ACTIVE VIBRATION CONTROL OF LAMINATED COMPOSITE THIN PLATES USING A SMART MATERIAL

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***Abstract*— The aim of this paper is the vibration control of piezo-covered composite thin plates with surface reinforced or installed piezo-electric sensors and actuators by utilizing the limited component examination and LQR input control procedure". The consequences of the limited component investigation are utilized to plan a direct quadratic controller (LQR) controller with a dynamic state onlooker to accomplish the control. The control configuration starts with an inexact decreased modular model which can speak to the framework progression with the minimum framework modes. "A state space modular model of the brilliant structure which coordinates the host structure with reinforced piezoelectric sensors and actuators, is then used to plan the control framework.**

Keywords*— *FE analysis, Thin composite plate, vibration control, LQR technique

I. INTRODUCTION

A framework is named as 'keen' on the off chance that it is fit for perceiving an outside jolt and reacting to it inside a given time in foreordained way. Moreover it should have the capacity of recognizing its status and may ideally adjust its capacity to outer boosts or may give proper flag to the client. Brilliant structures that can monitor their own condition, recognize approaching disappointment, control, or recuperate harm and adjust to evolving condition. Due to their characteristic capacity of distinguishing the any adjustment in structure, shrewd materials, frameworks and structures are being utilized for SHM and NDE from recent decades.

II. COMPONENTS OF SMART SYSTEM

A.Sensors

A smart system must have embedded intrinsic sensors to recognize and measure the intensity of stimulus (stress or strain) or its effect on the structure .

B.Actuators

"A smart system may additionally have embedded or bonded actuators, which respond to stimulus in predetermined manner."

C. Control mechanism

"A smart system must have a mechanism for integrating and controlling the actions of the sensors and actuators."

III. STYLING POTENTIAL APPLICATIONS OF SMART MATERIALS

One thought is to put containers or empty strands loaded with split fixing material into solid which if broke would break the fibre discharging the sealant. Optical filaments which change in light transmission because of stress are helpful sensors. They can be installed in concrete or joined to existing structures. Darker University and the University of Rhode Island explored the essentials and progression of inserted optical strands in concrete. Japanese scientists as of late created glass and carbon fibre strengthened solid which gives the pressure information by estimating the progressions in electrical protection in carbon strands .

IV. NECESSITY OF MODELLING

The joining of savvy materials with the customary ones is a key viewpoint in the conduct of the structures and their displaying. Demonstrating ought to be to such an extent that firmness and inertial mass of the structure not affected by transducers or sensors. The above contemplations give a thought of the inspirations that drive the examination exertion in displaying keen structures, and the motivation behind why this is an extremely difficult and open research field. The displaying of full material nonlinearities and the demonstrating of full coupling between keen structures and liquids may be said as conceivable cases for future research.

V. ANALYTICAL ANALYSIS

Analytical analysis were carried out for the above configurations in Figs. 1,2,3,are as by Law and Huang(2003). The deflection in the tip was found by

$$\delta = \frac{3E_pE_S(t_p+t_s)^2 d_{31}\Delta v L^2}{4E_pE_st_pt_s(t_p+t_s)^2+(E_pt_p^2-E_st_s^2)^2}$$

“Where, V = The potential contrast between the interface of the two piezo layers and the upper face of the upper piezoelectric layer or lower face of the base piezoelectric layer.

tp and Ep = The thickness and versatile modulus of the upper piezoelectric layer individually.

ts and Es = The thickness and flexible modulus of the base piezoelectric layer separately.

d31 = the piezoelectric coupling coefficient relates strain first way to the electric field third way.

L = aggregate length of the beam.”

VI. PARAMETRIC STUDY OF BIMORPH BEAM

A bimorph beam with upper layer as the active layer and lower layer as the inactive layer is bonded properly with application of electric potential. The beam width is taken as 20mm and the bonding of layers are of mesh size 25x5x3. An applied potential of 10V was carried out throughout the study. The parametric study was carried out in bringing variations in two parameters. (i) By varying thickness of the layers (ii) By varying length of the layers The static analysis of the bimorph beam was conducted by analytical analysis and is compared with the numerical results obtained. Numerical analysis was carried out by ANSYS Workbench 15.0 and the analytical analysis was carried out by deflection control equation from Law and Huang (2004).

