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Design and Analysys of Piezoelectric Energy Harvester Used in Car Tyres

N. Siddaiah[1&2], G. R. K. Prasad[1], G. Naga Divya[1], M. Rohith[1], P. Prudhvisiva Sai[1] and D. V. Rama Koti Reddy[2]

ABSTRACT

The main objective of this paper is to eliminate batteries and power lines and to design a MEMS energy generator to be as small, light, and strong as possible, with enough energy to power a system under a range of conditions. We have designed a micro-generator for an innovative tyre pressure monitoring system (TPMS) driven by motion.There is a great deal of interest in alternatives to batteries for TPMS systems. One of the best way to capture energy from the moving tyre, what are called "Energy Harvesters. It is usually connected to the engine by a belt and as it turns it transforms some of the mechanical energy of the engine into electricity. In this paper, we focused on enhancing the performance of piezoelectric harvesters through a multilayer and a multistep beam configuration. Based on simulation results, a MEMS Lead ZirconateTitanate (PZT-5H, PZT-5A) cantilever array with an integrated Si as substrate is designed and simulated to improve output voltage and power. For both multilayer and multistep beams we have calculated frequency, strain and corresponding voltage. Based on simulation results we have concluded that multistep with PZT-5A material having high energy density when compared with multilayer structure.

Keywords: Piezoelectric energy harvester, multilayer beam, multistep beam, MEMS, PZT-5H, PZT-5A

I. INTRODUCTION

Whenever the battery drains it should be either replaced or recharged which is very inconvenient when we need them most. so to avoid this, self powered devices are invented which are known as Energy harvesters. The main concept of energy harvester is to run the self powered electronic systems by harvesting the ambient energy mostly are vibrations. some of the methods to transform mechanical energy to electrical energy are electrostatics, electromagnetic, piezoelectric. Among all the ambient energy sources vibrational energy is the one which is mostly wasted. When piezoelectric material is subjected to strain it produces electric charge. In this way the power is generated and stored through electrostatic, electromagnetic, and piezoelectric methods.

In this paper piezoelectric method is adopted to generate the electrical energy. This method does not require any external power supply so, it is more economical. But these electromagnetic and electrostatic methods need some external power supply to start the system. Because of this reason piezoelectric energy harvesting technology has a prominent role in wearable and implantable medical applications and other applications which requires a very accurate and sensitive analysis.

TPMS SYSTEM

A Tire-Pressure Monitoring System is an electronic system which is designed in such a way that to monitor the pressure and this system is mounted on tires of vehicles like cars. Generally this TPMS system is powered by batteries. By having this batteries we have a disadvantage that those systems don't have longer

[1] Department of ECE, K. L. University, Vaddeswaram, Guntur, Andhra Pradesh, India
[2] Department of Instument Technology, College of Engineering, Andhra University, Visakapatnam, Andhra Pradesh, India
Corresponding author *E-mail: nalluri.siddu@kluniversity.in,gorantladivya246@gmail.com*

life and we have to recharge again. so due to this reason we are replacing this batteries by this energy harvesters and converting those mechanical vibrations to electrical using Piezoelectric material (PZT).

