A PROJECT REPORT

ON

"ACTIVE VIBRATION CONTROL OF CANTILEVER BEAM"

Submitted by

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In partial fulfillment for the award of the Degree
Of
BACHELOR OF ENGINEERING
IN
MECHANICAL ENGINEERING
UNDER THE GUIDANCE
Of
Prof. Atul N. Meshram

DEPARTMENT OF MECHANICAL ENGINEERING
ANJUMAN-I-ISLAM
KALSEKAR TECHNICAL CAMPUS NEW PANVEL,
NAVI MUMBAI – 410206

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ANJUMAN-I-ISLAM

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CERTIFICATE

This is to certify that the project entitled

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To the Kalsekar Technical Campus, New Panvel is a record of bonafide work carried out by him under our supervision and guidance, for partial fulfillment of the requirements for the award of the Degree of Bachelor of Engineering in Mechanical Engineering as prescribed by **University Of Mumbai**, is approved.

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APPROVAL OF DISSERTATION

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(Internal Examiner)	**(External Examiner)**
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Date: ___________

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Chapter 1

Introduction

1.1 Introduction to Active Vibration

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. Active vibration control makes use of smart structure and smart material. Smart materials and structures refers to structures that can assess their own health, perform self-repair or can make critical adjustments in their behavior as conditions change. The system mainly requires actuators, sensors, source of power and a compensator that performs well when vibration occurs.

1.2 Need of Control of Active Vibration

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 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 than the passive controllers.

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.

1.3 Piezoelectric Materials

1.3.1 Introduction to Piezoelectric Materials

Piezoelectric materials are materials that produce an electric current when they are placed under mechanical stress. The piezoelectric process is also reversible, so if you apply an electric current to these materials, they will actually change shape slightly (a maximum of 4%). Piezoelectric materials have a recoverable strain of 0.1 % under electric field; they can be used as actuators as well as sensors.

There are two broad classes of piezoelectric materials used in vibration control: ceramics and polymers. The piezopolymers are used mostly as sensors, because they require extremely high voltages and they have a limited control authority; the best known is the polyvinylidene fluoride (PV D F or PV F2)' Piezoceramics are used extensively as actuators and sensors, for a wide range of frequency including ultrasonic applications; they are well suited for high precision in the nanometer range (1nm = 1O-9m). The best known piezoceramic is the Lead Zirconate Titanate (PZT).

1.3.2 Different types of Piezoelectric Materials

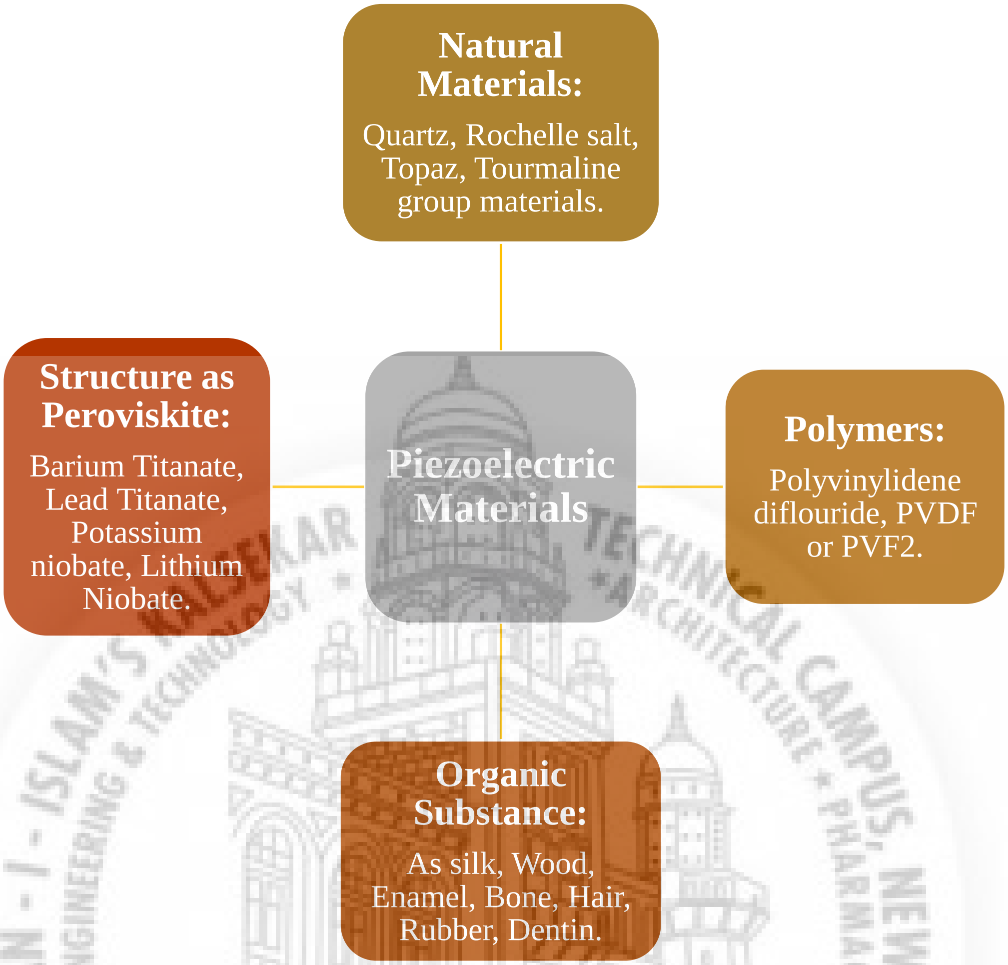


Fig No 1.3.2 Different types of Piezoelectric Materials

- **Natural Existing**

These crystals are anisotropic dielectrics with non-Centro symmetric crystal lattice. Crystal materials like Quartz, Rochelle salt, Topaz, Tourmaline-group minerals, and some organic substances as silk, wood, enamel, bone, hair, rubber, dentin comes under this category.

- **Manmade Synthetic Materials**

Materials with ferroelectric properties are used to prepare piezoelectric materials. Manmade materials are group into five main categories Quartz analogs, Ceramics, Polymers, Composites, and Thin Films. Manmade piezoelectric with crystal structure as perovskite: Barium titanate, Lead titanate, Lead zirconate titanate (PZT), Potassium niobate, Lithium niobate, Lithium tantalate, and other lead-free piezoelectric ceramics.

- ✓ Polymers: Polyvinylidene difluoride, PVDF or PVF2.
- ✓ Composites: Piezocomposites are the upgrade of piezopolymers. They can be of two types:
  - Piezo-polymer in which piezoelectric material is immersed in an electrically passive matrix.
  - Piezo-composites that are made by using two different ceramics example BaTiO3 fibers reinforcing a PZT matrix.

1.3.3 Properties of Different Piezoelectric Materials

- **Quartz**

Quartz is the most popular single crystal piezoelectric material. Single crystal materials exhibit different material properties depending on the cut and direction of the bulk wave propagation. Quartz oscillator operated in thickness shear mode of the AT-cut are used in computers, TV's and VCR's. In S.A.W. devices ST-cut quartz with X-propagation is used. Quartz has extremely high mechanical quality factor QM > 105.

- **Lithium Niobate and Lithium Tantalate**

These materials are composed of oxygen octahedron. Curies temperature of these materials is 1210 and 6600c respectively. These materials have a high electromechanical coupling coefficient for surface acoustic wave.

- **Barium Titanate**

These materials with dopants such as Pb or Ca ions can stabilize the tetragonal phase over a wider temperature range. These are initially used for Langevin -type piezoelectric vibrators.

- **PZT**

Doping PZT with donor ions such as Nb5+ or Tr5+ provides soft PZT's like PZT-5.Doping PZT with acceptor ions such as Fe3+ or Sc3+ provides hard PZT's like PZT-8.

- **Lead Titanate Ceramic**

These can produce clear ultrasonic imaging because of their extremely low planar coupling. Recently, for ultrasonic transducers and electromechanical actuators single crystal relax or ferroelectrics with morphotropic phase boundary (MPB) are being developed.

- **Piezoelectric Polymers**

  Piezoelectric polymers have certain common characteristics as Small piezoelectric d constant which makes them a good choice for the actuator. Large g constant which makes them a good choice as sensors. These materials have good acoustic impedance matching with water or human body due to their light weight and soft elasticity. Broad resonance bandwidth due to low QM. These materials are highly-opted for directional microphones and ultrasonic hydrophones.

- **Piezoelectric Composites**

  Piezoelectric composites made up of piezoelectric ceramic and polymer phases form excellent piezoelectric materials. High coupling factor, low acoustic impedance, and mechanical flexibility characterizes these materials. These materials are especially used for underwater sonar and medical diagnostic ultrasonic transducer applications.

1.3.4 Advantages

- Piezoelectric materials can operate at any temperature conditions.
- They have low carbon footprint making them the best alternative for fossil fuel.
- Characteristics of these materials make them the best energy harvesters.
- Unused energy lost in the form of vibrations can be tapped to generate green energy.
- These materials can be reused.

1.4 Active Vibration control using Piezoelectric patch

Piezoelectricity has two effect which are direct piezoelectric effect and indirect piezoelectric effect. In case of vibration control direct piezoelectric control is used. The direct piezoelectric effect is that these materials, when subjected to mechanical stress, generate an electric charge proportional to that stress.

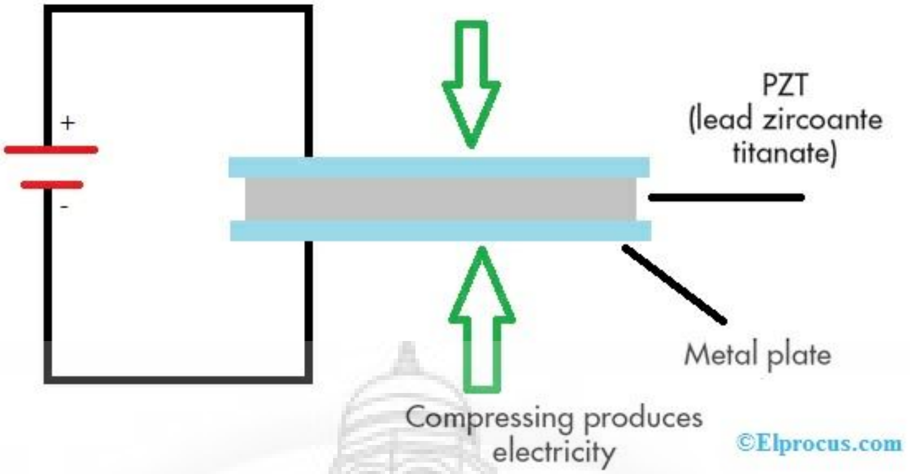


Fig No 1.3.4 Active Vibration control using piezoelectric Patch

Piezoceramic material-Nonconductive piezoelectric ceramic or crystal—is placed between the two metal plates. For piezoelectricity to be generated, it needs that material to be compressed or squeezed. Mechanical stress applied to piezoelectric ceramic material generates electricity.

