Piezoelectric Energy Harvester Energy Conversion Performance, Strain Distribution and Efficiency Improvements in Two Clamped Configurations with Cantilever Configurations

T. Ramachandran[1], Aruna Bansal[2]

[1]Research Scholar, Electrical and Electronics Enginnering, Subharti Institute of Technology and Engineering, Swami Vivekanand Subharti University, Meerut, India
Email: *ramspowerthangamugam[at]gmail.com*

[2]Supervisor, Faculty of Engineering and Technology, Subharti Institute of Technology and Engineering, Swami Vivekanand Subharti University, Meerut, India
Email: *arunabansal75[at]gmail.com*

Abstract: ***The use of Piezoelectric energy harvesters in many low power sensing and electronics device requirement as self power device is increasing day by day. So, it's very essential and important to improve the harvester energy conversion performance, strain distribution and increase the output power of the harvester so that the efficiency of the harvester can also be improved and increased. The way for improve the harvester generation voltage is depends on many factors, among them one way of approach is the uniform use of materials and balance with uniform strain stress imposed on the piezoelectric layer beam. Both of the approaches lead to improve the converter efficiency and also the requirements of the materials can be reduced by optimum use of the piezoelectric materials. The conventional cantilever arrangement with tip mass is not providing the uniform stress strain to the harvester but the strain is high near to tip mass and less to the fixed end of the harvester beam. The two clamped harvester beam in which the strain and the stress imposed on the energy harvester beam is more or less uniform. This paper focused on the comparisons between the cantilever piezoelectric energy generator performance with the clamped type configuration for the segmented and continuous cantilever piezoelectric layer beam configurations. In the cantilever beam with segmented harvester beam reduce the material requirements and provide the uniform strain stress spread to the harvester but still uniform strain distribution not present. The comparisons between the cantilever and clamped configuration proofs that the uniform stress strain achievement is more in clamed configuration and also the performance of the harvester improved and requirement of the piezoelectric materials reduced.***

Keywords: Piezoelectric harvester, cantilever configurations, strain stress comparisons, performance analysis, voltage generation

1. Introduction

The power generations by different non- conventional source are the main target of the energy generation companies. The demand for the electricity is grow very fast and the need will further increase because all electrical and electronics devices are use the supply of electrical energy [1 - 2]. The electrical devices may need high voltages and low voltages according to the power rating of the equipment's. The power generation for giving supply to electrical devices is happens in high power rating power generators. But in the technical field there are many devices which are comes under the electronics devices which also need of electrical supply but in low values. So, to give supply for this kind of low power electronics devices give more attention. In IoT applications there are many control circuits and devices are working which will be of need very low powers in the rage of micro Watts or milli watts [1]. These low ranges of power can be generated through the small power generating system like piezoelectric power harvester. The piezoelectric electrical energy generator harvesting system will not require any recourse but it can only use the waste energy available in the environment. So, for the generation of low value electric power, there will be no need of any extra fuel is needed. So, the energy harvesting from the waster energy available is fast growing [3 - 4]. In the field of waster energy available the vibration energy is more suitable for electricity generation in low values through the piezoelectric materials.

The power generation through the piezoelectric materials is takes place with two types of arrangements namely the cantilever piezoelectric beam harvester and clamped type both ends fixed type piezoelectric harvester beam. The cantilever arrangements the one end of the piezoelectric harvester beam will be fixed and the remaining one end will be free. The tip mass will be normally added to the free ended of the harvester. But in the clamped typed harvester the both the end of the harvester will of fixed and the force will be applied from the top of the harvester beam. To improve the performance of the harvester efficiency and conversion efficiency the different approaches are applied in the harvester such as different shaping of the harvester, change the putting places of the tip mass, use the segmented harvester and multi layer harvester with single beam multi layer arrangement and so on. The cantilever arrangement does not provide the uniform strain stress to the harvester and hence the life of the harvester gets reduced and also the materials are wasted because the bending during the vibration is not takes place in entire piezoelectric harvester layer [5]. So the use of the piezoelectric materials in the harvester can be reduced by doing proper segmentation in the harvester beam. Segmented cantilever arrangements gives the reducing in the need of the piezoelectric materials but the uniform strain stress is not applied in the harvester as the tip mass is located on the free end side of the harvester. So, to ensure the uniform strain stress distribution and improvement of the harvester efficiency the clamped type harvester beam with two end fixed arrangements were applied. This arrangement proved the best and better improvement on the harvester performance as far as energy conversion efficiency is concern. And also the uniform strain stress distribution to the harvester beam is achieved here with this model. Here the new system is proposed that the segmented harvester with the clamped type arrangements for further improvements in the harvester performance and to ensure the uniform strain stress with minimum use of piezoelectric materials [5]. The segmented harvester means that the entire beam of the harvester does not have the piezoelectric materials but in the layer the piezoelectric materials will be placed with small gap. This means that in single beam of the harvesters there will be a more than one piezoelectric harvesters will be placed. This arrangement will reduce the need of piezoelectric materials for the harvester.

