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Design and Analysis of Active Piezoelectric Vibration Absorber

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***Abstract*—Vibration control of cantilever beam using piezoelectric patches is carried out in this paper. Active vibration control for any structure can be carried out for reducing or controlling undesired vibrations in structures such as satellite, automobiles, space aircraft structures which are particularly used in low frequency regions. In this paper we was used two piezoelectric patches out of that one works as a sensor & other works as a actuator. The property of piezoelectric patches is that whenever they are embedded in a structure they are electromagnetically coupled with structure because of that a piezoelectric effect is produced i.e. (electric charge) due to that they are developed mechanical stresses in the structure & vice versa. In this paper Theoretical and experimental study on Active vibration control of Cantilever beam have been presented.**

***Keywords*—Steel beam, MATLAB, Piezoelectric Patches, ANSYS 14.5, Electrical control System etc.**

I. Introduction

Vibration is occurred in many engineering structures and component they are acceptable up to a certain limit, if the level of vibration exceeds beyond a certain limit they reduces life of equipment or structure, sometimes it causes failure of component. Thus to avoid this, vibration in the structure can be control by converting this vibration energy which is to be in the physical form into another energy. There are three types of converting principles i.e. Electrostatic, Electromagnetic and Piezoelectric. Out of that we are using piezoelectric principle for converting vibration energy which is to be in the physical energy into a low power electrical energy. Because the property of piezoelectric material is that it can be convert a physical energy into electrical energy and vice versa. There are basically two techniques are used for controlling vibration i.e. passive vibration control and active vibration control. In passive vibration control spring, mass, dampers, pads etc. have been used in previous years for controlling vibration in present structure. But they have certain limitations i.e. it is more versatile technique and can be used for frequency within a particular range of bandwidth. Hence there is need for developing active vibration control technique. In Active vibration control the vibration of structure is reduced or controlled by applying out of phase load which is equal in magnitude but in opposite direction of present original vibration. As a result two forces having equal magnitude and Applied at opposite direction to each other hence opposite forces are canceled each other and structure stops vibrating.

II. Liturature Review

A Shiraji use a fuzzy logic controller system in Active Vibration Control of a simply supported rectangular plate. The result obtained from this fuzzy logic controller shows good agreement with PID controller result and the natural frequency of rectangular plate is obtained by double Fourier series method (1).

A Waghulde and Bimlesh Kumar Uses a LQR controller for Active Vibration control of cantilever beam. In this Paper the effect of actuator placement on controlling the vibration of beam and beam was tested for experimental and numerical simulations. By using LQR controller, it shows good experimental results and finds suitable control methodology by which optimum controller gain is achieved to get more effective vibration control with minimum control input (2).

A Khot and Yelve use a PID controller with LAB VIEW software for generating required control signal. In this experiment is carried out for reducing a settling time and controlling a vibration in beam and experimental results are verified with simulation results from Matlab (3).

Tushar Choudhary and Mukesh Kumar Sahu gives a Active vibration control of a cantilever beam. In experimental process the voltage generated by piezoelectric patch was obtained in variation with input frequency of beam and finding out mode shapes of beam at different frequencies in ANSYS. Vibration Control of beam was achieved by feeding voltage response of sensor to suitable control system and optimum control of vibration of beam structure is achieved by generating controlled output through actuator (4).

A Sanjay Narayankar was developed Active Vibration control technique for a cantilever beam by using open loop control system with FFT analyzer.The experimental results are carried out for cantilever beam which is excited at one of its natural frequency. Then experimental results from FFT analyzer are well compared with results which are obtained from ANSYS (5)

III. Objectives

The objectives of Active Piezoelectric Vibration Absorber are as follows:

- To determine optimal location of Sensor and actuator patch.
- To determine natural frequency of beam theoretically and

validate with ANSYS natural frequency.

- To determine mode shapes of cantilever beam theoretically using MAT LAB and by ANSYS Software.

IV. Optimal Location of Piezoelectric Patch

For active vibration control using piezoelectric actuators, suitable size and appropriate location of actuators is important aspect for suppressing vibration in cantilever beam. The optimal position for actuator/sensor is extracted from the strain curve for each mode and sum of strain curve respectively. The strain curve for each mode and sum of strain curve are plotted in MATLAB© by using strain equation and sum of strain equation respectively, which are shown in fig.