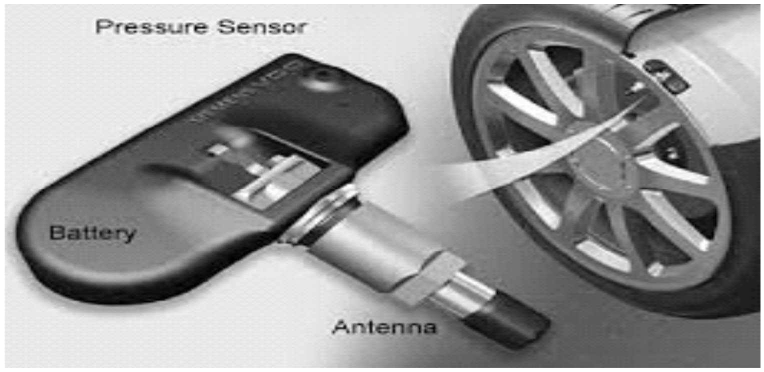


Figure1(a) : TPMS system mounted on car tyre

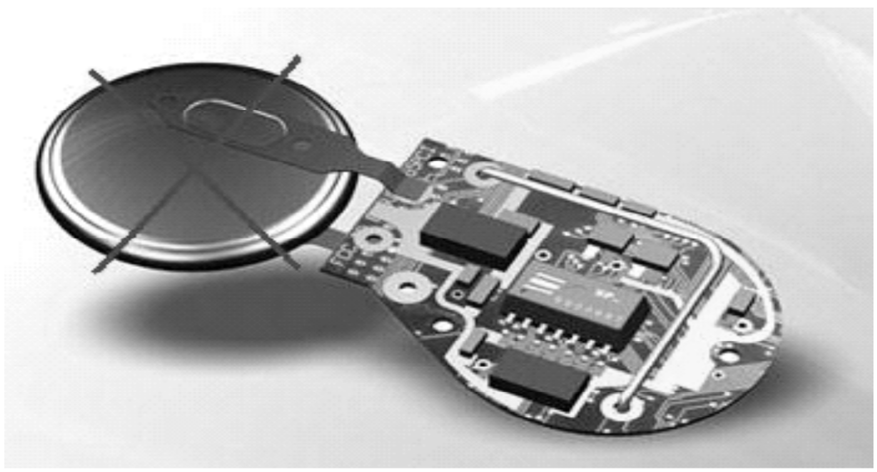


Figure1(b): battery replacement in TPMS

II. THEORETICAL BACKGROUND

Piezoelectric materials produce electricity when they are subjected to mechanical strain. There are different forms of piezoelectric constitutive equations which are mentioned by the IEEE standard on piezoelectricity. There are 4 forms for piezoelectric constitutive equations they are strain-charge form, stress-charge form, strain-voltage form, stress -voltage form. In this paper strain-voltage form is used and the related equations are as follows.

Maximum stress formula:

$$\text{Stress } (\sigma_{max}) = F/A \tag{1}$$

F: Force applied in proof of mass

A: Area of cross-section of proof of mass

Maximum strain formula:

$$\text{Strain } (\varepsilon_{max}) = \sigma_{max}/E \tag{2}$$

E: Young's modulus of silicon (1.9×10^{11})

The induced voltage per meter in the piezoelectric material

$$V = \varepsilon/d \tag{3}$$

Where d is the piezoelectric coefficient (480×10^{12}m/V).

Finally multiply with the length of the piezoelectric beam we get the voltage Among all the parameters the most important parameter is frequency. The ambient energy i.e the frequency of the vibrations in the environment is very low (less than 1KHz). If the energy harvester is designed for high resonant frequencies the sensitivity of the sensor is drastically reduced. So, there is a need to design the energy harvester for low resonance frequency applications. So the resonance frequency is desired to be closer to the frequency of environmental vibrations.

The cantilever beam has different modes of vibrations and each mode has different resonance frequency. The deformation of the cantilever beam is also depends on the frequency. Out of all those modes the first mode has lowest frequency and provides the maximum deformation and provides more electrical energy.

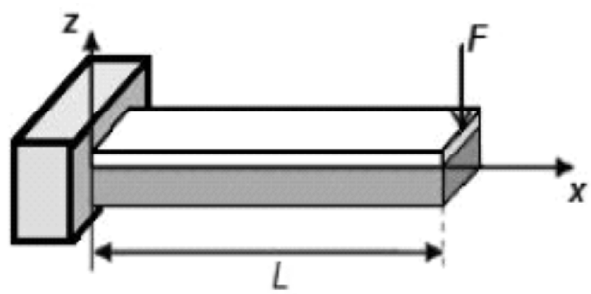


Figure 2: Configuration of piezoelectric cantilever beam

The resonance frequency is calculated by the following equation

$$f_n = \frac{v_n^2}{2\pi}\frac{1}{L^2}\sqrt{\frac{D_p}{m}} \tag{4}$$

Where

$$m = \rho_p t_p + \rho_s t_s$$

The mass per unit area m depends on the thickness and density of the material. Different materials has different densities so as there is a change in the material the value of m will also changes in turn changing the resonance frequency.

III. DESIGN METHODOLOGY

Using COMSOL piezoelectric energy harvesters with multilayer and multistep beams are designed using the piezoelectric materials. The entire modeling is done in 3D as shown in the figure 3(a) and figure 3(b)