As shown in Fig 1.4, there’s a voltage potential across the material. The two metal plates sandwich the piezo crystal. The metal plates collect the charges, which creates/produces voltage (lightning bolt symbol), i.e., piezoelectricity. In this way, the piezoelectric effect acts like a miniature battery, because it produces electricity. This is the direct piezoelectric effect. Devices that use the direct piezoelectric effect include microphones, pressure sensors, hydrophones, and many other sensing types of devices.

Chapter 2

Literature Review

ShravanKumar B. Kerur Et al. [1] used Simply Supported Beam made of Graphite Epoxy laminate is used & is tested for Thermal Loading (Pyro electric Effect), Beam Composition is 0/90/0/90. Beam is tested for Mechanical & Thermal Load. MFA Layer at the Top of Beam acting as actuator is used with 0 degree fiber Orientation and is tested for Mechanical, Electrical conditioned with and without Hygrothermal effect. Fiber Orientation of MFC is altered from 0 to 90 Degree and Tested for damping effect. Beam is also tested for different Voltage input. For 90/0/90/0/MFC, results are Reversing. Temperature ranging from 0 to 100 degree and Moisture Content 0 to 1% is considered. As the fiber orientation changes from 0 to Positive or Negative angle (+-90 Degree), Deflection increases. As the Voltage changes from 0 to +500, Deflection Decreases, for - Voltages, Deflection increases. In plane Stresses in x and Y direction are Studied for different fiber orientation of MFC. Introduction of temperature and Moisture results in Lateral Deflection which can be controlled by External Voltage.

ShravanKumar B. Kerur Et al. [2] use simply supported plate (PVDF/0/90/0/90/AFC) subject to time invariant UDL and transverse harmonic load. Active vibration control reaches maximum when fiber orientation angle in AFC layer is 0 degree. The actuation capability of actuator is maximum when difference between piezoelectric fiber orientation angle in AFC layer and fiber orientation angle in top substrate layer is 90 degree.

ShravanKumar B. Kerur Et al. [3] analyzed Response for cross ply (0/90/0/90) substrate with collocated and N on collocated arrangement. Active controlled response of both 0/90/0/90 and 90/0/90/0 cross ply arrangement for different piezoelectric fiber orientation angle in AFC layer are taken. The maximum damping control for collocated arrangement is better than that of noncollocated arrangement. The active control of decreases as piezoelectric fiber orientation angle in AFC varies from 0 to 90 degree. Result also show that the sign of piezoelectric fiber orientation angle in AFC layer has no effect on Actuation capability of AFC actuator for cross ply laminate. It is observed that actuation capability of actuator reaches maximum when difference between piezoelectric fiber orientation angle in AFC layer and fiber orientation angle in top substrate layer is 90 degree.

K Khorshidi Et al. [5] used a flat piezoelectric coupled circular plate with one plate host layer in middle and two identical piezoelectric layer bonded to upper and lower surface of host layer is used. LQR and FLC are both are applied to the system and dynamic equations are obtained. The piezoelectric patch is placed on actuator. For open circuit configuration, total surface charge is assumed to be 0, the sensor voltage is obtained by integrating electric field over thickness of sensor. The results indicate that output of system is reduced with LQR controller LQR method has better performance compared to FLC method Maximum voltage applied to system is less than or equal to 2.5 volt and for this voltage LQR performs better and system is more stable.

In **Zhiyuan Gao Et al. [6]** the experimental aircraft frame is made by aluminum alloy. The aircraft wing is made by epoxy resin board. The length of the experimental model is 1500 mm, the height is 160 mm, while the aircraft nose width is 500 mm, and aircraft tail width is 350 mm. Four FBG cables each contains sixteen surface-bonded FBG sensors are fixed in the aircraft frame and another 16 FBG sensors are bonded on the surface of the airfoil. Meanwhile eight groups of PZT sensors and actuators are bonded on the aircraft surface. The PZT actuator type is PZT-5H, the PZT sensor type is P51, and they are manufactured by Zibo Yuhai Electronic Ceramic Company. JZK-10 exciter is used to excite vibration. While the FBG sensors are used to obtain the vibration information.

Sharavari Heganna Et al. [7] used a smart structure which is finite and flat beam like fiber cantilever structure with PZT patches attached to surface. A simple function generator is employed to generate forced vibration. PZT patches used as vibration sensor which is subjected near a vibrator to sense vibration of structure. Output of inverter circuit is directly fed to PZT patch that is working as actuator. When PZT actuator is excited through exactly opposite waveform of that of the vibration sensor waveform, two signals, one because of forced vibrations and other from the actuators get added. If both the waveforms have same magnitude but are 180 degree out of phase their vector addition results into waveform of zero amplitude and frequency. Hence, basic mechanical vibrations present within the smart structure system are suppressed. For large structures vibration suppression within the system is very influenced by location of the PZT patches, i.e. sensors and actuators. This is observed by changing positions of the PZT vibrator and PZT actuator patch on the structure. It shows that distance between vibrator and actuator patch is directly proportional to the amplitude of structural vibrations, i.e. as distance decreases amplitude of structural vibrations decreases.

In **A.P. Parameswaram Et al. [8]** System parameter of the smart cantilever beam was obtained by subjecting the system to free vibration test. This was done to obtain critical parameter values like that of systems natural freq. stiffness, damping etc. The smart cantilever was subject to harmonic excitation at natural frequency. The piezo exciter excited the beam at its natural frequency as a results of which maximum displacement of the beam tip was observed at its free end. The maximum induced strain was developed at the fixed end and it was sensed as a voltage by the piezo sensor. Through software means, the smart beam was subjected to forced vibrations at its first natural frequency (27.05 Hz) through the PZT Exciter patch mounted at the bottom of the beam. The harmonic excitation at the systems first natural frequency ensured maximum tip deflection as well as maximum strain development at the fixed end. The model result for both experimental and simulated (LAB VIEW) were tested and validated. It is seen that when the control was initiated (at time (t)=7 s and controller gain =10), by employing strain feedback based control logic, the strain developed at the fixed end of the beam reduced from 1.5 mm to around 0.5 mm. This meant that nearly 67% reduction within the strain when active vibration control is applied. Similarly, when displacement feedback based control was applied, for an equivalent controller gain (at t = 9 s), it had been observed that displacement of the free tip of the smart cantilever beam decreases from about 0.35 cm to around 0.15 cm. this shows depletion within the vibration by about 57%.

Yusuf khan Et al. [9] made model of a cantilever beam with the single sensor/actuator in ANSYS software. And through modal analysis 10 ranks of modal frequencies and mode shapes are extracted. The beam having size of 508 x 25.4 x 0.8 mm3 and sensor/actuator of dimensions 76.2 x 25.4 x 0.305 mm3 are selected for analysis. Single pair of actuator/sensor is placed in collocated form at nearer to the root of the beam, with the sensor at the bottom surface of the beam. The element type chosen for beam is solid 45 and for piezoelectric patch is solid. Mesh size of 70 x 4 x 1, is arrived by mesh conversance study. The mathematical model of cantilever beam is made in MATLAB, with an impulse force as input at the tip, and therefore the tip deflection is output of the system. The state space matrices are constructed by using Eigen values and Eigen vectors obtained from modal analysis using ANSYS. The transient and frequency response for all 3 controllers are tested by output and state feedback. For transient response, the H-∞ controller contains a good close loop dynamic performance than LQR and LQG controller. It has been seen that in frequency response of three controllers, the amplitudes of LQR controller follow the pattern of the amplitudes of uncontrolled frequency response, the amplitude of LQG controller have considerably died down, while in case of H-∞ controller amplitude get constant at higher frequencies. The settling time for both state and output feedback is much less in H-∞ controller than LQR and LQG controller.

Giovanni ferrari Et al. [10] used One type of Macro Fiber Composite piezoelectric patch, produced by Smart Materials Corp., was chosen as actuator. Model M-8557-P1 has an active area 85 mm long, 57 mm wide and a unidirectional blocking force of 923 N. As sensors, Dura Act P-876.A15 patch transducers are used. They are 61 mm long, 35 mm wide and 0.8 mm thick, with a capacitance of 45 nF. Both sensors and actuators were glued to the carbon/epoxy surface by means of Loctite Hysol E-120HP epoxy resin. Both transducers contain as a piezoelectric element Lead Zirconium Titanate (PZT), a ceramic compound with a marked piezoelectric effect, and can be used as actuators or sensors interchangeably in a wide frequency band. The non-collocated configuration increases the effectiveness with respect to the previous collocated configuration. It is possible to approach, for the primary four resonances, reductions near to the values of 20 dB, both for the Multi SISO and MIMO configuration. The Multi SISO configuration proves effective without any modification, while in the MIMO case it is essential to introduce delays, in order to correct the detected phase lags.

Vidur V. Gundage Et al. [11] controlled the Vibrations of cantilever beam by using PZT patches. To find-out the appropriate controller for effective vibration control of cantilever beam with minimum control input. To find out the effectiveness of system when sensor placed at top and actuator at bottom and vice versa. The active vibration control of cantilever beam is done by using PZT patches in this paper. It is concluded that the SRF control method is more effective than the PID control method. The sensors placed at top and sensors placed at bottom are tested for optimized position. The sensor at top and actuators at bottom gives better performance. The main advantages: The reduction of the required space to install actuator and sensor (mechanical design). The possible use of simple control laws, such as positive position feedback. The main conclusion of this study is that the necessity to manage several sensors and actuators so as to ensure global quality of vibration rejection along the beam. More precisely, in keeping with the variability of measurements and actions, it'll be more or less easy to create the corresponding control scheme. Another aspect of this study concerns the extent of the attainable vibration reduction. Indeed, if disturbances come from the basis, it's impossible to eliminate its influence at the clamped end of the beam. In this case, the utilization of several actuators may cause a suitable compensation of their effect along an outsized section of the beam.

Jacques Lottin, Et al. [12] their work deals with the matter of efficient location of sensors and actuators encountered within the domain of active control of the flexible structure. The main conclusion of this study is that the necessity to manage several sensors and actuators so as to ensure the global quality of vibration rejection along the beam. More strictly, according to the variety of measurements and actions, it will be more or less easy to build the corresponding control scheme. Another aspect of this study concerns the level of attainable vibration reduction. Also, if disturbances come from the basis, it is not possible to eliminate its influence at the clamped end of the beam. In this case, the use of several actuators may lead to an acceptable compensation of their effect along a large section of the beam.

Fabio Botta, Et al. [13] reported that the multimode damping will be obtained by applying a counter phase load, by PZTs plates, to the external excitation. The effectiveness of the piezoelectric elements are going to be measured by the amplitude of the vertical displacement of the free end, in order that the most effective (optimal) position are going to be the location which maximizes this amplitude. A steel beam of 30 cm of length has been taken into account; with bimodal control in mind and that specialize in combinations of the primary five modes, the wavelength of the highest mode has been divided into 50 subintervals of length 3 mm, so that Δ◌ $= \Delta h = 3$ mm and 5000 different combinations for ◌ and h have been considered. For each of these, the amplitude of the response of the tip, to a periodic load, with the frequency corresponding to one of the first five Eigen frequencies has been calculated. Moreover the amplitude response to a linear combination of the previous loads has been obtained by superposition of the response to two of the Eigen frequencies. The optimal position has been chosen to be the one which corresponds to the maximum amplitude. In this work a replacement theoretical model for the optimal placement of piezoelectric plates to regulate the multimode vibrations of a cantilever beam is proposed. After an in depth description of the theoretical model, bi-modal excitation is taken into account.

