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A COMPREHENSIVE COMPARATIVE ANALYSIS ON THE PERFORMANCE OF TWO CLAMPED PIEZOELECTRIC ENERGY HARVESTER (PEH) WITH CANTILEVER BEAM PIEZOELECTRIC ENERGY HARVESTER (PEH) ENERGY CONVERSION TECHNOLOGY (ECT)

T. Ramachandran, Vishnubhai Patel, Manishkumar S Patel
E-Mail Id: ramspowerthangamugam@gmail.com, vishanu.patel@ganpatuniversity.ac.in, msp01@ganpatuniversity.ac.in
Department of Electrical Engineering, U.V. Patel College of Engineering, Ganpat University, Kherva, Mehsana, Gujarat, India

Abstract- The use of Piezoelectric energy harvesters in low power requirement self-power device applications is increasing day by day. So, it’s very essential and important to improve the harvester energy conversion performance and increase the output power of the harvester so that the efficiency of the harvester also improved and increased. The way for improve the harvester generation voltage depends on many factors, among them one way of approach is the uniform use of materials and minimizing that more strain stress on the piezoelectric layer. Both approaches lead to improving converter efficiency and the requirements of the materials can be reduced by optimum use of the piezoelectric materials. The conventional cantilever arrangement with tip mass does not provide uniform stress strain to the harvester but it’s high near to tip mass and less to the rest of the harvester beam. This paper focused on the comparisons between the cantilever piezoelectric energy generations with the clamped type of configuration. The comparisons between cantilever and clamped configuration proofs that the uniform stress strain achievement is more in clamed configuration and the performance of the harvester improved, and requirement of the piezoelectric materials reduced.

Keywords: Piezoelectric harvester, cantilever configuration, segmented clamped Harvester, performance improvement, comparisons of the harvesters’ results

1. INTRODUCTION

Power generations by different nonconventional sources are the main target of the energy generation companies. The demand for electricity is growing very fast, and the need will further increase because all electrical and electronics devices use the supply of electrical energy. The electrical devices may need high voltages and low voltages according to the power rating of the equipments. The power generation for giving supply to electrical devices happens in high power rating power generators. But in the technical field there are many devices which have come under the electronics devices which also need electrical supply but in low value. 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 for any extra fuel needed. So, the energy harvesting from the waste energy available is fast growing [2]. In the field of waste 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 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 end of the harvester. But in the clamped typed harvester 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, changing the place 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 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 does not take place in entire piezoelectric harvester layer [3] . So, the use of the piezoelectric materials in the harvester can be reduced by doing proper segmentation in the harvester beam. Segmented cantilever arrangements give 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 of 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 concerned. 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 [4]. The segmented harvester means that the entire beam of the harvester does not have 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 more than one piezoelectric harvester. This arrangement will reduce the need of piezoelectric materials for the harvester.

2. PIEZOELECTRIC ENERGY HARVESTER AND APPLICATIONS

2.1 Piezoelectric Energy harvester

This section is dedicated to explaining what piezoelectric energy harvester is and how does the piezoelectric materials are able to convert the mechanical strain energy that applied to them, from the vibration source, into the electrical energy and vice versa [5]

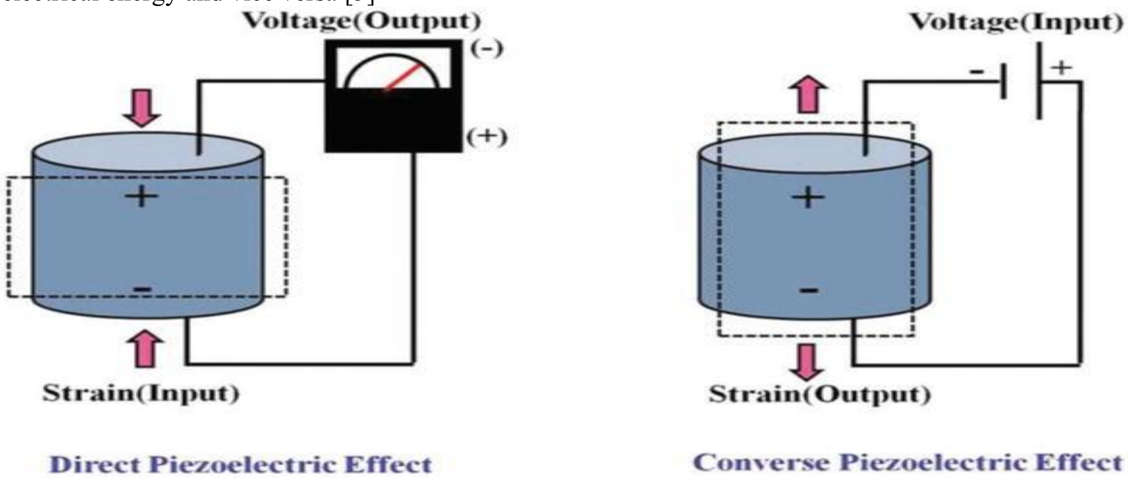

Fig. 2.1 Piezoelectric Effect

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.

