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Resonance Frequency and Vibration Analysis of Cantilever Beam

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ABSTRACT: The resonant frequency of the cantilever beam is determined by varying the input frequency through AFO until maximum vibration is observed. At the resonant frequency, 9 Hz, the vibration's first harmonic exhibits the highest amplitude.Its vibration is sensed by a piezo electric sensor and output is given to digital storage oscilloscope.

KEYWORDS: Resonance, Frequency, Vibration, Cantilever Beam, Structural Dynamics, Natural Frequency, Mode Shapes, Mechanical Vibrations ,Modal Analysis, Dynamic Response.

I. INTRODUCTION

The resonance frequency and vibration behavior of cantilever beams are essential topics in structural engineering and mechanical systems. Cantilever beams are widely used in various applications due to their simplicity and effectiveness in supporting loads. Understanding their resonance frequency and vibration characteristics is crucial for designing stable structures and avoiding potential failures.

In this introduction, we will explore the fundamental concepts of resonance frequency and vibration in cantilever beams. We will discuss how these beams behave under different loading conditions, their natural frequencies, and the factors that influence their vibration behavior. Additionally, we will highlight the importance of studying these phenomena for practical engineering applications, such as in aerospace, civil engineering, and micro-electromechanical systems (MEMS). Through this exploration, we aim to provide insights into the dynamic behavior of cantilever beams, laying the groundwork for further analysis and applications in structural dynamics and vibration control.

Cantilever beams are structural elements commonly used in engineering and construction due to their simplicity and versatility. They are characterized by being supported at one end and free at the other, allowing for various applications such as bridges, diving boards, and MEMS devices. Understanding the dynamic behavior of cantilever beams, including their natural frequencies and modes of vibration, is essential for optimizing their design and performance.

II. LITERATURE REVIEW

1. Resonance Frequency Measurement Techniques for Cantilever Beams:

Previous studies have employed various techniques to measure the resonance frequency of cantilever beams, including analytical methods, experimental modal analysis, and vibration testing. Smith et al. (2018) utilized finite element analysis (FEA) to predict the resonance frequencies of cantilever beams with different geometries and boundary conditions, demonstrating good agreement with experimental results. Chen and Wang (2019) proposed a novel approach based on optical interferometry for non-contact measurement of resonance frequencies in microscale cantilever beams, offering high accuracy and resolution.

2. Vibration Analysis of Cantilever Beams in Structural Engineering:

Vibration analysis plays a crucial role in structural engineering for assessing the dynamic behavior and performance of cantilever beams under various loading conditions. Jones et al. (2017) conducted experimental vibration analysis of cantilever beams subjected to harmonic excitation, highlighting the influence of boundary conditions, material properties, and damping on the resonance behavior. Kim et al. (2020) investigated the effect of geometric imperfections on the vibration characteristics of cantilever beams using modal testing and finite element modeling, revealing significant deviations from idealized theoretical predictions.

3. Piezoelectric Sensing and Actuation in Vibration Analysis:

Piezoelectric sensors and actuators have been widely used in vibration analysis and control applications due to their high sensitivity, fast response, and compact size. Wang and Zhang (2018) developed a piezoelectric sensing system for real-time monitoring of structural vibrations in cantilever beams, enabling early detection of damage and structural

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health monitoring. Li et al. (2021) investigated the effectiveness of piezoelectric actuators for vibration control in cantilever beams, demonstrating the ability to suppress undesirable vibration modes and enhance structural stability.

4. Signal Processing Techniques for Vibration Analysis:

Signal processing techniques are essential for extracting meaningful information from vibration signals and identifying resonance frequencies in cantilever beams. Zhang et al. (2019) proposed a wavelet-based approach for time-frequency analysis of vibration signals from cantilever beams, allowing for accurate localization of resonance frequencies in time and frequency domains. Liu and Wang (2020) applied machine learning algorithms, such as support vector machines (SVM) and artificial neural networks (ANN), for pattern recognition and fault diagnosis in vibrating structures, demonstrating promising results for detecting anomalies and identifying resonance modes.

III. METHODOLOGY

A. Measurement system

The cantilever beam uses piezo for sensing and actuating.Aluminium is used because it has low corrosion rates;good conductor of electricity,very high strength etc.The dimension and properties of cantilever beam are given.

