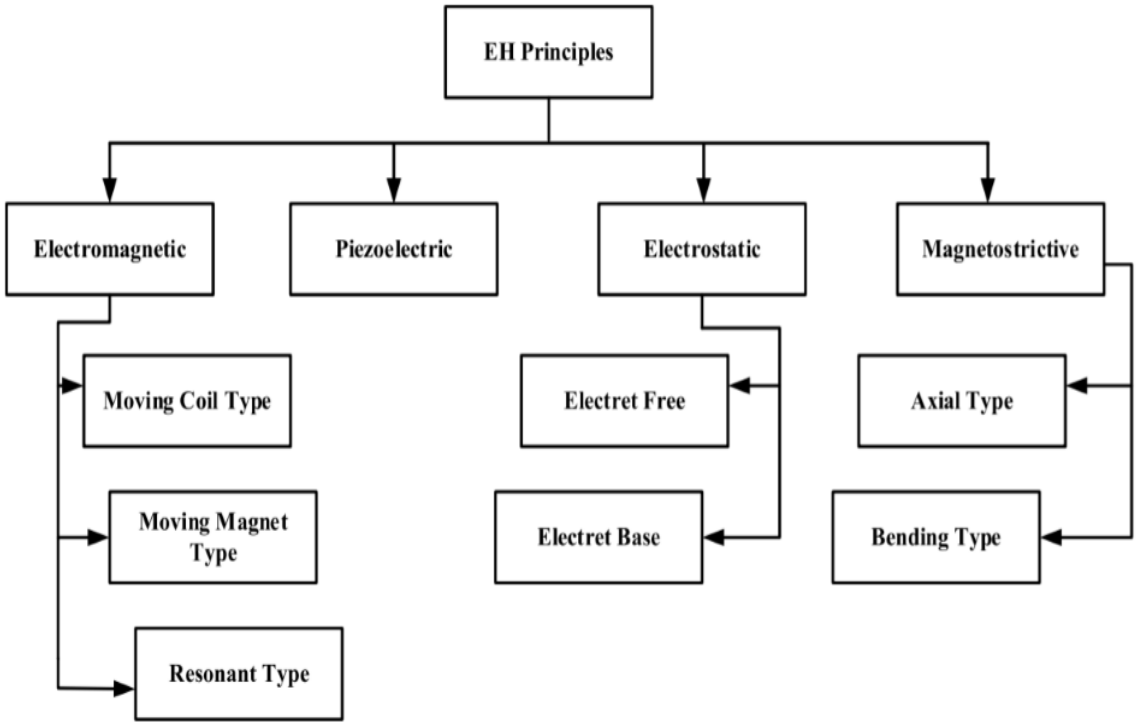

Fig. 1.1 principles used in VEH.[6]

VEH (Vibration energy harvester)

But due to some technical issues, viz current leakages in the battery, electricity resistance, and

practical difficulties in case of connections through a wire, etc., there is an increasing need to create other efficient energy storage methodologies. The use of a present source of energy are limited availability of energy source, maintenance at a regular interval, restricted life cycle, labour constraints, and delay of related materials, etc. To overcome all these problems, an innovative idea for energy generation from the environmental sources has been fabricated to supplement the present technological demands without polluting the environment.

Different options are available in the surrounding to harvest energy without its cleanliness and keeping the environment unhurt. Hence, with environmental concerns and the global energy crisis, various sources of energy like wind, solar, geothermal, hydropower, and vibration, etc. can be considered to generate power. By considering different favourable factors like technological usefulness, cleanliness, developmental scope, and maintenance cost, etc., both solar and vibration source of energy are better focus areas for research. But while we observe technology factor, the vibration energy source is the best for future research work. This can help not only to energize small-scale devices but also empower energy consuming instruments in transport, infrastructures, and human movement.

Vibration energy harvesting is the technique to stroll energy from the unwanted vibration occurrences in the environment. A large amount of vibration occurs due to the motion of vehicles on the bridges and moving trains on the railway track. These residual energies discharged into the surroundings may be considered as a wasted potential energy source. By using smart materials and adopting different techniques of energy harvesting, electrical energy can be harvested. As it is exploited from the environment belonging to nature. it is considered as free energy.

