



e-ISSN: 2319-8753 | p-ISSN: 2320-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 3, March 2021

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 7.512

9940 572 462

6381 907 438

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Design and Analysis of Micro-Cantilever Beam Attached with Piezoelectric Material for Vibration Control

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ABSTRACT: This study proposes dynamic model finite element formulation and the constituent equations of motion of the micro cantilever beam based finite element modelling with piezoelectric patches. The active vibration control technique is used to reduce the deflections, Vibrations and stresses in that beam. In this technique the vibrations in a structure is reduced by applying counter force. In present days the active vibration control technique is widely used in automobiles, naval vessels, helicopter plates, submarines, aerospace vehicles, and aircrafts. Here the micro cantilever beam material is aluminium. This aluminium beam modelled in fixed configuration with surface is bonded with one pair of piezoelectric patches on top and bottom of the beam. In this work the material of the piezoelectric patches is lead zirconate titanate. The study was carried out by analysis software i.e. ANSYS 14.0 to derive the finite element model of the cantilever beam. In this the mode shapes, natural frequencies, the position, shape and the geometry of the piezoelectric patch for optimizing the vibrations are determined. In this we used the piezoelectric material as actuator and sensor. The effect of piezoelectric material (Actuator/sensor) Pair is investigated at different locations of the beam in vibration control. Then it can be concluded from the work that the best result is obtained. Then the patches are bonded near the fixed end of the cantilever beam. Finally, the ANSYS results are compared with the existing literature survey.

KEYWORDS: Shear forces, bending stresses, Active and passive vibrations control techniques, piezoelectric materials

I. INTRODUCTION

Vibration is an oscillation where in the quantities a parameter that defines the motion of a mechanical system. Vibration can be defined as simply the cyclic or oscillating motion of a machine or machine component from its position of rest. The vibrations occur whenever there are rotating or moving parts in machinery. Ex – locomotives, diesel engines mounted on sound foundations, whirling of shafts. Vibration defined as mechanical oscillation about an equilibrium point. That mechanical oscillation may be periodic or non-periodic such as the motion of a pendulum or random such as the movement of a tire on a gravel road. Analysis of beams explores the interesting basic model for much enrichment of structural engineering applications which are widely applied in structural components in controlled conditions. Examples includes the structures that are modelled with the structural element such as beam-like elements like aircraft wings, spacecraft antennae helicopter rotor blades and robot arms. Many other structures to be considered as examples are beam like model elements are lengthy bridges, high rise buildings and robotic arms. Dynamic responses of entire structure can be significantly influenced by the existence of fracture in structural elements.

II. RELATED WORK

S. PRAVEEN KUMAR, SRIGITHA, S. NATH, G. DINESH RAM (2019) In This paper the design of a Micro – Cantilever beam based solar energy harvester is proposed. Solar energy is converted to electrical voltage using a MEMS solar cell that uses the principle of co-efficient of thermal expansion and Piezoelectric effect. Initially, the bilayer cantilever made of two different materials (AL & Sio₂) is displaced at the free end by absorbing the solar radiation converted to mechanical energy. Also, the developed Mechanical energy (stress) is converted to electric potential by using the Piezo electric material that is positioned at the fixed end of the cantilever. Then the Optimized structure with maximum at the voltage generations placing different Piezo electric Material at the fixed end the size of Designed solar cell is very small (4000 μm²) when compared to the conventional photo voltaic cell which ultimately reduces the cost by the batch fabrication process.

Saurabh Kumar, Rajiv Srivastava, R.K. Srivastava (2018) In this paper the modelling and design of a beam on which two piezoelectric ceramic lead zirconate titanate (PZT) patches are bonded on the top and bottom surfaces as sensor or actuator collated pair is presented. The work considers the active vibration control (AVC) using proportional integrative derivative (PID) controller. The beam is assumed as Euler-Bernoulli beam elements. The contribution of mass and stiffness of two PZT patches in the design of entire structure also to be considered. The beam is modelled using three finite elements. The patches can be bonded near the fixed end at the middle or near the free end of the beam as collated pair. The design uses first two domains at vibratory modes. The effect of PZT sensor/actuator is investigated at different locations of the beam in vibration control. It can be concluded from the work that best result is obtained when the PZT patches are bonded near the fixed end.

