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Beam Vibration Control Using Active Isolation System

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ABSTRACT

Vibration is the study of oscillatory motions. It can be useful as well as harmful at the same time, depending on the engineering objective. In the past, engineers worked on damping out unwanted vibrations using passive isolators mainly consisting of spring, damper, rubber, fleet, cork, etc. With an increasing demand for safety and comfort, these passive methods need a system that can work in a synchronized manner and make the system to be more resilient and faster in terms of response to incoming vibration. The term coined for this purpose was Active Vibration Control Technology, which has already been implemented in various fields of importance such as aerospace structures, the aviation industry, robotic arms movement manipulation, suspension rebound controlling, and active engine mounts in automobiles, etc. This paper presents the methodology of an active control scheme for vibration suppression of a rigid aluminum cantilever beam with bonded linear actuators and sensors. The PID output feedback-based active vibration control has been implemented on a cantilever beam using an accelerometer sensor (MPU6050) and a linear actuator to control the forced vibrations produced by the eccentric mass motor exciter at the free end.

Keywords: Modal Analysis, Harmonic Analysis, ANSYS, Arduino UNO, PID Control Algorithm, Actuation.

1. INTRODUCTION

Vibration plays a significant role in various fields such as music, sound propagation, sand strainer machines, and vibration therapy. However, excessive and loud vibrations can be uncomfortable, cause damage to structures, and accelerate the deterioration of machine components like gears and bearings. Resonance occurs when the natural frequency of a system matches the frequency of external stimulation, resulting in excessive amplitude vibrations. It is therefore crucial for designers to determine the natural frequency of a system to prevent resonance-related issues. Therefore, a thorough understanding of mechanical vibration is essential for engineering students and practitioners in disciplines like aeronautical, mechanical, and civil engineering. In the context of "Beam Vibration Control Using Active Isolation System," the study focuses on a cantilever beam with an exciter attached to its free end, causing transverse vibrations along its entire length. The goal is to develop a system that can analyse and detect the beam's motion and counteract it by applying an equal magnitude of force/vibration with a phase difference.

1.1 Road Map

The process begins with model formulation, where a visual analysis is conducted to define the problem and establish a suitable structure. In this case, a cantilever beam is chosen to represent various cantilevered structures like aircraft wings and control arms. Structural analysis is then performed using tools like ANSYS Workbench to determine internal forces, stress, strain, and deflection. Modal analysis is utilized to study the dynamic properties and vibration characteristics of mechanical structures. Harmonic response analysis is utilized to simulate how a structure responds to sinusoidal dynamic loading. After simulation, the model is fabricated into a physical 3D object, and sensors, actuators, and exciters are implemented. This allows for the validation of the simulated results. Finally, the obtained results are analysed, and any necessary modifications or rectifications are made to the design or control structures. The idea is then concluded with the successful execution and mapping of results.

