Experimental Analysis of the Flax Reinforced Composites

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Abstract— Active vibration damping using piezoelectric materials integrated with structural systems has found widespread use in engineering applications. 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. 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.

Keywords: Stress Concentration, Stress Analysis, Complex Structure

I. Introduction

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 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”. 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 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.

The Major components are

1) Sensor patch- it is bonded to the host structure (plate). It is generally made up of piezoelectric crystals. It senses the disturbance of the plate 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 plate. Converse piezoelectric is used.

The plate is clamped at one end using the specially made fixtures hence making it a cantilever plate, 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 plate which results in the formation of shear stress in the plate, 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 plate and the entire plate is balanced. Active vibration control finds its application in all the modern day machines, Engineering structures, automobiles, gadgets, sports equipment’s, 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 (Glass Fiber plate with viscoelastic layer) with one pair of piezoelectric lamination is used to study the active vibration control. The smart plate consists of rectangular aluminum plate modeled in cantilever configuration with surface bonded piezoelectric patches. The study uses ANSYS 19.1 software to derive the finite element model of the smart plate. Based on this model, the optimal sensor locations are found and actual smart plate 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.

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 developments in the field of piezoelectric materials have motivated many researchers to work in the field of smart structures. 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 plate 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. Thus, several studies have examined the increased damping of laminated structures brought about by the insertion of viscoelastic layers. Moreover, the ability of a viscoelastic layer to dissipate energy makes this type of material a good element in many areas of the industry.

II. Objective of Work

1) To develop a Glass Fiber composite plate having viscoelastic core.
2) To measure the Vibrations produced by piezo actuators.
3) To develop a suitable control methodology which optimizes the controller gain so that more effective vibration control can be achieved with minimum control input.
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 Fiber Glass Composite plate.

In spacecraft, automobiles, helicopter, bridges, marine applications. 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. A particular problem associated with machinery isolation in marine environment is structural resonance. This occurs both in the machinery support structure and in the hull. Such resonance leads to very high forces transmitted across machinery mounts where resonant frequencies coincide with modes of the hull. Passive solutions have limited performance particularly at lower frequencies. As a result there has been considerable interest in the use of active vibration control methods for machinery mounting structural vibration control. In aircrafts, spacecraft, automobiles, helicopters, active vibration control is gaining momentum.

III. Mathematical Modeling

Consider a precision structure subjected to varying thermal conditions; unless carefully designed, it will distort as a result of the thermal gradients. One way to prevent this is to build the structure from a thermally stable composite material this is the passive approach. An alternative way is to use a set of actuators and sensors connected by a feedback loop; such a structure is active. In this case, we exploit the main virtue of feedback, which is to reduce the sensitivity of the output to parameter variations and to attenuate the effect of disturbances within the bandwidth of the control system. Depending on the circumstances, active structures may be cheaper or lighter than passive structures of comparable performances; or they may offer performances that no passive structure could offer.

An active structure consists of a structure provided with a set of actuators and sensors coupled by a controller; if the bandwidth of the controller includes some vibration modes of the structure, its dynamic response must be considered. If the set of actuators and sensors are located at discrete points of the structure, they can be treated separately. The distinctive feature of smart structures is that the actuators and sensors are often distributed, and have a high degree of integration inside the structure, which makes a separate modeling impossible in some applications like vibro-acoustics, the behavior of the structure itself is highly coupled with the surrounding medium; this also requires a coupled modeling. From a mechanical point of view, classical structural materials are entirely described by their elastic constants relating stress and strain, and their thermal expansion coefficient relating the strain to the temperature. Smart materials are materials where strain can also be generated by different mechanisms involving temperature, electric field or magnetic field, etc, As a result of some coupling in their constitutive equations. The most celebrated smart materials are briefly described below:

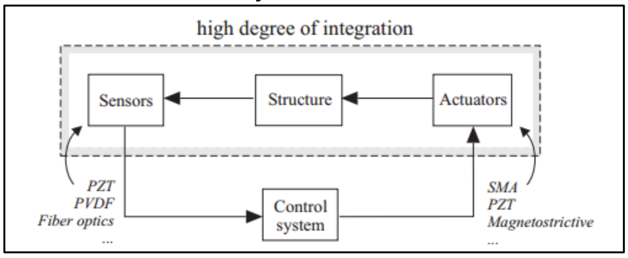


Fig. 3.1: Smart Structure

The principle of feedback is represented in the output y of the system is compared to the reference input r, and the error signal, $e = r - y$, is passed into a compensator H(s) and applied to the system G(s). The design problem consists of finding the appropriate compensator H(s) such that the closed-loop system is stable and behaves in the appropriate manner.

