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Reduction in Amplitude of Vibration using Piezoelectric Material Patch

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ABSTRACT: This paper presents a vibration reduction of a fixed free beam using smart material. The work aimed to reduce the amplitude of vibration of the beam. The Piezoelectric material patch is used to reduce the amplitude of vibration by supplying variable voltage. Rectangular beam modeled in fixed free configuration glued with piezoelectric material patch considered as a smart beam. The ANSYS software is used to derive the finite element model of a smart beam. The effects of position of a piezoelectric material patch on the aluminium beam at various locations are investigated to find optimal position using vibration analysis. The experimentation is carried out to verify the effectiveness of reduction in amplitude of vibration. The results show that as supplying voltage increases then the amplitude of vibration decreases.

Keywords: Amplitude, Natural Frequency, Piezoelectric Material, Vibration Control**.**

I. INTRODUCTION

Vibration is a physical phenomenon which oscillations occur about an equilibrium point and it also happens when the mechanical mechanism is moved intentionally and unintentionally. The unwanted vibration may cause damage to the structures or degradation to systems performance [1]. This vibration is a critical issue in present days. These vibrations can be controlled by two techniques, one is passive vibration control and another is active vibration control. The passive vibration techniques involve dynamic absorber or the damper or the neutralizer while the active vibration techniques involve distributed actuators and sensors along with some form of electronic control system, which specially aim to minimize the measured vibration levels. The drawbacks of passive techniques include: bulkiness and extra weight when being used for low frequency applications. The smart materials integrated with digital signal processing techniques may overcome these drawbacks. Many types of smart materials are finely accepted for actuation and sensation devices including shape memory alloy, electro-strictive, magneto-strictive, electro-rheological, magneto-rheological and piezoelectric materials. In general electro-strictive materials have low saturation strain and force generation, and large percentage of loss of strain unless operated under a very small thermal range. Among the many smart materials, piezoelectric and shape memory alloys are most comfortable for active control of smart flexible structures. They are able to produce a relatively large deflection. The drawbacks of shape memory alloy based actuators have slow response time as compared to piezoelectric material patch [2]. The piezoelectric materials integrated with digital signal processing techniques may overcome these drawbacks. Therefore, a sensible structure has four major components: the structure, sensor, actuator, and controller. Actuators and sensors are widely used in various applications and are generally integrated with main structures via surface bonding or embedding [3]. The design, characterization and testing of piezoelectric actuator for vibration control applications has been presented by Yuvaraja and Senthilkumar (2013) [4]. The theoretical model for the optimal placement of piezoelectric plates to control the multimode vibrations of a cantilever beam has been proposed and validated numerically [5]. Vibration suppression of some structures like beams with particular stress laid upon smart structures with piezoelectric control actuation presented by Song *et al*., (2006) [6]. An active vibration control setup has been prepared for smart beam with piezoelectric actuator and PVDF sensor using dSPACE controller [7]. Li *et al.,* (2011) designed relative circuits of piezoelectric ceramics and experimentally tested the feasibility of platform and the correctness of driving circuits [8]. Riessom *et al*., developed a mathematical model to predict the dynamic nature of a smart beam using system identification technique. They have used same model design and simulate displacement feedback control law without any physical displacement sensor [9]. The proposed work is to find the effect of position of piezoelectric material over the structure considered as fixed free beam using vibration analysis. Also to study the effect of variable supplied voltage to piezoelectric material for vibration reduction using frequency response analysis.

II. VIBRATION ANALYSIS ON FIXED FREE BEAM

The Euler-Bernoulli beam theory is used to obtain values for natural frequencies. It is assumed that the beam is homogeneous and constructed from a material, which essentially satisfies the Euler-Bernoulli theory for displacement. Analytically the natural frequency of the beam with fixed free boundary condition can be determined by using,

$$\omega = (\beta l)^2\sqrt{EI/\rho AL^4} \quad \text{in rad/sec}^2 \qquad (1)$$

Where A and L are cross-sectional area and the length of the flexible beam, respectively. βl is a constant relative to the vibration boundary condition. The constant βl for the first four modes of a fixed free configuration are 1.87504, 4.69049, 7.85475 and 10.99554 respectively. EI is the corresponding bending stiffness. The modal analysis is carried out using finite element software ANSYS for natural frequencies and mode shapes of the beam. The first four mode shapes of the fixed free aluminium beam without piezoelectric material patch are shown in Figs. 1-4.