1.2 Methodology

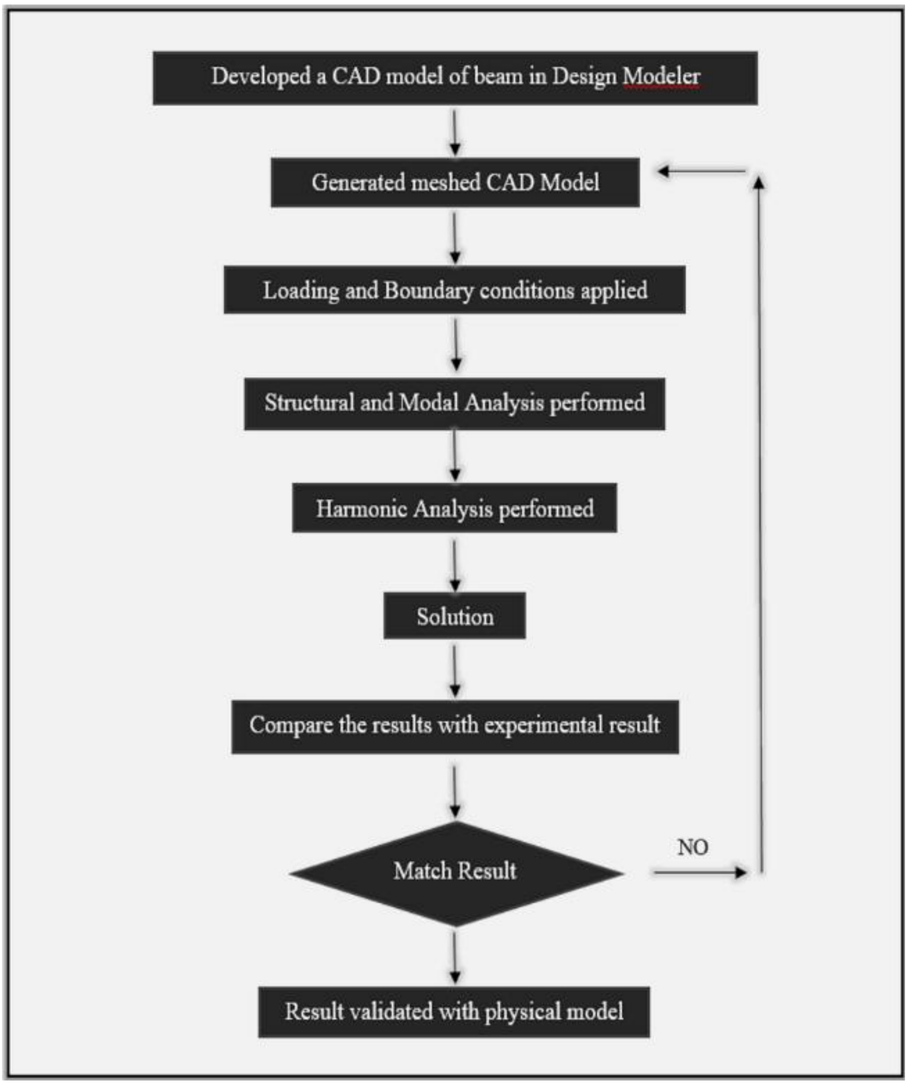


Fig no 1. Flow Chart of methodology adopted

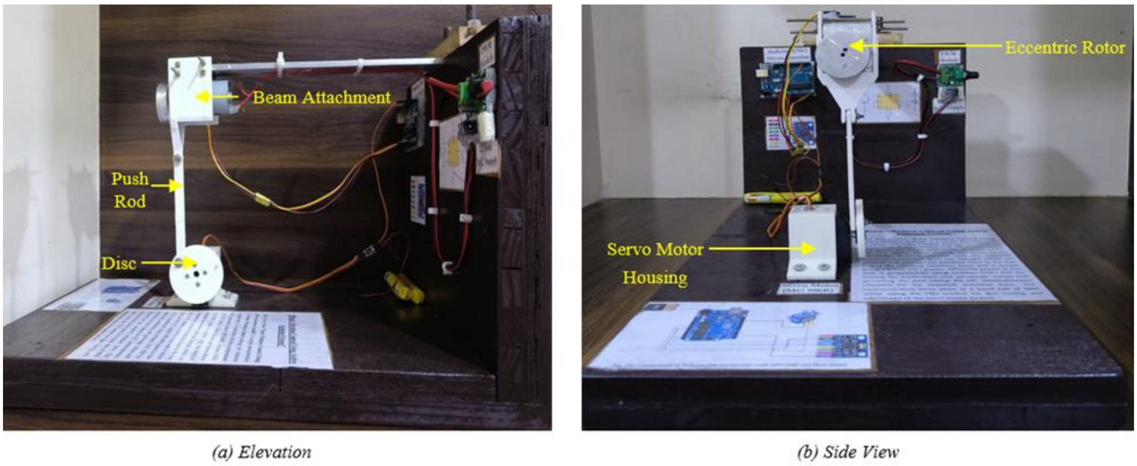
The purpose of the entire process is to create a comprehensive understanding of the beam's behaviour by developing a CAD model, generating a meshed model, applying loading and boundary conditions, and conducting structural, modal, and harmonic analyses. Structural analysis reveals internal forces, stress, strain, and deflection in the beam under applied load conditions. Modal analysis helps identify the dynamic behaviour of the beam at different modes of vibration or natural frequencies, aiding in the identification of potential resonance conditions. The harmonic analysis simulates the beam's response to sinusoidal dynamic loading, providing insights into its steady-state behaviour. Through these analyses, the aim is to accurately predict and refine the beam's performance under different loading and vibrations. The results are then compared with experimental data and validated using a physical model, ensuring the reliability of the analysis. This thorough approach ensures a robust design and enhances the beam's performance.

