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Active Vibration Control of Piezo-Laminated Cantilever Beam

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ABSTRACT

An experimental setup is designed to demonstrate reduction of flexible modes of the plate system. Actuators, accelerometers, and force sensors are specified to apply appropriate disturbance forces of varying complexity and to measure and record data necessary to update the theoretical model and design an effective controller. The experimental setup is initially made up of three relatively large stacked aluminum plates. After proof-of-concept results are obtained, the setup is scaled down to represent a more applicable system. The miniaturized setup is made up of a large base plate to distribute the input forces and a small flexible plate to be controlled. The control scheme involves non-collocation control of a location to which the accelerometer is mounted. With a desired range of reduction, the controller is designed and developed. Theoretical and experimental results of the modeling of a smart plate are presented for active vibration control. The smart plate consists of a rectangular aluminum plate modeled in cantilever configuration with surface bonded piezoelectric patches. The patches are symmetrically bonded on top and bottom surfaces. The study uses ANSYS 16.0 software to derive the finite element model of the smart plate. Current vibration suppression systems usually consist of piezoelectric extension actuators bonded to the surface or embedded within the structure. The use of piezoelectric shear actuators/sensors has been proposed as an alternative, where the electric field is applied perpendicular to the direction of polarization to cause shear deformation of the material.

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I. INTRODUCTION

As piezoelectric technology advances, dynamic systems present more complex problems with less obvious solutions. One common application for these advanced controllers is vibration reduction. In high precision systems, vibrations can decrease accuracies and efficiencies, and cause potentially disastrous damage. The ability to control these vibrations and minimize amplitude response to disturbances is valuable to many different industries across the board. This project focuses on vibration control of a flexible plate system. Adaptive structures using piezoelectric materials usually employ lead zirconium titanate (PZT) ceramic sensors and actuators to detect and mechanically deform a structure.

This involves a carefully designed experimental setup that allows for maximum adaptability as control methods evolve. The main methods that are explored in this project involve flexible control with a patch actuator and control with an inertial actuator. To implement each of these, separate experimental setups must be designed, built, characterized, and tested. The focus is on the systems response within a defined frequency range. The active vibration control of simple cantilever plates is studied in piezoelectric patches as actuators are mounted on the plates. Another piezoelectric patch or a strain gauge can be used to sense the vibration level. The system identification and pole placement control method is used. The plate and piezo-patches finite element model of the structure is constructed and the closed loop control is applied. 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 is too expensive, at such conditions Active Vibration Control techniques comes handy, it is very cheap requires no manual maintenance and the life expectancy is also much more than the passive controllers.

Active vibration control makes use of smart structure. 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 plate vibrations.

II. LITERATURE REVIEW

i. Jung Woo Sohn, Heung Soo Kim In this paper, an active control algorithm was adopted, in order to recover the vibration characteristics of a delaminated composite structure, and control performances were numerically investigated. Delamination of the laminated composite structure was modeled, using the improved layerwise theory. Higher order electric potential was used to describe the electro-mechanical coupling of a piezoelectric actuator. Dynamic equations of motion were derived, using a finite element scheme. Mode shapes and corresponding natural frequencies for healthy and damaged structures were identified. After implementing an active control algorithm in the system model, vibration characteristics of the controlled composite structure were compared to those of healthy and damaged composite structures. Vibration characteristics of the delaminated composite structure were effectively recovered to those of the healthy structure, and structural performances were also restored to those of the healthy structure.

ii. YavuzYaman, Tarkan Caliskan, Volkan Nalbantoglu proposed Theoretical and experimental results of the modeling of a smart plate is presented for active vibration control. The smart plate consists of a rectangular aluminum plate modeled in cantilever configuration with surface bonded piezoelectric patches. The patches are symmetrically bonded on top and bottom surfaces. The study uses ANSYS software to derive the finite element model of the smart plate. By using this model, the study first gives the influences of the actuator placement and size on the response of the smart plate and determines the maximum admissible piezoelectric actuation voltage. Based on this model, the optimal sensor locations are found and actual smart plate is produced. The experimental results of that smart plate are then used in the determination of a single input single output system model. By using this model, a single-input/single-output $H\infty$ controller is designed to suppress the vibrations due to the first two flexural modes of the smart plate. It has been shown that the designed controller guaranties robust performance.

iii. **H Karagu, L Malgaca**, **and H F Oktem** studied that model smart structures with piezoelectric materials using the product ANSYS. In this study, the integration of control actions into the ANSYS solution is realized. First, the procedure is tested on the active vibration control problem with two-degrees of freedom system. The analytical results obtained by the Laplace transform method and by ANSYS are compared. Then, the smart structures are studied by ANSYS. The input reference value is taken as zero in the closed loop vibration control. The instantaneous value of the strain at the sensor location at a time step is subtracted from zero to find the error signal value. The error value is multiplied by the control gain to calculate the voltage value which is used as the input to the actuator nodes. The process is continued with the selected time step until the steady-state value is approximately reached. The results are obtained for the structures analyzed in other studies. The active vibration control of a circular disc is also studied.