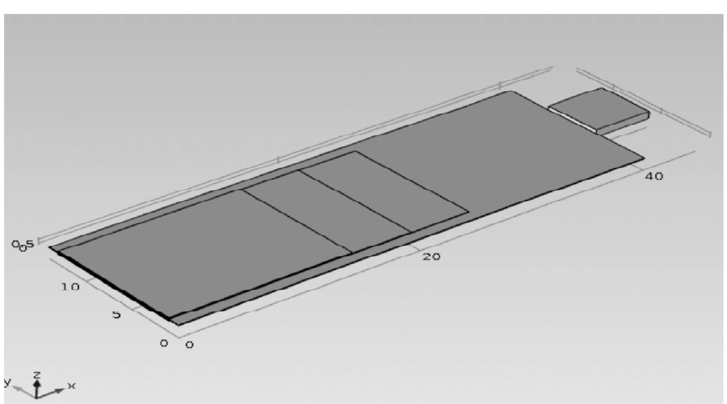


Figure 3(a): Multistep beam

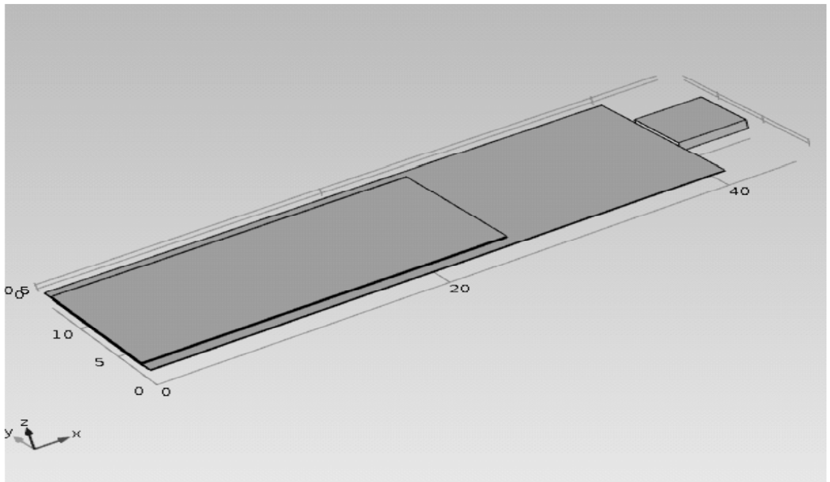


Figure 3(b): Multilayer beam

The entire geometry is divided into 7 layers for both multilayer and multistep beams and these layers are also called as sub domains. The first substrate layer is added with silicon material (SI) and the sub domain layers are placed above and below the substrate layer and added with piezoelectric material i.e Lead ZirconateTitanate (PZT-5H and PZT-5A).

One end of the cantilever beam i.e having block end is fixed and the other end is free to vibrate. The floating potential is applied at the upper surface of the piezoelectric layer and ground is applied to the bottom layer of the piezoelectric layer to obtain the d31 mode. All the other faces are set to zero charge constraint. The body load of F is applied in z-direction to the piezoelectric layer. The force is exerted to induce the strain. To find the voltage the floating potential should be disabled and terminal should be added to the piezoelectric layer.

IV. MESHING

After setting all the boundary conditions the geometry is meshed. The structure is reduced into a group of small blocks and given to the solver for FEA. In this paper a normal mesh is used for both beams as shown in the figure 4(a) and figure 4(b).