1.3 Material Selection Parameters

A cantilever beam made of aluminium is chosen for its low molecular density of about 2710 kg/m3, which helps prevent excessive bending due to its own weight. Aluminium is also preferred over steel due to its lower stiffness and higher ductility, allowing for a better representation of vibrations. The wooden base is utilized because wood frames have a high damping capacity due to their viscoelastic material properties, effectively converting mechanical energy into thermal energy. This high damping capacity helps reduce vibration amplitude and the time for vibrations to dissipate after an impulse. In contrast, metal frames (steel, titanium, aluminium) made of highly elastic materials have very low damping capacity and do not naturally dampen vibrations as effectively as wood does. The combination of an aluminium cantilever beam and a wooden base ensures a robust design that minimizes vibrations and enhances the overall performance of the system. The project involves the use of various electronic accessories like a PWM module is employed to control the excitation force generated. The MPU6050 accelerometer module is used to detect changes in motion, measure vibrations, and determine the beam's orientation and velocity. An Arduino UNO microcontroller board is utilized, which serves as the main control unit, receiving inputs from sensors and making decisions based on programmed instructions.

Metal	Molecular Density (kg/m³)
Aluminium	2710
Steel	7750-8050
Copper	8940
Bronze	8300-9500
Brass	8400-8700
Titanium	4500

Table no 1. Molecular Density values for different metals



(a) Elevation *(b) Side View*

Fig no 2. Beam assembled with sensor, microcontroller and actuation mechanism

1.4 ANSYS Analysis

The Cantilever beam is modelled in ANSYS Design Modeller and then Modal analysis is performed in ANSYS Mechanical, which focused on identifying the natural frequencies and mode shapes of the system. By studying the dynamic behaviour of the structure, this analysis provided information on the system's response to vibration and resonance, also deflection at different natural frequencies is found. The main purpose of finding out the natural frequencies is to prevent the resonance condition.

Mode	Natural Frequency [Hz]
1.	31.365
2.	203.95
3.	229.09
4.	386.94

Table no 2.Resonant Frequencies.