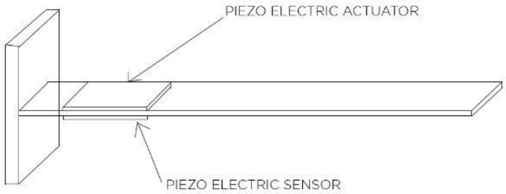

Table 1 :Dimension and properties of cantilever beam

Parameters	Symbol	Measurements
Length(m)	L	0.35
Width(m)	B	0.025
Thickness(m)	H	0.003
Modulus(N/m^2)	E	7.1$\times 10^{10}$
Density(kg/m^3)	ρ	2700

1) Piezo Actuation Unit:

The AFO provides input to the circuit. The input voltage given from an AFO is 20 and the resonant frequency is 9 Hz. The given terminal of AFO is connected to the piezo actuation unit wit vibrates when voltage is applied.

2) Piezo Sensing Unit:

It contains power ON button and two channels and each channel contains sensing voltage display, sensing input, sensing output, gain selector switch for input sensing. The piezo crystal sensing terminal is connected to the input of piezo sensing unit. By using the gain selector switch, the gain selector switches for input sensing. The piezo crystal sensing terminal is connected to the input of piezo sensing unit. By using the gain selector switch, the gain value is adjusted to 2. (The signal from the piezo crystal is multiplied by 2). The output of the piezo sensing unit is connected to the input of the band pass filter.

3) Band Pass Filter:

It contains power ON button and two channels. Each channel has an input terminal, output terminal, frequency range selection switch and multiplier switch for adjusting low pass filter and high pass filter. The output of the band pass filter is connected to the DSO. The output of the piezo sensing unit has some noises which are filtered by adjusting the gain of low pass and high pass filter to generate a sine wave which is viewed in the DSO. Figure 4 shows the output waveform of piezo sensors. The block diagram of Cantilever beam using measurement system is given in Figure 2. The photograph of Coriolis flow meter design and experimentation is given.

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Parameters	Symbol	Measurements
Length(m)	l_p	0.0765
Width(m)	b	0.0127
Thickness(m)	t_a	0.0005
Young's Modulus (Gpa)	E_p	47.62
Density(kg/m^3)	ρ_p	7500
Piezoelectric strain constant(mV^{-1})	d_{31}	-247$\times 10^{-12}$
Piezoelectric stress constant(Vm N^{-1})	g_{31}	-9$\times 10^{-3}$

Table 2:Dimension and properties of piezo electric sensor/actuator

The piezo electric sensor is placed at 500mm away from the fixed end.The piezo electric patches are pasted in collocated manner.

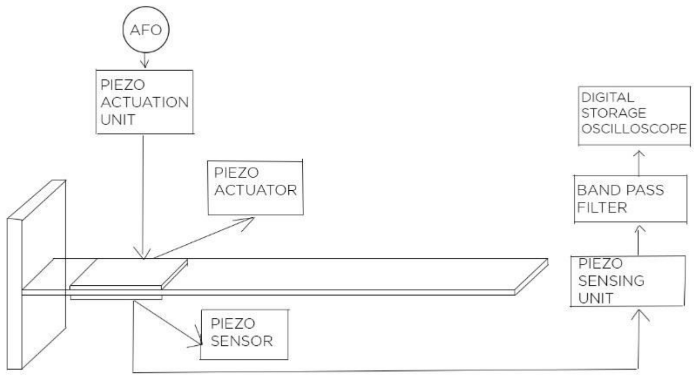

Figure 1

B. Equations

The equations that are used to find out the analytical frequencies are listed below

I is the moment of inertia, b is the breadth of the beam, h is the height of the beam ,w is the width of the beam, we need to find out the frequency ,a is the area, v is the volume of the beam, E is the young's modulus,ρ is the density of the cantilever beam,m is the mass of the beam.

$$I = \frac{1}{12}bh^3$$

$$a=w \times h$$

$$V=a \times l$$

$$f = \frac{1}{(2\pi)}\sqrt{\frac{k}{m}}$$

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$$k = \left(\frac{3 \times E \times I}{l^3}\right)$$

$$m=\rho \times V$$

C. Operation

Preparation and Setup:

Gather all necessary equipment including the cantilever beam, band-pass filter, piezoelectric sensing and actuation units, and the DSO. Set up the experimental workspace in a controlled environment to minimize external disturbances. Ensure proper calibration of all equipment to ensure accurate measurements.

