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# Design and Optimization of Piezoelectric Material for Active Vibration Control of Micro Cantilever Beam

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**Abstract:**
The study has been carried on technique in which the vibration of a structure is reduced by applying counter force on the structure. This technique is called Active vibration control. Now a day's active vibration control is frequently used in aircraft, submarine, automobile, helicopter blade and naval vessel. In this project work micro cantilever beam is bonded with one pair of piezoelectric patches on top and bottom surfaces which is used to study the active vibration control. The microcantiliver beam is aluminum beam modeled in fixed configuration with surface bounded piezoelectric patches (lead zirconate titanate). The study was carried out by using analysis software (ANSYS – 14.5) is to derive the finite element model of the microcanti lever beam. This study reveals that the vibrations of the cantilever beam are minimized, and deflection of the beam is also reduced to some extent. In this project just finding a suitable vibration controlling mechanism by which optimize the controller gain to get more effective vibration control with minimum control input.

**Keywords:**
Piezoelectric material, Shear force, Active vibration control, Ansys software, Optimization, Smart beam.

## I. INTRODUCTION:

Vibration is an oscillation where in the quantity is a parameter that defines the motion of a mechanical system. It can be defined as a simply the cyclic or oscillating motion of a machine or machine component from its position of rest. While dealing with the mechanical vibrations two important and related components must be considered namely, uncertainities and control for the analysis to be complete in modeling a dynamic system.

Two scenarios may be encountered. If the system parameters can be known under ideal conditions is called direct and inverse approach is used. Although these modeling approaches is more general and useful for many practical case dealing with uncertainties and modeled dynamics is not trivial task. As a remedy to remove this vibration control is to be used to overcome these uncertainties and modeling shortfalls. This forms our main motivation for developing this in vibration control system coupled with attractive features of piezoelectric materials these vibration control system can be practically implemented for many engineering and natural systems. Active vibration control system has been used as a solution for a flexible space crafts to achieve the degree of vibration or suspension for required precision painting accuracy. In this we used al beam which is bonded with leadzirconatetitante piezoelectric material. By varying sizes and position of the patch we can control the vibrations.

## II. Literature survey:

1. M.Yuvraj, M.Senthilkumar, I.Balaguru (2013) the study presents an active vibration control technique applied to a smart beam. This consists of a aluminum and mild steel beams modeled in cantilevered configurations with surface bonded piezoelectric patches. the natural frequency of smart beams were found using finite element code for first four modes by varying the location of actuator from the fixed end of the structure and it has good agreement with analytically found naturalfrequency.An experimental apparatus has been developed to study the vibration suppression of the smart beams. This results shows that the Ah aluminum beam will have little more damping effect than mild steel leads to less settling time of aluminum.

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2. Joybar,Peenakchatarjee,Siddharth das(2014)The investigation is on a smart plate with one pair of piezoelectric lamination is used to study the active vibration control .the smart plate consists of a rectangular aluminum beam modeled in cantilever configuration with surface bonded pzt patches. The study of ANSYS-12 software to derive the finite element model. Based on this sensor locations are found and actual smart beam is production control with minimum controller gain to get more effective vibration. In this experiment we find a suitable control methodology by which we optimize the control input.

**NOMENCLATURE:**

Pzt, Al, PbZt, BS,D,ρ, ƒ,δ,α,β

## III. EXPERIMENTAL WORK:

In this project the static and dynamic analysis are performed to determine the deflection, natural frequencies of a structure. Under different load conditions. Different analysis are performed on micro cantilever beam by varying length and width of pzt patches. Structural analysis by varying length of the patch: To study the effect of length of patch on deflection beam a voltage of 10V is applied on the top surface. By keeping width and thickness of patch constant for different lengths, finally bending stress and deflection values are obtained. Plot the graph between length of the patch Vs bending stress and deflections.