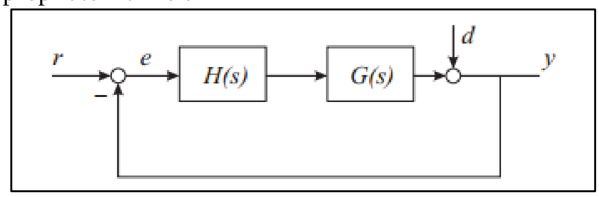


Fig. 3.2: Principal of Feedback Control

The control objectives can be more ambitious, and we may wish to keep a control variable y (a position, or the pointing of an antenna) to a desired value r in spite of external disturbances d in some frequency range. From the previous formula and

$$F(s) = \frac{y(s)}{r(s)} = \frac{GH}{1+GH}$$

We readily see that this requires large values of GH in the frequency range where $y \approx r$ is sought. $GH >> 1$ implies that the closed-loop transfer.

The constitutive equations of a general piezoelectric material are:

$$T_{ij} = c^{E}_{ijkl} S_{kl} - e_{kij} E_k$$

$$D_i = e_{ikl} S_{kl} + \varepsilon^{S}_{ik} E_k$$

where T_{ij} and S_{kl} are the components of the stress and strain tensors, respectively, $^{c}E_{ijkl}$ are the elastic constants under constant electric field (Hooke's tensor), the piezoelectric constants (in Coulomb/m^2) and ε_{Sij} the dielectric constant under constant strain. These formulae use classical tensor notations, where all indices i, j, k, l = 1, 2, 3, and there is a summation on all repeated indices. The above equations are a generalization of, with $S_{kl}$and E_j as independent variables; they can be written alternatively with T_{kl} and $E_j$as independent variables:

$$S_{ij} = s^E_{ijkl} T_{kl} + d_{kij} E_k$$

$$D_i = d_{ikl} T_{kl} + \varepsilon^T_{ik} E_k$$

where E_{ijkl} is the tensor of compliance under constant electric field, d_{ikl} the piezoelectric constants (in Coulomb/Newton) and T_{ik} the dielectric constant under constant stress. The difference between the properties under constant stress and under constant strain has been stressed earlier. As an alternative to the above tensor notations, it is customary to use the engineering vector notations

$$T = \begin{Bmatrix} T_{11} \\ T_{22} \\ T_{33} \\ T_{23} \\ T_{31} \\ T_{12} \end{Bmatrix} \qquad S = \begin{Bmatrix} S_{11} \\ S_{22} \\ S_{33} \\ 2S_{23} \\ 2S_{31} \\ 2S_{12} \end{Bmatrix}$$

With these notations, Equation can be written in matrix form

$$\{T\} = [c]\{S\} - [e]\{E\}$$
$$\{D\} = [e]\ T\ \{S\} + [\varepsilon]\{E\}$$
$$\{S\} = [s]\{T\} + [d]\{E\}$$
$$\{D\} = [d]\ T\ \{T\} + [\varepsilon]\{E\}$$

where the superscript T stands for the transposed; the other superscripts have been omitted, but can be guessed from the equation itself. Assuming that the coordinate system coincides with the orthotropy axes of the material and that the direction of polarization coincides with direction 3, the explicit form of

A. Actuation:

$$\begin{Bmatrix} S_{11} \\ S_{22} \\ S_{33} \\ 2S_{23} \\ 2S_{31} \\ 2S_{12} \end{Bmatrix} = \begin{bmatrix} s_{11} & s_{12} & s_{13} & 0 & 0 & 0 \\ s_{12} & s_{22} & s_{23} & 0 & 0 & 0 \\ s_{13} & s_{23} & s_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & s_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & s_{66} \end{bmatrix} \begin{Bmatrix} T_{11} \\ T_{22} \\ T_{33} \\ T_{23} \\ T_{31} \\ T_{12} \end{Bmatrix} + \begin{bmatrix} 0 & 0 & d_{31} \\ 0 & 0 & d_{32} \\ 0 & 0 & d_{33} \\ 0 & d_{24} & 0 \\ d_{15} & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{Bmatrix} E_1 \\ E_2 \\ E_3 \end{Bmatrix}$$