1) Piezoelectric energy harvester and applications

The properties of piezoelectricity of the PE layer are defined as" basic mechanism of PE energy Harvester that gives the coupling effects between the mechanical bending strain and electrical behaviors of piezoelectric materials" [6]. There are two different effects are produced due to the strain of mechanical bending. The first one is that the piezoelectric material deformation may vanguard to the electric charge accumulated at electrodes are bounded on its surface. This effect on the piezoelectric materials is called as direct piezoelectric effect. The second one is that in a situation when the PE material under the changes of electric charge in its electrodes, there may be a possibility for mechanically deform, and this may gives the converse piezoelectric effect. In fact the direct piezoelectric effects are very beneficial for the piezoelectric harvesters.

The piezoelectric energy harvester module is one of the best choices for feeding the power to the sensors and motors that are works in domestic and industrial applications [6 - 7]. The piezoelectric motors which use piezoelectric materials are performing very much excellent and accurately. Precise control as well as repeatable movements is achieved easily. So, piezoelectric materials inbuilt into the motors make the motor perform excellently in the field of motor control. Piezoelectric effect and its reverse effects are found in many applications like piezoelectric motors, actuators in industrial sectors, sensors in the field of medical, in consumers electronics as printers speakers buzzers, microphones etc.

2) Methodology and modeling of PEH

I most of the cases the PEH have the cantilever boundary conditions as common configurations [8]. In this cantilever arrangement one end is fixed whereas the other end is free configuration conditions provide non uniform stress and high stress near the clamped line. Because of this two conditions the harvester provide low power for the low stress area, and structure failure may occur for the high stress region, due to this two reasons the cantilever configuration with one end fixed and others one is free from fixing is not best suitable configuration in the piezoelectric energy harvesting technology. In this paper the cantilever beam boundary conditions numerical results on COMSOL is also compared with the new proposed PE harvester configurations. Both of the PE harvester boundary conditions are analyzed with a applied static force with the consideration of electromechanical coupling effect. The figure 3.1 shows a PEH cantilever with applied static force with tip mass on it, indicates the non uniform distribution of stress over the length.

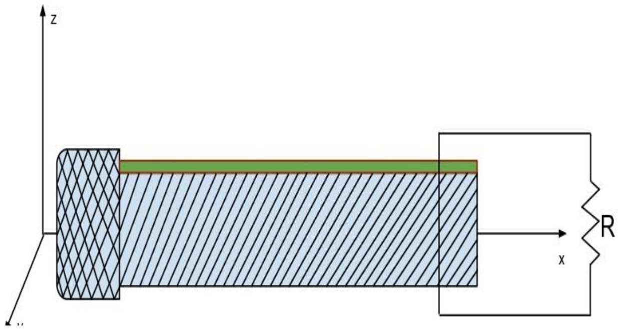

Figure 3.1: Piezoelectric harvester continious cantilever beam

The cantilever arrangement of the harvester with the tip mass can be of unimorph or bimorph. Moreover the multi layer configurations are also used in many applications for the improvements and best energy conversion purpose. Cantilever arrangements with segmented piezoelectric layer harvested are shows the energy efficiency improvements [8]. The segmented configuration the single cantilever beam will carry the many piezoelectric segments and they will be connected in series parallel configurations according to the need and agreements.

The segmentation for the harvester will be done so that the single beam will carry the more than one piezoelectric harvester. If the length of the cantilever is L then the different length of the piezoelectric harvester will be placed in the l length cantilever beam.