**Table I. Properties of micro cantilever beam**

| S.No | Parameter | Value |
|---|---|---|
| 1 | Modulus of Elasticity | 69 Gpa |
| 2 | Poisson’s ratio | 0.3 |
| 3 | Density | 2710KG/m3 |

**Table II. Properties of piezoelectric material**

| S.No | Parameter | Value |
|---|---|---|
| 1 | Density | 7400 kg/m3 |
| 2 | Thermal conductivity | 0 |
| 3 | Permeability | 0 |
| 4 | Permittivity | 4.89e-9 |

**Table III. Geometry of micro cantilever beam**

| S.No | Parameter | Value |
|---|---|---|
| 1 | Length of the beam | 200 |
| 2 | Width of the beam | 50 |
| 3 | Thickness of the beam | 10 |
| 4 | Length of the patch | 200 |
| 5 | Width of the patch | 50 |
| 6 | Thickness of the patch | 2 |

Primarily we do analysis on full length of the patch which is bonded to the micro cantilever beam

Structural analysis of full length patch

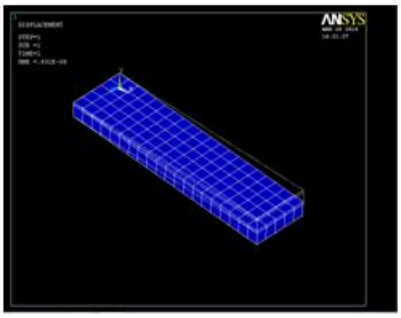


**Fig. 1.Deflection of beam**

Figure 1. Shows the deflection of the beam when full length of the patch is attached. After that by keeping width and thickness are constant then change the length of the patch we have to find out the deflection and bending stress values. After the getting those values plot the graphs between length of the patch Vs deflection and length of the patch Vs bending stresses.

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**Table IV.Output value of beam for constant width**

| Length(Microns) | Deflection (mm) | Bending stress(Mpa) |
|---|---|---|
| 10 | 1.32E-07 | 21881 |
| 20 | 3.14E-07 | 21744 |
| 30 | 3.93E-07 | 21742 |
| 40 | 4.21E-07 | 21741 |
| 60 | 4.35E-07 | 21741 |
| 80 | 4.37E-07 | 21741 |
| 100 | 4.37E-07 | 21741 |
| 120 | 4.37E-07 | 21741 |
| 140 | 4.37E-07 | 21741 |
| 160 | 4.37E-07 | 21741 |
| 180 | 4.37E-07 | 21741 |
| 200 | 4.37E-07 | 21741 |

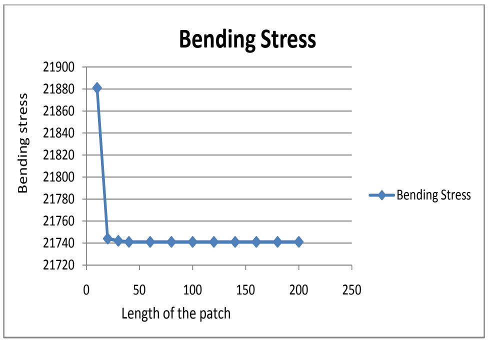



**Fig. 2.length of patch(microns) Vs Bending stress(mpa)**

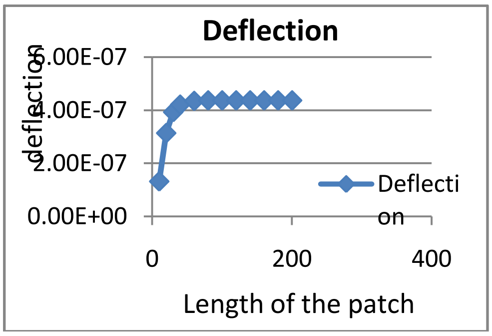
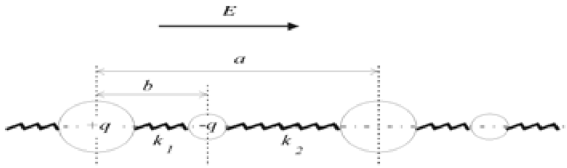



**Fig. 3.length of patch(microns) Vs Deflection(mm)**

Figure 2,figure3 shows how the deflection and bending stresses are varied with length of the patch.

**Constitutive Equations:**

The Cd S crystal structure can be seen as an array of identical rows composed of sub-structures, such as described in Fig. Where cations Cd (charge +q) and anions S (charge −q) alternate. The inter atomic cohesion forces are modeled by ideal springs of different stiffness k1 and K2, The distance between consecutive pairs of atoms being different.




