VIBRATION CONTROL ON COMPOSITE BEAMS WITH MULTIPLE PIEZOELECTRIC PATCHES USING FINITE ELEMENT ANALYSIS

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Abstract - *A smart structure can sense the vibration and generate a controlled actuation, so that the vibration can be minimized. For this purpose, smart materials are used as actuators and sensors. By changing the properties of smart materials it can sense faults and cracks and therefore are useful as an analytical tool. This characteristic can be utilized to activate the smart material embedded in the host material in a proper way to compensate for the fault. This process is called as self-repairing effect. Among all the smart materials Lead Zirconate Titanate (PZT) is used as smart material and the smart structures are taken as Carbon-Epoxy cantilever beams. In this work the simulation analysis were carried out on the carbon epoxy cantilever beams using ANSYS having different fibre orientations like 0^0,$30^0$and 60^0 with and without presence of PZT patches at multiple positions. The simulation results show the effective control in the vibration of the structure, the required decrease in the natural frequency is observed. Thus the results of this work conclude that the positioning of the PZT patch influences the natural frequency of the smart structure.*

Key Words: *Ansys, Modal Analysis, Natural frequency, Piezoelectric Material.*

1. INTRODUCTION

Most of the human activities involve vibration in one form to other form. For example, we hear because our eardrum vibrates and see because light waves undergo vibration. Breathing is associated with the vibration of lungs and walking involves (periodic) oscillation motion of legs and hands. Early scholars in the field of vibration focused their efforts on understanding the natural phenomena and developing mathematical theories to describe the vibration of physical systems. In recent time, many investigations have been inspired by the engineering applications of vibration, such as the design of machines, foundations, structures, engines, turbines, and control systems.

- If the body completes one to and fro motion about the mean position, then it is said to complete one cycle. Time taken to complete one cycle of motion is called time period and the number of cycles completed in unit time is called frequency.
- If the vibrations persuade in a member because of internal disturbances i.e., self-weight, then the persuaded vibrations is called free vibrations or natural vibrations and the related frequency is called natural frequency.
- If the vibrations persuade in a member because of external forces transmitted from the other machines or any other operations, then the persuaded vibrations are called forced vibrations and the related frequency is called forced natural frequency.
- The frequency is measured in cycles per second (Hertz).

1.1 Smart material

- Piezoelectric materials that develops a voltage when stress is applied. This result is reversible. A voltage applied to the sample will develop mechanical strain. Properly designed structures made of these materials can bend, expand or contract under the voltage.
- Thermo-responsive polymer materials that show an extreme and discontinuous change of their physical properties with temperature.
- Magneto rheological and electro rheological fluids that exhibit better viscosity under magnetic or electric field. MR fluids are made up of iron particles in oil that form chains along the magnetic field lines and they resist shearing perpendicularly to chains. ER fluids contain mineral particle rearranged in the electric field induced by high voltage, but low current.
- Ferro fluids which are liquids that become powerfully magnetized in the presence of a magnetic field. The size of particles varies ferro fluid from magneto rheological fluid. MR fluids contain micro meter-scale particles while ferro fluids have nanoparticles that are suspended by Brownian motion and generally will not settle under normal gravity conditions.
- Magneto rheological elastomers that are rubber-like materials having ferromagnetic particles, allowing the increase of stiffness under magnetic field.
- Granular materials controlled by under pressure, that exhibit important change of stiffness under atmospheric pressure when small under pressure is applied to the envelope containing granules. The increase of inter-granular friction is observed and that is why the material can be used to fill shared structural elements.

1.2. Piezoelectric material

Based on the direct and reverse effects, a piezoelectric material can act as a transducer to change mechanical to electrical or electrical to mechanical energy. When piezoelectric transducer changes the electrical energy to mechanical energy it is called as piezo-motor/actuator, and when it changes the mechanical energy to electrical energy it is called as Piezo-generator/sensor. The sensing and the actuation capabilities of the piezoelectric materials depend generally on the coupling coefficient, the direction of the polarization, and on the charge coefficients.