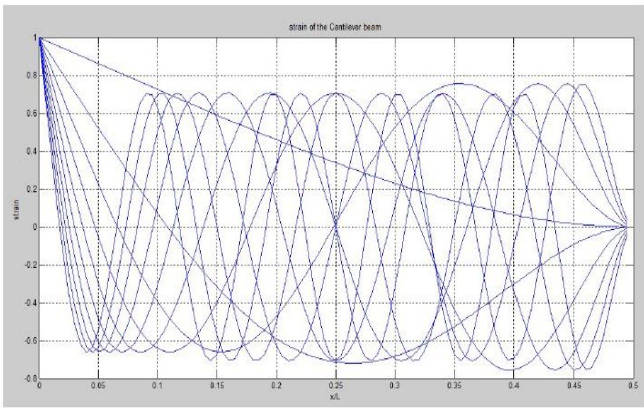


Fig. 1 Strain curve along length of beam.

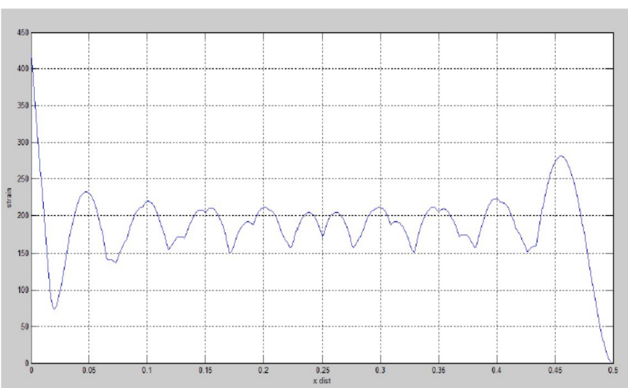


Fig 2 Sum of Strain curve

V. Numerical and FEA Modeling of Beam in Ansys

For beam which is elastic in nature having uniform cross-section area, the natural frequency can be obtained by using Euler's Bernoulli's Theory

$$\omega_i = (\beta_i L)^2 \sqrt{\frac{EI}{\rho A L^4}} \quad (1)$$

Where,

ω_i = Natural frequency of beam in HZ

L = Length of beam in m

E= Young's modulus of beam in N/m2

I= Moment of inertia in m4

A= cross-section Area of beam in m2

ρ = Density of material of beam kg/m3

$$\beta_n L = \frac{(2n-1)\pi}{2} \quad (2)$$

Where, n= 1, 2, 3, 4..........∞

$\beta_1 L = 1.875$

$\beta_2 L = 4.690$

$\beta_3 L = 7.8556$

Here $\beta_n L$ is constant, the constant $\beta_n L$ for first three mode of natural frequency of cantilever beam are 1.875, 4.690, 7.8556 respectively.

Beam Parameters

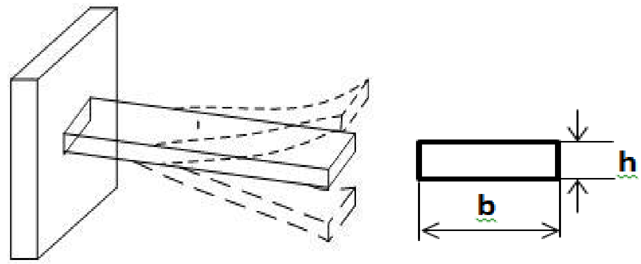


Fig. 3 Schematic of cantilever beam

Length of beam, L= 0.31 m

Width of beam, b = 0.015 m

Height of Beam, h = 0.001 m

Young's Modulus of beam material=200Gpa

ρ = Density of material of beam 8000 kg/m3

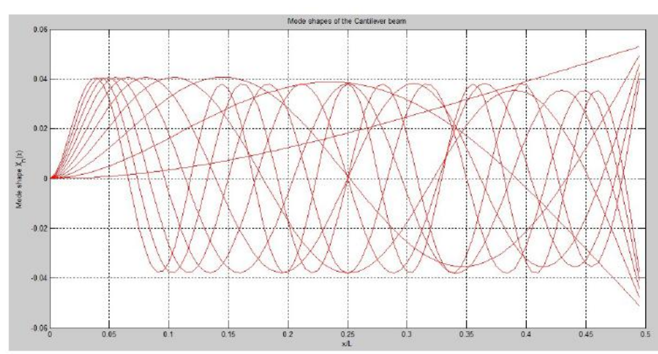
υ = poison's ratio = 0.3

I= Moment of inertia in m4

By using above equation we extracting first few natural frequency. Following table shows natural frequency of beam for first three modes of vibration of beam and mode shape of cantilever beam is determined following equation

$$W_i(x) = C_n[\sin\beta_i x - \sinh\beta_i x - \alpha_i(\cos\beta_i x - \cosh\beta_i x)] \quad \textbf{(3)}$$