B. Sensing:

$$\begin{Bmatrix} D_1 \\ D_2 \\ D_3 \end{Bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & d_{15} & 0 \\ 0 & 0 & 0 & d_{24} & 0 & 0 \\ d_{31} & d_{32} & d_{33} & 0 & 0 & 0 \end{bmatrix} \begin{Bmatrix} T_{11} \\ T_{22} \\ T_{33} \\ T_{23} \\ T_{31} \\ T_{12} \end{Bmatrix} + \begin{bmatrix} \varepsilon_{11} & 0 & 0 \\ 0 & \varepsilon_{22} & 0 \\ 0 & 0 & \varepsilon_{33} \end{bmatrix} \begin{Bmatrix} E_1 \\ E_2 \\ E_3 \end{Bmatrix}$$

Typical values of the piezoelectric constants for piezoceramics (PZT) and piezopolymers (PVDF) are Examining the actuator equation.we note that when an electric field E_3 is applied parallel to the direction of polarization, an extension is observed along the same direction; its amplitude is governed by the piezoelectric coefficient d_{33}. Similarly, a shrinkage is observed along the directions 1 and 2 perpendicular to the electric field, the amplitude of which is controlled by d_{31} and d_{32}, respectively (shrinkage, because d_{31} and d_{32} are negative). Piezoceramics have an isotropic behavior in the plane, $d_{31} = d_{32}$; on the contrary, when PVDF is polarized under stress, its piezoelectric properties are highly anisotropic, with $d_{31} \sim 5d_{32}$. Equation (12) also indicates that an electric field E_1 normal to the direction of polarization 3 produces a shear deformation S_{13}, controlled by the piezoelectric constant d_{15} (similarly, a shear deformation S_{23} occurs if an electric field E_2 is applied.

IV. EXPERIMENTAL SETUP

A. Piezoelectric Actuator & Sensor Arrangement:

1) Actuators:

The piezoelectric patches are attached to the plate as shown in figure. One Actuator is actuated at one time and the frequency is measured; this procedure is repeated for 6 actuators & the frequency is listed out for each actuator.

2) Sensors:

Same Arrangement is done on the opposite side of the plate. The numbering is given from the left side of the plate. The boundary condition used is Cantilever Boundary condition.

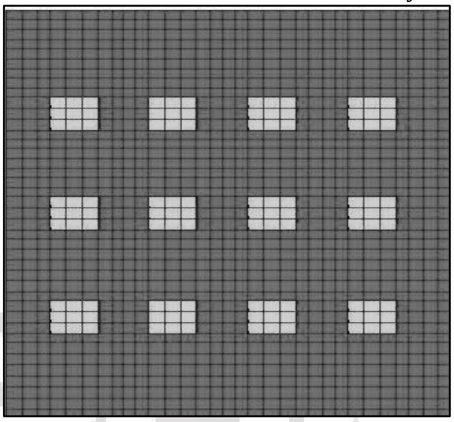


Fig. 4.1: Piezoelectric patch arrangement

a) FFT Analyser

FFT Analyser is used to measure the frequency ranges to which the foundation various machines are subjected to when the machine is running with no load and full load. This will help us in designing the foundations of various machines on such a way that they are able to resist the vibration caused in them.

b) Display unit for FFT analyser

This is mainly in the form of PC(Laptop) software, when the excitation occurs to the structure the signals transferred to the portable PULSE and after conversion comes in graphical form through the software . mainly the data includes graphs of force Vs time, frequency Vs time resonance frequency data etc.