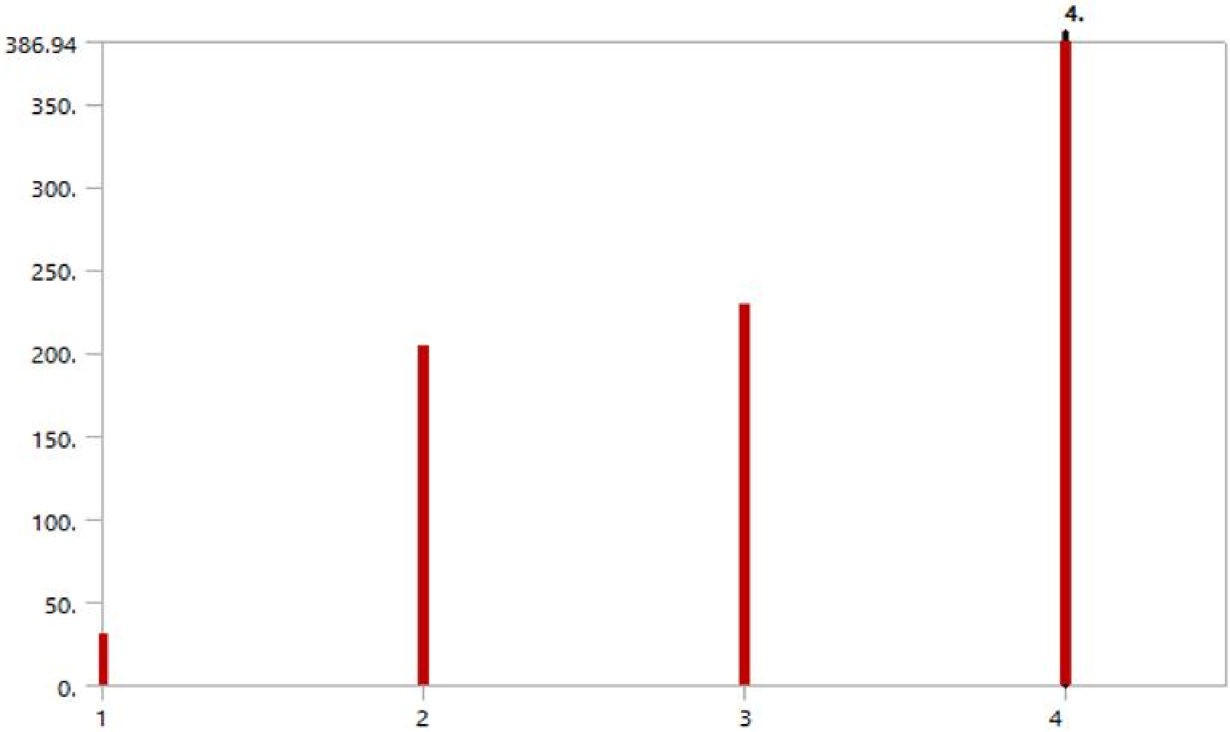


Fig no 3. Graphical representation of all mode shapes of beam

The maximum and minimum deformations in all the mode shapes are depicted in the modal analysis which is shown below. The maximum deformation in 1st, 2nd, 3rd, and 4th mode shapes are 123.38 mm, 123.07 mm, 188.86 mm, and 223.02 mm respectively.

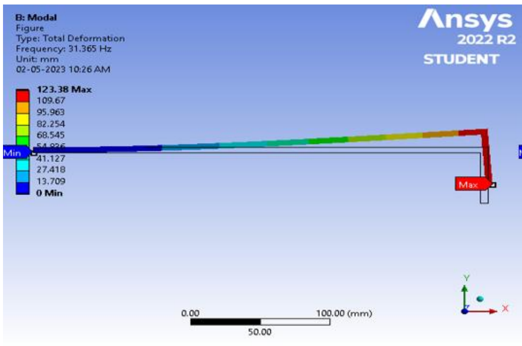

B: Modal
Figure
Type: Total Deformation
Frequency: 31.365 Hz
Unit: mm
02-05-2023 10:26 AM

Fig no 4. First mode shape of beam

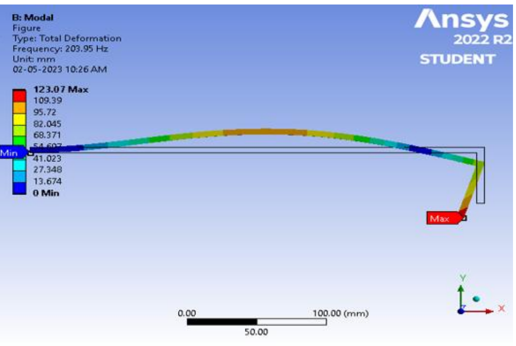

B: Modal
Figure
Type: Total Deformation
Frequency: 203.95 Hz
Unit: mm
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Fig no 5. Second mode shape of beam

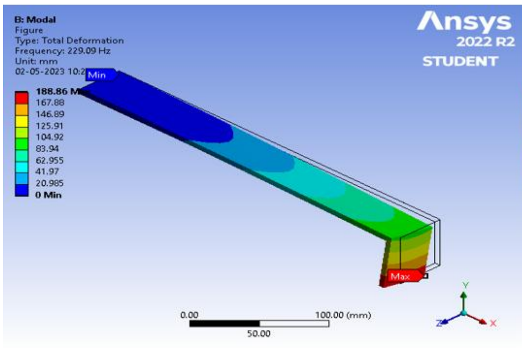

B: Modal
Figure
Type: Total Deformation
Frequency: 229.09 Hz
Unit: mm
02-05-2023 10:2