Suresh Venna, Et al. [14] made a finite element model of the plate with these actuators and sensor was built and modal analysis was performed to obtain the natural frequencies, mode shapes and strain energy distributions for various modes. The mass and stiffness of the piezoelectric materials is also considered. However, the piezoelectric effect was not taken into account, as it is not required. Then, five locations are chosen randomly for the placement of the passive piezoelectric vibration absorber. Passive damping piezoelectric transducer locations are considered on the surface of the plate on which there is no sensor. This surface is chosen, as it gives more options and the transducer locations can be chosen at a place closer to the actuator, where the strain energy concentration is high in the first mode. The properties of the piezoelectric materials are obtained from the manufacturer of the piezoelectric actuators from where the actuators, sensors and vibration absorber are acquired. In addition to the mass and stiffness of the vibration absorber, the piezoelectric properties of the vibration absorber are also defined, to perform the piezoelectric modal analysis. The results obtained from electric modal analysis serve as a very good tool in determining the location of the passive vibration absorber without much effort. This method, compared to others, is more effective which enables us to predict the electrical potential that might be generated within the vibration absorber on which the quantity of damping depends directly. This method also can be utilized in optimizing not only the location, but also the dimensions and shape of the passive vibration absorber to get maximum amount of damping. This can be achieved by simply changing the size and shape of the piezoelectric vibration absorber within the finite element model on an iterative basis to seek out the configuration that gives maximum electric potential. Piezoelectric modal analysis also can be utilized in optimization of the location of the actuators and sensors for various applications to attenuate the actuation effort and to maximise the sensing capability, respectively.

Jinhua Xie, Et al. [15] in this paper, based on the transmission and equilibrium relationship of vibration energy in beam-like structures, the Galerkin weighted residual method was applied to equation discretization. An equivalent transformation of feedback element is suggested to develop the Energy Finite Element model of a composite piezoelectric cantilever beam driven by harmonic excitation on lateral direction, both systems with and without time delay are being studied. And the power input estimation of harmonic excitation is discussed for the resolution of the Energy Finite Element function and then the energy density solutions of the piezoelectric coupling beam through Energy Finite Element Method (EFEM) and classical wave theory were compared to verify the EFEM model, which presented a good accordance. Further investigation was done about the influence of control parameters including the feedback gain and arrangement of piezoelectric patches on characteristics of system energy density distribution. The EFEM gives a time-averaged and space-averaged value of energy density at the conjunction node between discredited beam elements. In modeling the piezoelectric intelligent beam, the feedback gain might be like an additional increase of the flexural rigidity of the composite beam segment; that's, greater feedback gain would offer greater reduction of system vibration level, whereas the introduction of time delay would cause complicated situations. In general, both rigidity modification and damping modification should be taken into consideration, and attention should be paid to potential problems on negative rigidity and damping numerical analysis indicates that proper design of system configuration parameters would be essential in order to achieve the best control efficiency, and how to find the optimal system parameters would be of significant value to be explored further. For the piezoelectric cantilever beam as studied by their paper, the control efficiency would be raised by arranging the piezoelectric patches near-clamped-end in position, a touch longer in size and multiplied in number.

Jinqiang Lia, Et al. [16] in the study reported here, the active vibration control of the FGPM plate with four simple support edges under uniform and non-uniform electric field will be studied. The active damping is obtained by a velocity feedback control strategy. And the effects of the distribution type, volume fraction index and the total volume fraction of piezoelectric material on the vibration control of the FGPM plate are discussed. To obtain better control effect, different distributed types of piezoelectric material are considered and the control voltage is applied on different parts of the FGPM plate for evaluation of numerical results. It shows that the piezoelectric material component in the FGPM plate can be used as an efficient active actuator with an active strategy for suppressing excessive vibrations of system. The numerical results show that the volume fraction of piezoelectric material plays an important role in the vibration control. When the piezoelectric material density increases from inside to outside of the plate one can obtain a good control result. That's because in the bending of laminate the outer layer plays a more decisive role than the inner layer in influencing on the active damping and stiffness. For the same reason, the outside control voltage applying on the upper parts of the FGPM plate is more efficient than applying on the other parts for vibration active suppression.

Hui-Shen Shen Et al. [17] Developed a mathematical model for laminated plates with integrated piezoelectric actuators and sensor accounting for geometric nonlinear in the von Karman sense. A perturbation technique is to determine the load deflection and load bending moment curves. The simple higher order shear deformation plate theory in which the transverse shear strain are assumed to be parabolically distributed across the plate thickness. The dimensionless deflation of the plate with aspect ratio and width to thickness ratio is compared with the first order shear deformation plate theory which is seen that the discrepancy is attributed to the difference of in-plate boundary condition (movable and immovable). The effect of temperature and electric field on the nonlinear behavior of the plate with the help of this several numerical were solve for unsymmetrical cross ply plate with fully curved piezoelectric actuators. It can be seen that both deflection and bending moment are increased with increase in temperature. The three electric loading cases in which seen that plate with an embedded piezoelectric layer has lower bending moments. The bending moments are significantly but deflections are hardly influenced by lamination scheme and location of the layers.

Feng Chen, Et al. [18] used an 8 node quadrilateral isoperimetric element with a laminated plate being governed by distributed piezoelectric sensor and actuator was put forward based on a negative velocity feedback control method. Vibration of a cantilever under transient excitation was controlled using non-conforming single layer triangular plate element based on Kirchhoff laminated theory. Vibrations of a beam were suppressed using a constant gain feedback control theory. AVC of piezoelectric composite cantilever is simulated through the corresponding FORTRAN finite element programs and modeling based on a linear approach. Linear quadratic regulator output feedback control use to determine control gain. The finite element is 4 node and bilinear displacement element with 24 generalized displacement degree of freedom and one electric degree of freedom per piezoelectric layer expressed in terms of nodal variable through the shape function. The FORTRAN computer program was programmed and then high precise direct (HPD) integration method was proven for solving dynamic response.

Javad Alamatian Et al. [19] two types of boundary conditions are used for analyzing the laminated plates with variable cross section i.e. simply and clamped supports. By applying the essentials of the simply supports, a system of simultaneous equations is obtained which is solved by an independent DR (Dynamic Relaxation) algorithm. The composite plates with variable crossection has been analyzed for this purpose, the CPT theory in combination with the DR approach is utilized for analyzing the laminated plates. For the first numerical study, the angle ply laminated plates i.e. (±θ) n, are analyzed in which θ varies between 0 and 90. The boundary condition is considered as SCSC. Two types of cross ply laminated plates i.e. (0/90)n and (0n /90n), are nonlinearly analyzed for different boundary conditions i.e. SSSS, CCCC and SCSC.A quasi-isotropic ply laminated compos- its plate i.e. (0/45/-45/90) n is nonlinearly analyzed for different boundary conditions. The analysis results of the laminate plates with variable cross section show that in the angle ply plates, the maximum displacement of the nonlinear analysis has low sensitivity to the cross section variation however; linear analyses results are more sensitive to the variation of cross section. In the case of cross ply laminated plates, for all types of boundary conditions, the plate’s displacement in the case of (0n/90n) is higher than the case of (0/90)n if cross section varies. Moreover, the plate’s deflection increases by reducing the cross section of the quasi-isotropic laminated plate.

Fujun Peng, Et al. [20] Used a performance criterion to propose the optimization of piezoelectric patch actuator locations on flexible plate structures based on maximizing the controllability grammian. After this the determination of parameters required for actuator location optimization through Structuring Analysis in ANSYS Finite Element Analysis Package. Genetic Algorithm is then utilized to implement the optimization. The actuators are bonded on optimized locations, a filtered-x LMS-based multichannel adaptive control is applied for suppressing vibration response of the plate. Numerical simulations are done for suppressing tri-sinusoidal response at three points of the plates. K Ramesh Kumar and S Narayanan [21] showed from the results it can be concluded that the sensor–actuator pairs are optimally located in the regions of high modal strain energy. From the results it can be noted that the control effectiveness offered by direct proportional feedback, which is a displacement feedback, is insignificant when compared to the constant gain negative velocity feedback. The study also revealed that the LQR optimal control offers an effective control with lower peak actuator voltages when compared to classical control methods.

J. Fei Et al. [22] one model using singularity approach considering two moment case is derived. The dynamic modeling and the feasibility of active vibration control scheme SRF (strain rate feedback) and PPF (positive position feedback) control for the vibration suppression of steel cantilever beam are investigated and compared. Two vibration suppression methods are used, proportional integral-derivative (PID) compensator and strain rate feedback. Suppression of the only dominant mode vibration was administered and then the best result was obtained using SRF control. The PPF control was also effective in suppressing the vibration. Both SRF and PPF control have better vibration suppression result for the beam compared to PID controller.

Juntao Fei Et al. [23] one model using singularity approach considering two moment case is derived. The dynamic modeling and the feasibility of active vibration control scheme such as PID control and SRF control for the vibration suppression of steel cantilever beam are investigated. PID controller is the type of controller of which proportional gain and derivative gain are often determined based on desired specifications and dynamics of a plant. Strain rate feedback (SRF) control is employed for active damping of a flexible space structure. The SRF controller and optimized parameter PID compensator are employed to actively suppress vibration of a flexible steel cantilever beam. Suppression of the single dominant mode vibration was carried out and the best result was obtained using SRF control. The optimized parameter PID compensator was also effective in suppressing the vibrations. SRF controller results were little better than those with the PID compensator.

K. B. Waghulde, Et al. [24] a smart beam was constructed using a Lucite beam, PZT actuator, and PVDF sensor. A dSPACE controller card was installed and integrated with related electronics to make an active control setup. First, signal was sent to the beam without the controller and data was taken and saved in dSPACE controller. Then, with the controller added in the system, the signal was sent to the beam, the actuator implemented the response from the controller due to displacement detected by the sensor, and the data was taken and saved in dSPACE controller. Both of these data sets were loaded into MATLAB and imported to MATLAB’s identification toolbox. The same procedure from above was used to obtain a model closest to the original data set and these were sent to the command window where a Bode plot showed the reduction in vibration amplitude after the controller was implemented. Experiments were conducted to control the

Vibration response to broadband disturbance. A 30% reduction in 1st-mode vibration response was achieved.