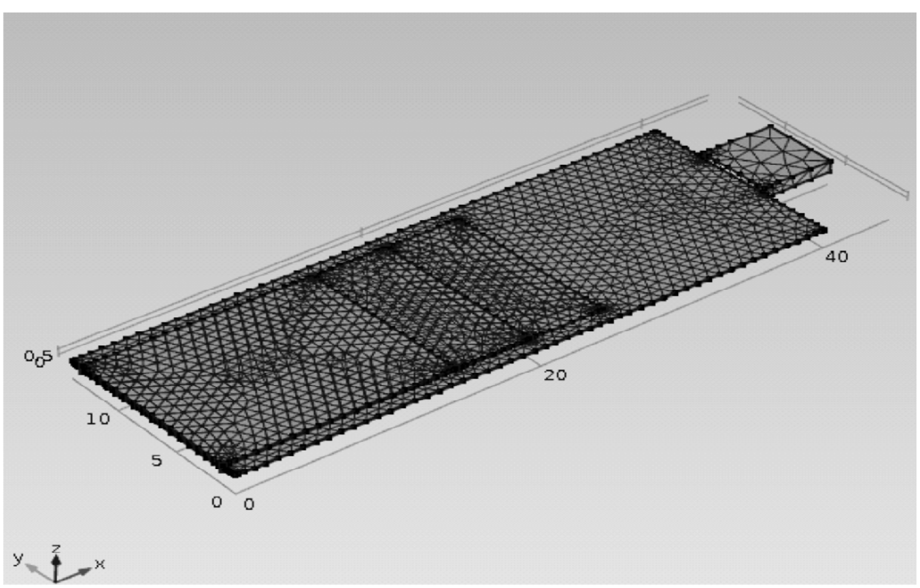


Figure 4(a): Multistep beam

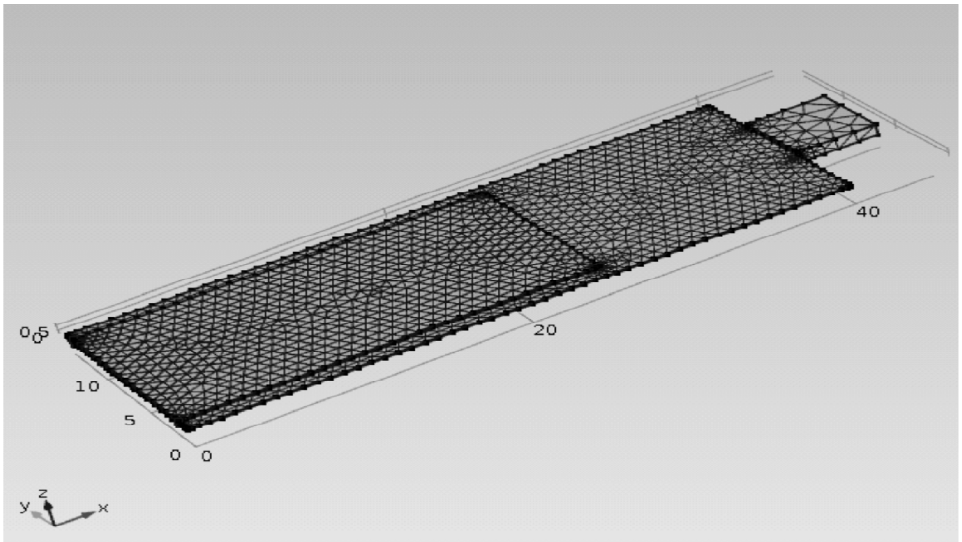


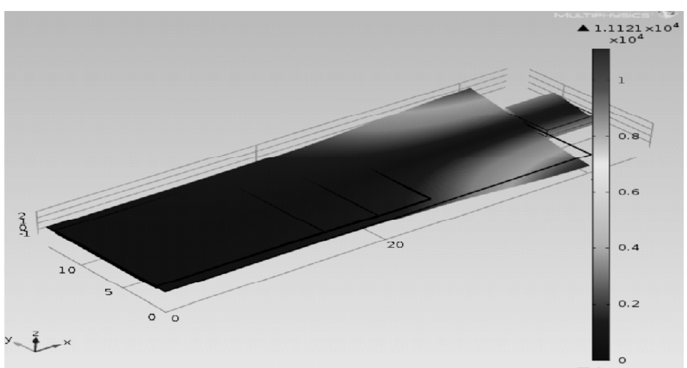
Figure 4(b): Multilayer beam

V. STUDIES AND RESULTS

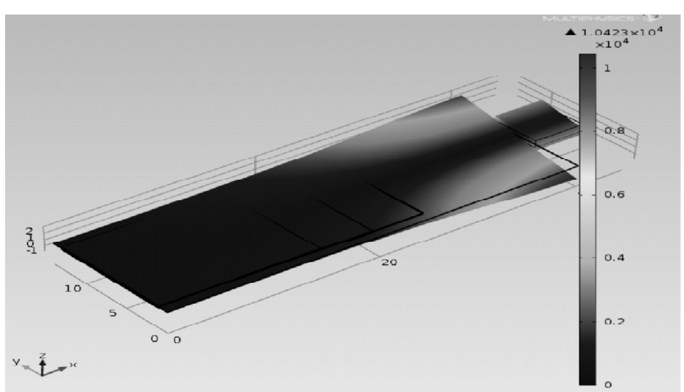
(A) Eigen frequency analysis

After the meshing is completed the geometry is ready for all the studies. We have studied Eigen frequency analysis along length of the geometry to observe what is the resonant frequency of the geometry and how does it change for different materials. The stationary analysis is to observe the variation of strain energy, output voltage.

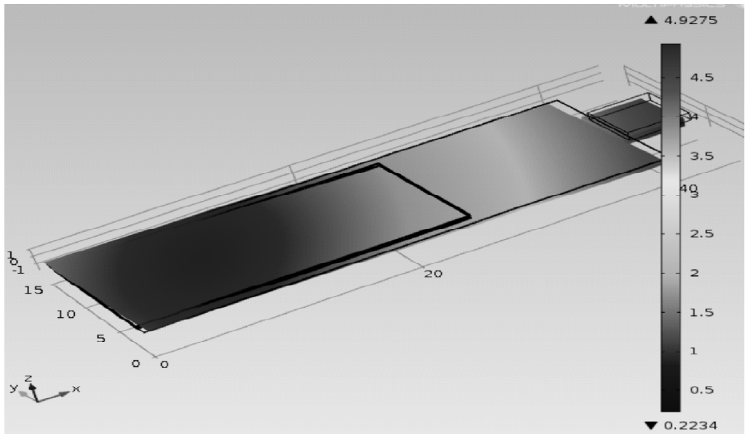
Multistep PZT-5A



Multistep PZT-5H



Multilayer PZT-5A



Multilayer PZT-5H

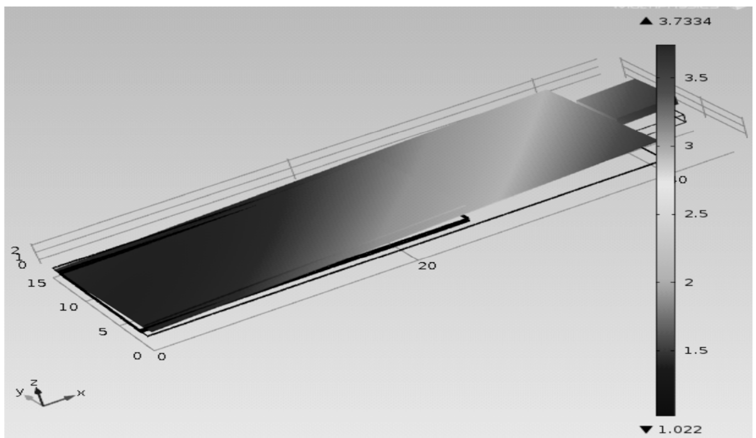


Figure 5: Eigen frequency values for both multilayer and multistep beam at first node