If the crystal is composed of n basic elements of length a, as shown on fig including 2 electrical dipoles $\frac{q}{2}(a-b)$ and $-\frac{q}{2}b$, the global free polarization will be given by $p_0 = n\frac{q}{2}(a-b)$

For a constrained crystal (along the axis of alignment),the interatomic distances change and a polarization p is induced ;this is the direct piezoelectric effect:

$$p = \Delta p_0 = n\frac{q}{2}(\Delta a - 2\Delta b)$$

Conversely, when an electric field E is applied along the same axis, the ions move and a global deformation is induced; this is the inverse piezoelectric effect. The static equilibrium relation for each ion can be written:

$$qE + k_1\Delta b - k_2\Delta(a-b) = 0$$

The induced polarization is related to the electrical field and to the atomic displacement by:

$$p = n\frac{q}{2}\left(\frac{2q}{k_1+k_2}E + \frac{k_1-k_2}{k_1+k_2}\Delta a\right)$$

Which can be written

$$p = (x_{ion}E + es)$$

Where

$$x_{ion} = n\frac{q}{2}\frac{2q}{k_1+k_2}$$

Is called the ionic polarizability of the crystal,

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$$s = \frac{\Delta a}{a}$$

S is the strain, and

$$e = na\frac{q}{2}\frac{k_1 - k_2}{k_1 + k_2}$$

E is the piezoelectric constant.

The electric displacement (induced polarization) can be written

$$D = eS + \varepsilon^s E$$

Where the permittivity at constant strain $\varepsilon^s$ is given by

$$\varepsilon^s = \varepsilon_0 + x_{ion}$$

Where $\varepsilon_0$ is the permittivity of the vacuum

The stress induced in a unitary section perpendicular to the considered axis, assuming a total of N rows on a unitary section and assuming an equal number of springs of each type $k_1$ and $k_2$ in such a section, is given by:

$$T = \frac{N}{2}k_1\Delta b + k_2\frac{N}{2}\Delta(a-b)$$

Considering that we have $N = na$ and using equ the above eq

One gets:

$$T = na^2 k_2 \frac{k_1 k_2}{k_1 + k_2} S - na\frac{q}{2}\frac{k_1 - k_2}{k_1 + k_2} E$$

Which can be written as

$$T = c^E S - eE$$

Where

$$c^E = na^2 k_2 \frac{k_1 k_2}{k_1 + k_2}$$

$c^E$ is the mechanical stiffness at a constant electric field, and $e$ is the piezoelectric constant given by eqn(1.8) . It is worth noticing that $c^E$ is related to the stiffness of the two springs $k_1$ and $k_2$ in series and that the piezoelectric constant $e$ is zero if the springs are of equal stiffness. Equations (1.9) and (1.13) are the piezoelectric constitutive equations.

However, ions are never connected by ideal springs. In most cases, these springs are harmonic $\left(F \cong k\Delta + k'\Delta^2\right)$.

A fraction of the stress induced is independent of the direction of the applied field.

$$T = c^E S - eE - e^* E^2$$

This effect is called the electrostictive effect, $e^*$ is the electrostrictive coefficient.

## Finite Element Formulation:

The dynamic equations of a piezoelectric continuum can be derived using Hamilton's principle:

$$\delta\int_{t1}^{t2}(L+W)\,dt = 0$$

Constitutive equations

$$\{T\} = \left[C^E\right]\{S\} - \left[e^t\right]\{E\}$$

$$\{D\} = [e]\{S\} - \left[e^s\right]\{E\}$$

Lagrangian equation

$$L = J \pm H$$

$$\int_{t1}^{t2}\rho\left(\delta\dot{u}\right)^T\left\{\dot{u}\right\}dt = \left[\rho\{\delta u\}^T\left\{\dot{u}\right\}\right]_{t1}^{t2} - \int_{t1}^{t2}\rho\{\delta u\}^T\left\{\ddot{u}\right\}dt$$

Virtual work

$$w = -\int_v\left[\rho\{\delta u\}^T\left\{\ddot{u}\right\}\right] - \{\delta s\}^T\left[c^E\right]\{s\} + \left\{\delta s^T\right\}$$