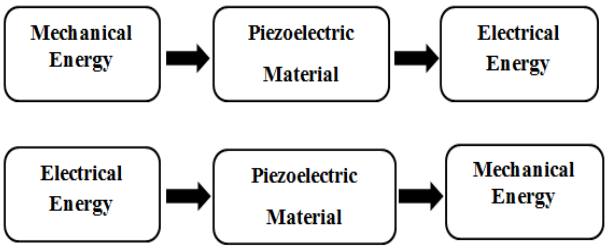

Fig- 1: Direct and Reverse effects

2. PROBLEM DESCRIPTION

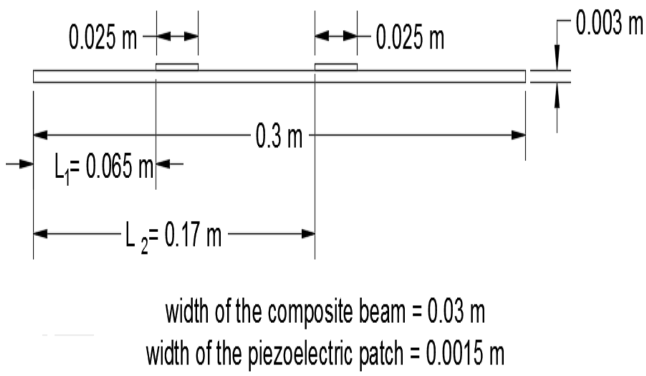

Fig- 2: Composite beam with patches at L_1=0.065 m and L_2= 0.017 m

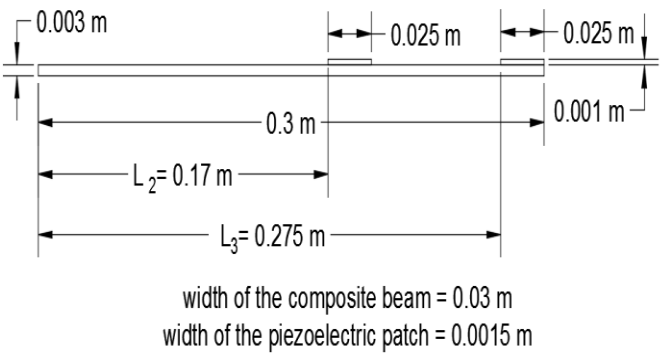

Fig- 3: Composite beam with patches at L_2=0.17 m and L_3= 0.275 m

2.1 Material Properties

Table - 1: Orthotropic Properties of the Carbon-Epoxy Composite Material

Young's modulus (E_X)	126 x10^9N/ m^2
Young's modulus (E_Y)	9.5 x10^9N/ m^2
Young's modulus (E_Z)	9.5 x10^9N/ m^2
Poisson's ratio (V_{XY})	0.263
Poisson's ratio (V_{YZ})	0.263
Poisson's ratio (V_{XZ})	0.27
Shear modulus (G_{XY})	1.07 x10^9N/ m^2
Shear modulus (G_{YZ})	0.8063 x10^9N/ m^2
Shear modulus (G_{XZ})	1.07 x10^9N/ m^2
Density	1600 kg/m^3

Table -2: Anisotropic Properties of Piezoelectric Material

Linear Elastic anisotropic properties	
D_{11}	1.26 x 10^{11} N/m^2
D_{12}	8.41 x 10^{10} N/m^2
D_{13}	7.95 x 10^{10} N/m^2
D_{22}	1.17 x 10^{11} N/m^2
D_{23}	8.41 x 10^{10} N/m^2
D_{33}	1.2 x 10^{11} N/m^2
D_{44}	2.3 x 10^{10} N/m^2
D_{55}	2.3 x 10^{10} N/m^2
D_{66}	2.35 x 10^{10} N/m^2

Table -3: Electromagnetic Properties of Piezoelectric Material

Electromagnetic Relativity Permittivity	
€$_{11}$	1.151 x 10^{-3} F/m
€$_{22}$	1.043 x 10^{-3} F/m
€$_{33}$	1.151 x 10^{-3} F/m

Table -4: Piezoelectric Properties of Piezoelectric Material

Piezoelectric constant stress matrix	
e_{12}	-5.4 C/m^2
e_{22}	15.8 C/m^2
e_{32}	-5.4 C/m^2
e_{41}	12.3 C/m^2
e_{53}	12.3 C/m^2