S. Gluhihs, Et al. [25] studied the behavior of the aluminum plate with the top surface bonded to piezoelectric actuators is studied in detail. The plate parameters are studied by varying the placement of the piezoelectric actuators. The plate is discredited using 10 equal coupling areas. The length of each piezoelectric actuator is the same as that of one area. The reduction of vibration in an aluminum plate under variable harmonic pressure loading with surface bonded piezoelectric actuators was studied numerically by using the commercially available ANSYS packages. A thermal load according to the thermal analogy modeled the applied voltage. By using this method, it is found that the form of torsion modes determines the optimum placement of actuators. It is also found that the length of piezoelectric actuators affects the active control of plates.

J Shivakumar Et al. [26] used an antisymmetric angle- ply smart composite plate integrated with a PFRC layer is used. PFRC is placed on the top of the plate which acts a distributed actuator. Various mechanical loads are applied on the plate to determine the variation of piezoelectric fiber orientation in the PFRC layer and nonlinear deformation. For optimum performance, fiber orientation in the PFRC layer also varies with the no of layers and stacking sequence in the substrate antisymmetric angle -ply composite plates. If the fiber orientation (θ) in the topmost layer of the substrate being integrated with the PFRC layer is positive then the fiber orientation (ψ) in the PFRC layer should be negative and vice versa for achieving maximum actuating capability of the PFRC layer.

Chapter 3

Objectives and Problem Definition

3.1 Objectives

- To Find the Optimized location of Lead Zirconate Titanate patch on E glass epoxy composite cantilever Beam.
- To Calculate the 5 Mode Shapes at Optimized Location.
- To Study the Variation in the Deflection by varying the Length of PZT patch on Cantilever Beam.

3.2 Problem Definition

- In the existing research done in the field of Active vibration control using PZT patch are focused on Optimized location of the patch and Corresponding single Mode shape.
- All the systems which existing in the space have "n" Number of natural frequency, hence "n" number of mode shapes existing. So it is necessary to have detail analysis on how the system will behave at different natural frequencies.
- Also to study Variation in the Deflection by varying the Length of PZT patch on Cantilever Beam.

3.3 Problem Solution

In this project work, Objective is to find the optimized location of Lead Zirconate Titanate PZT Material on E glass epoxy composite cantilever Beam and 5 natural frequencies and corresponding Mode shapes. This will help to understand the nature of vibration at different natural frequencies. Also focused to study the variations in the Deflection by varying the Length of PZT patch on Cantilever Beam.

Chapter 4

Methodology

First step is Finite Element Modelling of the Cantilever beam for Non-Linear analysis which will include designing the defined parameters like aspect ratio etc. will be included in Ansys software for non-linear conditions. A nonlinear analysis is an analysis where a nonlinear relation holds between applied forces and displacements. Nonlinear effects can originate from geometrical nonlinearity's (i.e. large deformations), material nonlinearity's (i.e. elasto-plastic material), and contact. These effects result in a stiffness matrix which is not constant during the load application. This is opposed to the linear static analysis, where the stiffness matrix remained constant.

As a result, a different solving strategy is required for the nonlinear analysis and therefore a different solver. Then Integration of piezoelectric patches is done on the beam. The size of the patch, thickness, fiber orientation will be determined for the present case and could be varied on basis of results. These patches are applied on simulation software. Different loading condition and boundary condition are applied on the beam for replicating different scenario and testing the performance and limit of piezoelectric material in suppression of vibration or the specified loading condition. Also calculating the response time and ability of the chosen material in handling the loading.

Fig No 4.1 Methodology of Project

At different location of patch on beam, calculating the deflection produced on the beam. The deflection on the beam will be calculated on Ansys and this result would show the maximum and minimum deflection produced on the beam. Optimum location of the piezoelectric patch is found out by simulation for the location which produces maximum damping on the cantilever beam.

The optimum location is found out for all the cases which makes gives a better output of vibration suppression then other locations. Then simulation is done for higher mode shapes which gives the results or the use of the system in real high speed application where greater suppression of vibration is requires.

Chapter 5

Layout of Active Vibration Control Using PZT materials

5.1 Cantilever Beam

5.1.1 Layout of Cantilever Beam

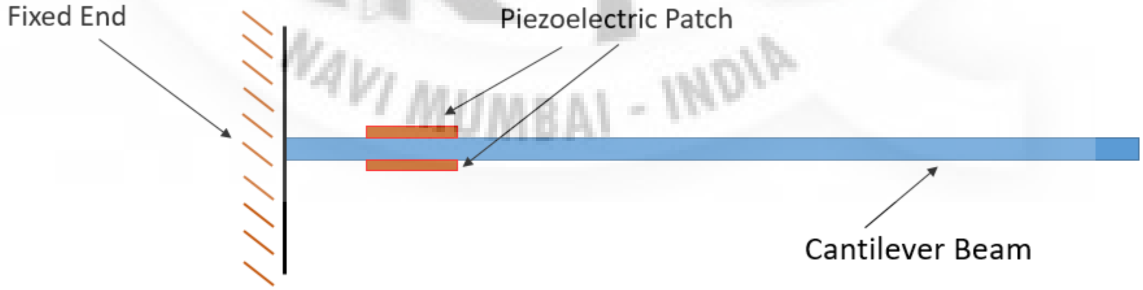


Fig No 5.1.1 Layout of Cantilever Beam

5.1.2 Specifications

Dimension of Cantilever Beam: 200 X 45 X 20mm (L X W X T)

5.1.3 Material properties

Material: Unidirectional Fiber, E-Glass Epoxy

Table No 5.1.3 Material properties of E-Glass Epoxy UD

Material properties of E-Glass Epoxy UD			
Sr. No	**Property**	**Value**	**Unit**
1	Density	2000	Kg/m^3
Orthotropic Elasticity			
2	Young's Modulus X direction	45000	MPa
3	Young's Modulus Y direction	10000	MPa
4	Young's Modulus Z direction	10000	MPa
5	Poisson's ratio XY	0.3	---
6	Poisson's ratio YZ	0.4	---
7	Poisson's ratio XY	0.3	---
8	Shear Modulus XZ	5000	MPa
9	Shear Modulus YZ	3846.2	MPa
10	Shear Modulus XZ	5000	MPa

5.1.4 Boundary Conditions

Cantilever Beam is fixed at one end and free at other End. Piezoelectric Patch is placed on the surface of the Cantilever Beam.

5.2 Piezoelectric Material

5.2.1 Lead Zirconate Titanate

Being piezoelectric, Lead zirconate titanate develops a voltage (or potential difference) across two of its faces when compressed (useful for sensor applications), and physically changes shape when an external electric field is applied (useful for actuator applications). The relative permittivity of Lead zirconate Titanate can range from 300 to 20000, depending upon orientation and doping.

Being pyroelectric, this material develops a voltage difference across two of its faces under changing temperature conditions; consequently, Lead zirconate titanate can be used as a heat sensor. Lead zirconate titanate is also ferroelectric, which means that it has a spontaneous electric polarization that can be reversed in the presence of an electric field.

The material features an extremely large relative permittivity at the morphotropic phase boundary (MPB) near x = 0.52. Some formulations are ohmic until at least 250 kV/cm (25 MV/m), after which current grows exponentially with field strength before reaching avalanche breakdown; but Lead Zirconate Titanate exhibits time-dependent dielectric breakdown — breakdown may occur under constant-voltage stress after minutes or hours, depending on voltage and temperature, so its dielectric strength depends on the time scale over which it is measured. Other formulations have dielectric strengths measured in the 8–16 MV/m range. Lead Zirconate Titanate-based materials are components of ultrasound transducers and ceramic capacitors, STM/AFM actuators.

Lead Zirconate Titanate is used to make ultrasound transducers and other sensors and actuators, as well as high-value ceramic capacitors and FRAM chips. Lead Zirconate Titanate is also used in the manufacture of ceramic resonators for reference timing in electronic circuitry. In 1975 Sandia National Laboratories created anti-flash goggles featuring PZLT to protect aircrew from burns and blindness in case of a nuclear explosion. The PLZT lenses could turn opaque in less than 150 microseconds.

Commercially, it is usually not used in its pure form, rather it is doped with either acceptors, which create oxygen vacancies, or donors, which create metal vacancies and facilitate domain wall motion in the material. In general, acceptor doping creates hard Lead zirconate titanate, while donor doping creates soft Lead zirconate titanate. Hard and soft Lead zirconate titanate generally differ in their piezoelectric constants. Piezoelectric constants are proportional to the polarization or to the electrical field generated per unit of mechanical stress, or alternatively is the mechanical strain produced by per unit of electric field applied. In general, soft Lead zirconate titanate has a higher piezoelectric constant, but larger losses in the material due to internal friction. In hard Lead zirconate titanate, domain wall motion is pinned by the impurities, thereby lowering the losses in the material, but at the expense of a reduced piezoelectric constant.

5.2.2 Dimensions

Dimensions of the PZT Patch is 50 X 45 X 5mm (L X W X T)

5.2.3 Material Properties

Material: Lead Zirconate Titanate

Table No 5.2.3 Material Properties of PZT patches

Material Properties of PZT patches			
Parameter	**Symbol**	**Values**	**Unit**
Density	ρ	7800	Kg/m^3
Dielectric loss factor	tan∂	0.02	
Compliance	S_{11}	15.0	$10^{-12}\ m^2/N$
	$S_{22} = S_{33}$	19.0	
	$S_{12} = S_{21}$	-4.50	
	$S_{13} = S_{31}$	-5.70	
	$S_{23} = S_{32}$	-5.70	
	$S_{44} = S_{55}$	39.0	
	S_{66}	49.4	

Electric Permittivity	ε_{11}^{T}	1.75	$10^{-8}\ F/m$
	ε_{11}^{T}	1.75	
	ε_{11}^{T}	2.12	
Piezoelectric strain coefficients.	d_{31}	-2.10	$10^{-10}\ m/V$
	d_{32}	-2.10	
	d_{33}	5.0	
	d_{24}	5.8	
	d_{15}	5.8	

5.3 Output Requirements

Output required in this project work is defined in terms of 3 objectives i.e. Case 1, 2 and 3. These three cases are studies using ANSYS Simulation Software.

5.3.1 Case 1: Optimum Location of PZT

Optimum Location means, the point on the Beam where Deflection will be less as compared to other Location.

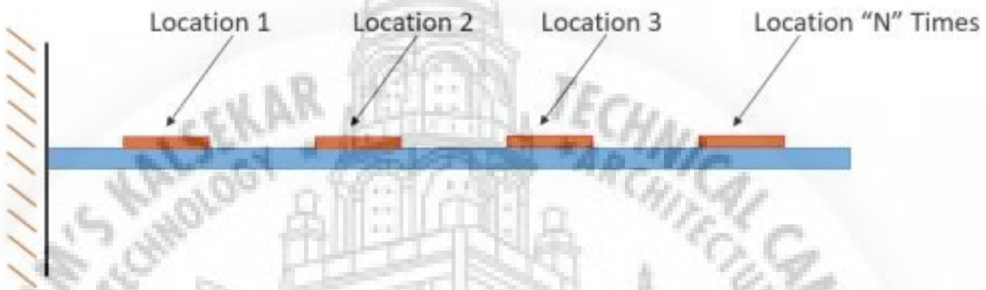


Fig No 5.3.1 Optimum Location of PZT

5.3.2 Case 2: Different Mode Shapes at Optimized Location

Mode Shape Means, At Optimized Location Beam will have "n" Number of Natural Frequencies and Mode Shapes. To Understand the Nature of Vibration, need to calculate the Mode Shapes.