Fig no 6. Third mode shape of beam

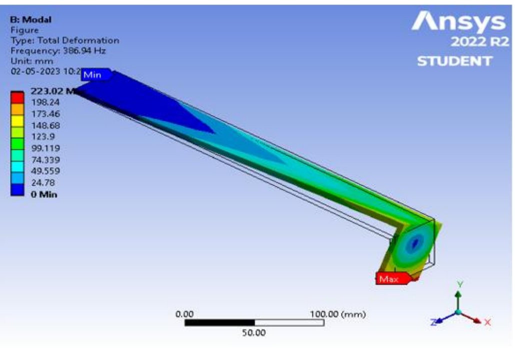

B: Modal
Figure
Type: Total Deformation
Frequency: 386.94 Hz
Unit: mm
02-05-2023 10:2

Fig no 7. Fourth mode shape of beam

The Harmonic analysis is further explored for the response of the structure to harmonic excitation. It helped identify the characteristic curves, which depict the relationship between the applied harmonic load and the resulting deformation. These findings are crucial for understanding the structural properties, deformation patterns, natural frequencies, and mode shapes of the system under different conditions.

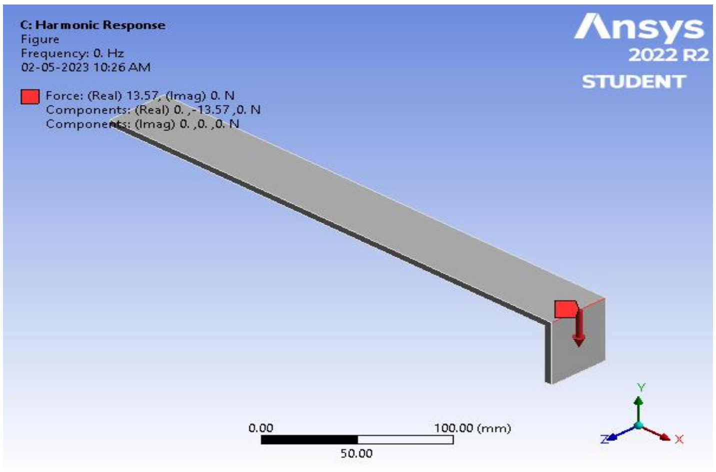


Fig no 8. Harmonic Force applied at the free end

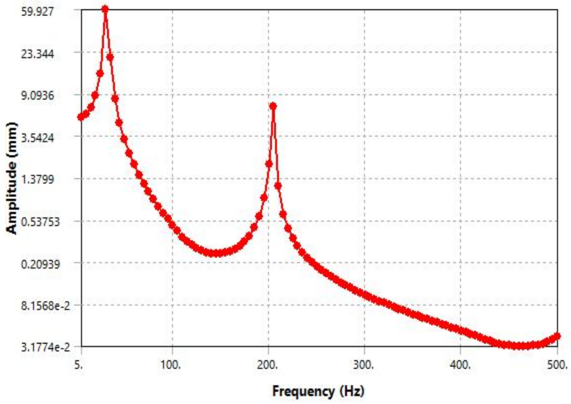


Fig no 9. Frequency Response Curve 1

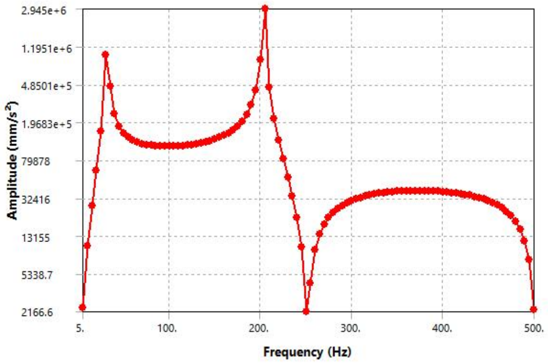


Fig no 10. Frequency Response Curve 2

From the frequency response curve 1 and 2, it can be seen that the maximum amplitude of 59.927 mm is attained at 30 Hz frequency. So, we need to develop such an actuation mechanism that can counteract all these frequencies and their respective amplitudes for constraining the motion of the beam in the transverse direction.