The length of the layers is varied in three cases for the static analysis for finding the tip deflection similarly thickness also. The upper layer of the beam is maintained half the length of the lower layer and analysis was carried out. Then both the layers were kept with same length, finally the lower layer was kept half the upper layer. Similarly, thickness of the beam was varied, by varying the thickness of the upper layer and keeping the lower layer as 1mm constant. The upper layer thickness was varied from 0.05mm to 2mm keeping the lower layer as 1mm. Also both the layers of same thickness are been taken for the analysis. The beam configurations are as shown in Fig. 1,2 and 3.

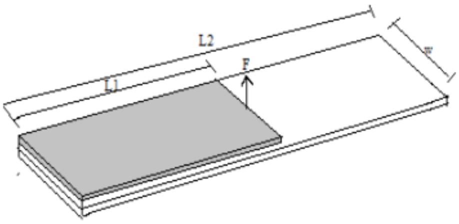

Fig.1. Upper layer half the lower layer

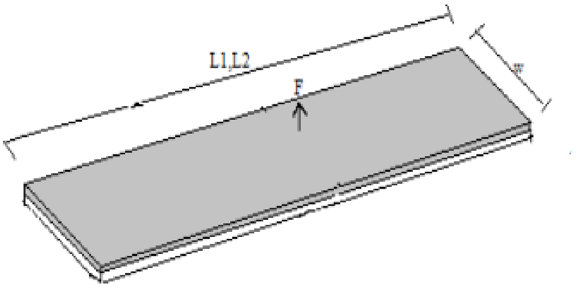

Fig.2. Upper layer same the lower layer

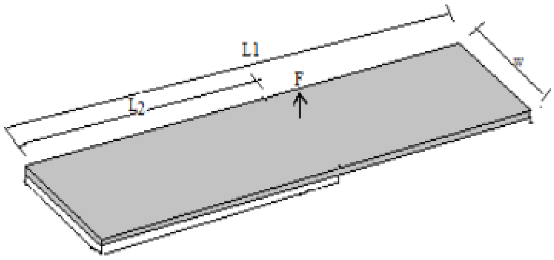

Fig.3. Lower layer half the upper layer

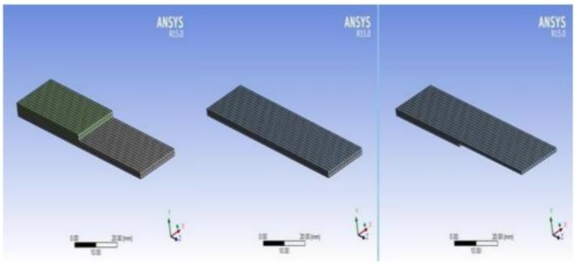

Fig.4. Meshed Model of the 3 configurations

VII. STATIC ANALYSIS OF LAMINATED COMPOSITE THIN PLATE

The static investigation for the present examination is been completed considering a thin square cantilever composite plate. The investigation is completed utilizing Ansys Workbench 15.0. The static investigation gives the tip redirection under static stacking which gathers the conduct of piezoelectric material. As the present investigation is constrained to thin plates just, the thickness of the plate is been taken as 1mm. A uniform weight of 3kPa is been connected on the plate surface and the examination is completed by contrasting the tip reaction of the plate with and without piezoelectric material. The material properties of the composite body and the piezoelectric body is as given in Table 1.

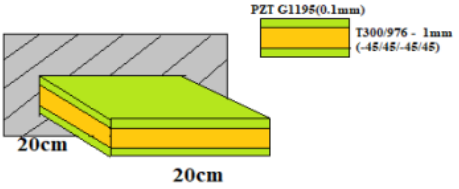

Fig.5. The laminated composite plate model with piezoelectric element for the present study

Further a parametric study under static analysis is also been done by varying the composite material and also the stacking sequences. The composite materials used in the parametric study are T300/976 and Er/Gp. The stacking sequence is also varied in symmetricaly and assymetricaly. ie, [0/90/90/0], [-45/45/45/-45], [-45/45/-45/45], [-30/30/30/-30], [-30/30/-30/30], [-15/15/15/-15], [-15/15/-15/15].