III. OBJECTIVE OF WORK

1) To measure the Vibrations produced by piezo acturators.
2) To develop a suitable control methodology which optimizes the controller gain so that more effective vibration control can be achieved with minimum control input.
3) To study the stability analysis for collocated and non-collocated optimal position of PZT sensor and actuator.
4) To validate the numerical results with experimental work for real life application.
5) To control the vibrations produced by piezoelectric patches.
6) To find out the optimum position to get control over produced vibrations on the aluminum plate.

IV. FINITE ELEMENT ANALYSIS

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. Young's modulus for the passive portion (Aluminum plate) is (E) =69GPa (69×10^9 N/m^2). The poison's ratio of the beam is taken 0.33 and the density of the aluminum Plate is 2710 Kg/m^3. The damping coefficient of the aluminum was taken as 0.0004. The dimension of the passive part (aluminum beam) is ($300\times200\times3$) mm*mm*mm and dimensions of the PZT is ($15\times15\times0.5$) mm*mm*mm. In the modeling first thepassive block was created and then the two patches were placed over it. The block is made of the material-1 using material attribute (SOLID186) 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 elements. 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. Then in the load step option we give the frequency in 100 sub-steps (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 plateModel, Figure 2 shows meshing of the PZT plate and Figure 3 shows Boundary Conditions onplate in ANSYS.

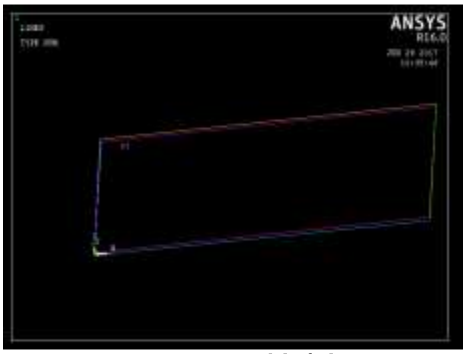


Figure 1: Line Model of Plate

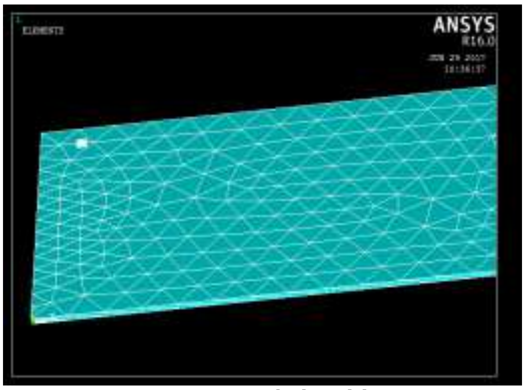
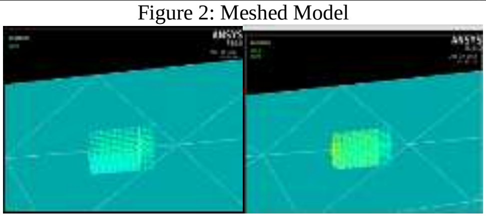