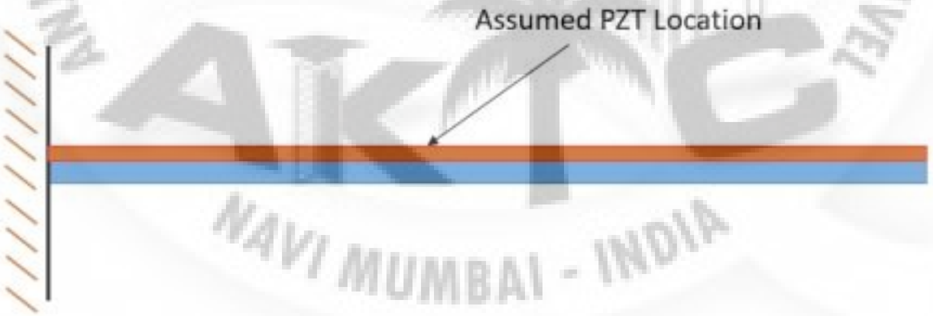
Fig No 5.3.2 Different Mode Shapes at Optimized Location

5.3.3 Case 3: Varying length of PZT patches

Case 3a: Under this case, PZT Patch length is changed to Half Length of Cantilever beam and Corresponding variation in Amplitude and frequency are Studied.

Fig No 5.3.3a Half Length of PZT Patch on Cantilever Beam

Case 3b: Under this case, PZT Patch length is changed to Full Length of Cantilever beam and Corresponding variation n Amplitude and frequency are Studied.



i

Fig No 5.3.3b Full Length of PZT Patch on Cantilever Beam

5.4 Boundary Conditions

- Multiphysics of Structural and Electric System are selected
- The E-Glass Epoxy composite cantilever beam is bonded with piezoelectric patches.
- A harmonic analysis of the beam is carried out.
- A force of 1000N with a frequency range of 1000Hz to 15000Hz is applied at the free end of the beam.
- Also, a voltage of 50V is applied on the PZT patches to generate a counterpoising force to that of the external exciting force.
- Voltage on each face of PZT crystal is coupled.

Chapter 6

Finite Element Analysis

6.1 Introduction to FEA

Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. Finite element analysis shows whether a product will break, wear out, or work the way it was designed. It is called analysis, but in the product development process, it is used to predict what is going to happen when the product is used.

FEA works by breaking down a real object into a large number (thousands to hundreds of thousands) of finite elements, such as little cubes. Mathematical equations help predict the behavior of each element. A computer then adds up all the individual behaviors to predict the behavior of the actual object.

Finite element analysis helps predict the behavior of products affected by many physical effects, including:

- Mechanical stress
- Mechanical vibration
- Fatigue

- Motion
- Heat transfer
- Fluid flow
- Electrostatics
- Plastic injection moldings

6.2 Procedure to FEA

Finite Element Analysis is a mathematical representation of a physical system comprising a part/assembly (model), material properties, and applicable boundary conditions {collectively referred to as pre-processing}, the solution of that mathematical representation {solving}, and the study of results of that solution {post-processing}.

6.2.1 Pre-processing

- Define the geometric domain of the problem.
- Define the element type(s) to be used.
- Define the material properties of the elements.
- Define the geometric properties of the elements (length, area, and the like).
- Define the element connectivity (mesh the model).
- Define the physical constraints (boundary conditions).
- Define the loading.

6.2.2 Solution

- Computes the unknown values of the primary field variable(s)
- Computed values are then used by back substitution to compute additional, derived variables, such as reaction forces, element stresses, and heat flow.

6.2.3 Post processing

- Post processor software contains sophisticated routines used for sorting, printing, and plotting selected results from a finite element solution.
- It deals with the representation of result. Typically, the deformed configuration, modes shapes, temperature, and stress distribution are computed and displayed at this stage.

6.3 Simulation using ANSYS APDL

The Ansys finite element solvers enable a breadth and depth of capabilities unmatched by anyone in the world of computer-aided simulation. Thermal, Structural, Acoustic, Piezoelectric, Electrostatic and Circuit Coupled Electromagnetic are just an example of what can be simulated. Regardless of the type of simulation, each model is represented by a powerful scripting language … the Ansys Parametric Design Language (APDL). APDL is the foundation for all sophisticated features, many of which are not exposed in the Workbench Mechanical user interface. It also offers many conveniences such as parameterization, macros, branching and looping, and complex math operations. All these benefits are accessible within the Ansys Mechanical APDL user interface.

The Mechanical APDL work flow, graphical user interface, and APDL command syntax will be introduced. With this foundation in place, users can apply this knowledge to efficiently set up, solve, and post process virtually any type of analysis.

6.4 Steps to perform harmonic analysis

- Open ANSYS Multiphysics With ANSYS APDL Product launcher
- In preference select structural and electric disciplines.
- Create element Shell--> 3D 4node181
- Create Material model for both e-glass composite and PZT material (material data is given in previous chapter)
- Create Lay-up of 20 layer for beam of composite material with each layer thickness of 1 mm and same material id.
- Create Geometry of beam as shell element and PZT Patch as Solid element for given dimension(dimensions are mentioned in above chapter)
- Now mesh all geometry with global element size 5 mm.
  - Solid geometry is meshed as Volume with sweep command for hex element.
  - Surface geometry is meshed with quad element.
- Apply boundary condition as follows:
  - Displacement on one end with value of 0 and all DOFs
  - Force in down direction of magnitude 1000N on other end of beam.
  - Apply voltage of 50 V on top surface of PZT crystal and couple all element together.
  - Apply voltage of 0 V on top surface of PZT crystal and couple all element together.

- Apply harmonic frequency range from 1000HZ to 15000 HZ with 20 sub-steps
- From Solution select solve from current LS.
- After solution is done, Plot a graph of Deformation (UY) v/s frequency for node at free end of beam.