2.2 Piezoelectric Energy Hharvester Applications

At the time of working of piezoelectric materials along with sensors, the piezoelectric material will detect even very small and minute disturbances that occur in the input level of the piezoelectric materials. So, 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 [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.

3. METHODOLOGY AND MODELING OF PEH

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 these two conditions the harvester provide low power for the low stress area, and structure failure may occur for the high stress region, due to these 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.

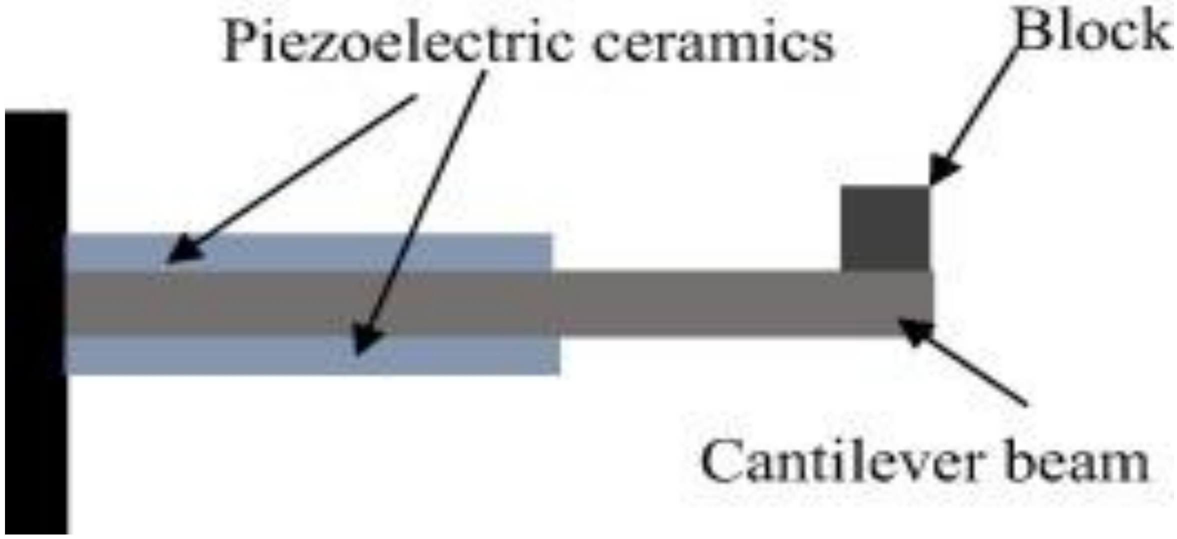

Fig. 3.1 Piezoelectric harvester cantilever beam

3.1 Cantilever Arrengment

The cantilever arrengment of the harvester with the tip mas can be of unimorph or bimorph. Moreover the multi layer configurations are also used in many applications for the improvemts and best energy conversion purpose. Cantilever arrengments with segmented piezoelectric layer harvestered are shows the energy efficicncy imrovements [8]. The figure 3.1 is the piezoelectric harvester cantilever configuration with unimorph. The figure 3.1 is the representations of the piezoelectric energy harvester cantilever configuration with bimorph configurations. The both the figure 3.1 and 3.2 are the not segmented configurations. The segmented configuration the single cantilever beam will carry the many piezoelectric segments and they will be conneted in series parellel configurations according to the need and areegnemtrs.

