Active Vibration Analysis of Piezo-Laminated Cantilever Beam

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Abstract— In active vibration control the vibration of a structure is reduced by using opposite directional force to the structure. Now a day's active vibration control is frequently being used in aircraft, submarine, automobile, helicopter blade, naval vessel. In this paper a smart plate (aluminum plate) with one pair of piezoelectric lamination is used to study the active vibration control. The smart plate consists of rectangular aluminum beam modeled in cantilever configuration with surface bonded piezoelectric patches. The study uses ANSYS 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 experiment we find a suitable control methodology by which we optimize the controller gain to get more effective vibration control with minimum control input.

Index Terms— Active Vibration, Control, Piezoelectric, actuators, Sensors, FEM, Aluminium Beam,

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1 INTRODUCTION

Active vibration control is defined as a technique in which the vibration of a structure is reduced or controlled by applying counter force to the structure that is appropriately out of phase but equal in amplitude to the original vibration. As a result two opposite force cancel each other and structure stops vibrating. Techniques like use of springs, pads, dampers, etc have been used previously to control vibration. These techniques are known as "Passive vibration control technique"[1]. They have limitations of versatility and can control the frequencies only within a particular rage of bandwidth hence there is a requirement for active vibration control. Active vibration control is a modern approach towards vibration control at various places; classic control techniques are becoming too big for modern machines where space is limited and regular maintenance is not possible and if possible, it's too expensive, at such conditions AVC techniques comes handy, it is very cheap requires no manual maintenance and the life expectancy is also much more then the passive controllers. Active vibration control makes use of smart structure [2]. The system mainly requires actuators, sensors, source of power and a compensator that performs well when vibration occurs. Smart structure are used in the bridges, trusses, buildings, mechanical systems etc. analysis of a basic structure can help in improving the performance of structure under poor working conditions involving beam vibrations.

The Major components are

1. Sensor patch- it is bonded to the host structure (beam). It is generally made up of piezoelectric crystals. It senses the disturbance of the beam and generates a charge which is directly proportionally to the strain. Direct piezoelectric is used.
2. Controller- the charge developed by the sensor is given to the controller, the controller lines are charged according to the suitable control gain and charge is fed to the actuator. Controller also forms the feedback functions for the system.
3. Actuator patch- the lined up charge from the controller is fed to the actuator causes pinching action (Or generates shear force) along the surface of the host which acts as a damping forces and helps in the alternating vibration motion of the beam. Converse piezoelectric is used.

The beam is clamped at one end using the set table hence making it a cantilever beam, the excitation is given from the other end, the free end using an exciter, excitation of which can be controlled using a function generator (Producing a wave form of sinusoidal, triangle, Square) and an amplifier. The excitation produces vibrations in the beam which results in the formation of shear stress in the beam, the sensor patch present at the fixed end acts to this shear stress and produces proportional electrical signals which is fed to the computer through the D/A system and finally from the computer the signal is fed to the actuator and it produces opposite shear in the beam and the entire beam is balanced. Active vibration control finds its application in all the modern day machines, Engineering structures, automobiles, gadgets, sports equipments, ceramics, electronics etc. As it needs only a little actuation voltage hence it does not requires any external power source, the power can be directly derived from the host machine itself. As the electronics is also developing at a very fast rate hence the size of a processor is also reducing, which is very useful in the design of the control system.

In this work a smart plate (aluminum plate) with one pair of piezoelectric lamination is used to study the active vibration control. The smart plate consists of rectangular aluminum beam modeled in cantilever configuration with surface bonded piezoelectric patches. The study uses ANSYS-12 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 experiment we find a suitable control methodology by which we optimize the controller gain to get more effective vibration control with minimum control input.

2 OBJECTIVE AND SCOPE OF THE WORK

The main objective of the work is given below.

1. To develop a suitable control methodology which optimizes the controller gain so that more effective vibration control can be achieved with minimum control input

2. To study the stability analysis for collocated and non-collocated optimal position of PZT sensor and actuator
3. To detect the damages such as debonding between substrate and piezo-patches delamination between the interfaces of substrate
4. To validate the numerical results with experimental work for real life application.

In spacecrafts, automobiles, helicopter, bridges, marine applications [3] we use active vibration control techniques as it can control the frequencies within a particular range of bandwidth. Working machinery is a major source of vibration in marine vessels and considerable effort is devoted in developing isolation system that reduces transmission to hull. This is partly for improving crew and passenger comfort, but in case of naval vessels it is primarily to reduce the associated acoustic signature and hence the vulnerability to detection by hostile sensors such as acoustic mines or passive sonar.