Joy Bara, Peenak Chatterjee, Sidharth Das (2017) In active vibration control technique the vibrations in a structure are reduced by applying counter force on the structure. Now a day's active vibration control is widely used in aircraft, submarine, automobile, helicopter blade, naval vessel. The smart plate having rectangular aluminium beam modelled in cantilever configuration with surface bonded piezoelectric patches. The study uses ANSYS-12.0 software to derive the finite element model of the smart plate. Based on this model, the optimal sensor locations are found and actual smart beam is produced. In this project a smart plate (aluminium plate) with one pair of piezoelectric laminations is used to study the active vibration control.

Pradeep Kumar Sharma and shankha Baduria (2016) The purpose of this study is to focus on the application of the piezoelectric material to control the vibration of the structures. Piezoceramics are low cost, light weight and easy to implement materials which can be applied to minimize the amplitude of structural vibration. The basic principle of piezo electric actuation is also discussed in the study. Piezoceramics are acted as sensors or actuators or in both form of sensor and actuator by different authors. It is available in various forms such as rigid patch, flexible patch, stack etc. In this study an attempt has been taken to discuss the application of various forms of Piezoceramics for active control of structural vibration

II.METHODOLOGY

In the modelling and analysis of piezoelectric crystals the typical finite elements used are the solid elements, whereas in the analysis of thin plates, usually shell elements are utilized. The use of elements possessing different degrees of freedoms in the same model requires coupling of the consistent degrees of freedoms at the contact surfaces where these elements interface. Although the application of the coupling strategies guaranties the appropriate transfer of the nodal forces between the active and passive portions at the interface, the nodal moments corresponding to the nodal rotations do not transfer [7]. Hence, the first part of the study gives the effects of element selection in finite element modelling. For this reason, a case given in reference [5] is considered. The smart beam was a derivation of coupling equation: An intuitive explanation of the piezoelectricity can be given by a simple one-dimensional example. Let us consider a simple bi-ionic crystal.

III. EXPERIMENTAL RESULTS

Structural analysis is the study of the static response of the structures under varying the loads. In structural mechanics is to determine the deflections of an object or structure during different load conditions.



It is common to use the finite element method the types of equations which arise from static analysis. Different analysis performed on micro cantilever beam.

- Structural analysis by varying length of the patch
- Structural analysis by varying width of the patch

Figure 1 shows the deflection of a rectangular beam with full length patch. Table 1 represents the properties of the beam and the piezoelectric patch and table 2 represents the Geometry of the micro cantilever beam attached with piezoelectric patch.

S.NO	PARAMETER	VALUE
1	MODULUS OF ELASTICITY	69GPA
2	POISSON'S RATIO	0.3
3	DENSITY	2710KG/M ³

TABLE 1

S.NO	PARAMETER	VALUE
1	DENSITY	7400 KG/M3
2	THERMAL CONDUCTIVITY	0
3	PERMEABILITY	0
4	PERMITTIVITY	4.89E-9

S.NO	PARAMETER	VALUE(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

TABLE 2

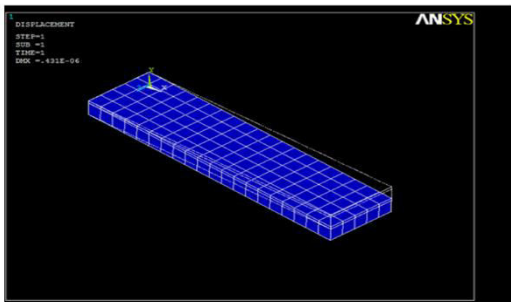
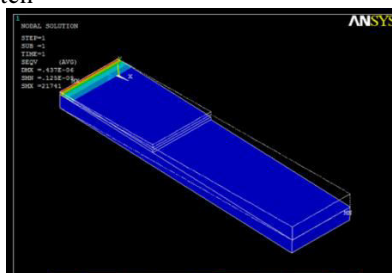
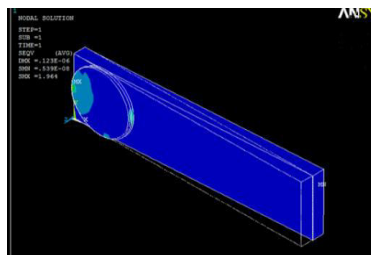