For Multistep

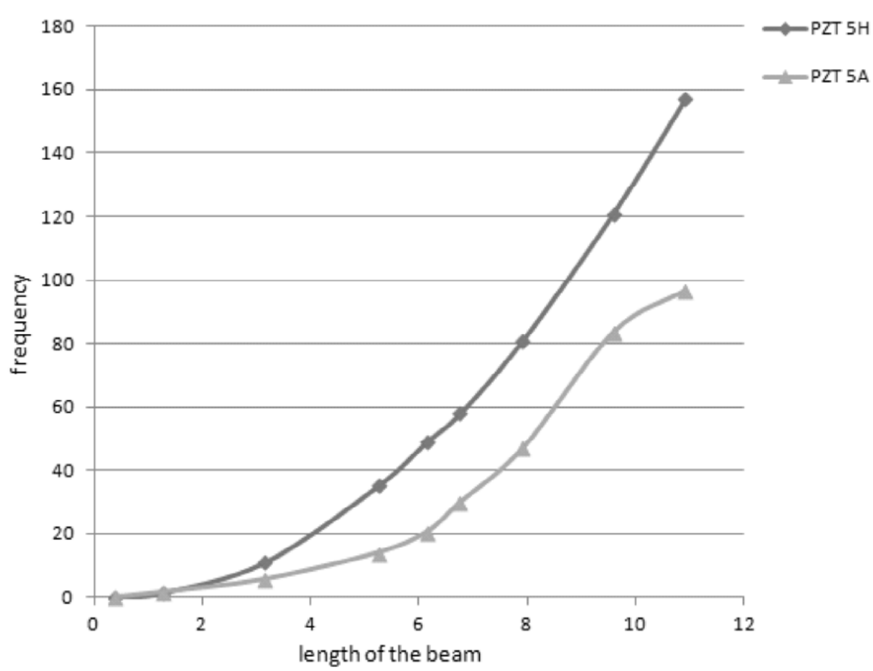


Figure 6(a): Frequency analysis along length of beam

For Multilayer

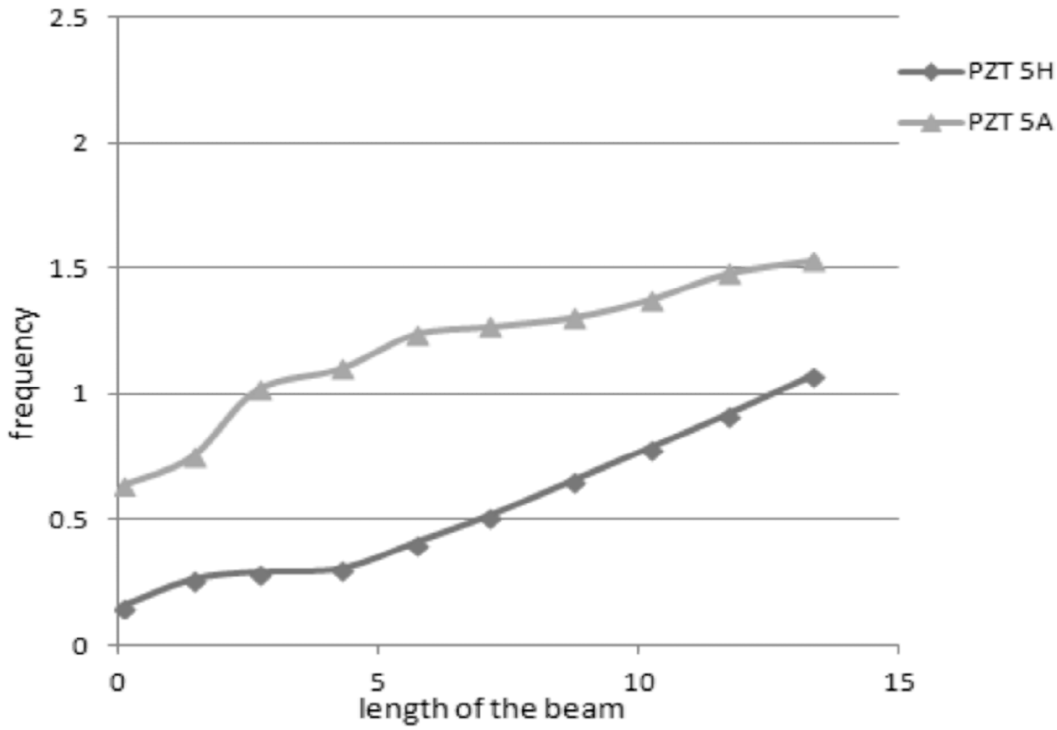
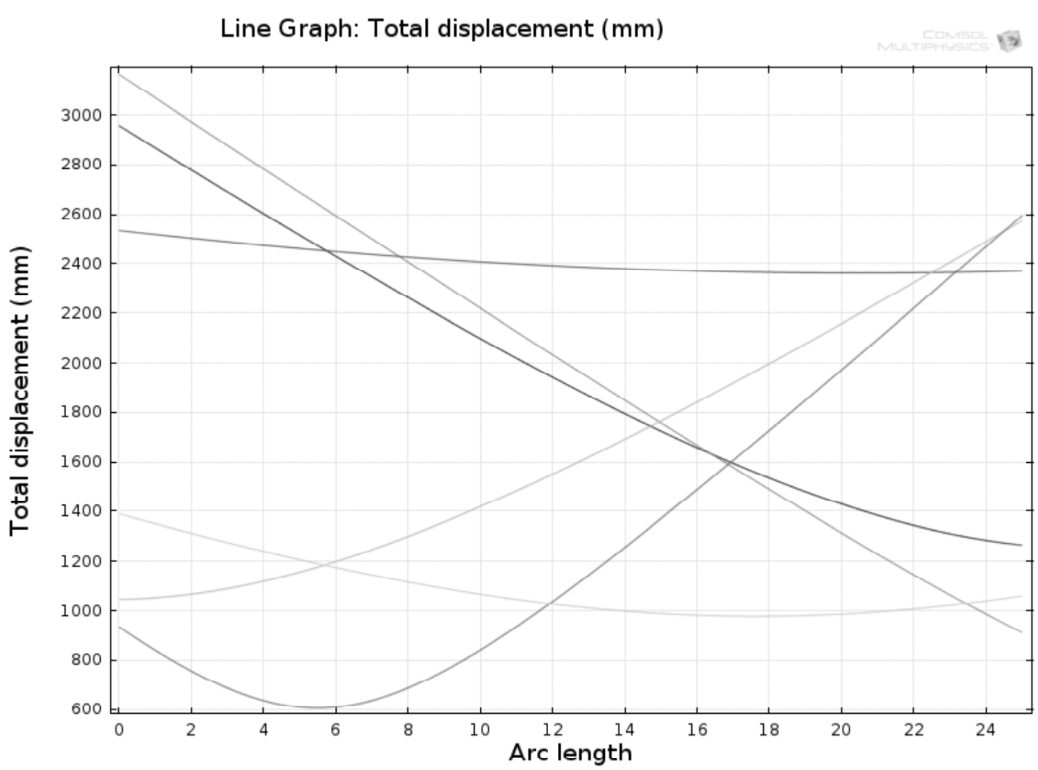