Figure 2: Meshed Model



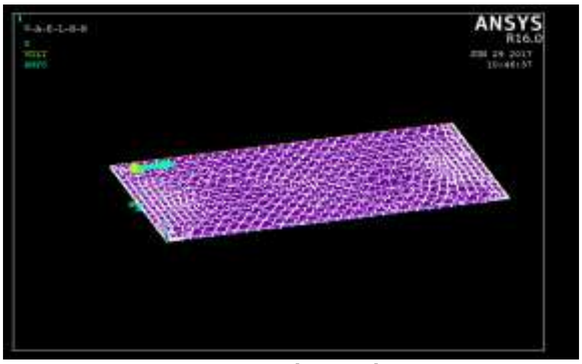
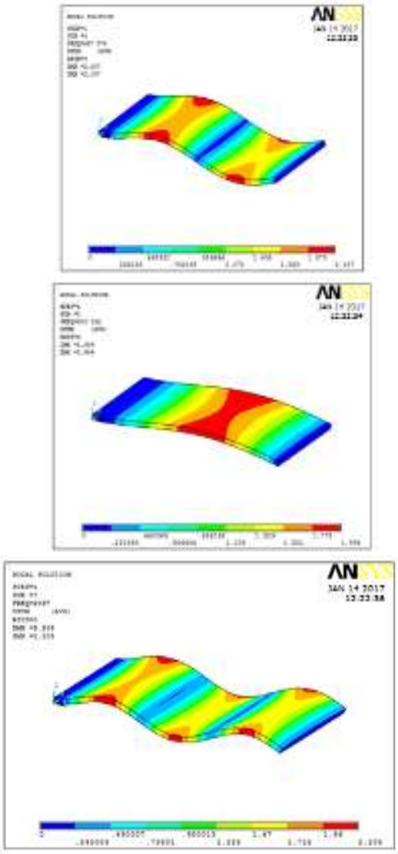


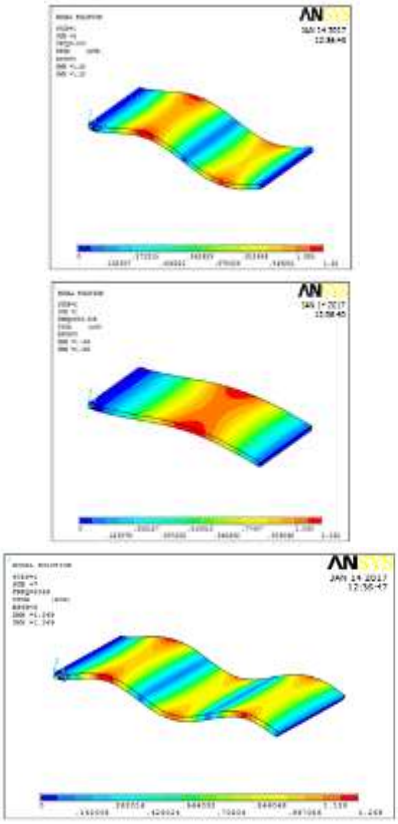
Figure 3 : Boundary Conditions

V. ANSYS RESULTS FOR ALUMINIUM PLATE

1.a) Frequency plot position 15 without controller



1. b) Frequency plot position 15 with controller



Similarly results are obtained for different positions as shown in following figure

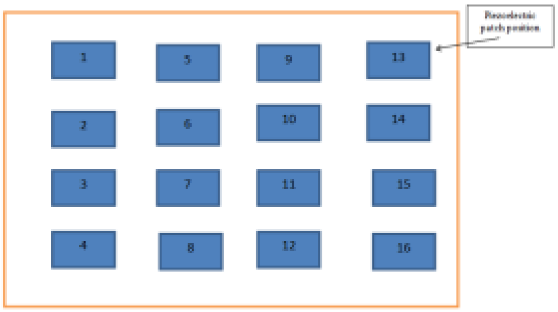


Figure 4: Piezoelectric patch position

Table 1: Finite Element results of 1st 2nd and 3rd mode of frequency

Frequency Number	Without Control	With Control	% Control Obtained
Frequency for Position 15			
1	309.026	303.212	2
2	1005	987.376	1.75
3	2099	2067	1.52
Frequency for Position 11			
Frequency Number	Without Control	With Control	
1	309.96	307.24	0.90
2	1005	988.157	16.90
3	2099	1966	6.33
Frequency for Position 6			
Frequency Number	Without Control	With Control	
1	81.225	60.127	26
2	366.651	229.41	37
3	996.579	547.86	45.05
Frequency for Position 5			
Frequency Number	Without Control	With Control	
1	70.055	65.16	9.98
2	438.962	373.371	14.94
3	1226	1014	17.22

VI. EXPERIMENTAL RESULTS OBTAINED

The piezoelectric patches are attached to the plate as shown in figure 4. One Actuator is actuated at one time and the frequency is measured, this procedure is repeated for 12 actuators & the frequency is listed out for each actuator.