The first equation gives the natural frequency value in rad/sec and third equation gives mode shapes respectively. A MATLAB code is written to extract n number of natural frequency (in rad/sec & Hz) and to plot mode shape by using Eq. (1) and Eq. (3) respectively. The mode shape plot for first 10 modes is shown in following fig.



Fig, 4: Firest 10 modes shapes of cantilever beam

Following fig. () Shows first few natural frequencies of beams in ANSYS.

TABLE I: NATURAL FREQUENCY OF BEAM FOR FIRST SIX MODES OF VIBRATION

n	$\beta_n L$	frequency **(rad/sec)**	frequency (Hz)
1	1.8751	0.05293	8.442
2	4.6059	0.3592	57.163
3	7.8539	0.8409	133.83
4	11	0.9975	158.76
5	14.1372	1.9976	317.92
6	17.2787	2.1937	349.13

In FEA analysis of cantilever beam a solid model of beam is generated as per dimensions and determining mode shape of cantilever beam for each mode of vibration and comparing hese results with Analytical results.
In following fig shows a mode shape of cantilever beam for first four modes.

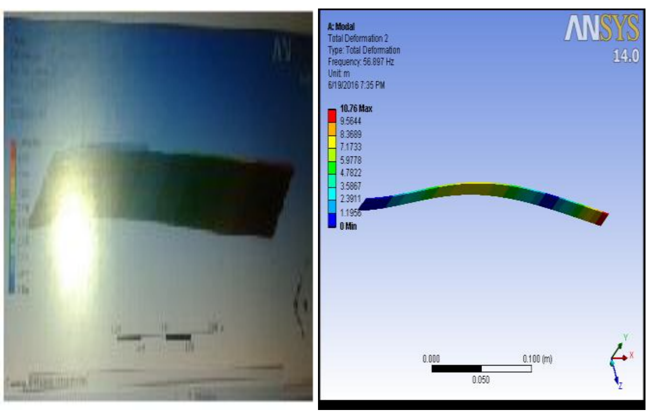


Fig.5 Mode Shape of Cantilever Beam for First and second mode

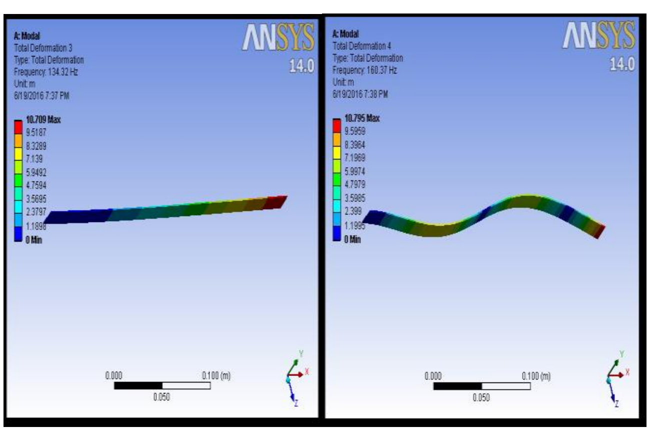


Fig.6 Mode Shape of Cantilever Beam for Third and Fourth mode

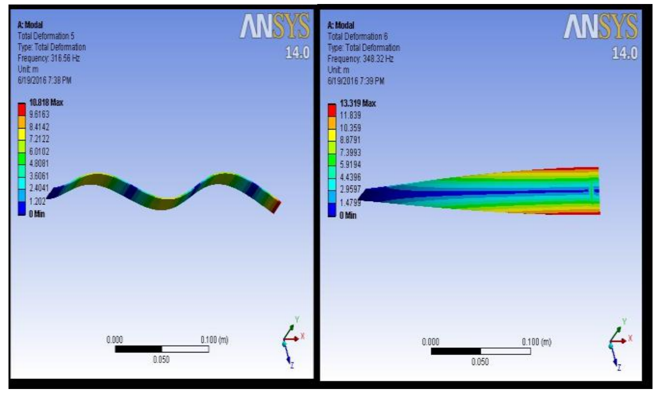


Fig.7 Mode Shape of Cantilever Beam for Fifth and Sixth mode

We also get various mode shapes for a natural frequency of beam. We were comparing this frequency with the theoretical frequency.
Following table shows the comparison between analytical and FEA natural frequency.