Density of the piezoelectric material is 7800 kg/m^3

3. SIMULATION USING ANSYS

- The composite beam is modelled by using SOLSH190 element. It is used to generate composite beam and layer thickness, material and orientation of fiber were specified. The beam is developed by using volume option and then enters the dimensions of the beam.
- The piezoelectric patch is modelled by using SOLID226 element.
- For meshing purpose mesh the composite beam and PZT patch are separately by selecting the material and element type.
- The boundary conditions were applied to fix one end of the beam to make it as cantilever.
- Modal analysis is performed by using Block Lonczos method and the required first four natural frequencies were obtained from the general post processor tool bar.
- The same procedure was repeated to obtain the frequencies by changing the orientation of fiber like 30^0,$60^0$of the composite beam.

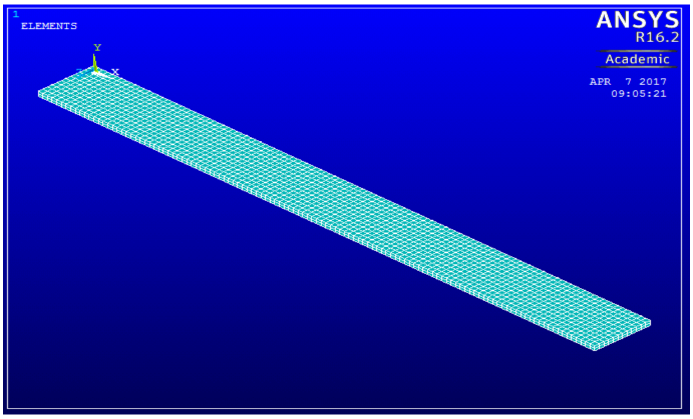

Fig -4: Cantilever composite beam

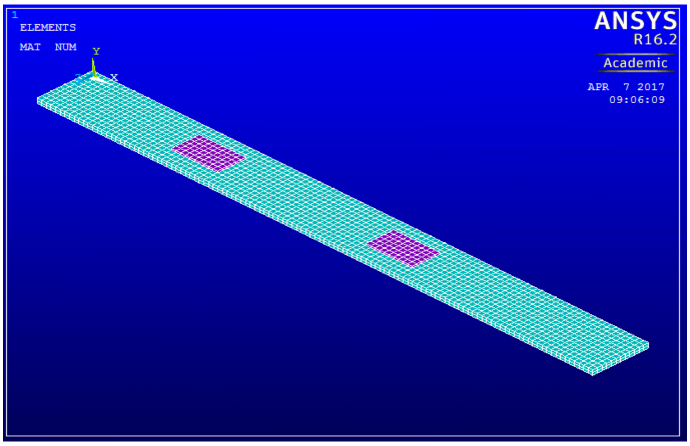

Fig -5: Composite beam with Piezoelectric patches at L_1=0.065 m and L_2= 0.017 m

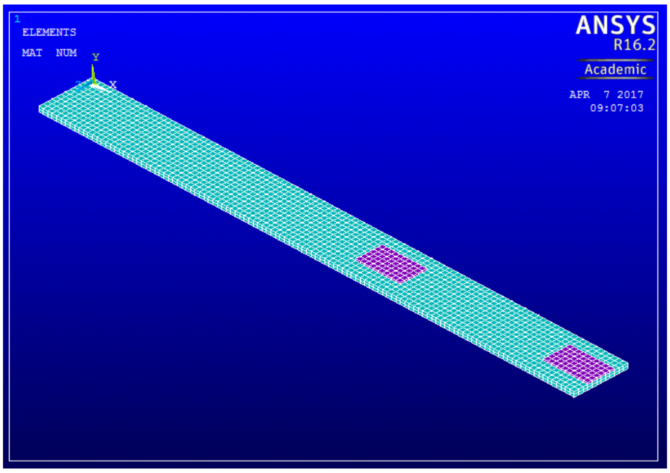

Fig -6: Composite beam with Piezoelectric patches at L_2=0.17 m and L_3= 0.275 m

3.1 Elements Types Used

3.1.1 SOLSH190 Element Description

SOLSH190 is used for simulating shell structures with a wide range of thickness (from thin to moderately thick). The element possesses the continuum solid element topology and features eight-node connectivity with three degrees of freedom at each node translations in the nodal x, y, and z directions. Thus, connecting SOLSH190 with other continuum elements requires no extra efforts. A degenerate prism option is available, but should only be used as filler elements in mesh generation. The element has plasticity, hyper elasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed u-P formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials. The element formulation is based on logarithmic strain and true stress measures.