TABLE I MATERIAL PROPERTIES OF THE LAMINATED COMPOSITE PLATE

Properites	PZT piezoceramics	T300/976
Young's Modulus, E_{11}	63 x 10^9	150 x 10^9
Young's Modulus, E_{22}=E_{33}	63 x 10^9	9 x 10^9
Poisson's Ratio ν_{12}=ν_{13}=ν_{23}	0.3	0.3
Shear Modulus, G_{12}	24.2 x 10^9	7.1 x 10^9
Shear Modulus, G_{13}=G_{23}	24.2 x 10^9	2.5 x 10^9
Density	7600	1600
Piezoelectric constant, d_{31}	2.54 x 10^{10}	-
Electric Permitivity ε_{11}=ε_{22}	1.53 x 10^8	-

VIII. PARAMETRIC STUDY OF LAMINATED COMPOSITE THIN PLATE UNDER STATIC ANALYSIS

The parametric study was conducted by varying the material of composite body and the stacking sequence of the composite material. The results of composite material T300/976 was used under varying stacking sequence is given in Table 2 and Table 3 with comparison to effect of piezoelectric element.

From Table 9, it can be noted that the deflection is lesser when the plate is merged with piezoelectric body. Also there is an influence for the stacking sequence in the tip response of the plate.

TABLE II COMPARISON OF TIP DEFLECTION OF THE COMPOSITE PLATE WITH AND WITHOUT PIEZOBODY UNDER VARYING FIBER ORIENTATIONS FOR T300/979

Sl.no	Fibre Orientation Angle	Tip Deflection (m)	
		With PZT-G1195	Without PZT-G1195
1	0/90/90/0	0.039625	0.054233
2. a	-15/15/15/-15	0.044694	0.071422
b	-15/15/-15/15	0.042058	0.06047
3. a	-30/30/30/-30	0.061683	0.11672
b	-30/30/-30/30	0.057122	0.09652
4. a	-45/45/45/-45	0.086735	0.22603
b	-45/45/-45/45	0.0825	0.19336

TABLE III COMPARISON OF TIP DEFLECTION OF THE COMPOSITE PLATE WITH AND WITHOUT PIEZOBODY UNDER VARYING FIBER ORIENTATIONS FOR ER/GP

Sl.no	Fibre Orientation Angle	Tip Deflection (m)	
		With PZT-G1195	Without PZT-G1195
1	0/90/90/0	0.04328	0.056772
2. a	-15/15/15/-15	0.04932	0.073453
b	-15/15/-15/15	0.046602	0.062234
3. a	-30/30/30/-30	0.067776	0.132344
b	-30/30/-30/30	0.063123	0.10675
4. a	-45/45/45/-45	0.093342	0.25664
b	-45/45/-45/45	0.089861	0.22315

From the parametric study, it can be observed that there is influence of the composite material and the stacking sequence on the tip deflection of the plate. Also on varying the material, it is found that Epoxy T300/979 is more capable in reducing the deflection than Graphite Epoxy- Gr/Ep. Also the piezo electric element plays a keen role in reducing the deflection of structures. The unique property of the piezoelectric element helps in sensing and actuating the external applied loads.

IX. DYNAMIC ANALYSIS OF LAMINATED COMPOSITE THIN PLATE WITH VIBRATION CONTROL TECHNIQUE

After the static examination, the plate structure experiences modular investigation inorder to get the frequencies and the conduct of structure inclined to vibration. A load of 0.1N is applied at the free end of the plate. The dynamic reaction is figured by utilizing just the principal mode. As in the problem by Balamurugan and Narayanan(2008), the damping is disregarded[16]. To plan a LQR controller, we have one mode minimum diminished model to control. As the subordinate of the sensor yield is thought to be figured, with one surface reinforced sensor and one surfaced fortified actuator, a full state criticism LQR controller can be planned. While the tip vertical relocation is set as execution yield, the state weight network Q can be figured from yield matrix C with Q = CTC and control parameters are taken as α =104 and β = 1. At that point the dynamic vibration control of the plate subjected to arbitrary stacking is considered.