FIGURE 1

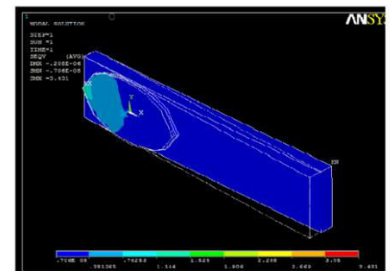
Figure 1 represents the structural analysis of a full-length patch attached to a micro cantilever beam. Figure 2 represents the various shapes of patches attached to a micro cantilever beam. (a) Rectangular patch (b) elliptical patch (c) circular patch



(a)



(b)



(c)

Figure 2



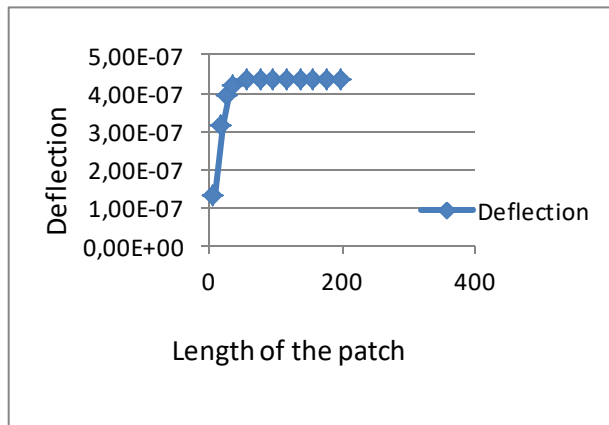
Table. 3 represents the deflection of the micro cantilever beam by varying the length of the patch (a) graph between deflection of the patch by varying length of the patch (b) bending stress of the patch at different lengths of the patch Table. 4 represents the deflection of the micro cantilever beam by varying the Width of the patch (c) graph between deflection of the patch by varying width of the patch (d) bending stress of the patch at different width of the patch

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

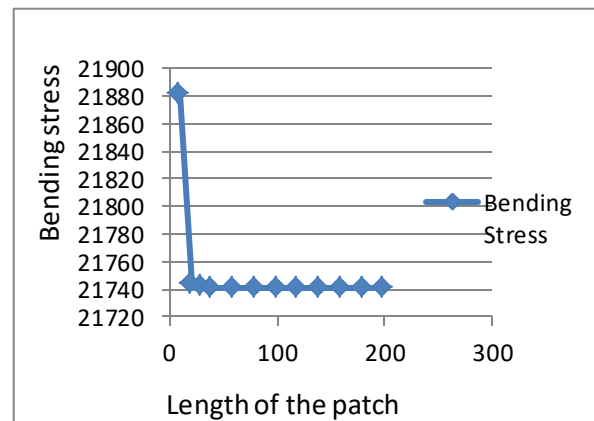
Table 3

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

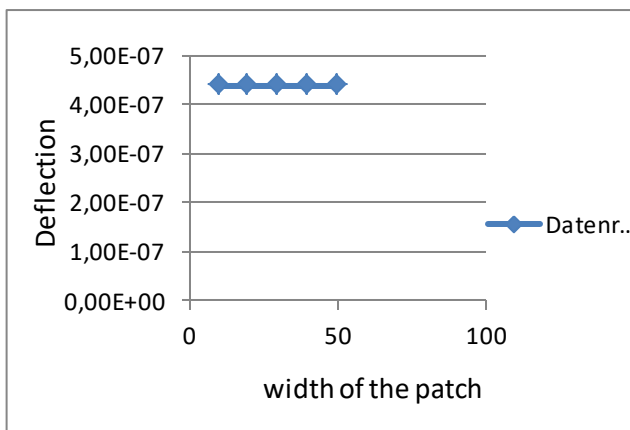
Table 4



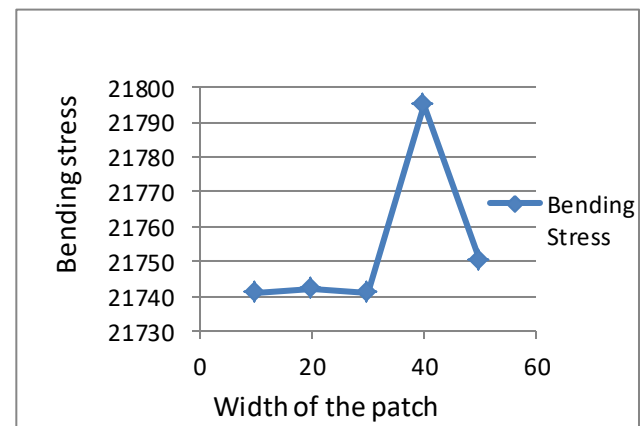
(a)