6.5 Simulation Images

Case 1: Patch at Free End

Maximum amplitude of vibration occurs at 2866.7Hz of amplitude 1.278 mm

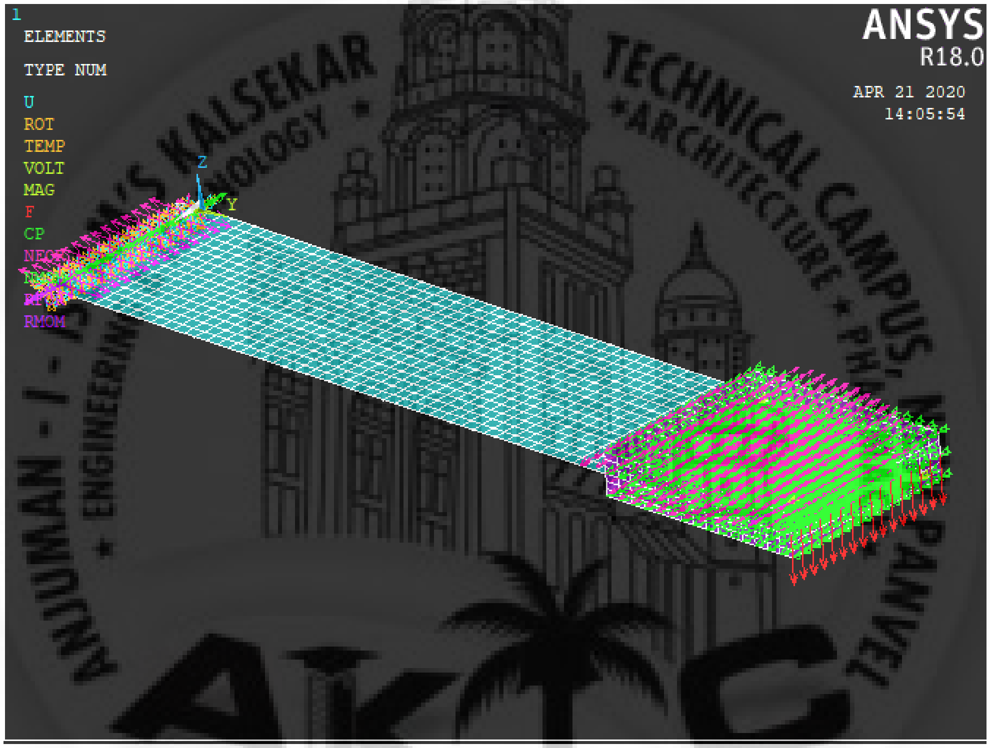


Fig No 6.5.1: Patch at Free End

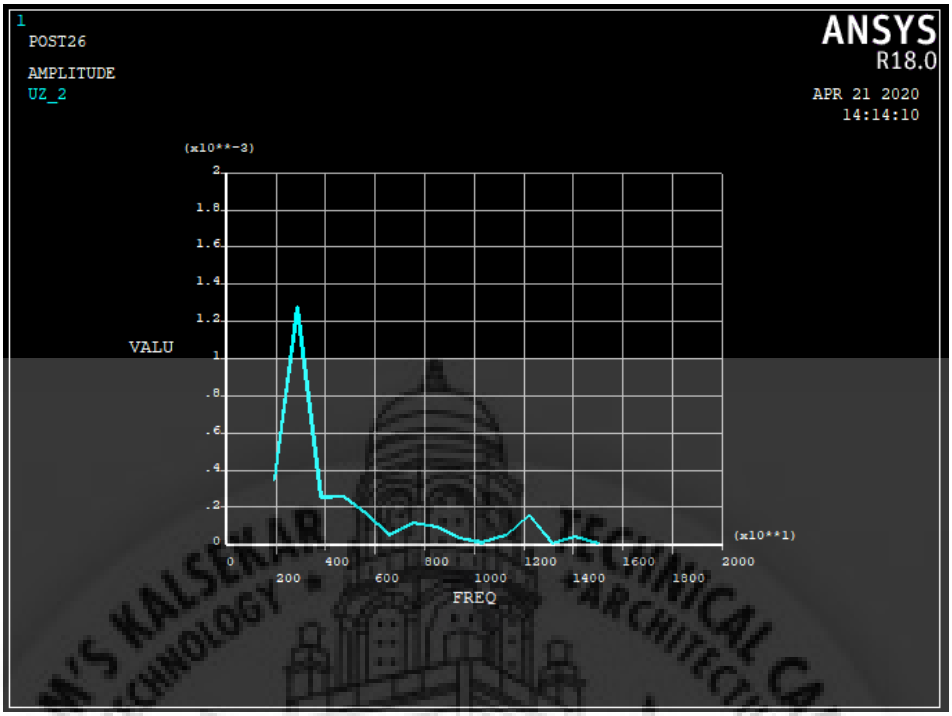


Fig No 6.5.2: Result of Patch at Free End

Case 1: Patch at Middle of the Beam

Maximum amplitude of vibration occurs at 3800Hz of amplitude 3.621 mm

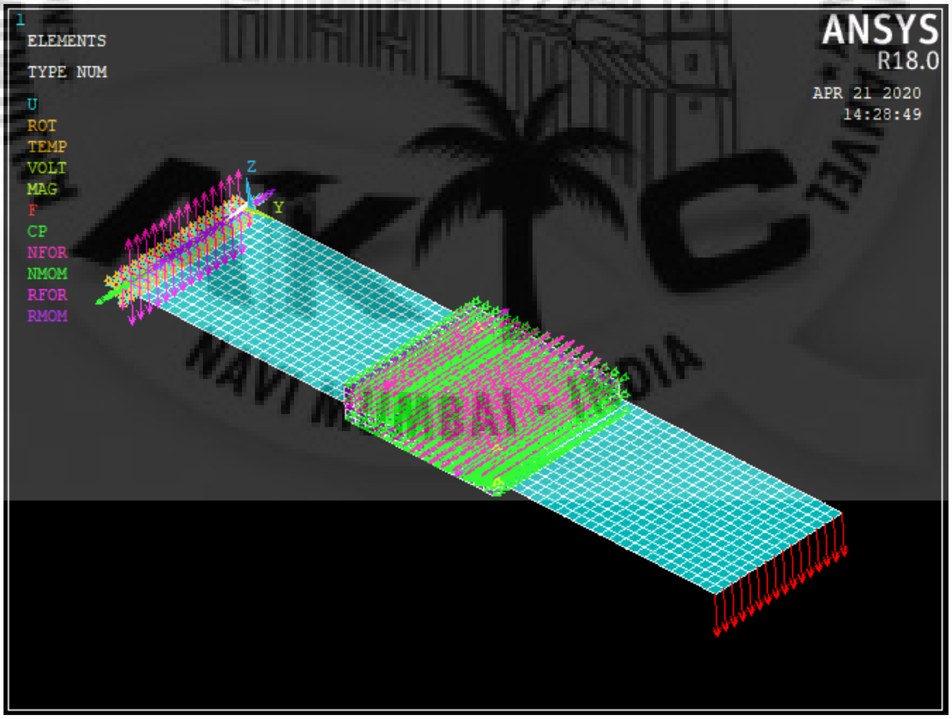


Fig No 6.5.3: Patch at Middle of the Beam

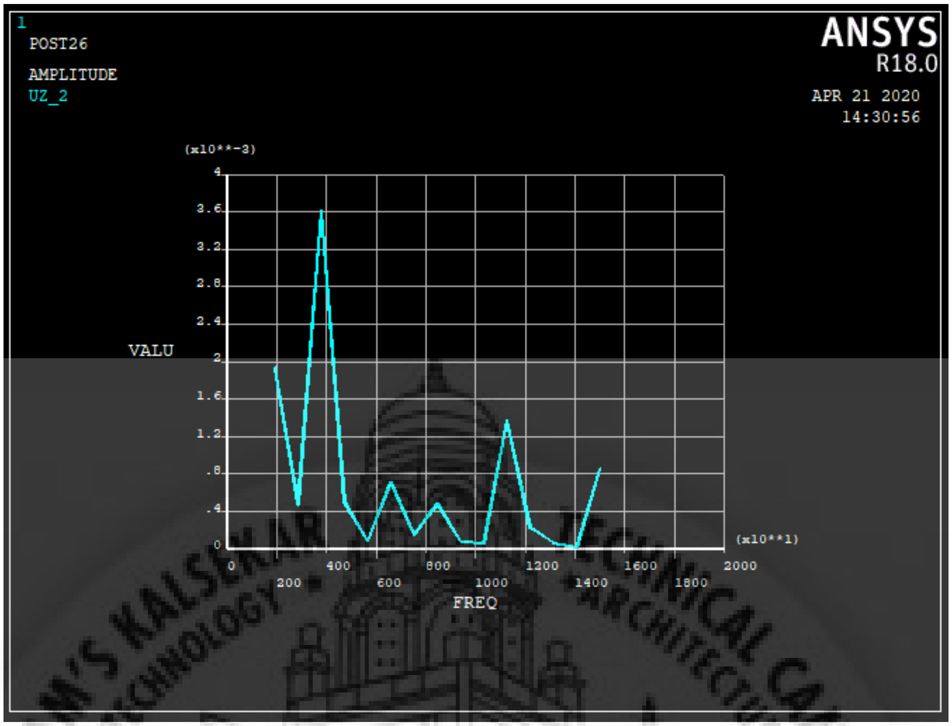


Fig No 6.5.4: Result of Patch at Middle of the Beam

Case 1: Patch at Fixed End

Maximum amplitude of vibration occurs at 2000Hz of amplitude 0.9305mm

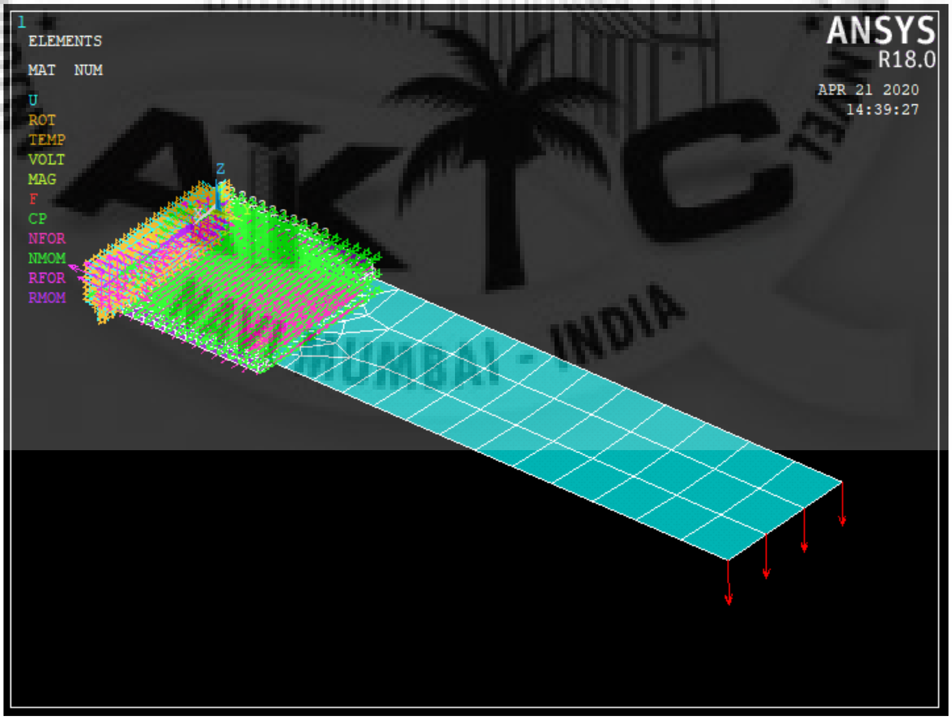


Fig No 6.5.5: Patch at Fixed End

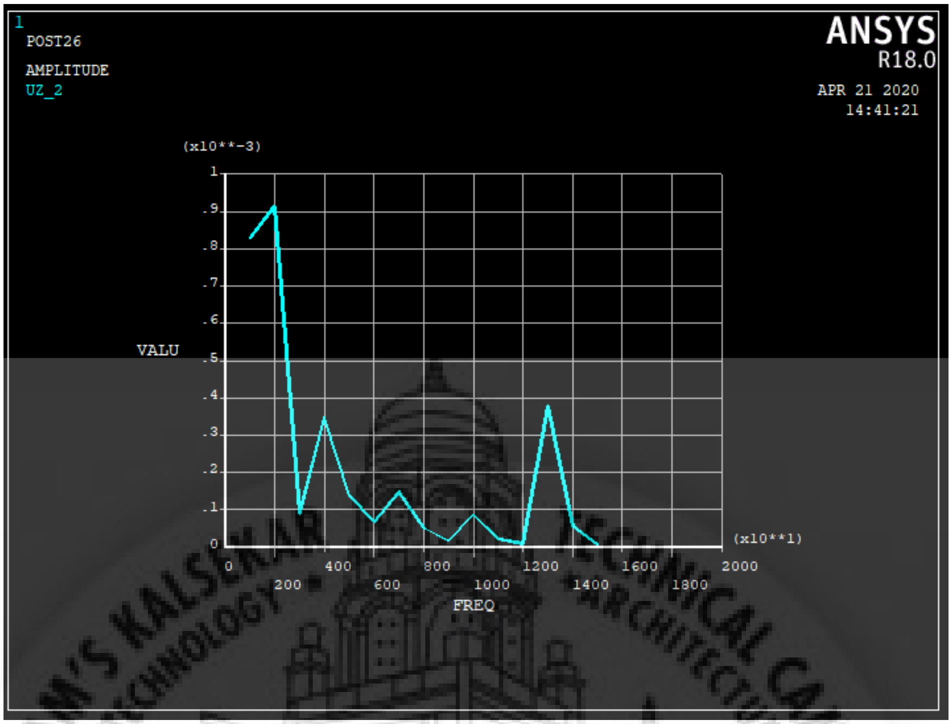