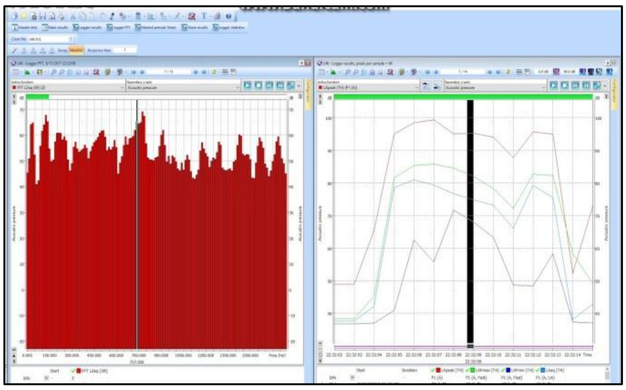


Fig. 4.2: FFT Analyser

B. Specification of Plates:

Plate dimension		
Materials For Plates	Aluminium Glass Fiber	
Length of Plate	270 mm.	
Thickness (t)	3mm.	
Width	150 mm	
MATERIAL	Aluminium	Glass Fiber
Young's modulus (N/mm^2)	0.69×10^{11}	3×10^6
Poisson's Ratio	0.33	0.25
Density (kg/m^3)	2700	1799

Experimental Results are shown further. The Actuation at Locations 1 to locations 4 are very less therefore it is neglected.

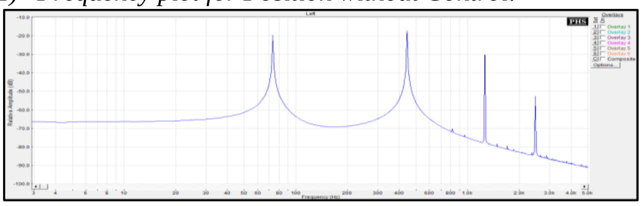
C. Procedure for Experimental Setup by using FFT analyzer:

– 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 function generator is used to excite the piezo patch connected to piezo by thin wires.
– Then the voltage is provided by using the function generator to the different piezo patches 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.
– The above procedure is repeated for all the nodal points and all materials plates and all structures.

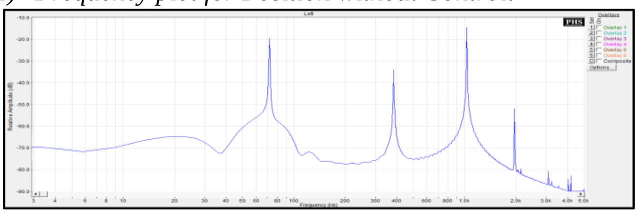
V. EXPERIMENTAL RESULTS

A. For AL Plate:

1) Frequency plot for Position without Control:



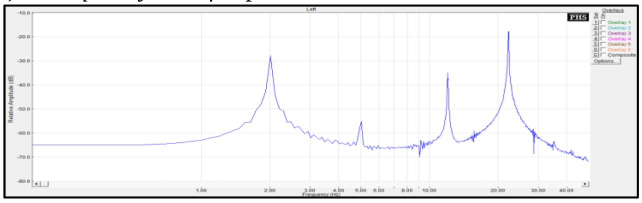
2) Frequency plot for Position without Control:



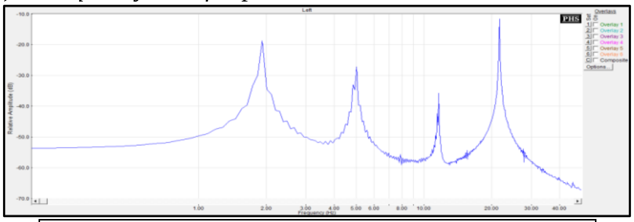
Frequency for Position		
Frequency No	Without Control	With Control
1	73	71
2	441	381
3	1251	1021

B. For Glass Fiber Pate:

1) Frequency Plot for position without control:



2) Frequency Plot for position with control:



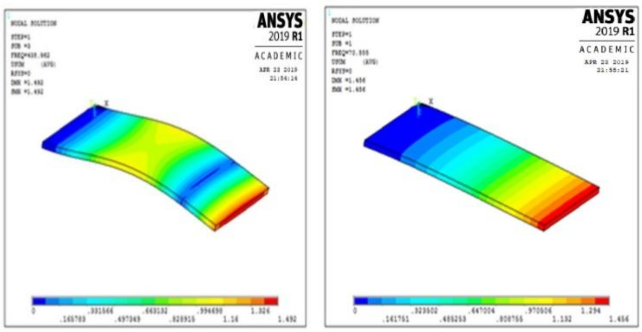
Frequency for Position		
Frequency No	Without Control	With Control
1	1.99	1.89
2	5.01	4.97
3	12.03	11.57