TABLE II: COMPARISON BETWEEN ANALYTICAl AND FEA NATURAL FREQUENCY OF BEAM

n	$\beta_n L$	frequency (Analytical)	Frequency (FEA)
1	1.8751	8.42	9.1298
2	4.6059	57.163	56.897
3	7.8539	133.83	134.32
4	11	158.76	160.37
5	14.1372	317.92	316.56
6	17.2787	349.13	348.32

VI. EXPERIMENTAL SETUP

Following are the various equipment's which are to be required for Experimental setup of Active Piezoelectric Vibration Absorber.

Steel Beam: This is the object on which experiment is done and our finding will be based. It is a simple beam which is to be made up of a material stainless steel with density 8000Kg/m3 and a dimension of beam is (0.31×0.015×0.001) m. The beam which is fixed at one end and other end is free .

Sensor Patch: Sensor Patch which is made up of piezoelectric material which is attached nearer to the fixed end of a beam. It is responsible for sensing stresses produced in the beam and generating proportional voltage, the current produced is called as piezoelectric current. The main function of sensor patch is vibration produced in the cantilever beam which is to be in the physical energy converting into a low power electrical energy.

Actuator Patch: When we feed certain amount of voltage to the actuator then it produces a opposite effect and acts as a actuator, this voltage comes from the electrical control circuit which gets the input low power electrical energy from the sensor. Actuator is used to produce mechanical stresses in the beam which is also made up of a piezoelectric material. For proper actuation in the beam, the actuator is located at near to the fixed end.

Set Table: In this project the nature of beam which is to be a cantilever beam and hence it is clamped at one end and mounting of electrical control System for that purpose set table is required.

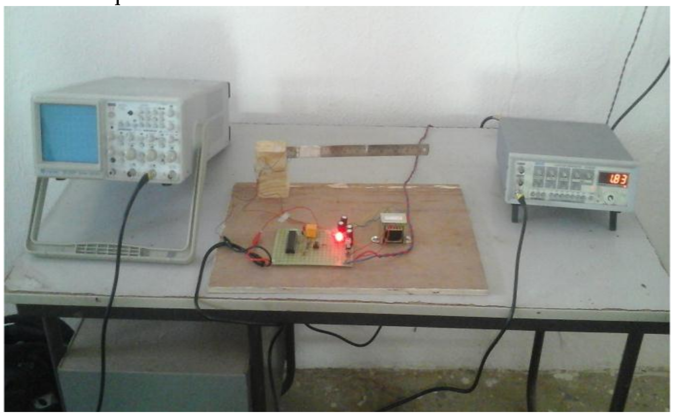


Fig. 8 Experimental Setup

Function Generator: The main function of function generator is to generate a similar kind of vibration in the beam and it is mainly gives function usually sinusoidal, square, or triangular waveform.

Oscilloscope: It is very important electronic device and its main function is to see pattern of the signal forming in the sensor and also we can measure various parameters using the oscilloscope such as voltage, gain etc.