3 FINITE ELEMENT ENALYSIS BY USING ANSYS

In the theoretical analysis we used ANSYS software to derive the finite element model of the smart beam. From this analysis we can determine the optimal position and size of the actuator and sensor. We also determine the maximum admissible actuation voltage and the maximum deflection the beam. Based on this model the smart beam is produced and result of the smart beam is then used in the determination of the single input and single output system model. By this model a single input/single output controller is designed to suppress the vibrations due to the first two flexural modes of smart plate. At the initial stage of design, the finite element model is sufficient which allows determining the location, size of an actuator and its power requirement. In the modeling and analysis of piezoelectric crystal typical finite element used was (SOLID5), which has piezoelectric capacity in three dimensional couple field problem. Like other structural solid elements, this element has three displacement degrees of freedom per node. In addition to this degree of freedom the element has also potential degree for the analysis of the electromechanical coupling problems. Piezoelectric actuator inherently exhibits anisotropic and yield three-dimensional spatial vibration in their response to the piezoelectric actuation.

The models developed for the passive portion should include consistent degree of freedom at the location where these elements interface. For modeling the passive portion of the smart structure solid element used is (SOLID45). The passive portion is made of aluminum. In these modeling we could use shell element as (SHELL99) also. But experimental results shows that the hybrid solid -solid model yielded results are closer to the experimental values than hybrid shell-solid model. So solid –solid modeling is more precious. Young's modulus for the passive portion (Aluminum beam) is (E) =69GPa (69×109 N/m2). The poison's ratio of the beam is taken 0.33 and the density of the aluminum beam is 2710 Kg/m3. The damping coefficient of the aluminum was taken as 0.0004. The dimension of the passive part (aluminum beam) is (310×26×2.6) mm*mm*mm and dimensions of the PZT is (15×15×0.5) mm*mm*mm. In the modeling first the passive block was created and then the two patches were placed over it. The block is made of the material-1(SOLID45) and the two patches are of same material-2(SOLID5). Next the meshing is done on the two types of materials. Meshing is the process to divide the whole matrix in small-small parts. As a result we can get the exact amount of force, displacement etc. for each small part and the result become more accurate. As one portion of the beam remain fixed (there will be no displacement), we make that portions degree of freedom zero. Actually we arrest that portion. Then in the load step option we give the frequency in 100 substeps (0.0 Hz to 100.0 Hz). The damping constant ratio for aluminum is 0.0004. Next we apply a constant force of 9 N on the middle node of the cantilever edge. The direction of the force is positive Z direction. At the solution we find the result that the maximum displacement value 0.00273 m. The value of maximum shear stress is 0.260×108 N/m2 and it is acting on the node number 49. Figure 1 shows the PZT beam with loading condition, Figure 2 shows meshing of the PZT beam and Figure 3 shows deflected beam in ANSYS.