2. ACTUATION AND CONTROL MECHANISM

The beam's behaviour was analysed using the MPU6050 sensor, Arduino microcontroller, and IDE. The Arduino microcontroller processes the data and uses the serial plotter feature of the Arduino IDE to print the vibration amplitudes. The gyroscopic and acceleration values are captured in the X and Z axes, respectively, and plotted in the serial monitor and plotter. The servo's rotation is transferred through a disc and a push rod, which is connected to an attachment at the free end of the beam using a turning pair, allowing smooth motion transfer. Now the developed feedback mechanism-based control loop system works by implementing PID (Proportional Integral Derivative) algorithm which sets up an Arduino microcontroller to control a servo motor based on readings from an MPU6050 sensor. In the loop function, it continuously retrieves the accelerometer and gyroscope values from the sensor, converts them to appropriate units, calculates errors by comparing them with set points, and uses a PID control algorithm to compute an output. This output is then adjusted and constrained to control the servo motor's position. In summary, the system's compatibility was successfully tested, and the vibration amplitudes were plotted using the Arduino's serial plotter without and with actuation.

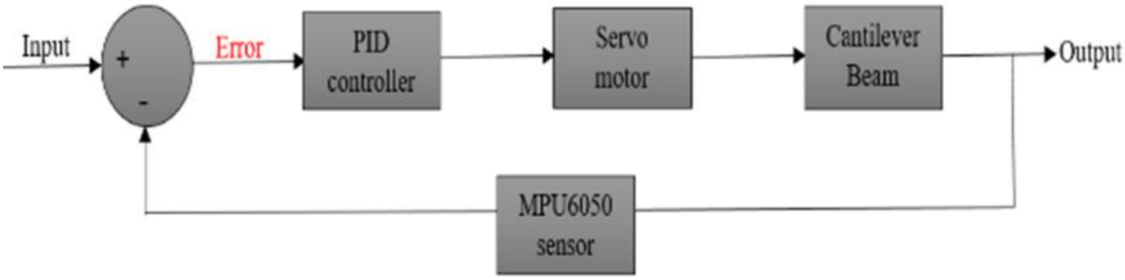
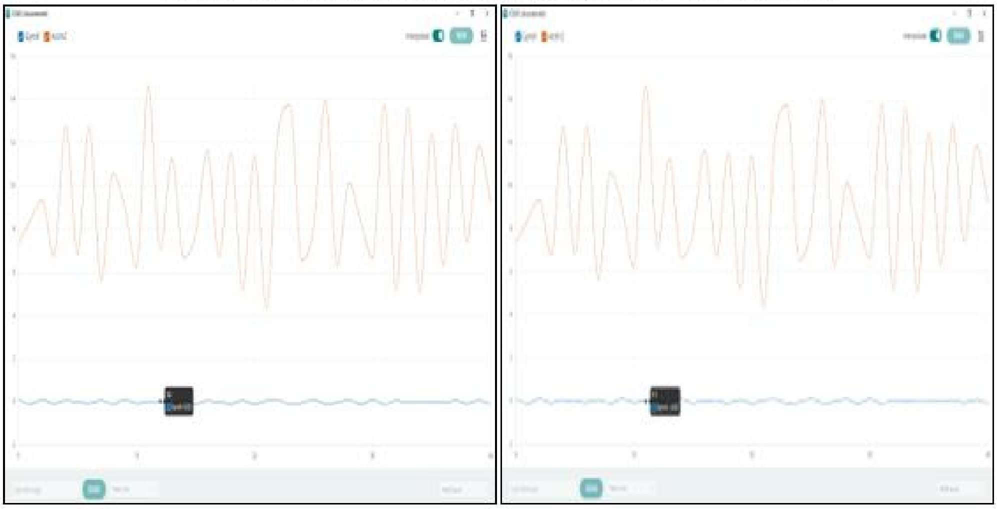