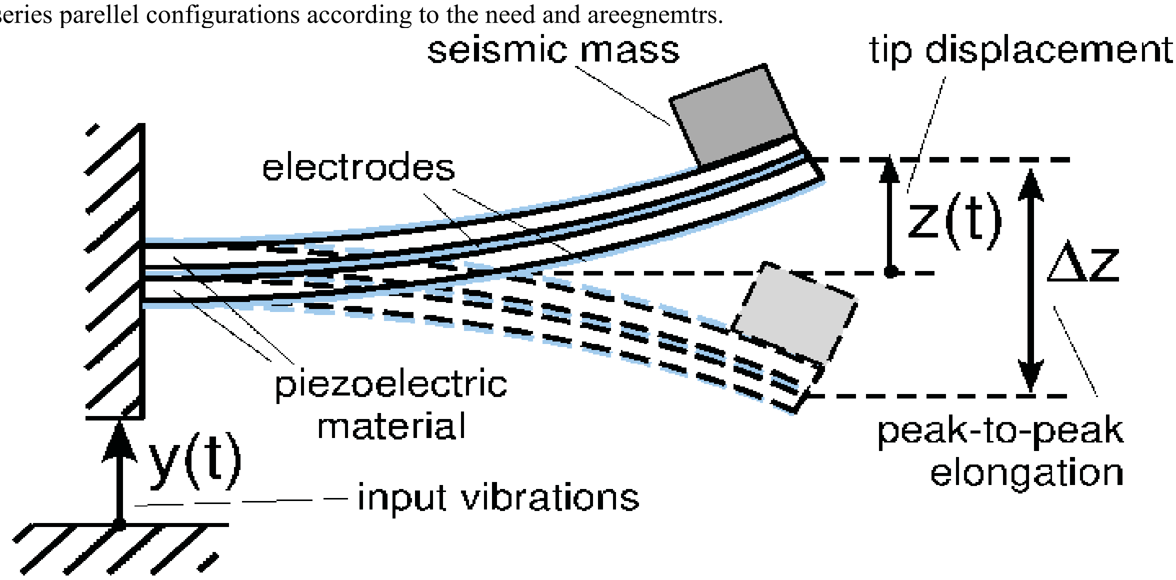

Fig. 3.2 Piezoelectric harvester cantilever bimorph

3.2 Segmentation Configuration

The segmentation for the harvester will be done so that the sigle 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 covers the top of the piezoceramic layer whereas another one electrode covers the bottom of the layer. The purpose of the connection of these electrodes 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 are attached to the harvester beam. Normally resistive load is connected to electrodes in all types of analysis of the piezoelectric energy harvesters. The load is an electric circuit which is 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

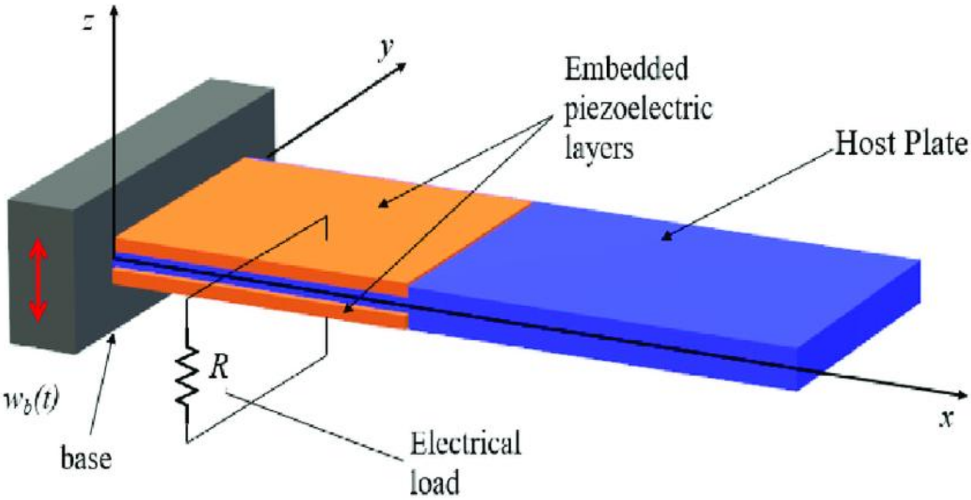

Fig. 3.3 Piezoelectric energy harvesre single layer with R load

However, the model equations are same for unimorph or bimorph. The values which will be entered in to the equations will be different. Unimorph piezoelectric harvester is modeled as below with initial boundary condition.

It is assumed that a piezoelectric layer is fixed to Euler – Bernoulli beam of a finite length L, 0 < L ∞,

Let w(x,t) – beam transverse displacement at a position x and corresponding time t, $0 \le x \le L$, $t \ge 0$.