Figure 6(b): Frequency analysis along length of beam

For Multilayer

PZT-5H



PZT-5A

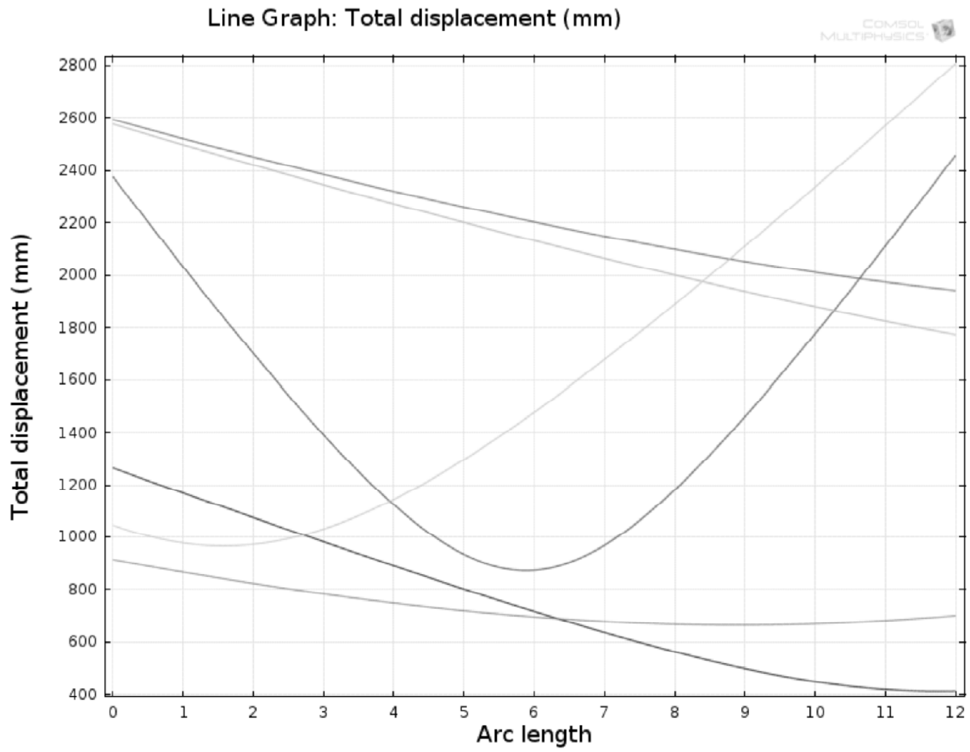
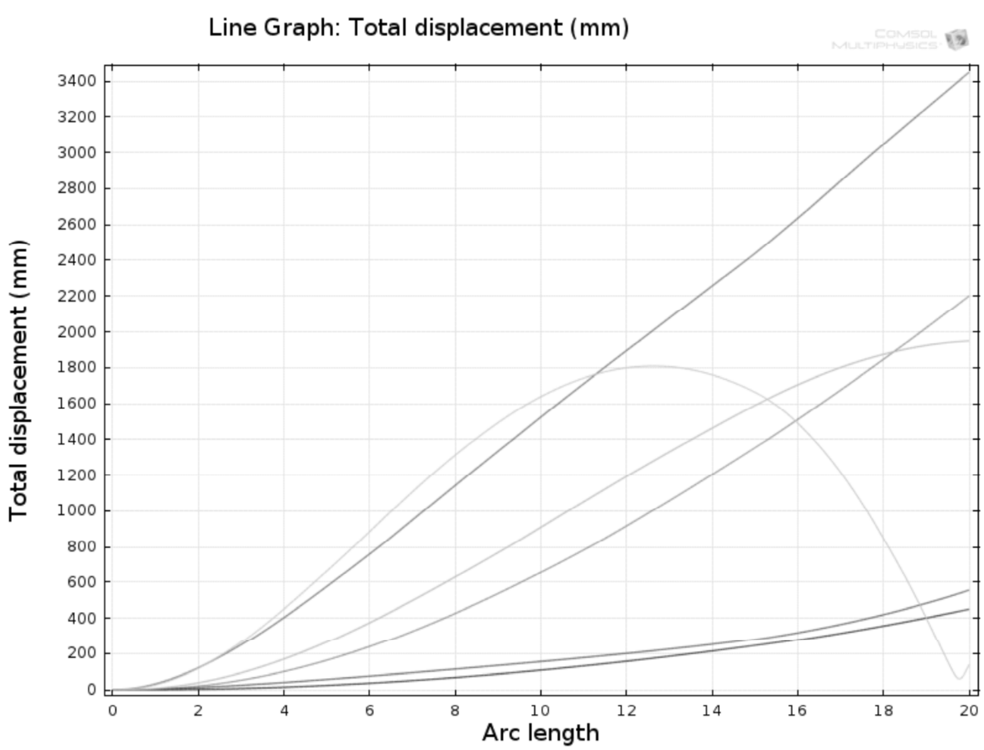