Fig no 11. Block Diagram of System

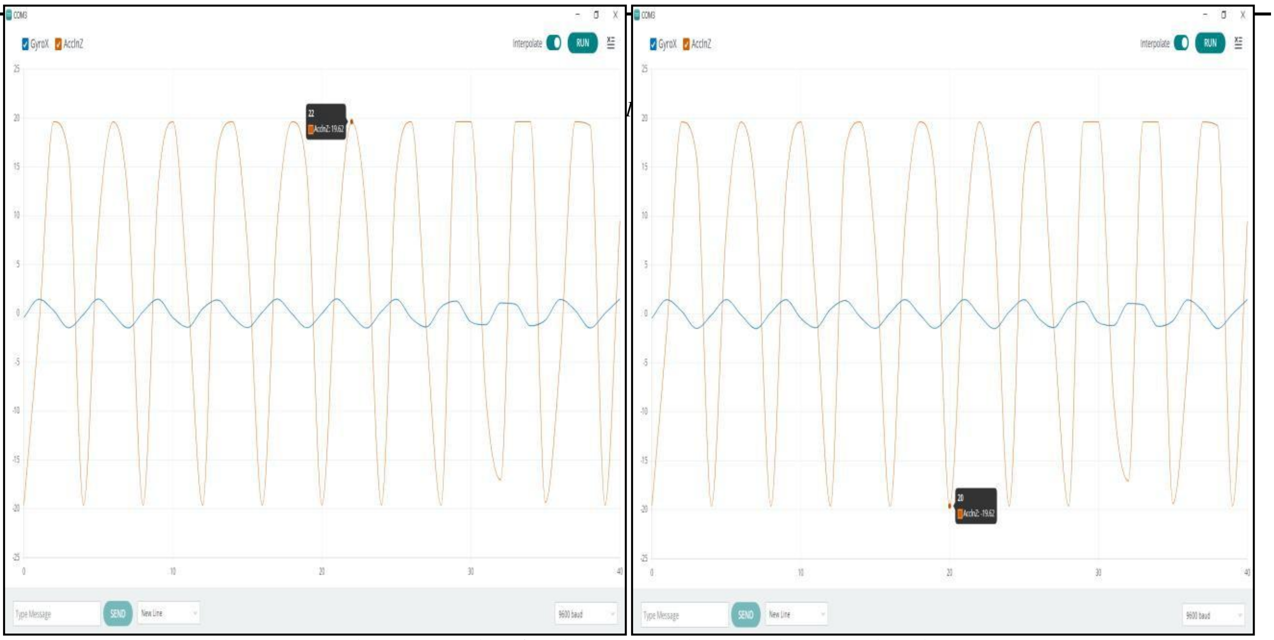
3. RESULTS AND DISCUSSIONS

The implementation of the PID control algorithm in the code successfully controls the position of the servo motor based on sensor readings from the MPU6050. By minimizing the errors between the measured values and the desired set points, the PID controller enables accurate adjustment of the servo motor's position to maintain the desired behavior of the beam. Through the tuning of PID gains, the system achieves stability and responsiveness in controlling the servo motor, ensuring it tracks the desired set points. The PID control algorithm provides a continuous feedback mechanism, allowing the system to quickly respond to changes in the beam's behavior and maintain stability and accuracy in controlling its position. Overall, the results demonstrate the effectiveness of the PID control algorithm in achieving precise servo motor control based on sensor feedback.