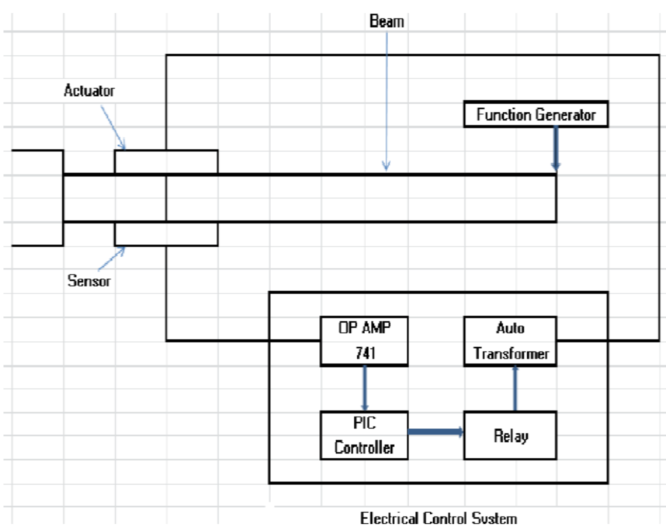


Fig. 9 Experimental Layout

Electrical control system: The output of sensor patch is given to the PIC microcontroller through OP AMP. Because the output of sensor patch was in millivolts (mv). Thus for amplification i.e. converting signal from millivolts to volts OP AMP is used. Then this signal is fed to the 18F4520 PIC controller. The function of this controller is switching operation of relay switch according voltage signal received from Sensor patch through OP AMP. The output of relay switch is given to the Step down Transformer. According to specification of piezoelectric patch, the patch is vibrating in the range between 50-80 Volts a.c. supply. Thus the auto transformer is used having capacity of step down voltage from 230V to 12 Volts which is sets at 70 volts a.c. supply. Thus the output of auto transformer is given to the actuator patch which vibrates and controls the vibration in beam structure. The actuator patch was stops vibrating when the relay switch is get open circuited because when beam stops vibrating which is sense by sensor the output of OP AMP was 0 volts and hence controller output was switch of the relay.

VII. Results and Discussions

The electrical signal generated by piezoelectric patches was monitored in the oscilloscope and all the parameters are recorded. In this project we are only considering maximum voltage generated by sensor. So we will concentrate our finding on the same and plot graph with gathered data. For that purpose we was varying input frequency from function generator and taking observation of reading of maximum voltage and amplitude of voltage signal for this various frequency and Showing the signal pattern formed by various frequencies.

- Frequency: 12.5 Hz

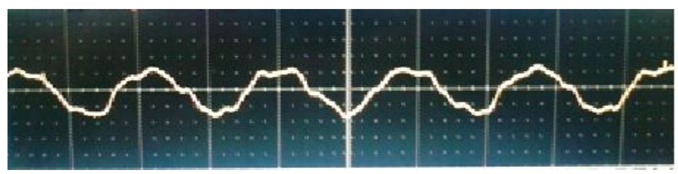


Fig. 10 showing the signal **pattern formed by input frequency 12.5** Hz

By applying the frequency of 12.5 Hz the maximum voltage generated by piezoelectric patch is 1.30V and maximum amplitude of voltage signal is 2.31V.

- Frequency: 15 Hz

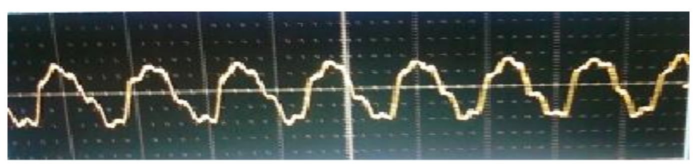


Fig.11 Showing the signal pattern formed by input frequency 15 Hz

By applying the frequency of 12.5 Hz the maximum voltage generated by piezoelectric patch is 1.72V and maximum amplitude of voltage signal is 2.58V.

- Frequency: 17.5 Hz

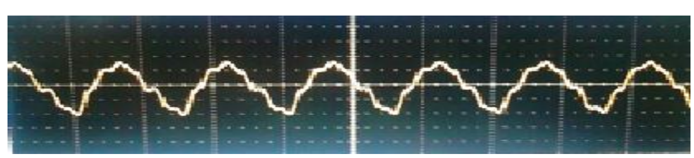


Fig. 12 showing the signal pattern formed by input frequency 17.5 Hz

By applying the frequency of 17.5 Hz the maximum voltage generated by piezoelectric patch is 2.38V and maximum amplitude of voltage signal is 3.47V.

- Frequency: 20 Hz

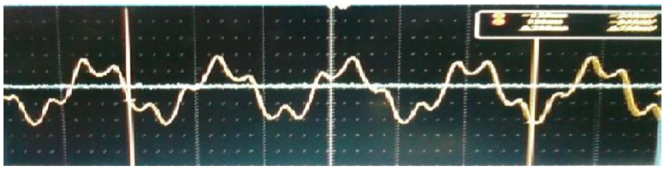


Fig. 13 Showing the signal pattern formed by input Frequency 20 Hz

By applying the frequency of 20Hz the maximum voltage generated by piezoelectric patch is 2.73V and maximum amplitude of voltage signal is 2.88V.