Let v(t) – output voltage that appears across the piezoelectric layer electrodes

Then, the below equations is valid for the linear system of coupled differential equation for the unkown values of w and v [9]

$$m\frac{\partial^2 w(x,t)}{\partial t^2} + c_s I\frac{\partial^5 w(x,t)}{\partial x^4 \partial t} + c_a\frac{\partial w(x,t)}{\partial t} + YI\frac{\partial^4 w(x,t)}{\partial x^4}$$
$$-\theta v(t)\left\{\delta'(x) - \delta'(x-L)\right\} = 0,$$

Where,

m = Beam density (mass/unit length)
Ca = viscous air damping coefficient
Cs = damping coefficient Kelvin – voigt (strain – rate)
Y = Young modulus
I = cross sectional moments of inertia w r t neutral axis
YI = bending Stiffness
θ = backward coupling coefficient of converse piezoelectric effect

$$C\frac{dv(t)}{dt} + \frac{1}{R}v(t) + k\int_0^L \frac{\partial^3 w(x,t)}{\partial^2 x \partial t}dx = 0,$$

Where,

C = Piezoelectric layer initial capacitance
R = external load resistance
k = coupling coefficient of direct piezoelectric effect

$$w(0,t)=0,\quad \left.\frac{\partial w(x,t)}{\partial x}\right|_{x=0}=0,$$

$$\left[YI\frac{\partial^2 w(x,t)}{\partial x^2}+c_s I\frac{\partial^3 w(x,t)}{\partial x^2 \partial t}\right]_{x=L}=0,$$

$$\left[YI\frac{\partial^3 w(x,t)}{\partial x^3}+c_s I\frac{\partial^4 w(x,t)}{\partial x^3 \partial t}\right]_{x=L}=0,$$

$$w(x,t)=w_o(x),$$

$$\left.\frac{\partial w(x,t)}{\partial t}\right|_{t=0}=w_1(x), v(0)=v_0$$

3.3 Clamped – Clamped Configuration

The clamped – clamped configuration [10] in the piezoelectric harvester is design and developed to ensure the uniform strain distribution in the harvester beam. And also to reduce the materials requirements the clamped – clamped configurations are used.