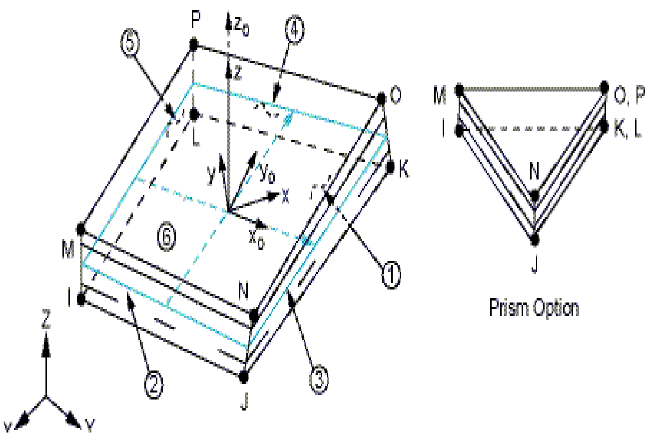

Fig -7: SOLSH190 element

3.1.2 SOLID226 Element Description

The element has twenty nodes with up to five degrees of freedom per node. Structural capabilities include elasticity, plasticity, viscoelasticity, viscoplasticity, creep, large strain, large deflection, stress stiffening effects, and prestress effects. Thermoelectric capabilities include Seebeck, Peltier, and Thomson effects, as well as Joule heating. In addition to thermal expansion, structural-thermal capabilities include the piezocaloric effect in dynamic analyses. The Coriolis Effect is available for analyses with structural degrees of freedom. The thermoplastic effect is available for analyses with structural and thermal degrees of freedom. The diffusion expansion effect is available for analyses with structural and diffusion degrees of freedom.

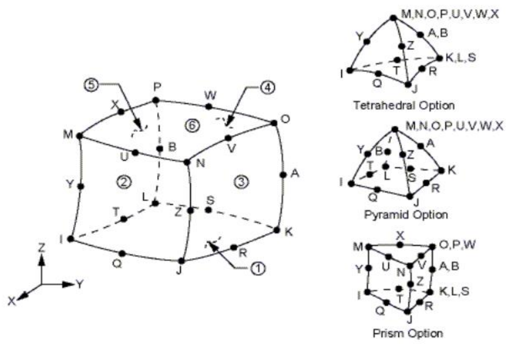

Fig -8: SOLID226 element

4. RESULTS AND DISCUSSION

4.1 Composite beams without patches

Simulation was done using ANSYS16.2 on the composite beam at 0^0 fiber orientation and then calculation of the first four Natural frequencies of the beams was carried out. Later the analysis is continued by changing the fiber orientations like 30^0 and 60^0.

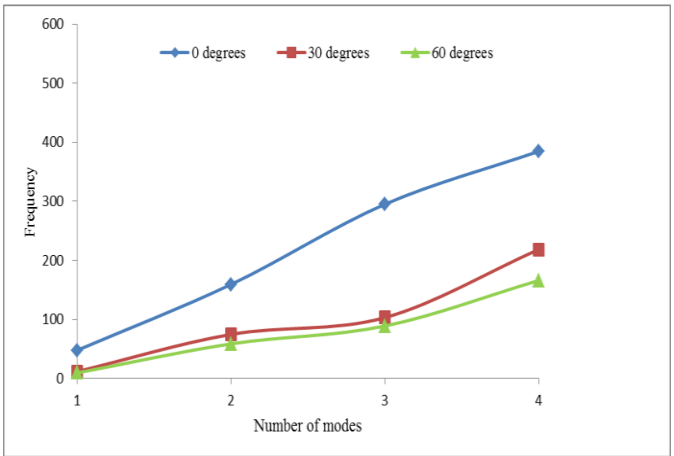

Chart -1: Modes v/s Natural Frequency at different fiber orientations like 0^0,30^0 and 60^0 without patches

The “Chart-1” shows that when the orientation of the fibres is changed from 0^0 to 30^0 and 60^0 it is observed that the natural frequency is decreases with increase in the orientation of the fibres. When the fibres are lying along the length of the beam they support maximum share load on the beam, then the strength of the beam increases.