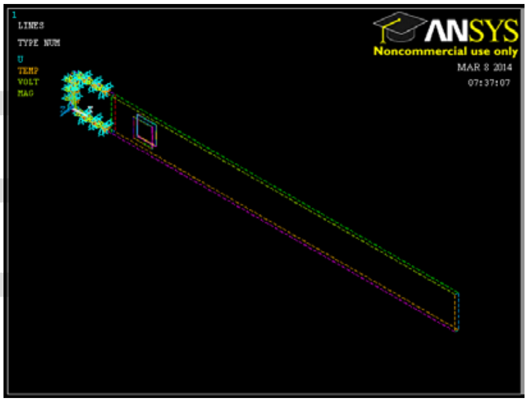


Fig. 1. Ansys model for piezoelectric beam

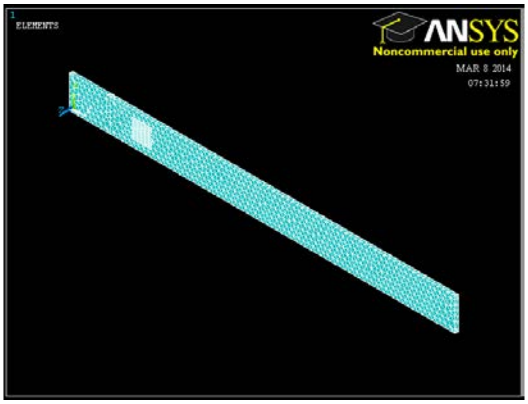


Fig. 2. Meshed model for piezoelectric beam

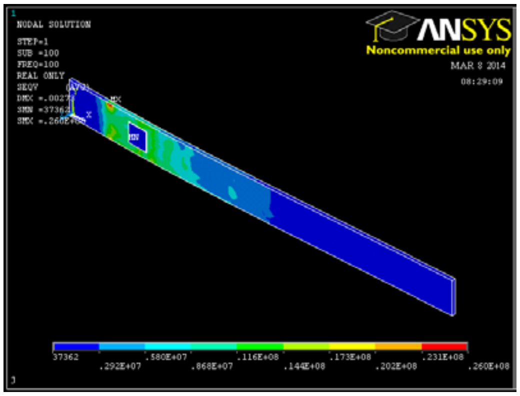


Fig. 3. Deflected model for piezoelectric beam

4 EXPERIMENTAL SETUP

The aluminum beam (substrate) is fixed at one end on the set table and other end is hanging freely hence is a cantilever beam, from the end we will give under control vibration and this is accomplished by using a exciter the function of the exciter is to produce under control vibration on the beam and the nature of the vibration will depend upon the input signal form the function generator, whatever will be the nature of the waveform similar kind of vibration will be produced in the beam, the function generator is used to generate the desired wave form which can be either of sinusoidal, triangle, Square the rang of the frequency can be adjusted and can be set anywhere between 1Hz to 1000 KHz but as our exciter has limitations so we can only set the frequency between 1Hz to 1Khz the frequency is high but the amplitude of the wave form is very low to produce any notable vibration in the beam hence an amplifier is used to amplify the signal the range of amplification can be varied using the knob provider at the amplifier but we should not amplify more than the safe limit of the exciter and also the quality of the vibration will be degraded and also the PZT patches may be damaged. Vibration produces deflection in the beam which is maximum at the free end, and to measure this deflection scanning laser Doppler vibrometer is used, it is very accurate and can record even the smallest deflection which is produced in the beam.

On doing the modeling of this experiment in ANSYS we computed the area of stress formation an interesting observation which was made was that the maximum stress which was developed in the beam was not where it was clamped, it was little away from it, hence we will attach our sensor and actuator here because the sensor will produce the correct voltage only here as the current developed is directly proportional to stress hence we will get the maximum current here. The actuator which is responsible to produce opposite stress in the beam is also located at the location of maximum stress formation so that it may control the vibration more efficiently. The signal which we get from the sensor is in electrical in nature and cannot be fed to the computer directly hence the signal has to be modified to be made compatible with our control system hence we use data acquisition system, this convert the signal from analog to digital as computer can only read and interpret digital signals so encryption satisfied that, now the signal is given to the computer system which is having a suitable software which facilitates in the manipulating and storing of the data's, also the health of the patches can be checked using this software. From the software the signal is fed to data acquisition system again to convert again to analog electrical signals and from here finally the signal is fed to the actuator which actuates a stress in the beam, to understand this effect we can take an example of sine wave which initiates form +1, this sine wave is the vibration induced in the beam by the exciter now to control this vibration the actuator have to actuate a signal which will be of the same magnitude but will be of opposite phase hence the actuator will actuate a wave which will start from -1 hence when both of this vibration meet with each other then the cancel out each other, which results in the damping of the beam. The whole process can be monitored in an oscilloscope which can be attached to the sensor and the actuator at the same time, the electrical signal produced by the sensor can be monitored in the oscilloscope and the pattern of wave formation can be noted down.

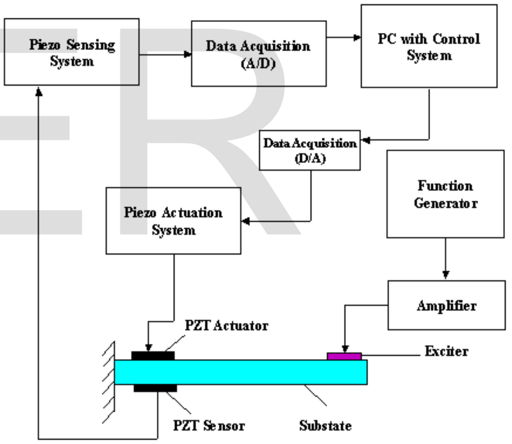


Fig. 4.Line diagram for experimental setup of piezoelectric beam

5 RESULTS

The electrical signal generated by the piezo electric patch due to the vibration was monitored in the oscilloscope and all the parameters were recorded, as in this experiment we are only concerned with the maximum voltage which is produced by the sensor so we will concentrate our findings on the same and plot the graph with the gathered data. Total we recorded 6 observations with frequency as a variant.
By applying the frequency range of 12.5 Hz to 22.5 Hz we get the data of the maximum voltage which the piezo electric material produces, the maximum amplitude of the signal, the peak to peak voltage and the RMS value of the voltage which are given in following table-1 and figures 5 and 6.