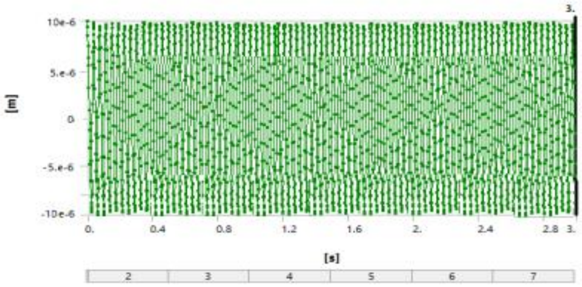

Fig.6. Uncontrolled response of the plate due to impulse loading

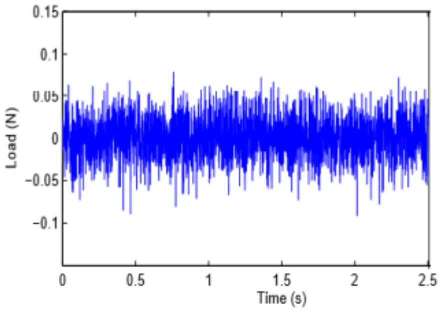

Fig.7.Uncontrolled response of the plate due to random loading

Figs. 6 and 7 gives the uncontrolled response of the laminated composite plate under impulse and random loading respectively. So the control has to be implemented to decrease the drastic response of the plate. The control was set to start after 0.5s time lapse. The dynamic response of the composite plate was studied by modal analysis.

The mode shapes obtained during the modal analysis is given from Fig.8 - Fig.13. The modal frequencies are also noted. The least modal model is taken further for the vibrational control. Table4 shows the modal frequencies obtain during the modal analysis.