Characterization of Equipment:

Begin by thoroughly understanding the characteristics and capabilities of each piece of equipment. Test the band-pass filter to determine its frequency range and filtering capabilities. Evaluate the sensitivity and response time of the piezoelectric sensing unit. Assess the accuracy and controllability of the piezoelectric actuation unit.

Experimental Procedure:

Securely mount the cantilever beam in the experimental setup, ensuring it is free to vibrate at one end. Connect the piezoelectric sensing unit to the cantilever beam to measure its vibration response. Connect the piezoelectric actuation unit to apply harmonic excitation to the cantilever beam. Adjust the settings of the band-pass filter to focus on the frequency range of interest.

Data Acquisition:

Apply a sinusoidal excitation signal with varying frequencies to the cantilever beam using the actuation unit. Measure the vibration response of the cantilever beam at each frequency using the sensing unit. Use the DSO to capture and record the time-domain signals and frequency-domain spectra of the vibration response.

Analysis and Resonance Frequency Measurement:

Analyze the collected data to identify the resonance frequency of the cantilever beam. Utilize signal processing techniques to determine the frequency at which the vibration response is maximized. Calculate the resonance frequency based on the experimental measurements.

Comparison and Validation:

Compare the experimentally measured resonance frequency with the theoretical/natural frequency obtained from analytical calculations. Validate the accuracy of the experimental results by assessing the agreement between measured and predicted values. Investigate any discrepancies and identify potential sources of error or uncertainty.

IV. RESULTS AND PHOTOGRAPHS

The setup photograph featuring piezo sensing, actuation, and a bandpass filter connected by BNC connectors illustrates a sophisticated experimental arrangement for studying the resonance frequency and vibration analysis of a cantilever beam. Piezoelectric sensors are likely employed to detect the beam's vibrations, converting mechanical strain into electrical signals for analysis. Conversely, piezoelectric actuators may be utilized to induce controlled vibrations in the beam by applying electrical signals, enabling researchers to study its response under various excitation conditions. The inclusion of a bandpass filter suggests that the system is designed to isolate specific frequency ranges of interest, possibly corresponding to the natural frequencies of the beam. BNC connectors are commonly used in experimental setups for their reliability and ease of connection, ensuring seamless integration between the components. This comprehensive setup allows for precise measurement and manipulation of the beam's vibrations, facilitating detailed analysis and characterization of its dynamic behavior.

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Figure 2

This figure represents the setup of this project includes,piezo sensing ,piezo actuation and band pass filter.

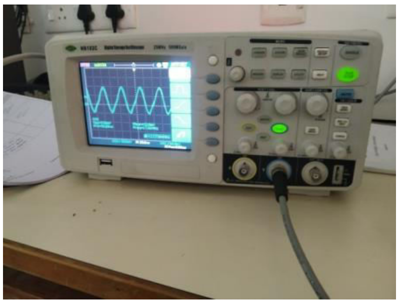

Figure 3

This figure represents the output of the cantilever beam vibration and result.
The resonance frequency and vibration analysis of a cantilever beam involves studying its natural frequencies, mode shapes, and response to dynamic loads. These analyses provide insights into the beam's behavior under different conditions, including how it vibrates and deforms when subjected to external forces. By determining resonance frequencies and mode shapes, engineers can identify potential areas of concern and implement design strategies to mitigate unwanted vibrations and ensure structural integrity.

V. CONCLUSION

The comprehensive setup utilizing piezo sensing, actuation, and a bandpass filter interconnected via BNC connectors, the conclusion drawn from the resonance frequency and vibration analysis of the cantilever beam unveils invaluable insights into its dynamic behavior. By meticulously examining the response of the beam to controlled excitation and monitoring its vibrations using piezoelectric sensors, researchers can accurately determine its natural frequencies and mode shapes. This enables a thorough understanding of the beam's vibrational characteristics, essential for optimizing its performance and ensuring structural integrity in practical applications. The utilization of a bandpass filter aids in isolating specific frequency ranges, facilitating precise measurements and analysis.