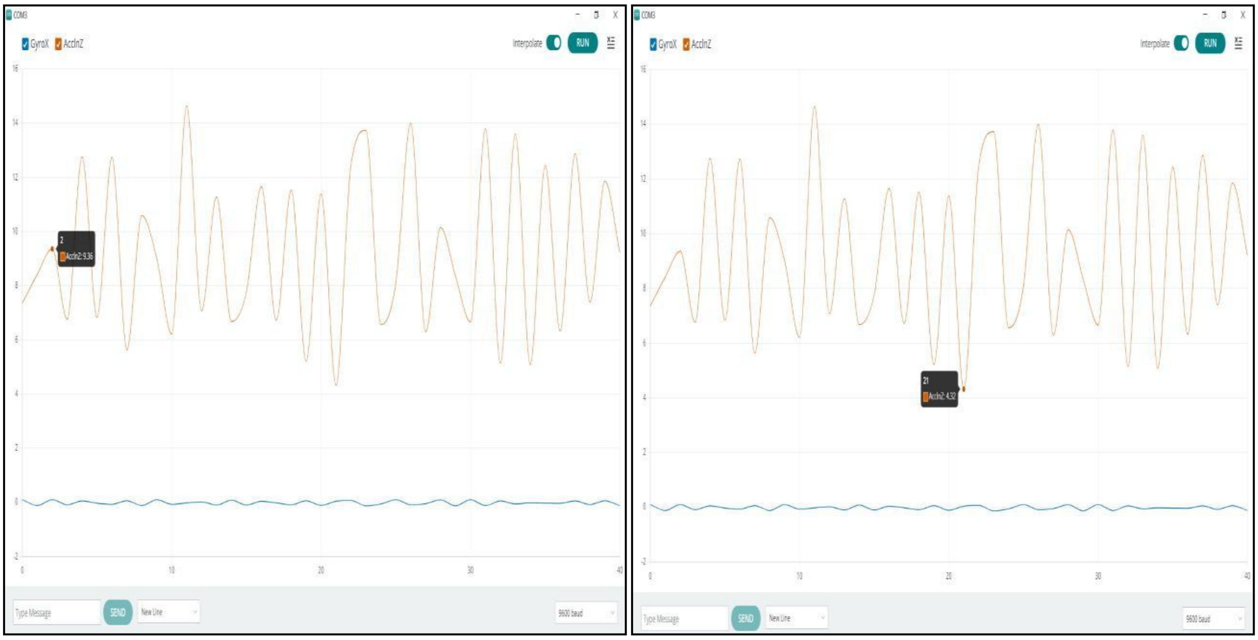
(a) Maximum and Minimum Value of GyroX at t=0.5 and 12 second respectively without actuation.



(b) Maximum and Minimum Value of GyroX at t=6 and 5.5 second respectively with actuation



(a) Maximum and Minimum Value of Accln Zatt=11 and 10 second respectively without actuation.



(a) Maximum and Minimum Value of AcclnZ at t=1 and 10.5 second respectively with actuation

Fig no 12.Comparisons of the graph obtained without actuation and with actuation

The value for maximum and minimum Gyroscopic values about the X axis attained without actuation in a period of 20 seconds are 1.52 rad/sec (at t=0.5 sec) and -1.47 rad/sec (at t=12 sec) respectively and the value for maximum and minimum Acceleration value in Z axis attained without actuation in a period of 20 seconds are 19.62 m/s^2 (at t=11 sec) and -19.62 m/s^2 (at t=10 sec) respectively. The value for maximum and minimum Gyroscopic values about the X axis attained after actuation in a period of 20 seconds are 0.02 rad/sec (at t=6 sec) and -0.02 rad/sec (at t=5.5 sec) respectively and the value for maximum and minimum Acceleration value in Z axis attained without actuation in a period of 20 seconds are 9.36 m/s2 (at t=1 sec) and 4.32 m/s2 (at t=10.5 sec) respectively. The plots signify that there is a reduction in acceleration and gyroscopic values, thus implying a reduction in vibration.

4. CONCLUSIONS

This project titled "Beam Vibration Control using Active Isolation System" incorporates the implementation of a PID control algorithm and the utilization of ANSYS software for modal, harmonic, and structural analysis. The Arduino IDE and its libraries facilitated programming in C language, controlling the system with PID functions, and utilizing the MPU6050 sensor. The PID control algorithm plays a crucial role in accurately controlling the position of the linear actuator based on sensor feedback, effectively suppressing vibrations induced by an eccentric mass motor exciter. ANSYS software is a valuable tool in this project, providing capabilities for modal analysis to determine natural frequencies and mode shapes, harmonic analysis to prevent resonance conditions, and structural analysis to determine the appropriate beam dimensions. By leveraging the strengths of the PID control algorithm and ANSYS software, the project successfully achieves the goal of actively controlling and suppressing vibrations in the rigid cantilever beam.

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