(b)



(c)



(d)



From the above graph we conclude that the dimensions of the patch are

Length of the patch=80microns

Width of the patch=50microns

Thickness of the patch=2microns

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

Shape of the patch	Deflection(mm)	Bending Stress (MPa)
Rectangle	0.437e-6	21741
Circle	0.123e-6	1.964
Ellipse	0.208e-6	3.431

Table 5

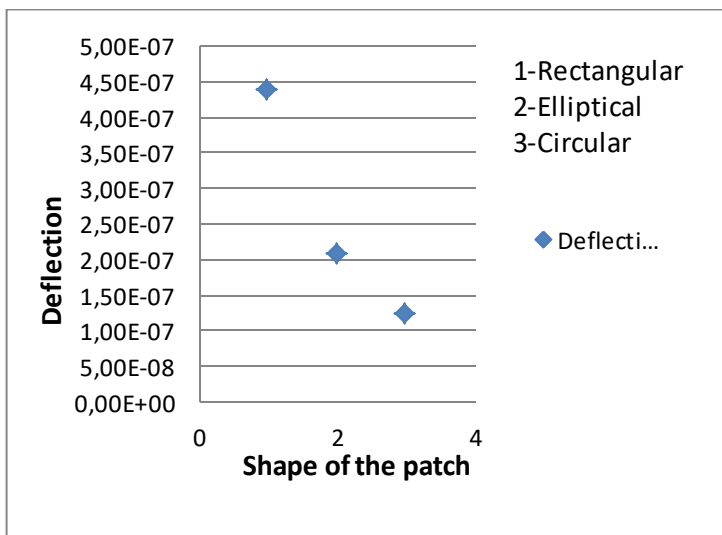


Figure 4

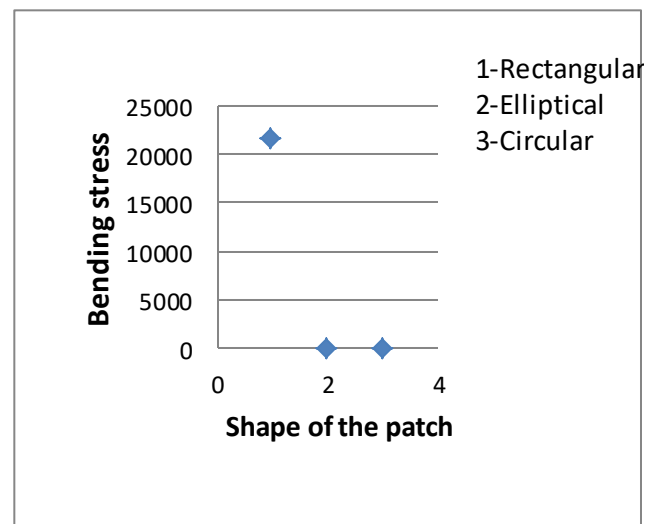


Figure 5

From the above fig 4and fig5 we conclude that the effective shape of the piezoelectric patch is rectangle. Finally, the shapeof the piezoelectric patch is the rectangle with dimensions of length=80microns, width=50microns, thickness=2microns.

Modal analysis:

FEA is done out by element modelling software to obtain solution to a wide variety of problems. Problems of FE analysis of nonlinear heat transfer and By using ANSYS Workbench modeler the solution is obtained. Following are the steps Modal analysis is the study of the frequency response of the structures under varying the lengths and diameters. In structural mechanics is to determine the natural frequency of a object or structure during different lengths and diameters. It is common to use the finite element method the types of equations which arise from modal analysis.

s.no	Natural frequency of full-length patch	Natural frequency of optimized patch
1	16.800	0.54590
2	71.890	2.27891
3	75.841	2.65180
4	76.457	3.3736
5	77.0042	8.172

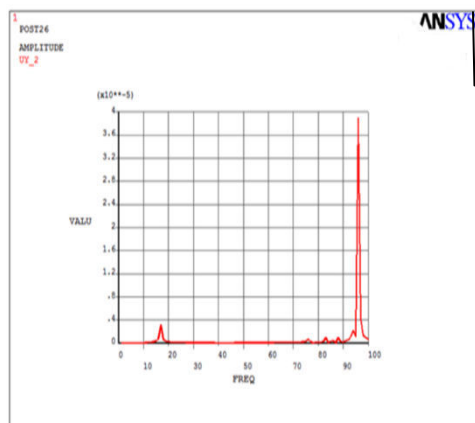


The above tables shows that the natural frequencies of the micro cantilever beam with optimized patch is less compared to the natural frequencies of the micro cantilever beam with full length patch. The beam with optimized patch is very sensitive, so we use the full-length patch. The dimensions of the piezoelectric patch is Length =200microns, Width=50microns, Thickness=2microns