Table 1: Material Properties and Dimensions of Aluminium Beam and Piezoelectric Material.

Material	Aluminium	Piezoelectric Material Patch
Length	550 mm	68 mm
Width	38 mm	37 mm
Thickness	3 mm	0.2 mm
Young's Modulus	70 GPa	76 Gpa
Density	2700Kg/m^3	7800 Kg/m^3

Table 2: First Four Natural Frequencies of Fixed Free Aluminium Beam.

Mode	*f* (Theoretical) Hz	*f* (ANSYS) Hz	*f* (Experimental) Hz
1	8.315	8.195	9.160
2	51.205	51.357	52.180
3	143.452	143.833	148.550
4	281.166	282.268	290.090

III. EFFECT OF POSITION OF PIEZOELECTRIC MATERIAL PATCH ON BEAM

The aluminium beam is divided in to four equal segments and these are measured from fixed end. The first location is nearer to fixed end had high stiffness while the fourth location is nearer to free end had low stiffness. The beam and piezoelectric material patch were modeled in ANSYS. SOLID45 and SOLID5 element types are used for aluminium beam and piezoelectric material patch respectively. The ANSYS models of beam with piezoelectric material patches at various locations are shown in Fig. 5. The mass and stiffness of beam gets slightly increased due addition of piezoelectric material patch and therefore the natural frequency of the beam is also gets increased. Modal analysis is carried out using ANSYS to find the effect of position of piezoelectric material patch on natural frequency.

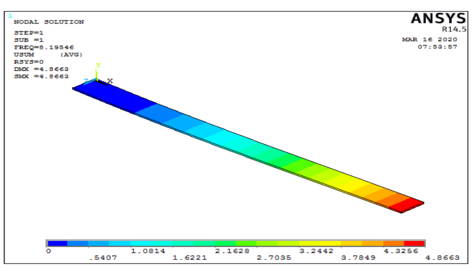


Fig. 1. First Mode Shape of Fixed Free Aluminium Beam.

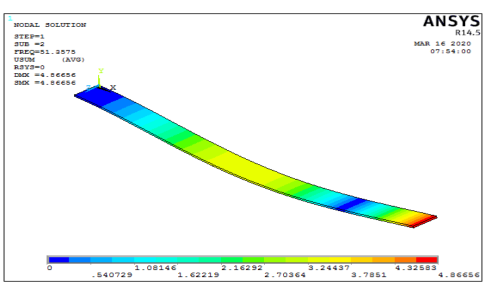


Fig. 2. Second Mode Shape of Fixed Free Aluminium Beam.

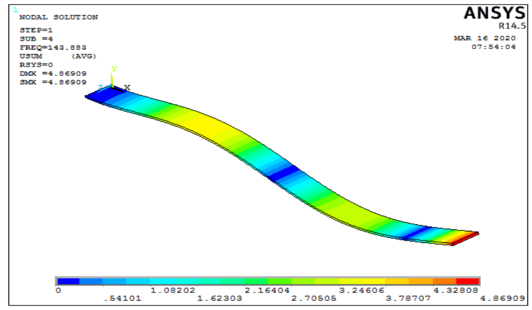


Fig. 3. Third Mode Shape of Fixed Free Aluminium Beam.

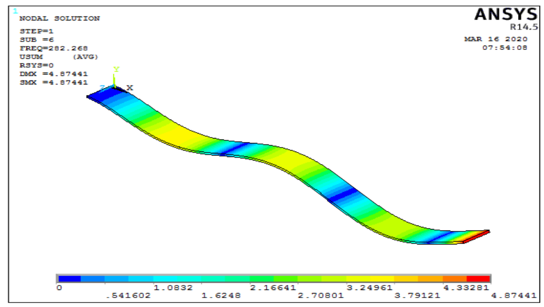


Fig. 4. Fourth Mode Shape of Fixed Free Aluminium Beam.

Harmonic response analysis is carried out to find the effect of piezoelectric material patch on amplitude of vibration. In harmonic response analysis the piezoelectric material patch was placed near fixed end of beam with variable supplied voltage range from 0V, 3V, 6V, 9V and 12V. Total 100 sub steps are used in load steps frequency (0 Hz to 500 Hz) with 1N load at edge of free end. The amplitude of vibration for fundamental mode is measured at tip of the beam. From the harmonic response analysis it is cleared that the amplitude of vibration of the beam reduces when supplied voltage increases.