4.1 Composite beams with patches in 0^0 fiber reinforcement

The analysis is carried out by placing PZT patch at multiple patches are placed at positions L_1=0.065m & L_2=0.17m and L_2=0.17m & L_3=0.275m.

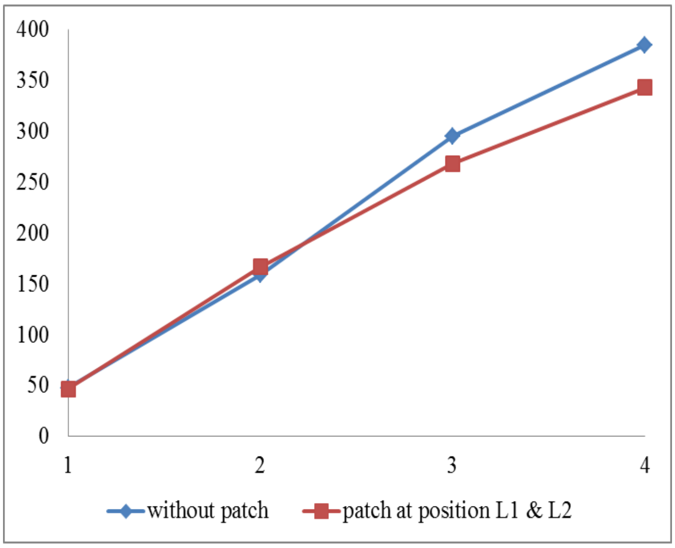

Chart -2: Modes v/s Natural Frequency with patches at positions L_1=0.065m & L_2=0.17m

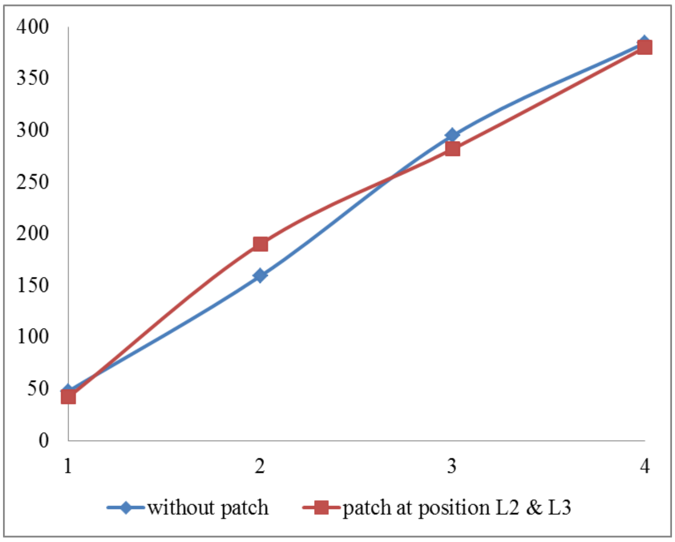

Chart -3: Modes v/s Natural Frequency with patches at positions L_2=0.17m & L_3=0.275m

4.2 Composite beams with patches in 30^0 fiber reinforcement.

The analysis is carried out by placing PZT patch at multiple patches are placed at positions L_1=0.065m & L_2=0.17m and L_2=0.17m & L_3=0.275m. It is observed that at position L_2=0.17m & L_3=0.275m more vibration is controlled.