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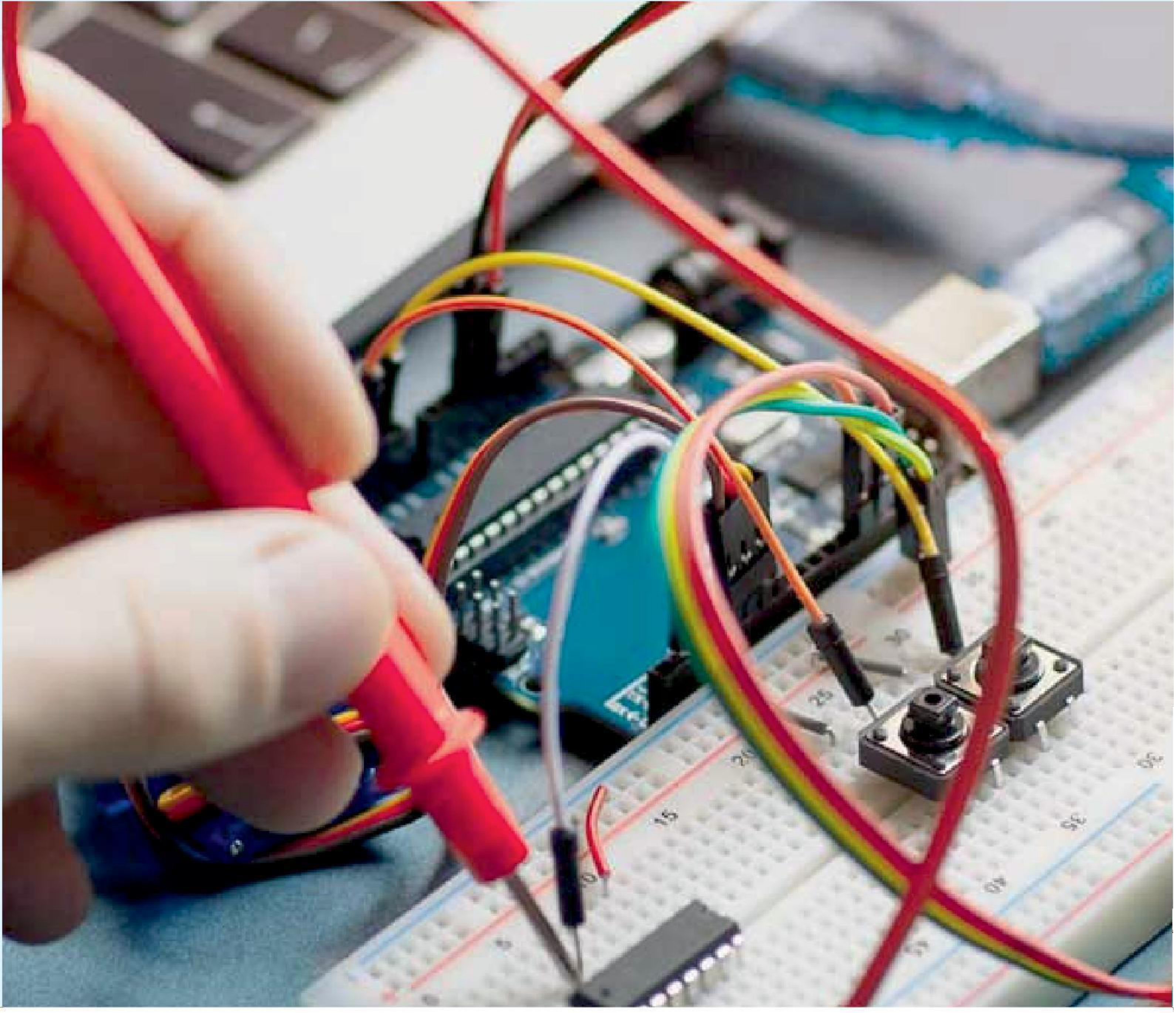

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