Figure 7(a): Arc length vs Total displacements graphs

For Multistep

PZT 5A



PZT 5H

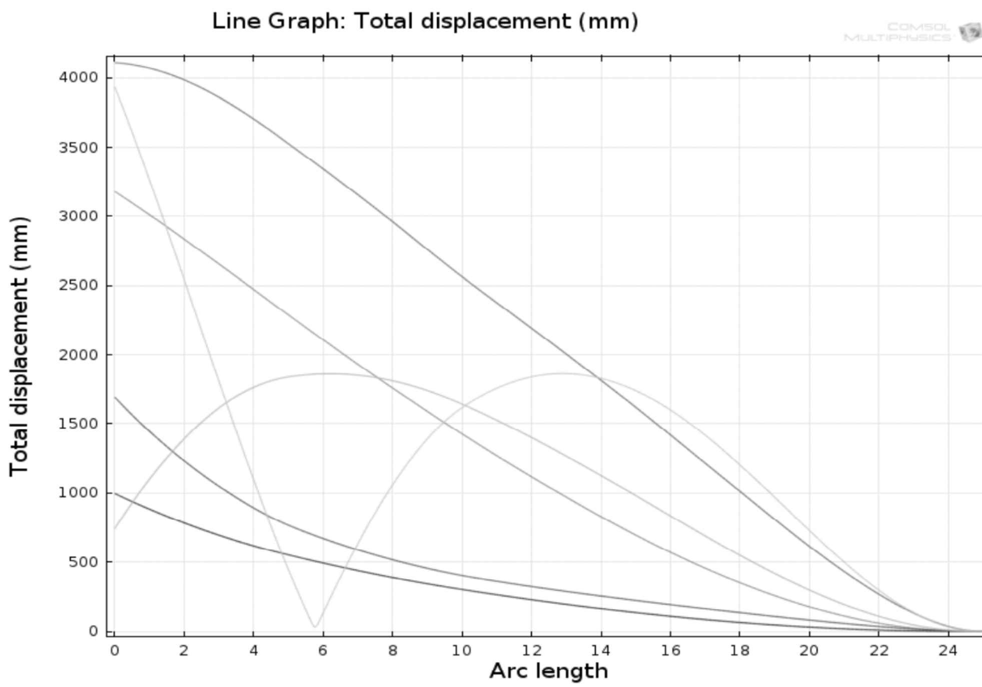


Figure 7(b): Arclengthvs Total displacements

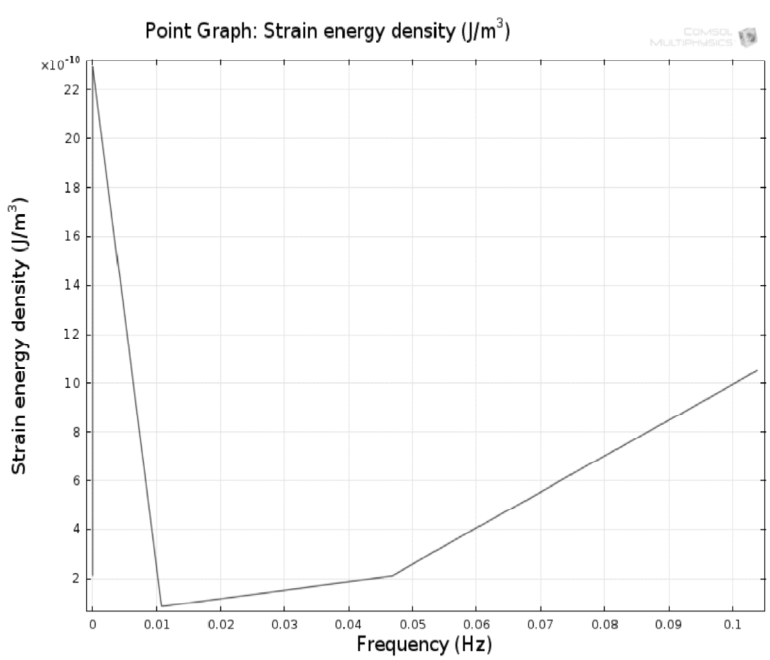
(B) Strain analysis

The stationary analysis is to observe the variation of strain energy, output voltage, and output energy for the geometry of

Both multilayer and multistep is analyzed, by applying both materials PZT-5H and PZT-5A .