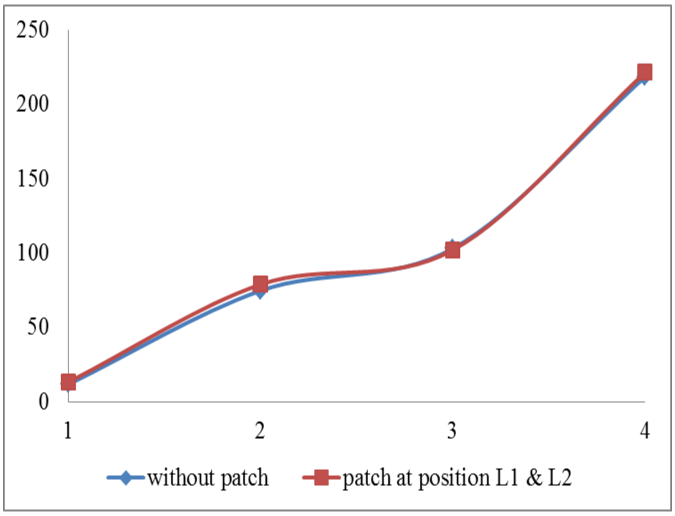

Chart -4: Modes v/s Natural Frequency with patches at positions L_1=0.065m & L_2=0.17m

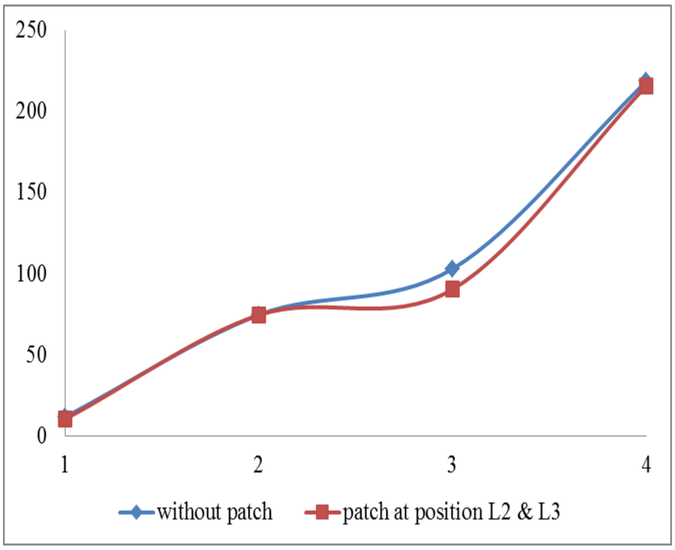

Chart -5: Modes v/s Natural Frequency with patches at positions L_2=0.17m & L_3=0.275m

4.3 Composite beams with patches in 60^0 fiber reinforcement.

The analysis is carried out by placing PZT patch at multiple patches are placed at positions L_1=0.065m & L_2=0.17m and L_2=0.17m & L_3=0.275m. It is observed that at position L_2=0.17m & L_3=0.275m more vibration is controlled.

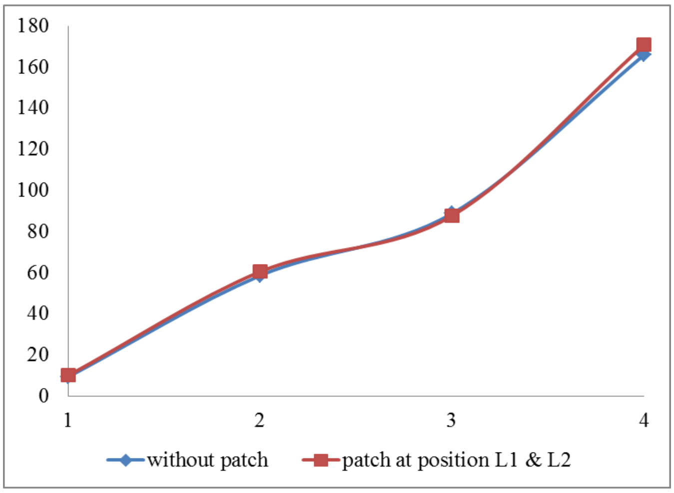

Chart -6: Modes v/s Natural Frequency with patches at positions L_1=0.065m & L_2=0.17m