VI. FINITE ELEMENT MODELING

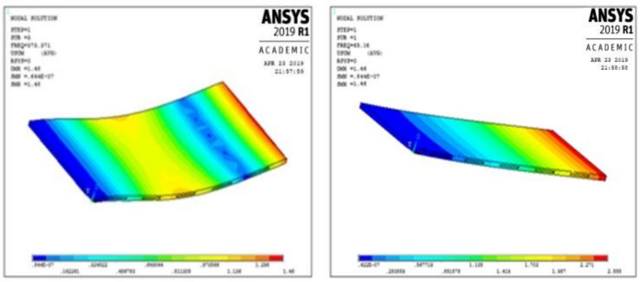
The models developed for the passive portion should include consistent degree of freedom at the location where these elements interface. For modeling the passive portion of the smart structure solid element used is (SOLID186). The passive portion is made of aluminum. In these modeling we could use shell element as (SHELL99) also.

A. ANSYS Results for Aluminium Plate:

1) Frequency plot position without controller:



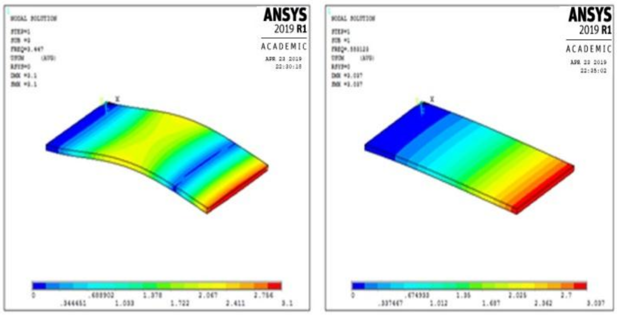
2) Frequency plot position with control:



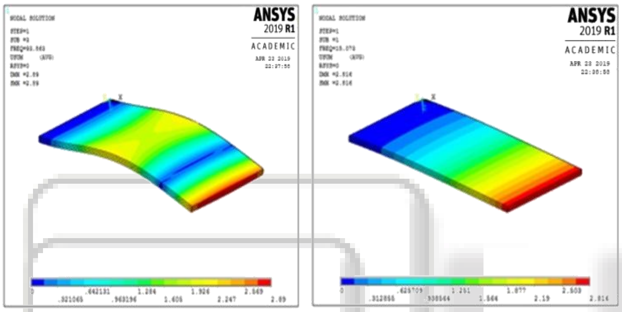
Frequency for Position		
Frequency No.	Without Control	With Control
1	70.055	65.16
2	438.962	373.371
3	1226	1014

B. ANSYS Results for Glass Fiber Plate:

1) Frequency plot position without control:



2) Frequency plot position with control:



Frequency for Position		
Frequency No.	Without Control	With Control
1	0.553	0.473
2	3.447	2.863
3	9.625	6.546

VII. RESULTS & DISCUSSIONS

A. For Aluminum Plate:

The positions are specified in the experimental & Finite Element Setup is considered for the Results & Discussions.

Frequency for Position			
Frequency No	Without Control	With Control	% Control Obtained
1	73	61	16.43
2	441	381	13.60
3	1251	1021	18.38

Table 7.1: Results Obtained From Experimental Analysis for Al Plate.

Frequency for Position			
Frequency No	Without Control	With Control	% Control Obtained
1	70.055	65.16	9.98
2	438.962	373.371	14.94
3	1226	1014	17.22

Table 7.2: Results Obtained From Finite Element Analysis for Al Plate

B. For Glass Fiber Plate:

Frequency for Position			
Frequency No	Without Control	With Control	% Control Obtained
1	1.99	1.89	5.02
2	5.01	4.97	2.19
3	12.03	11.57	4.04

Table 7.3: Results Obtained From Experimental Analysis for Glass Fiber Plate.

Frequency for Position			
Frequency No	Without Control	With Control	% Control Obtained
1	0.553	0.473	0.90
2	3.447	2.863	1.75
3	9.625	6.546	2.13

Table 7.4: Results Obtained From Finite Element Analysis for Glass Fiber Plate.

VIII. CONCLUSION

Vibrations are a major constraint that limit the accuracy and productivity in centerless 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 1 near the fix end 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. For comparing the Aluminum plate & Glass Fiber Plate with viscoelastic core it is observed that vibrations produced in the composite plate are very less as compared to the aluminum plate. It is also observed that Viscoelastic core has a great impact over the vibrations, it can be used to produce the damping effect. 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 are less as compared to isometric plates.

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