So, vibration is a tempting source of energy to allow small-scale devices. It is nothing but the collection of traveling waves on solid materials. To convert mechanical energy to electrical energy, vibration movement has to be coupled with a generator by using the inertia of seismic mass. For this purpose, different transduction mechanisms have been designed.

Renewable energy harvesting plants using wind energy, solar energy, etc. can generate kilo Watt, Mega Watt range of power and are called as macro-energy harvesting system,

generates milli Watt and micro Watt range of power. However, the major issue of concern is to power wireless devices. Energy harvesting from a clean energy source of vibration gives a long-term solution to drive remote devices. So current research focuses on vibration energy generation as it is eco-friendly and applicable with low installation and maintenance cost. Energy generated from this vibration EH (VEH) can be used in condition monitoring of railway network, the functioning of health monitoring devices such as low power wearable sensor, electrocardiogram (ECG) machine, electronic microscope, serum analyser and magnetic resonance imaging (MRI) machine, etc.

To improve power generation capacity, various strategies have been reviewed in different studies. Although it has not yet been possible to replace the batteries completely, a lot of research studies are being conducted to reduce its risk towards the environment and the present invention will definitely be helpful to strengthen the previous research works making a mark in the field.

1.2 MOTIVATION

Sensor technologies have made positive and less expensive sensors available, but their large scale and high impact applications such as condition monitoring of railway network are not fully unused due to the limited availability of power required for such sensors and wireless network unit. These are usually powered by rechargeable batteries that store energy from energy harvesters whose source can be sun-light, wind, heat, radio wave, vibration, etc. In the case of a railway sensing network, one of the main sources of energy that can be used is from the vertical movement of the rail when the train goes. Harvesting this energy is a challenge as the movement of rail is limited to about 1 to 2 cm and the frequency is usually <5 HZ.

1.3 OBJECTIVE

To obtain energy from low frequency vibrations which can give sufficient power required for electronics appliances. To develop a prototype which gives sufficient energy to the railway track sensors with low cost.

CHAPTER-2

2.1. INTRODUCTION

In this work, an energy harvester based on electromagnetic energy is proposed. Mainly coil is required for the production of flux or current which is attached to the Circular Permanent Magnet (CPM). In order to produce the flux, either coil or field must be rotating. As the coil is fixed to the CPM, there should be change in the field direction so that flux can be produced. So, there are two Square Permanent Magnets (SPM) to rotate and to produce sufficient low vibrations. This induces sufficient voltage in the coil.

2.2. OPERATION:

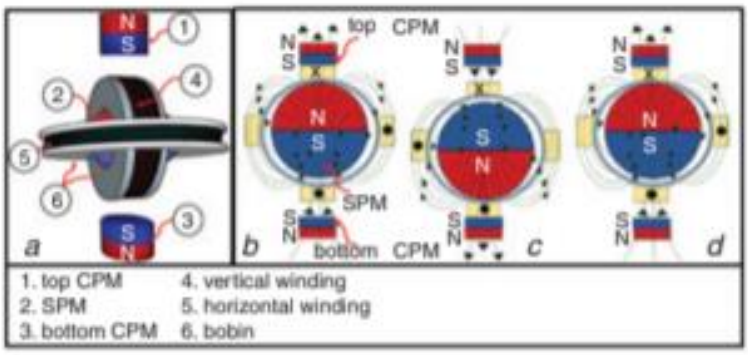

Fig.2.1. Pictorial Representation of the EEH [5]

Similar way of arrangement is provided to the present work as shown in the Fig.2.1. where the cylindrical permanent magnets are replaced by Circular and Spherical are replaced by square. These two SPM's are aligned in the direction of vibrations whereas the vibrations are provided by using a motor. Since the coil is fixed and the CPM is fixed with respect to coil there is only one chance to produce flux and that is rotation of SPM's. Let us assume that the vibration source i.e. Motor is kept near the top SPM, the SPM gets closer to CPM as they are opposite poles. So, there is a force of attraction.