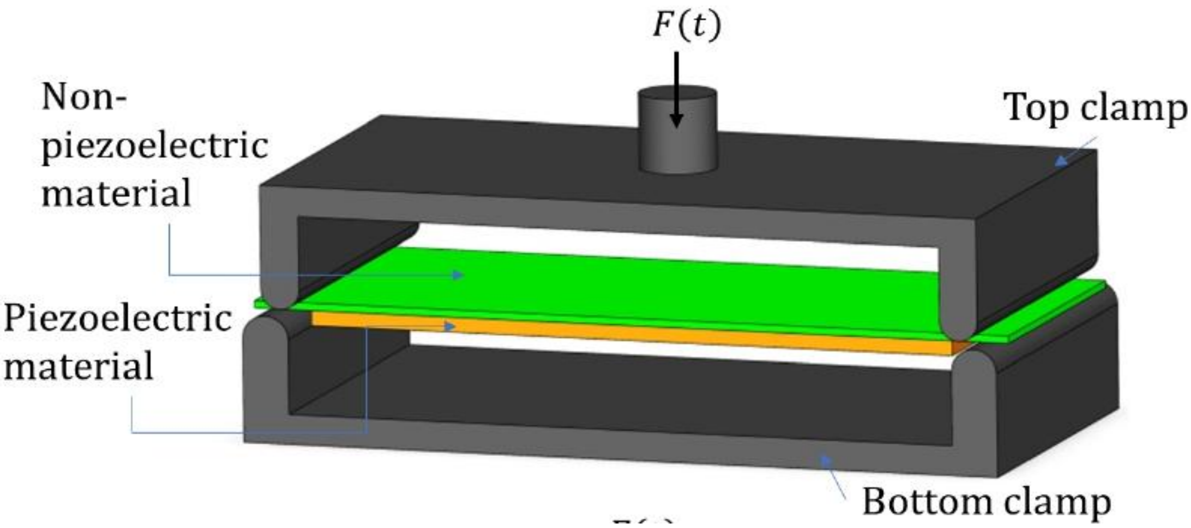

Fig. 3.4 Two clamped harvester configuration

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

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

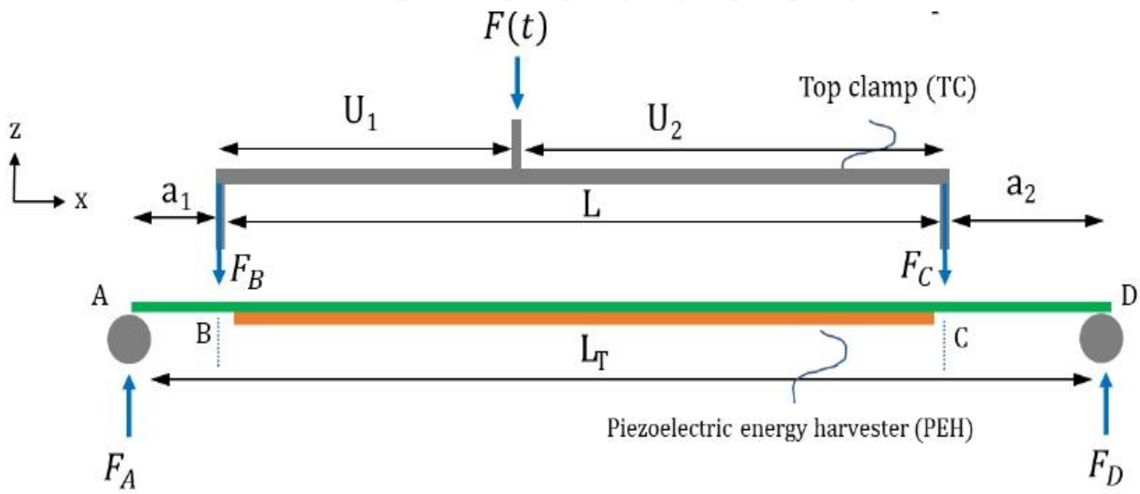

Fig. 3.5 Four point bending PEH

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

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

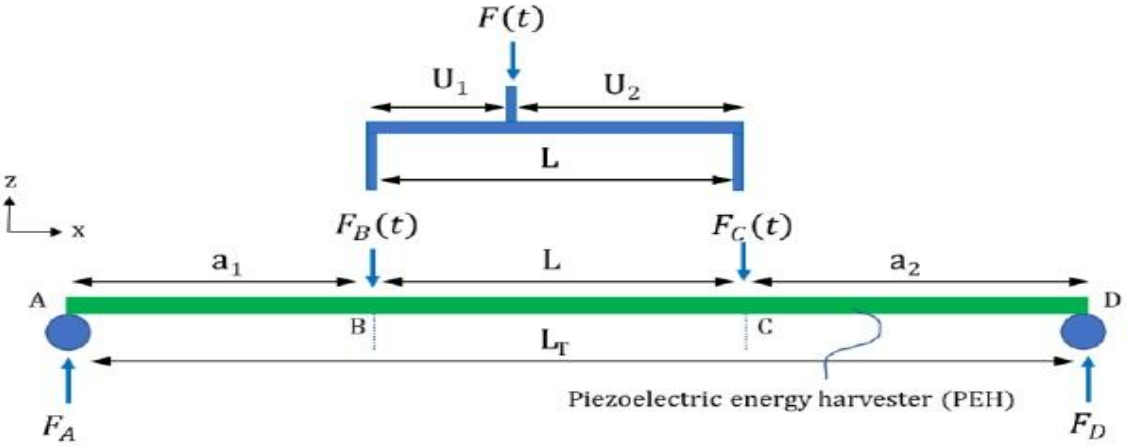

Fig. 3.6 Force indication on clamped PEH

In the clamped – clamped configirations 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 coeefficit of the force is given as below

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

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 nd for multi layer the eqution will be modified as per the requirement.

4. RESULTS AND DISCUSSIONS

The energy harvester design by using the piezoelectric composite material which consists of macro-Fiber composite, it is simply called MFC. This MFC is 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 clamper and the impact of the vibration is applied on the top clamp, the top clamp have the variable span el L. the energy harvester force span is L- 90 mm, (k= 0.44), for L less than 70 mm the impact force applied is nil to the Piezoelectric material, and hence very less impact strain is observed by MFC along with constant bending movement were experienced by the PE Harvester material. The selection of MFC as harvester material is selected by keeping the flexible characteristics of the MFC material in comparison with other composite materials. Moreover, it has reasonable and considerably very favorable conversion efficiency. The selection of bending layer choice is since it has low material damping, as discussed and shown in [11]. In that case also good and high-power output came 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.

To study the PEH output voltage performance, the hammer impact force applied method is widely and commonly used. 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 learned that impact force of hammer is a single hit, which is just corresponds to the assumptions made for the analytical impact. Figure 3.6 is the indicating 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

CONCLUSION

The power generation performance and conversion efficiency of the piezoelectric energy harvesters that are using the two clamped configuration and cantilever configurations like cantilever analyzed so that 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 get. The uniform strain stress will ensure the long life of the energy harvester and also will reduce the need for materials to make the harvester for energy conversion beam.

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