Fig No 6.5.6: Result of Patch at Fixed End

Case 2: Different Mode Shapes at Optimized Location

Mode Shape 1

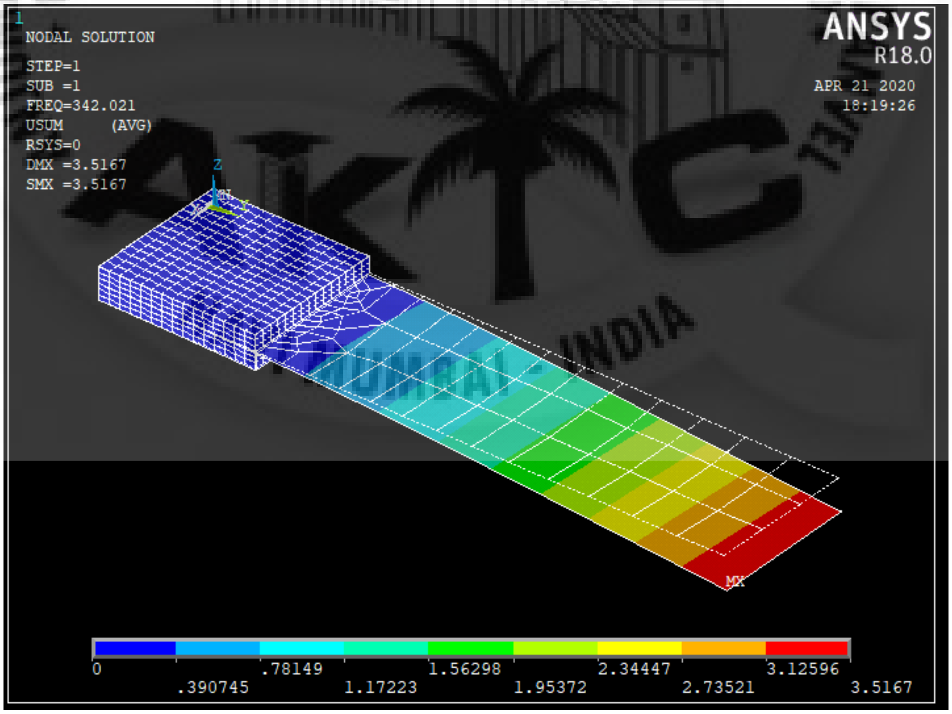


Fig No 6.5.7 Mode 1 Frequency

Mode Shape 2

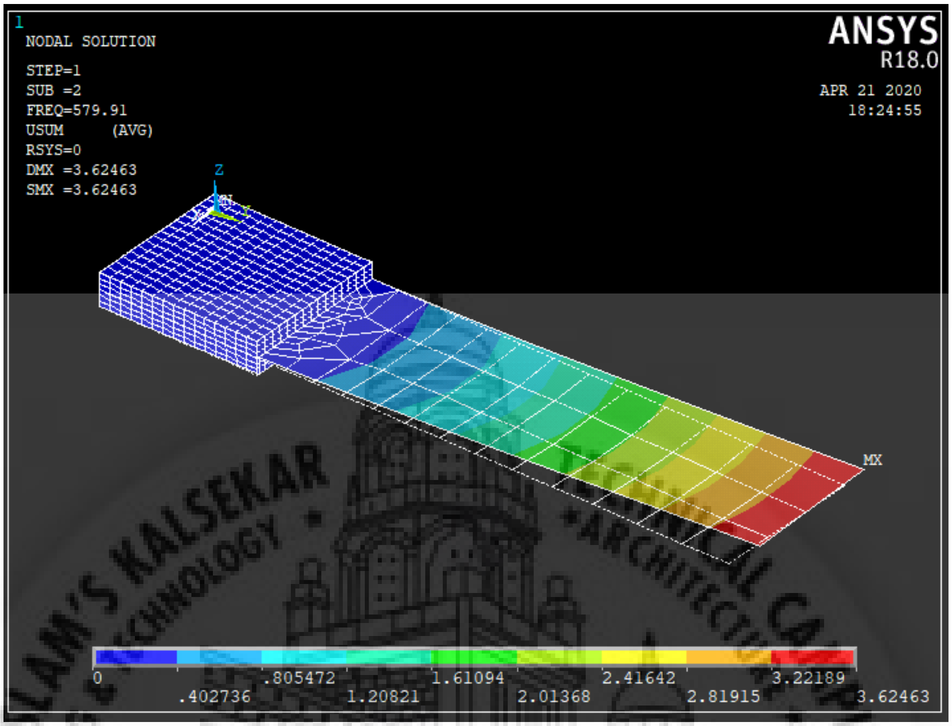


Fig No 6.5.8 Mode 2 Frequency

Mode Shape 3

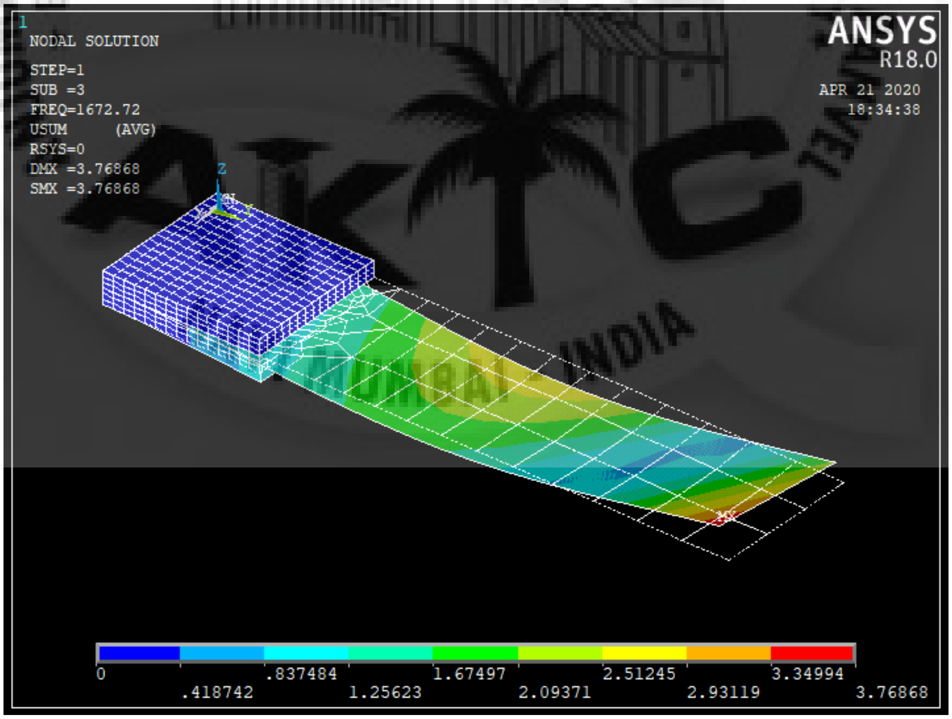
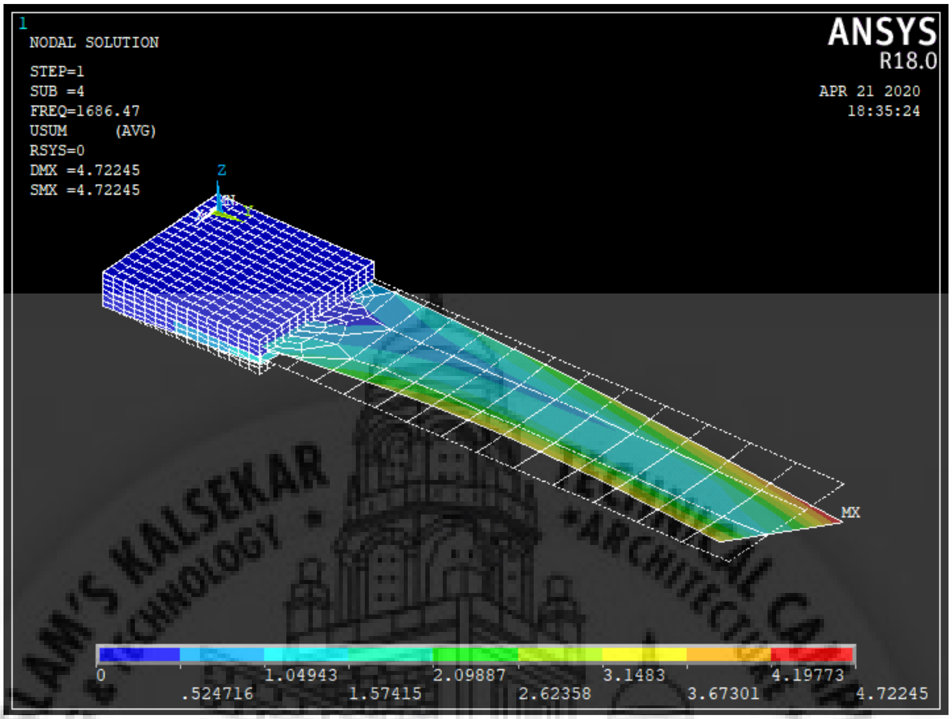


Fig No 6.5.9 Mode 3 Frequency

Mode Shape 4

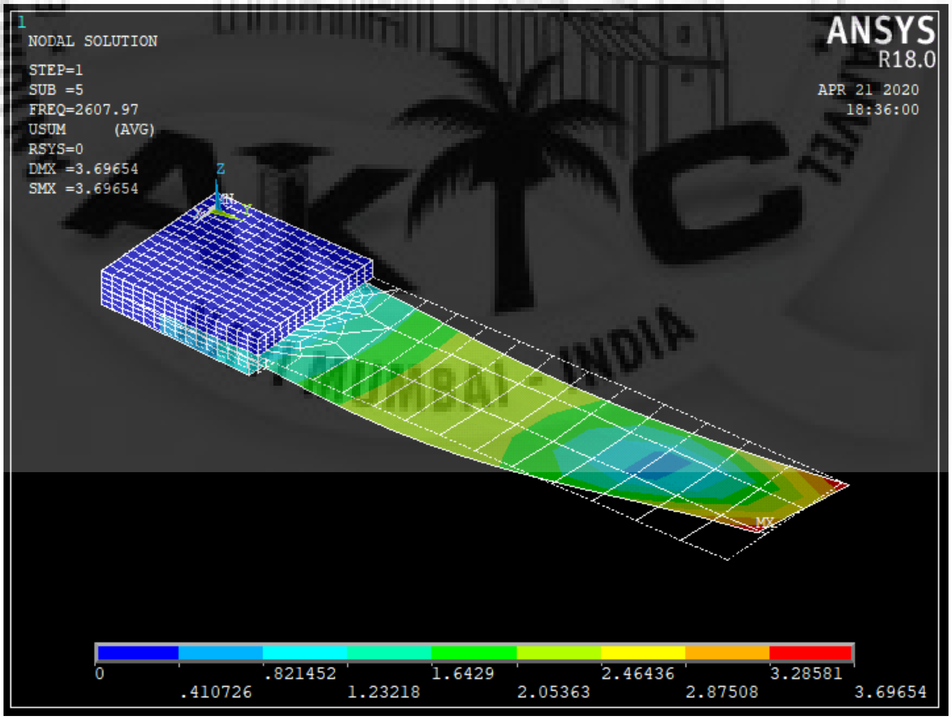


```
1
NODAL SOLUTION

STEP=1
SUB =4
FREQ=1686.47
USUM      (AVG)
RSYS=0
DMX =4.72245
SMX =4.72245
```

Fig No 6.5.10 Mode 4 Frequency

Mode Shape 5



```
1
NODAL SOLUTION

STEP=1
SUB =5
FREQ=2607.97
USUM      (AVG)
RSYS=0
DMX =3.69654
SMX =3.69654
```

Fig No 6.5.11 Mode 5 Frequency

Case 3a: PZT Patch Length Variation (Half)