When the vibration source is removed or moved away, the CPM will leave the top SPM and enter

into the magnetic field of the bottom SPM. As the top face of bottom CPM is south, now the SPM will get repelled. As there is in change in the field, there will be change in the angle. Once it rotates by some angle, the north face of SPM will get attracted towards the south of the bottom CPM and will quickly align. Similar process gets repeat each and every time. Whenever SPM flips, there will be a rate of change of flux linkage occurs in the coil connected.

2.3 Introduction of Energy Harvesting (EH):

1. Energy Harvesting (EH) is the process in which energy is captured from a variety of ambient energy sources and converted into usable electric power.

2. Energy harvesters provide a very small amount of power for low-energy electronics.

3. EH allows electronics to operate where there's no conventional power source, eliminating the need for wires or replacement of batteries.

4. EH systems generally include circuitry to charge an energy storage cell, and manage the power, providing regulation and protection.

5. EH-powered systems need reliable energy generation, storage and delivery.

2.4. General Overview of Ambient Energy Sources:

1) **Light Energy**: This source can be divided into two categories of energy: indoor room light and outdoor sunlight energy. Light energy can be captured via photo sensors, photo diodes, and solar photovoltaic (PV) panels.

2) **Mechanical Energy**: Vibrations from machines, mechanical stress, strain from high-pressure motors, manufacturing machines, and waste rotations can be captured and used as ambient mechanical energy sources.

3) **Thermal Energy**: Waste heat energy variations from furnaces, heaters, and friction sources.

4) **Electromagnetic Energy**: Inductors, coils, and transformers can be considered as ambient energy sources, depending on how much energy is needed for the application.

5) **Human Body**: Mechanical and thermal (heat variations) energy can be generated from a

human or animal body by actions such as walking and running.

6) **Natural Energy**: Wind, water flow, ocean waves, and solar energy can provide limitless energy availability from the environment.

7) Additionally, chemical and biological sources and radiation can be considered ambient energy sources.

2.5 Electromagnetic EH (EMEH)

In EMEH, mechanical energy is converted to electrical energy during the occurrence of relative motion between the conductive coil and a magnetized body. The magnetic circuit which is implemented in this configuration for power generation requires a magnetic field. This is generated either by a permanent magnet or by an electromagnet. The permanent magnet is more suitable than electromagnet for low power devices as it does not require power input. These permanent magnets contain ferromagnetic or ferrimagnetic material.

2.6 Principle

The principle of EM generator is based on Faraday's law of electromagnetic induction which asserts direct proportionality of voltage to the change of magnetic flux linkage with respect to time. Therefore, the voltage developed in the coil is

$$V_{\text{coil}} = -\frac{d\Phi}{dt} = -N\left(\frac{d\psi}{dt}\right) \qquad (1)$$

where N is the number of turns in the conductive coil and average magnetic flux in single loop, respectively. is the total flux linkage and can be calculated as

$$\Phi = \sum_{i=1}^{N} \int_A B\,dA \qquad (2)$$

Here, dA is the change in the area, B is the magnetic field vector and i represents the number of turns. While the flux density is assumed to be uniform throughout the coil area, then the flux density becomes

$$\Phi = \text{NBAsin}(\alpha) \qquad (3)$$

And the resulting voltage is given by

$$V = -NA \frac{dB}{dt} \sin(\alpha) \qquad (4)$$

where α denotes the angle between flux density direction and coil area. However, the flux linkage gradient is mainly based on various parameters of system design such as types of magnets, its position in the system arrangement, and number of turns in the coil.