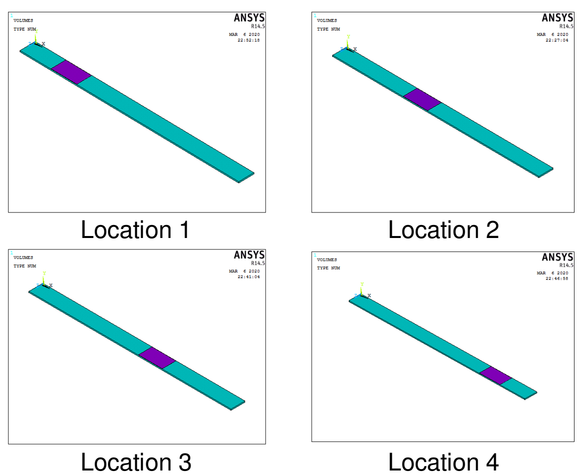


Fig. 5. Various Locations of Piezoelectric Material Patch on the Beam.

IV. EXPERIMENTAL APPROACH

The experimentation is carried out to verify the effectiveness of reduction in amplitude of vibration. The experimental setup is shown in Fig. 6.

The setup consists of the following four main parts: (i) externally glued piezoelectric material patch on beam and fixture table (ii) Data Acquisition System interference with laptop iii) Piezoelectric shaker system iv) Laptop with interfaced DASYLab software to process the measured signal. The vibrations are picked up using an acceleration sensor pickup. A fixed free aluminium beam considered in this study which is fixed horizontally along its width. The material properties and dimensions of aluminium beam and piezoelectric material are listed in Table 1. The piezoelectric material patch was procured from Longzhichuang Co. Ltd., China. Using the experimental setup as described the beam was vibrated using piezoelectric shaker. The piezoelectric material patch was glued on beam at a various locations measuring from fixed end using fevitite fast solution.
The one end of the beam was fixed in the fixture at preferred height. The acceleration sensor was placed nearer to edge of free end of the beam for sensing the amplitude of vibration in that position. The piezoelectric material patch was activated using DC power supply because of limitation in power supply due to size and weight constraints.

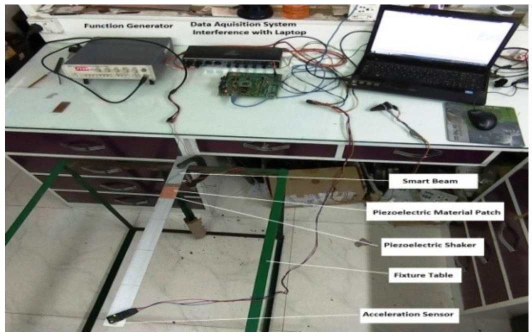
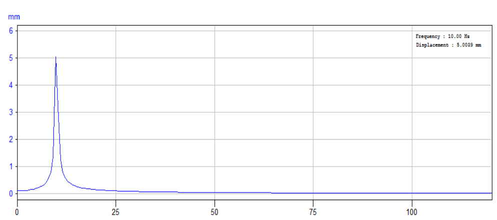


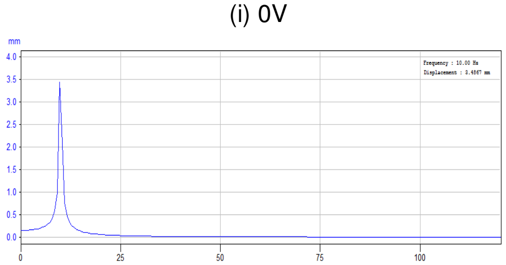
Fig. 6. Experimental Setup.

Table 3: Natural frequencies in Hz Various Locations of Piezoelectric Material Patch on the Beam.

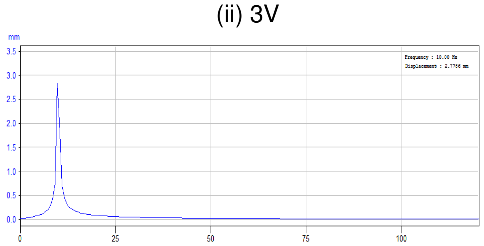
Modes	**Location of Piezoelectric Material Patch (centre point from fixed end) in mm**							
	Location 1 (110mm)		**Location 2 (220mm)**		**Location 3 (330mm)**		**Location 4 (440mm)**	
	f_{Ansys} **Hz**	$f_{Expt.}$ **Hz**	f_{Ansys} **Hz**	$f_{Expt.}$ **Hz**	f_{Ansys} **Hz**	$f_{Expt.}$ **Hz**	f_{Ansys} **Hz**	$f_{Expt.}$ **Hz**
Mode 1	8.67	8.86	8.33	8.69	8.16	8.35	8.02	8.16
Mode 2	51.31	52.88	52.16	52.18	53.21	55.23	52.04	55.69
Mode 3	144.51	151.23	145.52	147.88	147.23	154.05	151.20	152.29
Mode 4	288.57	291.99	284.47	293.06	285.37	291.47	304.83	320.95



