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EXPERIMENTAL INVESTIGATION ON ENFORCING NODE AT DIFFERENT LOCATIONS ON BEAM USING VIBRATION NEUTRALIZER

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ABSTRACT
The purpose of this research is to conducts experimental investigation on vibration reduction of beam subjected to harmonic excitation by enforcing nodes at desired locations using vibration neutralizer. The experimental setup was design and developed to enforce node at different location on beam using variable stiffness neutralizer. For given excitation frequency neutralizer is tuned such that the vibration amplitude of beam reduced to minimum level. The result shows that the neutralizer is effective to enforce nodes at required location on the beam. .
Keywords: Vibration Neutralizer, Experimental Test, Enforcing Nodes, Modal Analysis, Beam

I. Introduction
The occurrences of vibration in structures equipped with sensitive elements are required to eliminate to avoid the vibration-induced problems such as structural degradation, human discomfort and performance deterioration. Many components in a mechanical system can be modelled as beams subjected harmonic excitations resulting propagation of vibration throughout the structure. Therefore vibration suppression of a beam subjected to external excitations has been the subject of numerous investigations. Cha [1-3] discussed the scheme to impose nodes at required locations in a harmonically excited structure using simple oscillators. Patil and Awasare [4-5] proposed the algorithm to find required neutralizer parameters to create nodes at desired locations on beam. Bassam [6] designed a control force to create nodal point(s) having zero displacement and/or zero slope at selected locations in a harmonically excited vibrating structure. Recently Shover et al [7] conducted the parametric study of Euler–Bernoulli beams by leveraging closed-form sensitivity expressions to rapidly account for inverse problems involving parameter tolerances and perturbations to induce node at desired locations on beam. Most of the previous research is limited to vibration suppression of beam using spring mass neutralizer without considering the effect of amplitude of neutralizer mass on system. The amplitude of neutralizer mass is significant because the large vibration amplitudes of the neutralizer masses leads to failure of the neutralizer then the theoretically feasible solutions could not be implemented in practice. Consequently the focus of this paper is to conduct the experimental investigation of vibration reduction of beam at desired locations using vibration neutralizer considering neutralizer mass amplitude.

II. Experimental set-up and Test
Figure 1 illustrates the experimental setup used in the experiments. The electrodynamic vibration exciter (Syscon SI-230) with stringer was used to excite the beam at the free end with a single harmonic excitation at 53 Hz i.e. $\omega_e \approx 22\sqrt{EI/(\rho L^4)}$. The neutralizer was attached at the length $0.4L$ to the beam. The force with an amplitude $F = 4.5N$ exerted by the exciter on the beam was measured by a force transducer (PCB 208C01). The amplitude of force kept constant throughout the experiment and is used to non-dimensionlised the displacements of the beam and neutralizer masses amplitude by dividing by $F/EI/L^3$. The light-weight ICP accelerometer (PCB 333B32) was used to measure the amplitude of vibration read from a FFT vibration analyzer (Adash 4300).

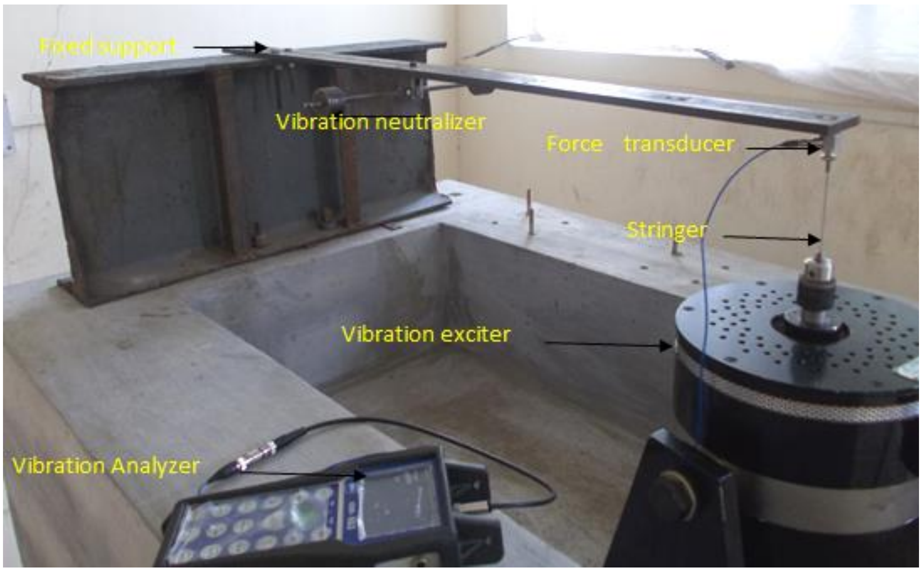

Figure 1. Experimental Setup

Table 1. The system parameters and material properties used in the experimental test.