TABLE 1
OBSERVATIONS WITH FREQUENCY AS VARIENT

Frequency (Hz)	*Amplitude (V)*	*RMS (mV)*	*Voltage (V)*	*Mean (mV)*	*Area (mVs)*
12.5	*2.12*	*1.112*	*1.12*	*166.5*	*66.59*
15	*2.64*	*1.134*	*1.80*	*126.5*	*50.59*
17.5	*3.36*	*1.505*	*2.44*	*117.2*	*46.89*
20	*2.44*	*1.611*	*2.56*	*123.9*	*49.54*
22.5	*9.08*	*1.905*	*5.32*	*89.58*	*35.83*

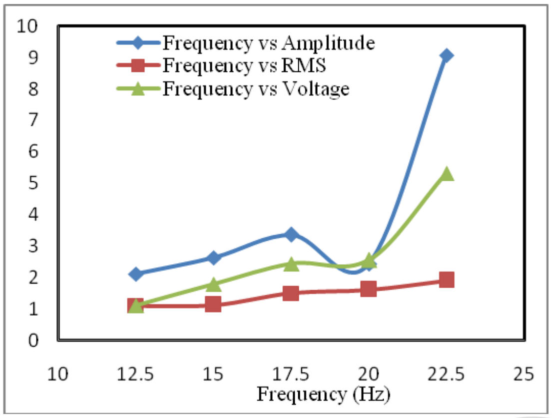
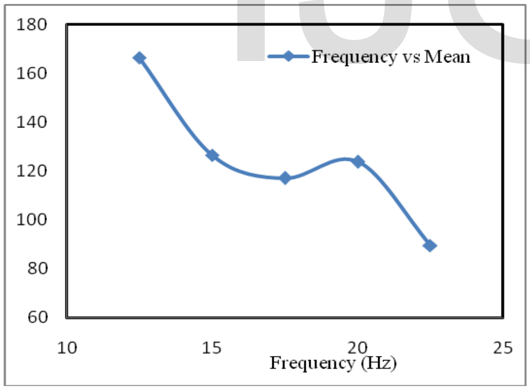


Fig. 5 Frequency Vs amplitude, RMS value and voltage



In this study, we control the vibration in an alumunium beam element by applying counterforce. In finite element modelling using ANSYS, the location of piezo sensor was first determined. In the modelling, cantilever alumunium beam was subjected to a constant force of 9 N at the free end. The beam was divided into 1320 nodes. On a frequency variation of 0-100 Hz in 100 sub-steps, the readings of shear stress and displacement at each node was recorded. For 100 Hz frequency, it was found that the minimum value of shear stress was minimum at node 49. The maximum deflection was 0.0273 m. At different frequencies the voltage generated by piezo-electric patch was observed and noted down. Chart 1 is a plot between the maximum voltage generated and frequency input for the set of observation. Frequencies used were 12.5 Hz, 15 Hz, 17.5 Hz, 20 Hz, 22.5 Hz and 25 Hz. The voltages generated were in the range of 1.7 V to 5.3 V. The graph obtained signifies that for increase in frequency input the maximum voltage value generated by the piezo-patch increases. Chart 2 is a plot between the mean voltage and frequency. For the same set of frequencies the mean voltage ranges were found to be between 90 to 170 mV. Here we obtain a decreasing trend. Chart 4 is a plot between the area of Voltage signal and input frequency where we find a decreasing trend. With decrease in frequency the area of voltage signal increased and the range was between 30 to 70 for the same set of frequency values. Chart 6 is a plot between the amplitude of voltage signal generated by piezo-electric patch and frequency input. The graph shows an increasing trend. As frequency increases, amplitude of vibration obtained is greater.

6 CONCLUSION

From the finite element analysis the location where the maximum value of shear stress is obtained was determined. From this, the optimal location of the sensor and actuator was found by taking into consideration the clamping area. From the experimental process, the volatage generated by the piezo-electric patch was obtained in variation with frequency input. It was found that if a sinusoidal waveform is provided, with increase in frequency the voltage generated by the piezo-electric patch increased. The plot between voltage generated and frequency input was almost an exponential curve. When we feed the voltage response of sensor into a control system, we generate a controlled output through the actuator, that can be used to control beam vibration actively.

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