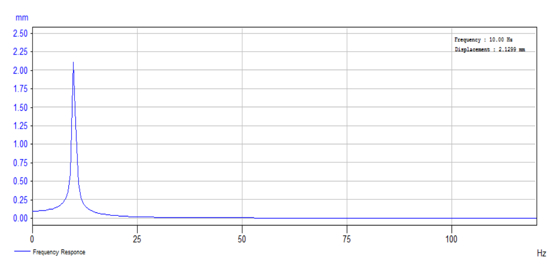
(i) 0V



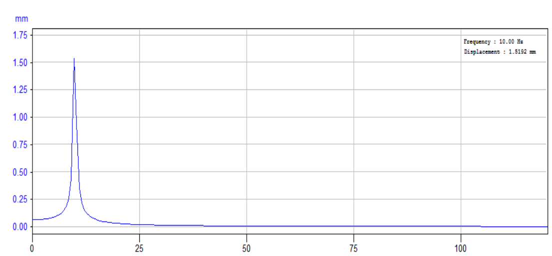
(ii) 3V



(iii) 6V



(iv) 9V



(v) 12V

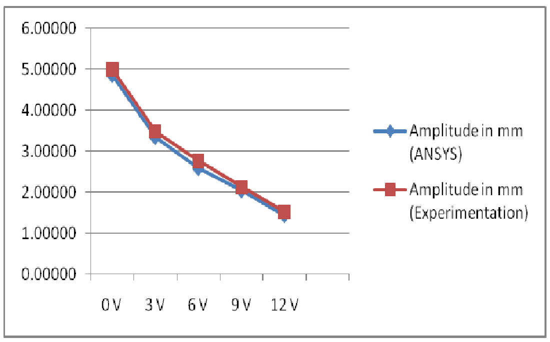
Fig. 7. (i) – (v) Amplitude of Vibration Responses with Variable Supplied Voltage.

The voltage supplied to the piezoelectric material patch was varied in the range from 0V, 3V, 6V, 9V and 12V and the amplitude of vibration values for respective supplied voltage was found out.

V. RESULT AND DISCUSSION

The position of the piezoelectric material patch has a significant effect on the natural frequency of the beam. The piezoelectric material patch was shifted from fixed end to free end of the beam. Total of four equal locations are considered for this study. For every location of the patch, the first four modal natural frequencies are calculated using free vibration analysis and it is listed in Table 3. From the results, it is clear that the natural frequency is higher when the piezoelectric material patch is glued near fixed end. It is also shown that the natural frequencies obtained from numerically are closely mapped with experimental results. From the harmonic response analysis, it is seen that the range of supplied voltage increases then the amplitude of vibration decreases. The graphs are shown in Fig. 7. Graph 1 show that the amplitude of vibration for 1st mode with variable supplied voltage has been reduced by about 69.62%.

Graph 1: Amplitude of Vibration for 1st Mode with Variable Supplied Voltage.



VI. CONCLUSION

The application of piezoelectric material in vibration control has been presented in this study. The piezoelectric material will control the system in terms of reducing the amplitude of vibration to improve the efficiency of the system. In this study, it is found that the piezoelectric material is can be used for vibration suppression. The amplitude of vibration is decreased by increasing the supplied voltage to the piezoelectric patch. The optimal position for the piezoelectric patch was found using vibration analysis. From these analyses, it is clear that the patch plays an effective role when it is placed near the fixed end. Thus the amplitude of vibration was reduced by supplying various voltages to piezoelectric material patch.

VII. FUTURE SCOPE

Modeling of other smart actuators and sensors such as Fiber Optics and Photostrictive Optical Actuators would be appropriate for the continuation of this work to improve active control systems and to extend them to more complex smart structures.

Conflict of Interest. There is no conflict of interest for any of the authors in this paper.

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