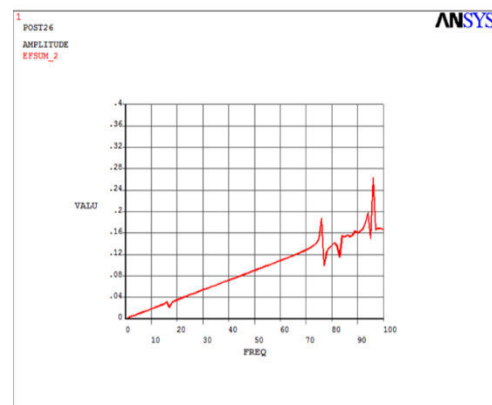
Harmonic and transient analysis:

Harmonic analysis is to find out the deflections of a cantilever beam at the natural frequencies of the beam. In harmonic analysis we apply the load at the end of the micro cantilever beam, we obtain the deflections. Transient dynamic analysis is a technique which is used to determine the dynamic response of a structure under a time-varying load. Sensor converts the mechanical force into the electrical voltage. In this we apply the force of $1e-4N$ at the free end of the micro cantilever beam. We obtain voltage as an output from that we also obtain the graph between time and deflection.

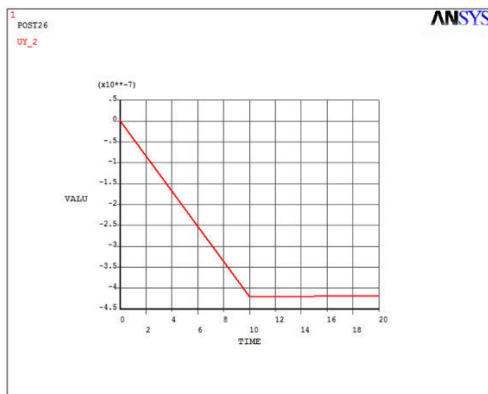
Actuator converts the electric voltage into the mechanical deflection. In transient analysis we apply the displacement of 1mm at free end of the cantilever beam after 10 seconds we apply voltage 10V on top surface of the piezoelectric patch and 0V on the bottom surface of the piezoelectric patch after 20 secondstime. We obtain the graph between frequency and displacement. Fig(a) represents the graph plotted between frequency and deflection and (b) represents frequency and voltage (c) represents the graph plotted between time and fig (d) represents deflection and time and voltage.



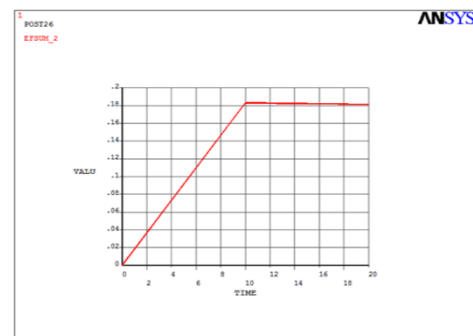
(a)



(b)



(c)



(d)

IV. CONCLUSION

Based on the analysis the we have given the following conclusions are the present work deals with the suppression of vibrations by using active vibration control technique in micro cantilever beam which is laminated with one pair of piezo electric patches on top and bottom surfaces from this the optimal location, geometry (shape and size) of the piezoelectric patch was found by taking into the consideration on the clamping area.

- a) Location of the patch (at fixed end of beam)
- b) Shape of patch (rectangular patch)
- c) Geometry of patch (length=80 microns, width=50 microns, thickness=2 microns)
- d) compare results with theoretical values

By clamping the piezoelectric patch at maximum value of shear force obtaining area the vibration the fixed beam is minimized and the deflection of the beam is also reduced to some extent. And finally, it is very suitable methodology for controlling the vibrations in ships, submarines, naval vessels. Due to the patching of piezoelectric material the out coming vibrating signals can easily detected, whenever enemies attacking upon us, we can easily escape from them because of getting vibrating signals. By clamping the piezoelectric patch, the induced shear stresses and the bending stresses increased with respect to load variations. Active vibration controlling mechanism is very useful to security regions in naval ships and submarines.

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