Procedure for Experimental setup by using FFT analyzer

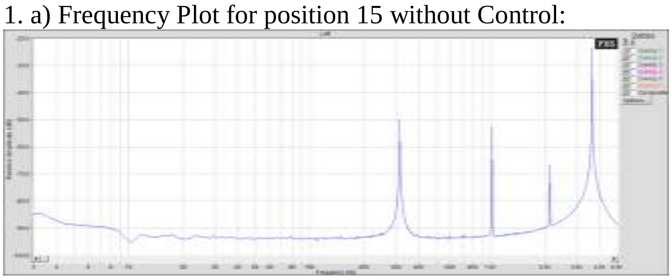
- Plate of required length is taken.
- By the use of screw gauge the depth and width of plate section were measured.
- The connections of the FFT analyzer, laptop, transducers, and model hammer along with the requisite power connections were made.
- The accelerometer was fixed by beeswax to the plate at one of the nodal points.
- The hammer was kept ready to strike the plate at the singular points.
- Then at each point the modal hammer was struck once and the amplitude Vs frequency graph was obtained from graphical user interface.
- The FFT analyzer and the accelerometer are the interface to convert the time domain response to frequency domain. Hence the frequency response spectrumH1 (response, force) was obtained.
- By moving the cursor to the peaks of the FFT graph, the cursor values and the resonant frequencies were recorded.
- At the time of the striking with modal hammer to the singular point precautions were taken whether the striking should have been perpendicular to the aluminum beam surface.
- The above procedure is repeated for all the nodal points and all materials plates and all structures.
- The values (i.e., natural frequencies and resonant frequencies) obtained from the FRF spectrums were compared with respect to the FEM analysis.

Figure 5: Al Plates

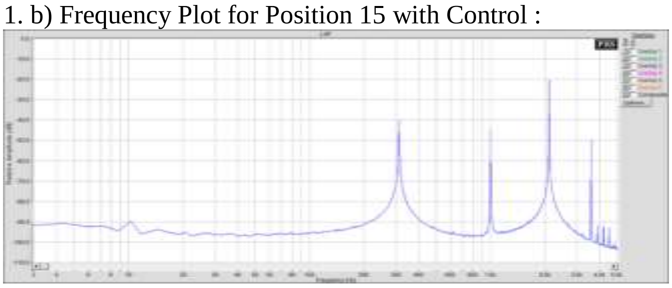
Experimental Results Obtained:

For AL Plate:

1. a) Frequency Plot for position 15 without Control:



1. b) Frequency Plot for Position 15 with Control :



Similarly results are obtained for different locations.

Table 2: Experimental Results obtained from FFT

Frequency for Position 15			
Frequency No	Without Control	With Control	% Control Obtained
1	313	309	1.2
2	1012	991	2.07
3	2105	2089.01	0.759
Frequency for Position 11			
Frequency No	Without Control	With Control	
1	312	310	0.6
2	1010	993	1.7
3	2101	2093	0.47
Frequency for Position 10			
Frequency No	Without Control	With Control	
1	174	63	29.67
2	682	370	45.74
3	1501	1004	33.11
Frequency for Position 6			
Frequency No	Without Control	With Control	
1	74	52	29.72
2	443	421	4.96
3	1258	1219	3.100
Frequency for Position 7			
Frequency No	Without Control	With Control	
1	82	63	23.17
2	235	370	36.48
3	428	1004	57.37
Frequency for Position 5			
Frequency No	Without Control	With Control	
1	73	61	16.43
2	441	381	13.60
3	1251	1021	18.38

VII. CONCLUSION

Vibrations are a major constraint that limits the accuracy and productivity in center less grinding practice. To overcome this limitation, an active vibration reduction system using piezoelectric actuators has been implemented, which is a novel solution to improve the performance of structures.

From the Finite Element & Experimental Results It is seen that the piezoelectric material is an effective tool for control of vibration. The size of piezoelectric patch also plays an important role to control the vibrations. Here we have used small patch but the actuations produced are good as compared. The position of sensor is also an important factor to detect the vibrations in the plate structures.

We have applied the piezoelectric patch at the position 15 at nearly center of plate. The piezoelectric patches are assumed to be perfectly bonded on to the plate, they were assumed to be operated in their linear region during the experimentation.

It is observed from results that the control obtained near to free end is less as compared to other locations.

Here in this project the actuation given by means of impact hammer at the free end & the actuator placed at the center position 15 of the plate.

For comparing the Aluminum plate & Glass Fiber Plate Fiber Plate it is observed that vibrations produced in the composite plate are very less as compared to the aluminum plate.

The control obtained is less in composite plate, but satisfactory as compared to amplitude of vibrations.

It is can be concluded that the vibrations response in laminated plates is less as compared to isometric plates.

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