For Multilayer

PZT- 5A



PZT-5H

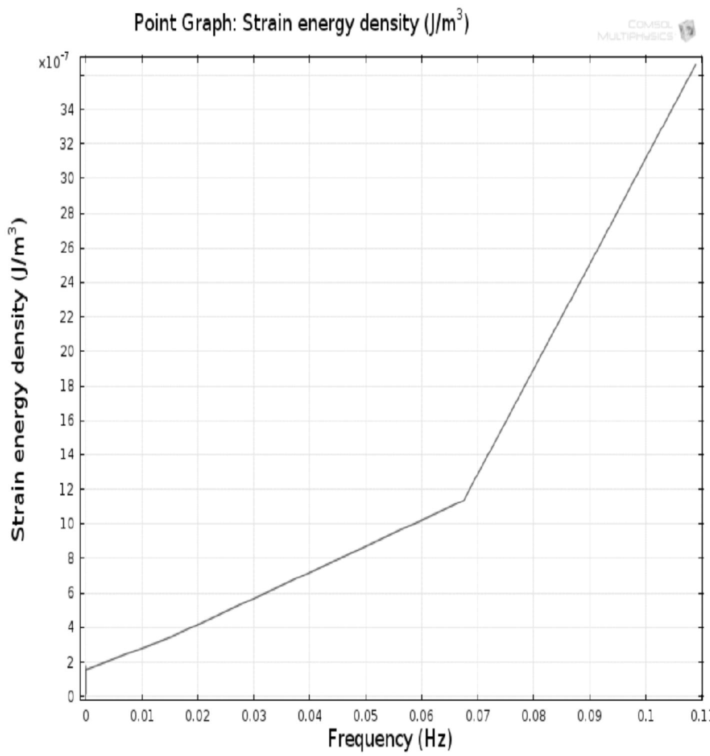


Figure 8(a): Starinenergy density along with frequency

For Multistep

PZT-5H

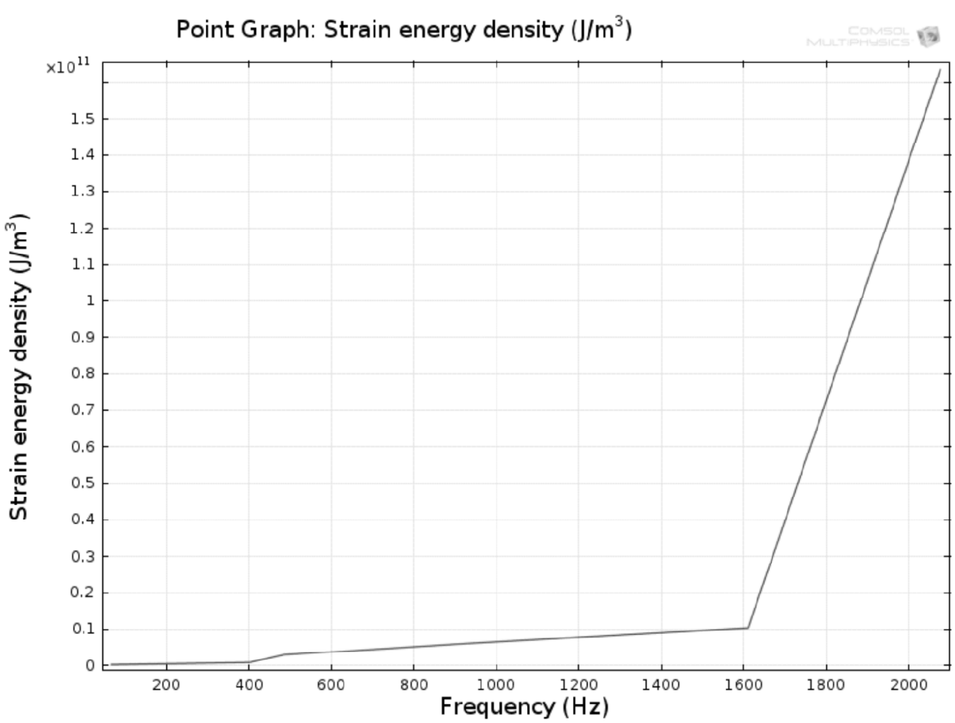


Figure 8(b): Strain energy density graph along with frequency

CONCLUSION

An energy harvester based on cantilever beam with multilayer and multistep structures is modeled and simulated. The simulation results (resonant frequency, strain, voltage and energy) were analyzed and Based on simulation results we have concluded that multistep with PZT-5A material having high energy density when compared with multilayer structure.

By using this mems piezoelectric energy harvester we can replace all batteries mainly in automobile applications by this energy harvesters .

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