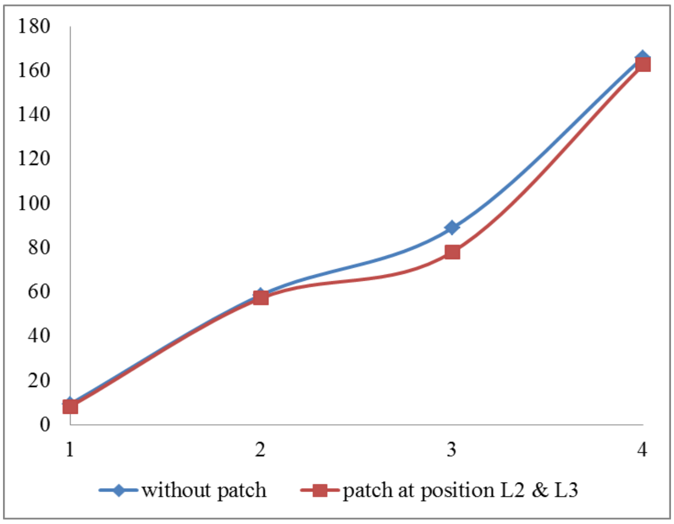

Chart -7: Modes v/s Natural Frequency with patches at positions L_2=0.17m & L_3=0.275m

5. CONCLUSIONS

In this work the carbon epoxy composite beam of dimensions 0.3m x 0.03mx 0.003m were simulated in ANSYS 16.2 keeping the orientation of fiber as 0^0, 30^0 and 60^0. The first four natural frequencies were found for all these beams with and without presence of PZT at multiple positions, it is observed that at L_2=0.17m & L_3=0.275m positions of the beams, the natural frequencies is decreases compared to the positions L_1=0.065m & L_2=0.17m from fixed end to free end of the beam. The variation in the natural frequency is observed. Hence the positions of the patches along length of the beam are influencing the natural frequencies.

In future scope the work can also be carried out by using MATLAB programing for obtaining the accurate results.

REFERENCES

1. Allik, H. and Hughes, T. J. R., "Finite Element Method for Piezoelectric Vibration," International Journal for Numerical Methods in Engineering, 2, pp. 151–157 (1970).

2. Boucher, D., Lagier, M. and Maerfeld, C., "Computation of the Vibrational Modes for Piezoelectric Array Transducers Using a Mixed Finite Element Perturbation Method," IEEE Transactions on Sonics and Ultrasonics, Su-28(5), pp. 318–330 (1981).

3. Kunkel, H. A., Locke and Pikeroen. B, "Finite Element Analysis of Vibrational Modes in Piezoelectric Ceramic Disks,"IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 37(4), pp. 316–328 (1990).

4. Ha, S. K., Keilers, C. and Chang, F. K., "Finite Element Analysis of Composite Structures Containing Distributed Piezo ceramic Sensors and Actuators," AIAA Journal, 30 (3), pp.772-780(1992).

5. Kagawa, Y. and Yamabuchi, T., "Finite Element Simulation of a Composite Piezoelectric Ultrasonic Transducer," IEEE Transactions on Sonics and Ultrasonics, pp. 81-88 Su-26(2(1979).

6. Challande, C., "Optimizing Ultrasonic Transducers Based on Piezoelectric Composites Using a Finite-Element Method," IEEE Transducers on Ultrasonics, Ferroelectrics, and Frequency Control, 37(2), pp. 135–140 (1990).

7. Tsuchiya, T. and Kagawa, Y., "Finite Element Simulation of Piezoelectric Transducers," IEEE Transducers on Ultrasonics, Ferroelectrics, and Frequency Control, 48(4), pp. 872-878 (2001).

8. Sun, F. P., Liang, C. and Rogers, C. A., "Experimental Modal Testing Using Piezo ceramic Patches as Collocated Sensor-Actuators," Proceedings of the 1994 SEM Spring Conference and Exhibits, Baltimore, Maryland, pp. 871–879 (1994).

9. Norwood, C., "The Measurement of Natural Frequencies and Mode Shapes of Submerged Cylinders Using PVDF Strip Excitation," Proceedings of Inter-Noise 95, Newport Beach, CA, pp. 1337–1340 (1995).

10. Wang, B. T., "Characterization of Transfer Functions for Piezo ceramic and Conventional Transducers," Journal of Intelligent Material Systems and Structures, 7, pp.390–398 (1996).