In this configuration consider a layer of piezoceramic attached in the upper side of the harvester cantilever beam. The Eular - Bernoulli model [9] is used to explain the transverse vibration of this cantilever beam. One electrode is covering the top of the piezoceramic layer whereas another one electrode is covering the bottom of the layer. The purpose of the connection of these electrodes is is to collect the electrical energy generated from the piezoceramic layer. The electrical load is connected to these electrodes to use the electrical energy generated from the piezoceramic materials that attached with the harvester beam. Normally resistive load is connected to the electrodes in all types of analysis of the piezoelectric energy harvesters. The load is an electric circuit which considered along with the internal capacitance of the piezoelectric layer. The energy harvester may be unimorph, bimorph, or multi layer configurations. In case of bimorph, the layers will be connected to a electrical resistive load with series or parallel arrangements

3) Clamped –Clamped Configurations

The clamped– clamped configuration [10] in the piezoelectric harvester is design and developed to ensure the

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uniform strain distribution in the harvester beam. And also to reduce the materials requirements the clamped – clamped configurations are used.

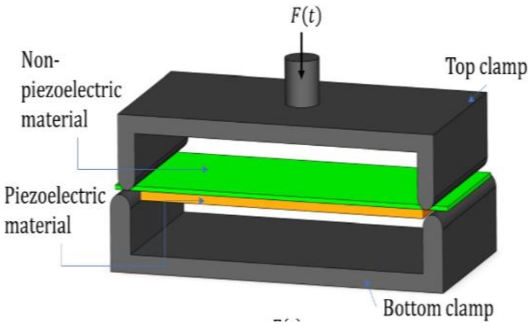

Figure 3.5: Two clamped harvester configurations

The total force that distributed along with the beam is given as below

$$Q(x,t) = F_A.\delta(0) - F_B.\delta(a_1) - F_C.\delta(L_T - a_2) + F_D.\delta(L_T)$$

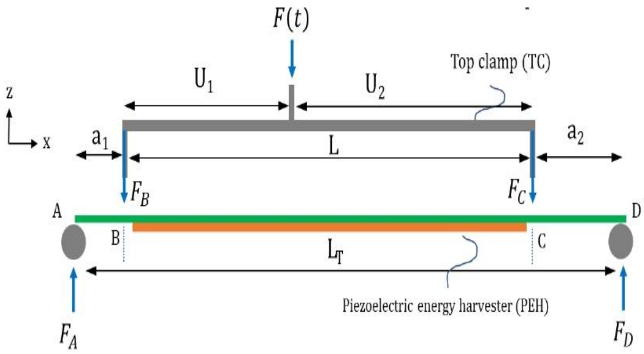

Figure 3.6: Four point bending PEH

By using the static relations among the F_A, F_B, F_C, and F_D the equation for force can be futher simplified as below

$$Q(x,t)=\left(\left(1-\frac{a_1+U_1}{L_T}\right)\delta(0)-\left(1-\frac{U_1}{L}\right)\delta(a_1)-\left(\frac{U_1}{L}\right)\delta(L_T-a_2)+\left(\frac{a_1+U_1}{L_T}\right)\delta(L_T)\right)F(t)$$

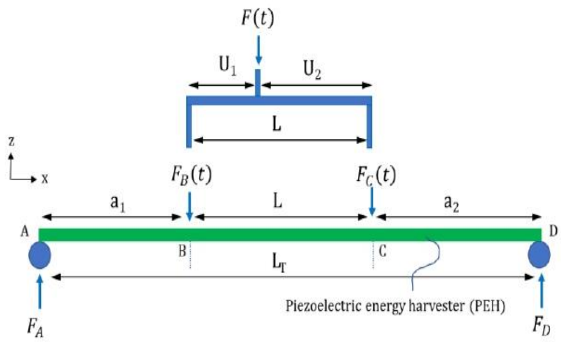

Figure 3.7: Force indication on clamped PEH

In the clamped- clamped configurations the motion's differential equation write as below

$$YI\frac{\partial^4 w(x,t)}{\partial x^4} + C_a\frac{\partial w(x,t)}{\partial t} + m^*\frac{\partial^2 w(x,t)}{\partial x^2} +$$

$$\mathcal{P}V_R(t)\left(\frac{d\delta(x-x_i)}{dx} - \frac{d\delta(x-x_f)}{dx}\right) = Q(x,t)$$

The coupling coefficient of the force is given as below

$$\sigma_n = -\left(\left(1-\frac{U_1}{L}\right).\phi_n|_{x=a_1} + \frac{U_1}{L}.\phi_n|_{x=L_T-a_2}\right)$$

The equation that represents the electric equation is given as below

$$C_P\frac{dV_R(t)}{dt} + \frac{V_R(t)}{R_L} = I_P(t)$$

The above equation is for single layer and for multi layer the equation will be modified as per the requirement.