By substituting lagrangian and virtual work in the Hamilton's principle After applying the boundary conditions to the above equation, we get

$$[M]\{ui^{\bullet\bullet}\} + [KuU]\{ui\} + [Ku\phi]\{\phi i\} = \{fi\}$$

$$[K\phi u]\{ui\} + [K\phi]\{\phi i\} = \{gi\}$$

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Where

$$M = \int_v \rho [Nu]^T [Nu] dv$$

$$KuU = \int_v Bu^T \left[c^E\right][Bu] dv$$

$$Ku\phi = \int_v Bu^T \left[e^T\right][B\phi] dv$$

$$K\phi u = [Ku\phi]^T$$

$$\{fi\} = \int_v Nu^T \{Pb\} dv + \int_\Omega Nu^T \{P_s\} d\Omega + \int_v Nu^T \{P_s\}$$

$$\{gi\} = \int_\Omega [N\phi] e^T d\Omega - [N\phi]^T Q$$

$$\{u_i\}^k = [Lu]^k \{u\}$$

$$\{\phi_i\} = [L\phi]\{\phi\}$$

## IV. RESULTS AND DISCUSSIONS:

Now keeping length and thickness are constant at different widths we find the deflections of the micro cantilever beam. Plot the graphs between width of the patch Vs Deflection and width of the patch Vs bending stress. Based on those values we can decide the geometry and dimensions of the patch. After that based on those values and results we can decide the shape of the patch, based on those values draw the graphs between stresses and deflection we can exactly find where the deflection is high then we can find position of the patch for the optimization purpose.

**Table IV. Output values for the beam with constant length**

| Width(microns) | Deflection(mm) | Bending stress(mpa) |
|---|---|---|
| 10 | 0.437e-6 | 21750 |
| 20 | 0.437e-6 | 21795 |
| 30 | 0.437e-6 | 21741 |
| 40 | 0.437e-6 | 21742 |
| 50 | 0.437e-6 | 21741 |

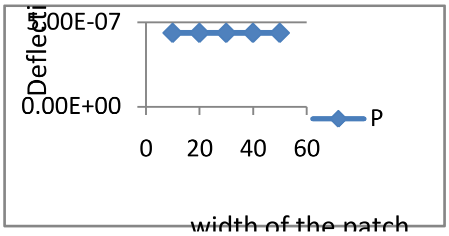


**Fig. 4.width of patch(microns) Vs Deflection(mm)**

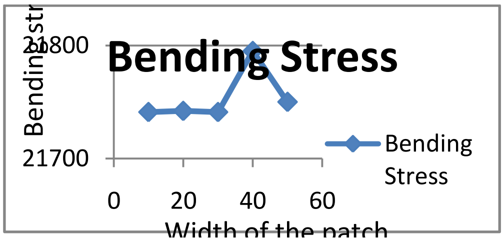


**Fig. 5.width of patch(microns) Vs Bending stress(mpa)**

From the Figure 5. We conclude the dimensions of the patch are given below

Length=80 microns, width=50 microns, thickness=2 microns

To find the optimum position of the patch we have done structural analysis at various positions of a cantilever beam, we were obtained deflections. Using these deflections plotted a graph between positions of the patch and the deflections of the micro cantilever beam.

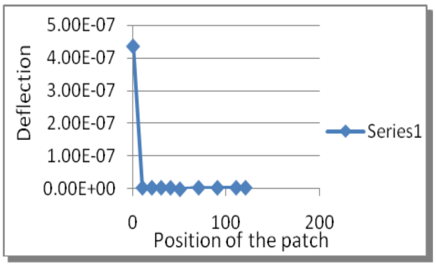


**Fig. 6.width of patch(microns) Vs Deflection(mm)**

From Fig.6. We can find out the position of the patch is at the fixed end of the beam.