Maximum amplitude of vibration occurs at 6600 Hz of amplitude 0.937186 mm

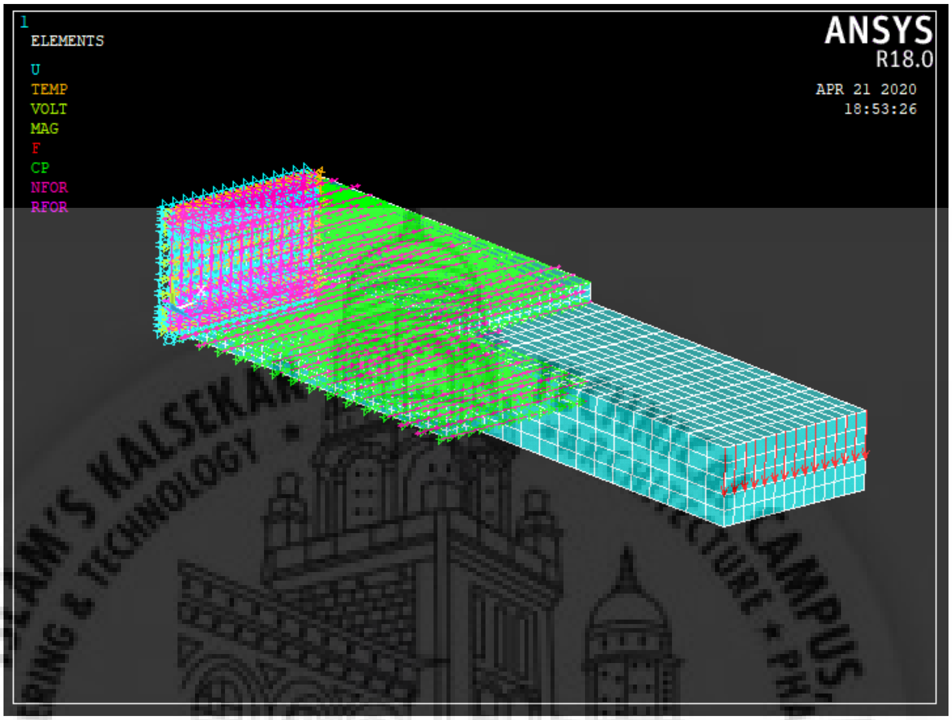


Fig No 6.5.12 Half Length Patch

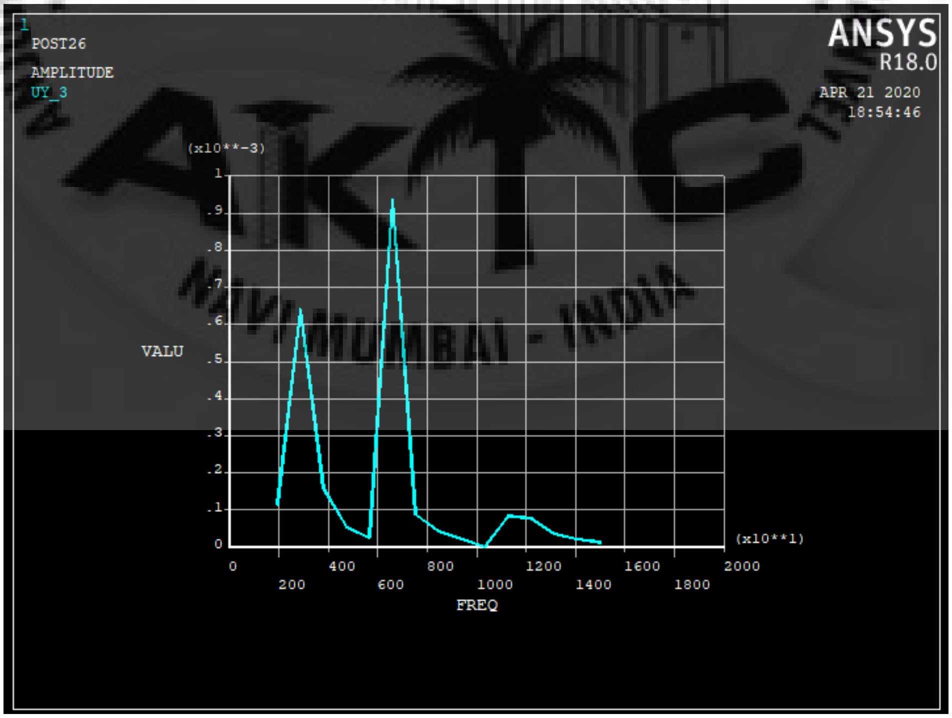


Fig No 6.5.13 Result of Half Length Patch

Case 3b: PZT Patch Length Variation (Full)

Maximum amplitude of vibration occurs at 6600 Hz of amplitude 1.22429 mm

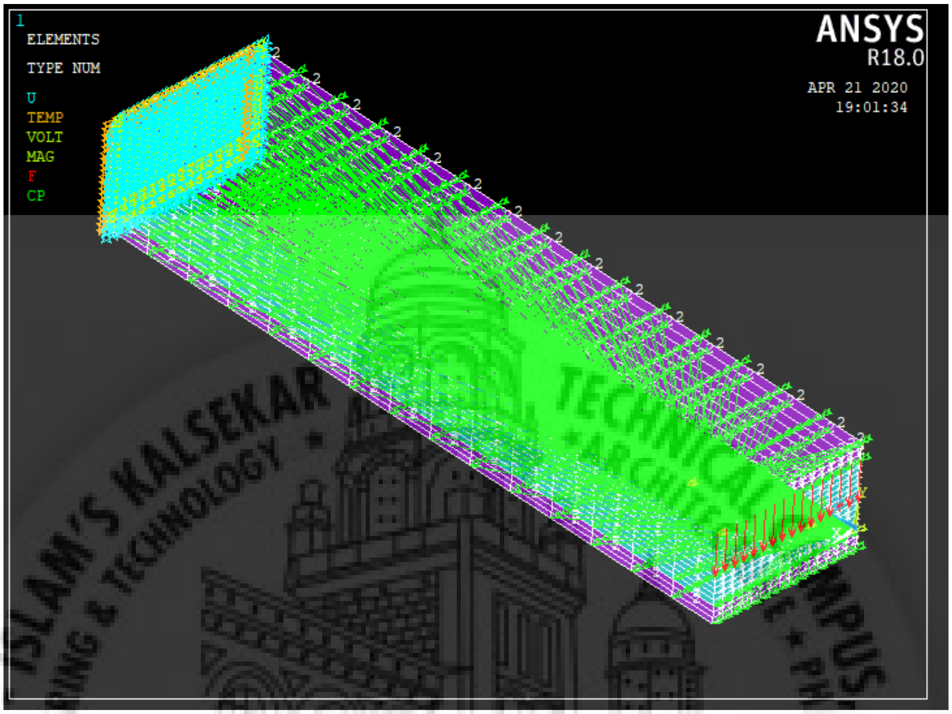


Fig No 6.5.14 Full Length Patch

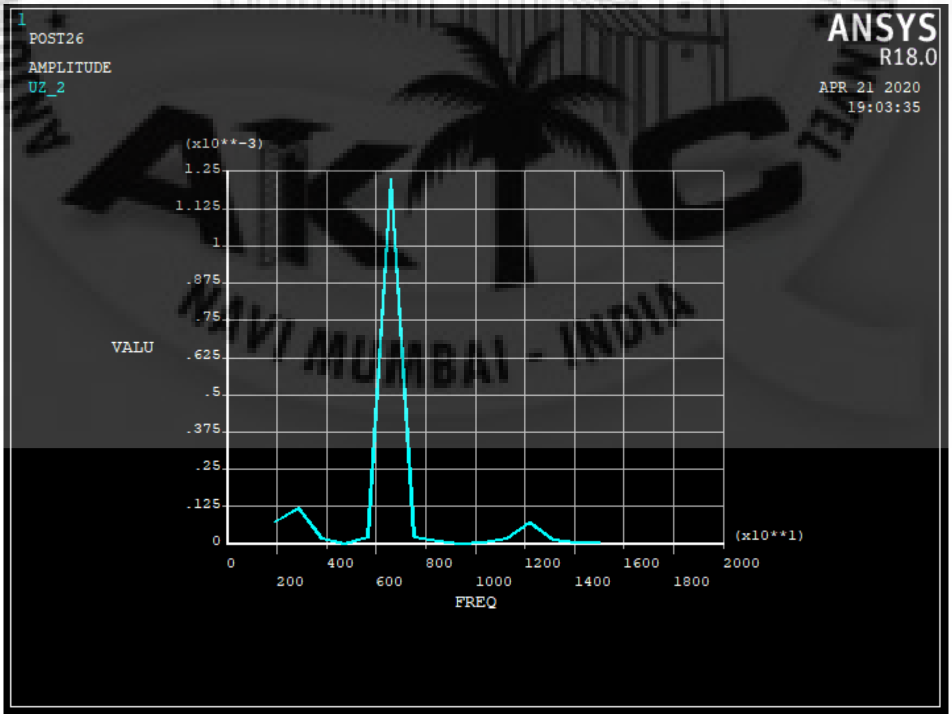


Fig No 6.5.15 Result of Full Length Patch

Chapter 7

Results, Conclusion and Future Scope

7.1 Results

Case 1: Results

Sr. No	Boundary Condition	Maximum Amplitude, mm	Frequency, Hz
1	Patch at Free End	1.278	2866.7
2	Patch at Mid Span	3.621	3800
3	Patch at Fixed End	0.9305	2000

In this simulation, it was noted that Amplitude of vibration is Maximum at particular Frequency then it's fluctuate and then it goes to zero after some frequency value. Our Objective is to calculate, at what frequency, Amplitude is Maximum. It was found from above three Simulation results, as the patch is placed nearer to fixed end, Amplitude of Vibration goes on decreasing as compared to patch at Free End.

Case 2: Results

Sr. No	No. of Modes	Maximum Amplitude, mm	Frequency, Hz
1	Mode 1	3.5167	342.02
2	Mode 2	3.62463	579.91
3	Mode 3	3.76868	1672.72
4	Mode 4	4.72245	1686.47
5	Mode 5	3.69654	2607.97

Case 2 results shows that, 5 Natural Frequencies of the system when patch is placed at the fixed end. When external force frequency is near to any of the natural frequency, it will deform in the nature of its mode shape. It’s also helps to find the safe frequency range to avoid the resonance stage.

Case 3: Results

Sr. No	Boundary Condition	Maximum Amplitude, mm	Frequency, Hz
1	Half Length Patch	0.937186	6600
2	Full Length Patch	1.22429	6600

In both the cases, the frequency for maximum amplitude occurs at 6600 Hz. This means that, Safe Frequency range increase from 2000Hz from case 1 to 6600Hz of Case 3. But the value of vertical deformation i.e. maximum amplitude occur for full length of patch is more than half length Patch. Thus half-length PZT patch is more suited for vibration control activity.

7.2 Conclusion

- Application of Lead Zirconate Titanate PZT Patch on Cantilever beam decreases the magnitude of Maximum Deflection compared to non-use of PZT Results.
- It is also found that, in some cases frequency at which maximum amplitude occurs also moved to higher range because of use of PZT Patch, Which results into increase in safe range of frequency i.e. Resonance occurs at high frequency levels.
- Mode shapes also helps to find the resonance frequency & nature of failure occurs if external frequency reaches the resonance level.

7.3 Future Scope

- This research project has huge future scope because of latest research idea and non-availability of content.
- This research work can be extended in number of ways
    - By changing the material of Cantilever beam.
    - By changing the material of PZT Patch.
    - By Changing the Thickness of PZT Patch.
    - By Changing the Voltage input to PZT Patch.
    - By Changing the Cross section of Cantilever beam i.e. I section, T Section etc.
    - By Changing the Boundary conditions of Cantilever Beam.
    - By testing it in Vacuum or Temperature Conditions.

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