TABLE IV MODAL FREQUENCIES OF THE COMPOSITE PLATE

Mode	Frequency [Hz]
1.	21.528
2.	63.614
3.	134.08
4.	187.45
5.	224.13
6.	404.8

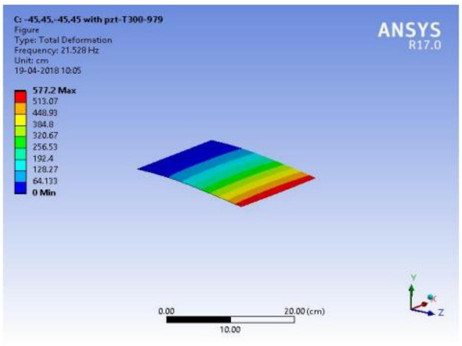

Fig.8.Model Shape 1

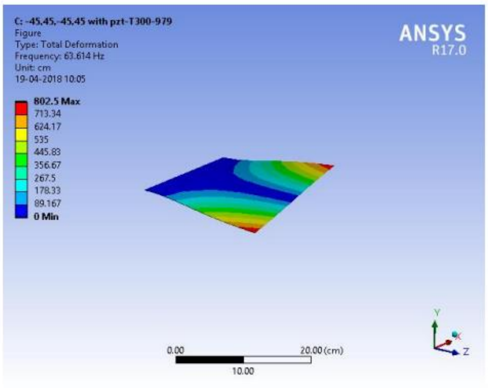

Fig.9 .Model Shape 2

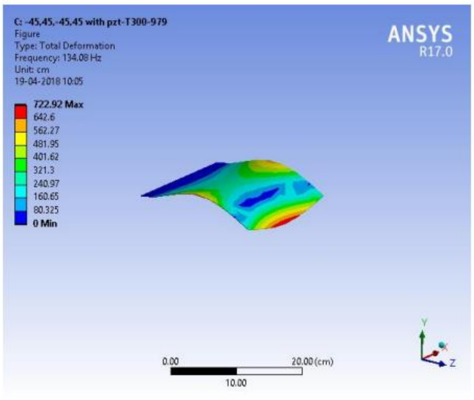

Fig.10 .Model Shape 2

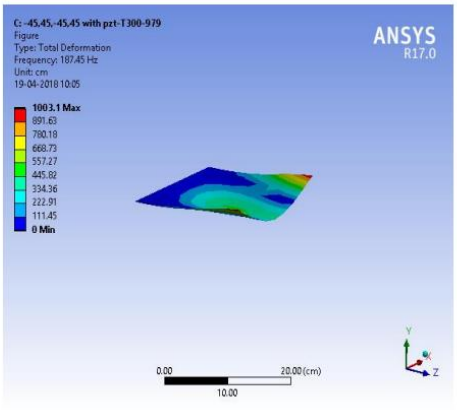

Fig.11 .Model Shape 3

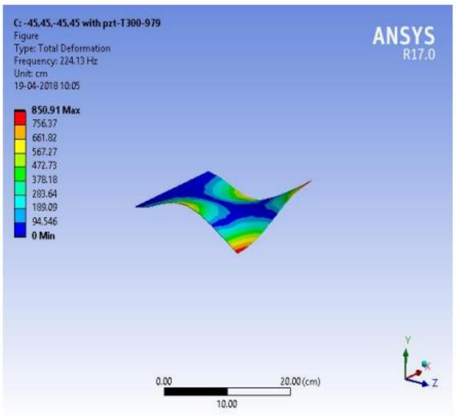

Fig.12 .Model Shape 4

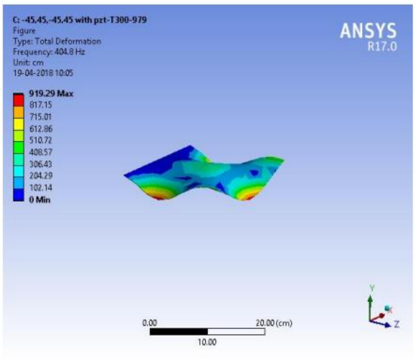

Fig.13 .Model Shape 5

Fig.14 shows the impulse response of the plate's tip displacement, for which the control is started after a lapse of 0.5s . It shows good agreements with the study in literature. The corresponding frequency response of the uncontrolled and controlled tip displacement is shown in Fig15.

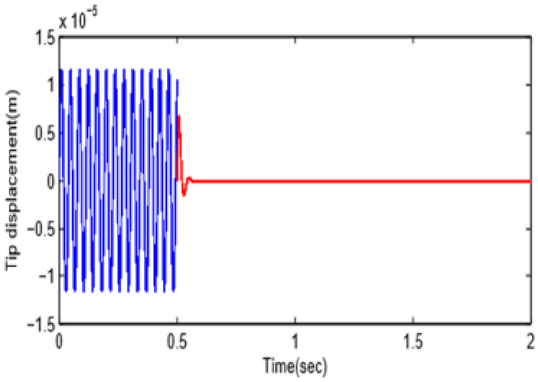

Fig.14 Impulse Response of the plate on control after 0.5s

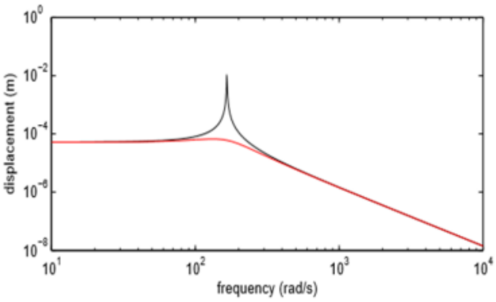

Fig.15 Frequency responses of the smart composite plate

The uncontrolled and controlled reactions at the free end of the plate because of irregular stacking are appeared in Fig.16and Fig17. Fig.18 demonstrates the control contribution of the actuator is well underneath the breakdown voltage. The mean square reaction (MSR) for the both uncontrolled and controlled cases are 7.4421x 10^{-8} and 2.0486 x 10^{-10}, separately. The MSR decrease factor is around 363, which shows that the appropriated sensors and actuators are effective in controlling the irregular vibration too.