CHAPTER 3

EXPERIMENTAL SETUP

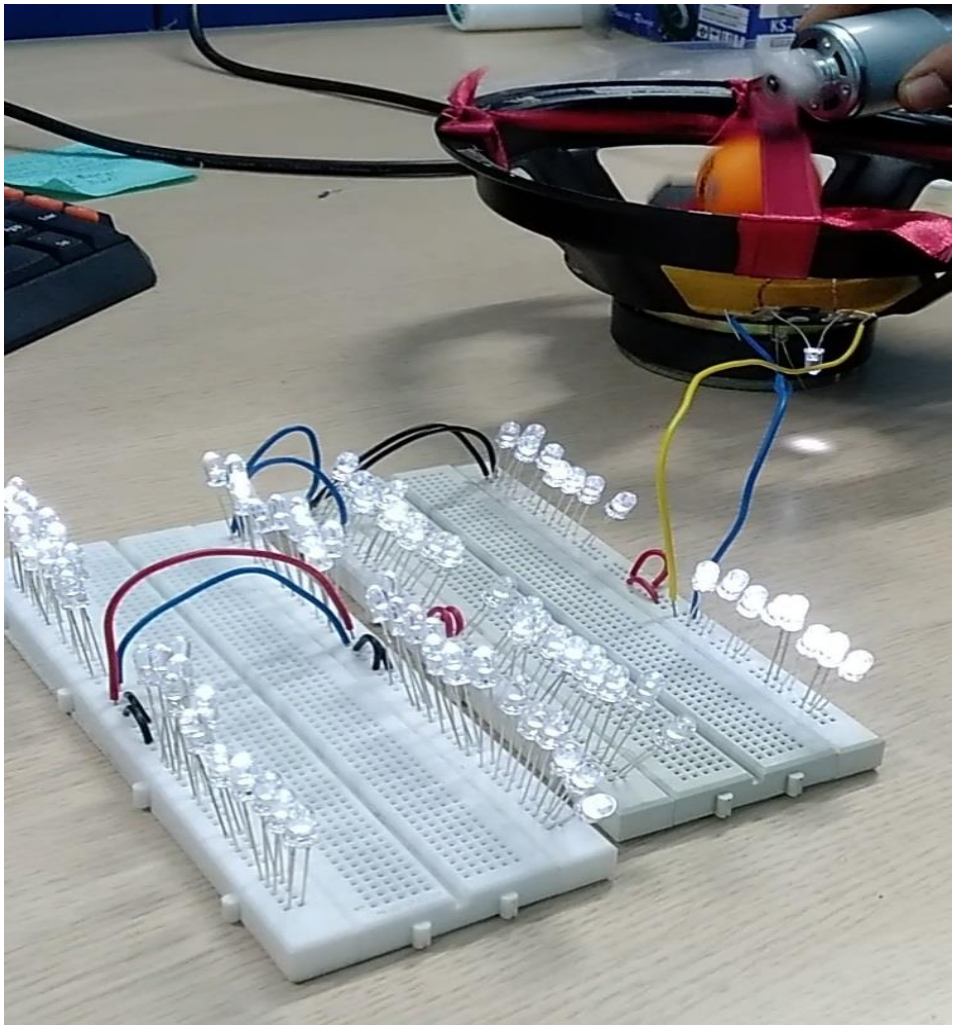

Fig.3.1. Glowing led bulbs with energy harvester

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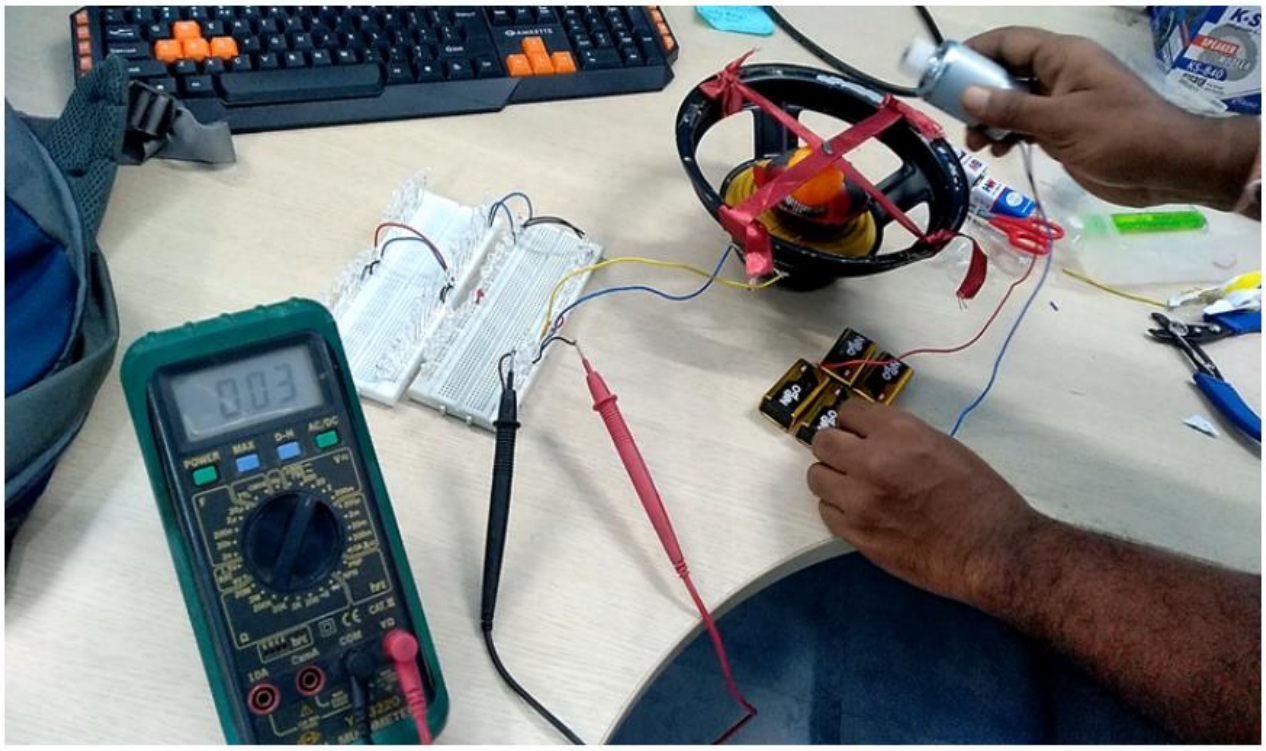

Fig.3.2. schematic diagram of hardware setup

3.1 Components used

- Speaker for providing CPM
- Coil
- Square permanent magnets
- 70 LED bulbs
- DC motor
- Ball
- Measuring components
- Probes and bread board

3.2 Operation

In this setup, there will be two kinds of magnets.

1) Circular Permanent Magnet(CPM)

2) Square Permanent Magnet(SqPM). Based on the coil movement attached to CPM , changes in the flux linkage occur. So emf is induced. Coil movement is caused by attraction and repulsion of SqPM with the magnet attached to the DC Motor. This change in the flux induces emf and when the induced emf reaches threshold voltage required to glow the LED's, all the parallel combination of LED's starts to glow. Similarly when induced emf becomes less than threshold value they stop glowing.

By this setup, it is clear that if the voltage reaches the threshold value, the LED bulbs starts to glow and the voltage, current and power can be calculated. This power is sufficient to the railway track sensors and if the necessary power is high it can be increased by increasing the vibrations.

CHAPTER 4

RESULTS, CONCLUSION AND FUTURE WORK

4.1. RESULTS

- Total number of bulbs used = 70
- Output current =40 mA
- Threshold Voltage = 1.2V
- Output power = 48mW

4.2. CONCLUSION

The Electromagnetic Energy Harvester designed by using Circular permanent magnet (CPC), strong square permanent magnet and DC motor for providing vibrations. The constructional details and its operation are described. Prototypes of the EEH have been built and tested in the laboratory. From the tests conducted, it can be concluded that output voltage is 2.02 V and output power is 48mW.

4.3. FUTURE WORK

- Vibrations are created by other sources instead of DC motor since it finds its applications in sensors for monitoring railway tracks.
- Capturing of induced voltage waveforms in the windings in NI ELVIS.

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