2. Results and Discussions

The performance of the PEH improvements are continuously being done through the various approaches like change of materials combinations, configuration changes, breaking the beam layer in to different sections and make changes on the shape of the harvesters etc. the two main configurations are used in the PEH beam configurations namely cantilever with tip mass continuous and segmented layer beam. And the next one is two clamped configuration in the harvester beam. In the two clamped energy harvester design use the piezoelectric composite material which consists of macro Fiber composite, it is simply called as MFC. This MFC made as copper substrate shim and developed as a double layer tape which acts as bonding layer. The piezoelectric harvester is placed between the two clamps and the impact of the vibration is applied on the top clamp, the top clamp has the variable span of L. The selection of MFC as harvester material is selected by keeping the flexible characteristics of the MFC material in comparison with other composite materials. More over it has reasonable and considerable very favorable conversion efficiency. The selection of bending layer choice is based on the fact that it has low material damping, as discussed and shown in [11 - 12]. In that case also good and high power output was come as result. The Piezoelectric materials needed for this proposed approach is considerably reduced from the case where the PE materials used for the entire layer of the harvester.

Segmented Cantilever Beam: The clamped free configurations with tip mass harvester's performance are compared with the continuous cantilever harvester bream configurations. The voltage value shown in fig.4.1

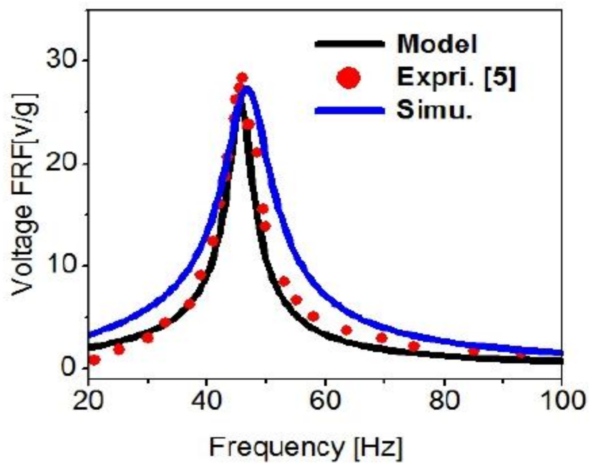

Figure 4.1: Voltage generated in 1st mode

The power output of the segmented cantilever harvester is taken to compare with the continuous beam cantilever configuration PEH. The output power has been shown in the fig.4.2

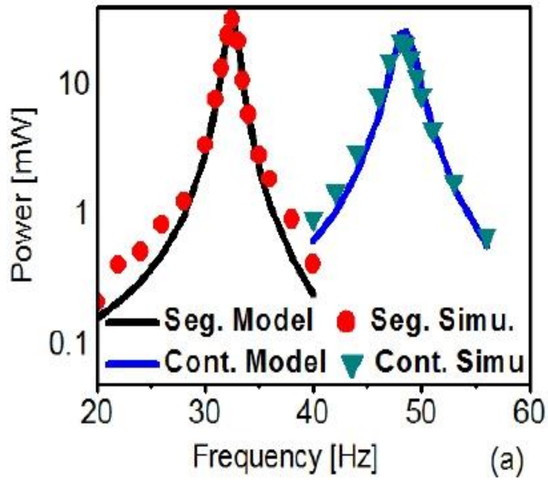

Figure 4.2: Power output produced for mode 1

The power output of the PEH of segmented beam of cantilever has been shown in the fig.4.3. But the 3rd natural frequency of the segmented harvester is higher than cantilever spring effect and hence the motion is opposite to the cantilever spring effect [12 - 13]. This results as higher resonance frequency in segmented PZT in comparison with the continuous PZT layer configurations. The performance of the harvester improved in the segmented beam harvester of cantilever but the strain imposed is not uniform