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## STRUCTURAL ANALYSIS FOR DIFFERENT SHAPES OF THE PATCH

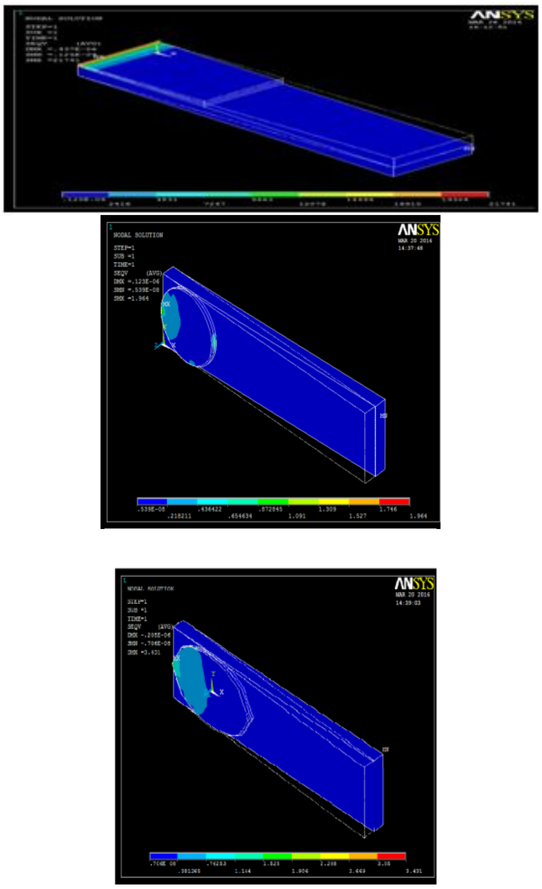


Fig. 7.Structural analysis for different shapes of patch

Figure 7 shows the deflections of beam which was attached with different shapes of the patches based on those values the Graph was plotted between shape Vs deflections and shape Vs bending stresses, from that we conclude that the effective shape of the piezoelectric patch is in rectangular shape with the certain dimensions.

Dimensions of the patch:
Length of the patch = 80 microns
Width of the patch = 50 microns
Thickness of the patch = 2 microns

## MODAL AND HARMONIC ANALYSIS FOR THE FULL LENGTH PATCH

Table V. Geometry of patch

| S.No | Parameter | Values(microns) |
|---|---|---|
| 1 | Length of the beam | 200 |
| 2 | Width of the beam | 50 |
| 3 | Thickness of the beam | 10 |
| 4 | Length of the patch | 200 |
| 5 | Width of the patch | 50 |
| 6 | Thickness of the patch | 2 |

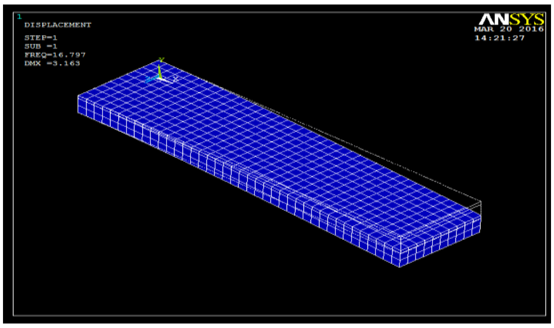


Fig. 8.deflection of full length patch

Table VI. Output values of modal analysis

| S.No | Frequency(Hz) |
|---|---|
| 1 | 16.797 |
| 2 | 71.890 |
| 3 | 75.853 |
| 4 | 76.444 |
| 5 | 77.004 |

## MODAL AND HARMONIC ANALYSIS FOR THE OPTIMIZED PATCH

Table VII. Geometry of patch

| S.No | Parameter | Values(microns) |
|---|---|---|
| 1 | Length of the beam | 200 |
| 2 | Width of the beam | 50 |
| 3 | Thickness of the beam | 10 |
| 4 | Length of the patch | 80 |
| 5 | Width of the patch | 50 |
| 6 | Thickness of the patch | 2 |

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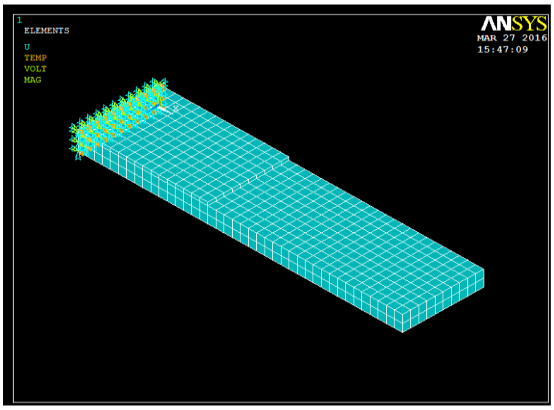


Fig. 9.modal analysis of optimized patch

**Table VIII. Output values of modal analysis**

| S.No | Frequency(Hz) |
|---|---|
| 1 | 0.54589 |
| 2 | 2.2787 |
| 3 | 2.6414 |
| 4 | 3.335 |
| 5 | 8.265 |

In the harmonic analysis we applied 10 V voltages on the top surface of the beam, and then we obtain the graph between natural frequency and deflection values.