- Frequency: 22.5 Hz

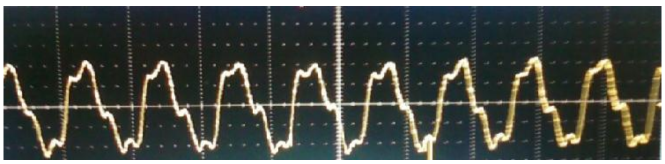


Fig. 14 showing the signal pattern formed by input Frequency 22.5 Hz

By applying the frequency of 22.5Hz the maximum voltage generated by piezoelectric patch is 5.22V and maximum amplitude of voltage signal is 9.15V.

Tabulating above values of maximum voltage and amplitude of voltage with various frequencies in following Table and plot a graph of Maximum voltage verses Frequency and Amplitude of Voltage Signal Verses Frequency.

TABLE III: MAXIMUM VOLTAGE AND AMLITUDE OF VOLTAGE SIGNAL FOR VARIOUS FREQUENCIES

Frequency (Hz)	12.5	15	17.5	20	22.5
Maximum Voltage	1.30	1.72	2.38	2.73	5.22
Amplitude of Voltage Signal	2.31	2.58	3.47	4.13	9.15

In this Paper we obtained values of maximum Voltage and amplitude of voltage signal with various frequencies then we plot a graph for maximum Voltage verses input frequency and Amplitude of voltage signal verses input frequency. The various input frequency are 12.5, 15, 17.5, 20, and 22.5. According to graph shown in figure (14) we can say that as frequency of vibration of beam increases then voltage generated by piezoelectric patch is also increases. According to graph shown in figure (15) it shoes increasing trend i.e. frequency of vibration of beam increases amplitude of vibration obtained is greater.

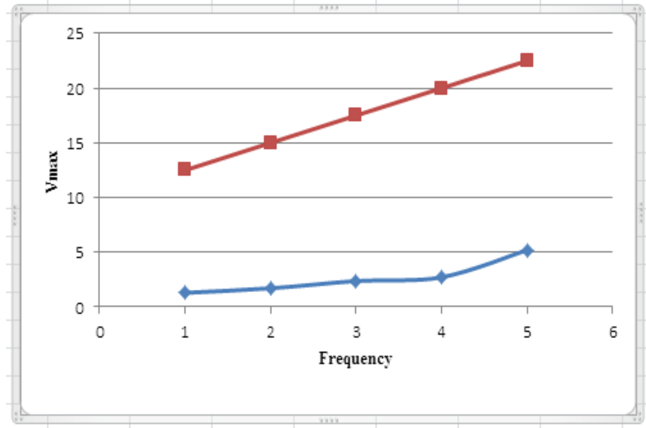


Fig.15 Shows the Graph between the frequency verses maximum voltage

Following fig shows the variation of amplitude of voltage signal with input frequency.

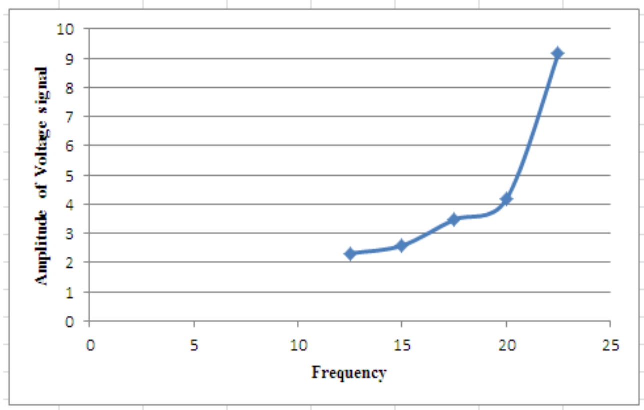


Fig. 16 Shows the Graph between the frequency verses Amplitude of voltage Signal

VII. CONCLUSIONS

From experimental process the Voltage generated by piezoelectric Patch is obtained with variation of frequency input. It is concluded that if we provided a sinusoidal waveform from function generator with increase in frequency the voltage generated by piezoelectric patch also increases. As we feed this voltage signal of sensor to the electrical circuit with micro controller we generate a controlled output through the actuator that can be used to control the vibration produced in cantilever beam.

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