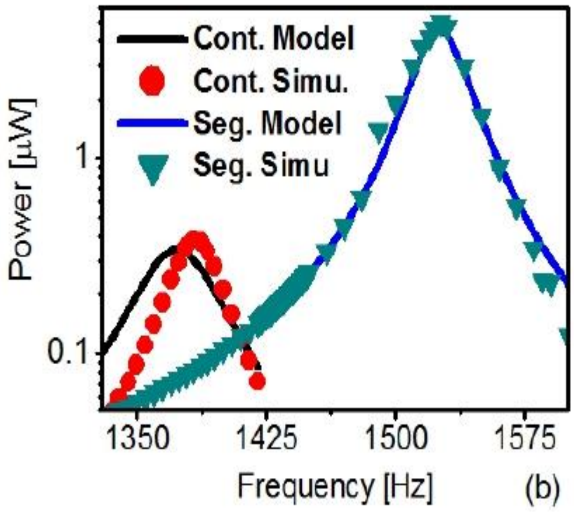

Figure 4.3: Power output produced for mode 3

Two Clamped Harvester Beam: To overcome the non uniform strain distribution and improve the harvester energy generation performance the two clamped beam harvester configurations have been analyzed. Force is applied from the topand not directely but through the top clamp**.** The resuls of the voltages, strain distribution and power output are shown through the graphs**.** For this energy harvester the undamped natural frequencies are compared with COMSOL the multi physics software along with the FEM presented in [12]. The table shown in the table number 1for this two clamped model ensure the error below 5%

Undamped natural Frequencies in Hz		
	COMSOL software	Finite Element numerical Model
Bending mode 1	48.7	49.6
Bending mode 2	196.7	198.7
Bending mode 3	448.4	448.4
Bending mode 4	807.7	799.7

To study the PEH output voltage performance, the hammer impact force applied method is widely and commonly used. The voltage generation is shown in fig.4.4

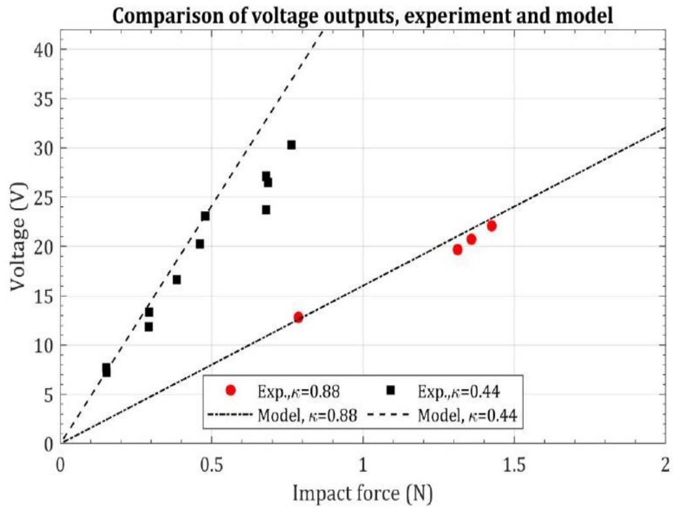

Figure 4.4: Voltage output comparisons

The figure 3.5 shows the typical force measurement at the value of K= 0.88 for the span of 90mm. The impact force applied duration is just for the time periods of 0.05s; the voltage generation went to peak after the impact applied force moment.

From the force time graph it is learn that impact force of hammer is a single hit, which is just corresponds to the assumptions made for the analytical impact. The figure 3.6 is the indicating the graph of impact force for the various test K=0.44 and k=0.88. in the case where k=0.88, if the upper clamp span comes close to support then the response of the support is very more severe; due to this reason, the measured force in the hammer becomes higher. This is the reason that the measured force in case of k=0.88 span is 1 - 8 N but for k=0.44 range is just 0.2 - 1.1 N

Force span changes: The results is compare the design model and experimental voltage value for the dimension less factor k=0.44 and k=0.88 span. From the graph it is evidence that increase in applied force impact leads to increase the liner voltage generation. In other way it can be said that in terms of span k values that if the k value is smaller the voltage leads to higher. The experimental data also indicate that the voltage generation increase along with increase in impact force increments. The agreements between model and data is reasonably ok for both k=0.44 and k=0.88 spans. In fact that the generated voltage is higher for k - 0.44 than k=0.88, this is because of the higher bending moments observed at low value of the span k.

3. Conclusion

The power generation performance and conversion efficiency of the piezoelectric energy harvesters that are using the different configurations like cantilever with tip mass bimorph, multimorph, clamped - clamped type energy harvester configurations performance were analyzed with the parameters of voltage, power output and the distribution of the strain on the harvester beam. This comparative analysis help in the selection of the best suitable energy harvester modal will be readily available to use in the low power need sensing devices. The cantilever arrangements with tip mass configuration does not provide the uniform stain stress in the harvester beam but the clamped – clamed configurations with the top side force applied approach the uniform strain stress achievements were proofed from the results comparisons of the both configurations. The uniform strain stress will ensure the long life of the energy harvester and also will reduce the need of materials to make the harvester for energy conversion beam.

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