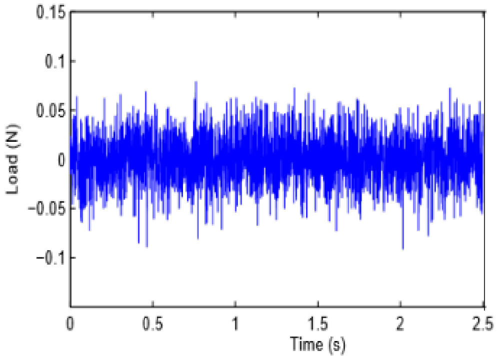

Fig.16. Uncontrolled response of the smart composite plate due to the random loading

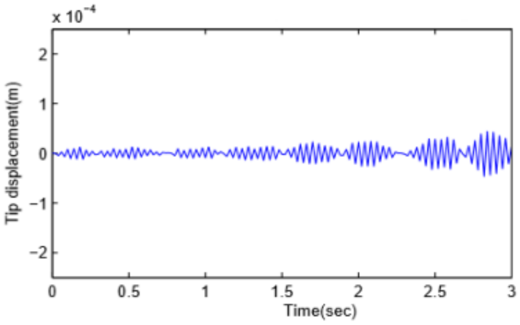

Fig.17. Random load history in the frequency range of 0–1000Hz

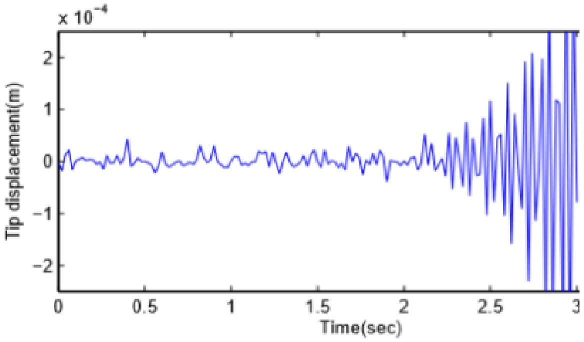

Fig.18. Controlled response of the smart composite plate due to the random loading

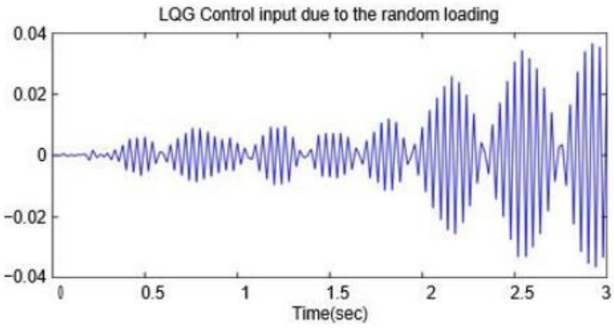

Fig.19. Controlled input voltage of the smart composite plate due to the random loading.

The modal model approach with an LQR control technique gives much more efficient control results to the vibration suppression with lesser control input peak voltages when compared to the classical controls.

CONCLUSION

The vibration control of piezolaminated composite plate structures with coordinated piezoelectric sensors and actuators are considered in this paper. The limited component demonstrate depends on layer-wise first request shear distortion hypothesis in conjunction with straight piezoelectric constitutive relations. The proposed plate components are approved by contrasting and existing outcomes in the writing. Modular model approach with LQR control strategies is connected to plan the input control frameworks for the vibration concealment of the structures. The control comes about demonstrate that a full state LQR compensator with a dynamic state onlooker are effective in controlling the motivation or irregular load energized vibrations and are proficient to accomplish control of the ecological unsettling influences and sensor clamor.

The model size decrease method is utilized to decide the littlest states show while keeping exact portrayal of the recurrence reaction qualities. By particular qualities examination, the minimum modes which have the most commitments to the auxiliary framework reaction are chosen to fabricate the approximate decreased modular model which makes the control of the extensive states limited component model of the structures conceivable.

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