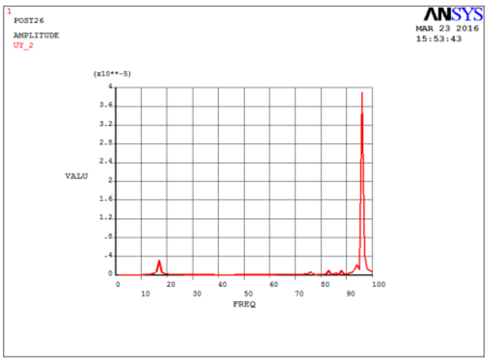


Fig. 9.modal analysis of full length patch

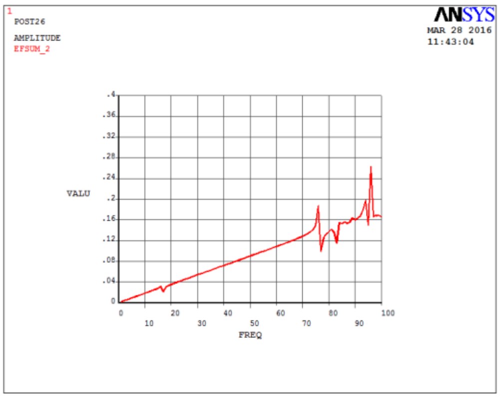


Fig.10.harmonic analysis of optimized patch

## TRANSIENT ANALYSIS OF A CANTILEVER BEAM:

Transient dynamic analysis is a technique used to determine the dynamic response of a structure under a time-varying load. The time frame for this type of analysis is such that inertia or damping effects of the structure are considered to be important. Cases where such effects play a major role are under step or impulse loading conditions.

## PIEZOELECTRIC MATERIAL AS AN ACTUATOR:

Actuator converts the electric voltage into the mechanical deflection. In transient analysis we apply the displacement of 1mm at the free end of the cantilever beam after 10seconds and the voltage of 10V on the top surface of the piezoelectric patch and 0V on the bottom surface of the piezoelectric patch after 20 seconds time. We obtain the graph between frequency and displacement.

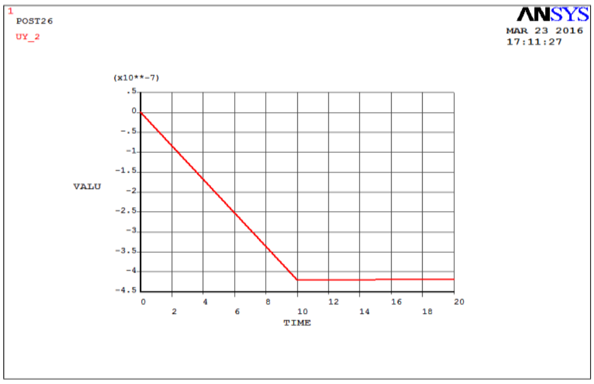


Fig.11. Graph between time and deflection

## PIEZOELECTRIC MATERIAL AS A SENSOR:

Sensor converts the mechanical force into the electrical voltage. In this we apply the force of 1e-4N at the free end of the cantilever beam. We obtain the voltage as output and we obtain the graph between time and deflection.

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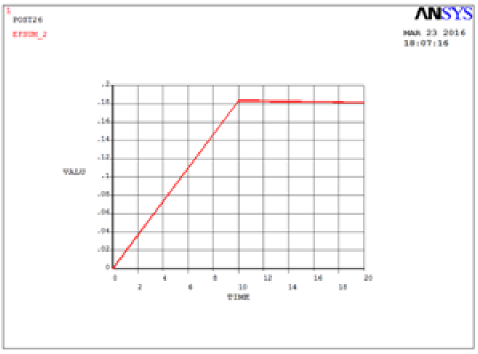


**Fig.12. Graph between time and voltage**

## V. CONCLUSION:

Present work deals with the active vibration control of cantilever beam bonded with two piezoelectric patches, it is observed that without control response is paramount, but After applying counter force sufficient vibration suppression has been achieved. In this by using ansys 14.5 designing and analysis of a beam and piezo electric patch is done successfully And also find the geometry, location and shape of the patch was done. Present study is useful in controlling the vibrations of modern day machines, engineering structures, automobiles, gadget space crafts, bridges, marine equipments machine tools etc.

**1.** Location of the patch (i.e. at the fixed end of the beam).

**2.** Shape of the patch (Rectangular patch).

**3.** Dimensions of the patch (length = 80 microns, width=50 microns, thickness =2microns).

**4.**Derive the computational equations and finite element formulation.

**5.** Compare these ANSYS results with theoretical calculations.

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