Length of the beam	L	1 m
Thickness of the beam	t	0.01 m
Width of the beam	b	0.065 m
Mass per unit length of beam	ρ	5 Kg/m
Parameter EI/L^3 used to non-dimensionlise stiffness of beam		1137.5 N/m
Parameter $\sqrt{EI/\rho L^4}$ used to non-dimensionlise frequencies.		14.95 N/m/Kg
Parameter $F/EI/L^3$ used to non-dimensionlise vibration amplitude of beam and neutralizer masses		0.004 m

The system parameters and material properties for beam are listed in Table 1. The experiments were performed to impose node at different locations on beam and to record the resonance frequency of the neutralizer, neutralizer mass amplitude, amplitude at node location, and the vibration amplitude along the beam length to plot steady state response of the beam. The procedure is as follows

1. The neutralizer was tuned by moving end masses in or out such that the displacement at the node location on the beam was minimum.
2. Vibration amplitudes were measured at twenty equi-spaced points on the top of the beam by the accelerometer and recorded by vibration analyser to plot experimental steady state response.
3. The vibration amplitude at node location on beam and neutralizer masses was also measured. .
4. The experimental modal analysis of the tuned neutralizer only was conducted to record the required resonance frequency of the neutralizer to impose the node experimentally.

The procedure of tuning of neutralizer, measurement of the forced vibration amplitudes and experimental modal analysis was carried out to impose node at $1L$ $0.9L$ $0.7L$, $0.6L$, $0.5L$ and $0.4L$ location of beam.

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III. Result and discussion.

Table 2 lists the resonance frequency of the neutralizer, the amplitude of absorber mass and amplitude at node locations obtain from experimentation

Table 2 Experimental resonance frequencies required to impose node at different locations on uniform cantilever beam, corresponding vibration amplitudes of the neutralizer masses and displacement at node locations for neutralizer attachment $x_p = 0.4L$. The system parameters are $\omega_e \approx 22\sqrt{EI/(\rho L^4)},\ x_f = 1L$ and $m_1 = 0.1\rho L$.

Node Location	**0.4L**	**0.5L**	**0.6L**	**0.7L**	**0.9L**	**1L**
Resonance frequency (Hz)	53	54	58	78	44	48
Resonance frequency	22.27	22.69	24.37	32.78	18.49	20.17
Vibration amplitude (micron)	110	112	114	116	108	109
Vibration amplitude	2.750 $\times 10^{-2}$	2.800 $\times 10^{-2}$	2.850 $\times 10^{-2}$	2.900 $\times 10^{-2}$	2.70 $\times 10^{-2}$	2.72 $\times 10^{-2}$
Displacement (micron)	5	4	7	8	12	16
Displacement	1.25 $\times 10^{-3}$	1.0 $\times 10^{-3}$	1.75 $\times 10^{-3}$	2.00 $\times 10^{-3}$	3.00 $\times 10^{-3}$	4.00 $\times 10^{-3}$

Figure 2 depicts the steady state deformed shapes of the beam obtained from the experiments. It is observed that by tuning the neutralizer at required resonance frequency the nodes are enforced at different location on the beam. The frequency response plot for absorber is shown in Figure 3 which gives the required resonances frequencies of neutralizer to impose nodes. The results listed in Table 2 are both in dimensional and non-dimensional form.

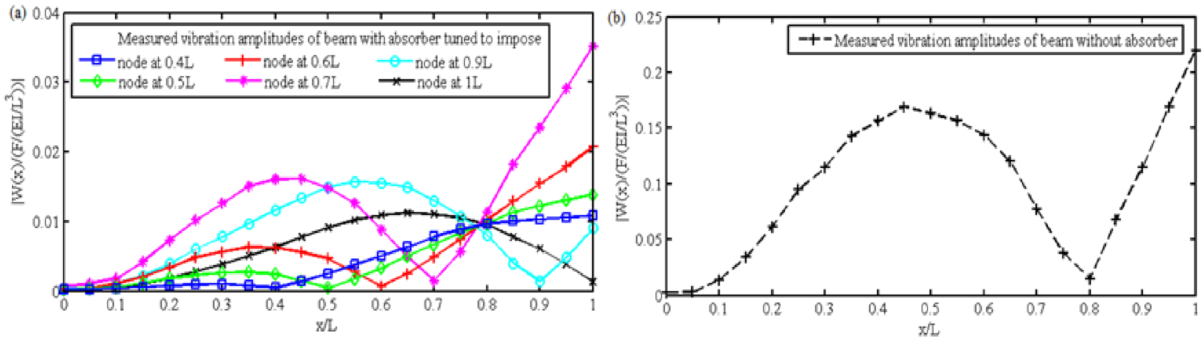

Figure 2 Experimental measured vibration amplitudes of a uniform cantilever beam, (a) with, neutralizer tuned to the resonance frequency to create node at different locations and (b) without neutralizer. The experimental parameters are $\omega_e = 53\text{HZ} \approx 22\sqrt{EI/(\rho L^4)},\ x_f = 1000\text{mm} = 1L$, $x_p = 400\text{mm} = 0.4L$, and $m_1 = 0.5\text{kg} = 0.1\rho L$.

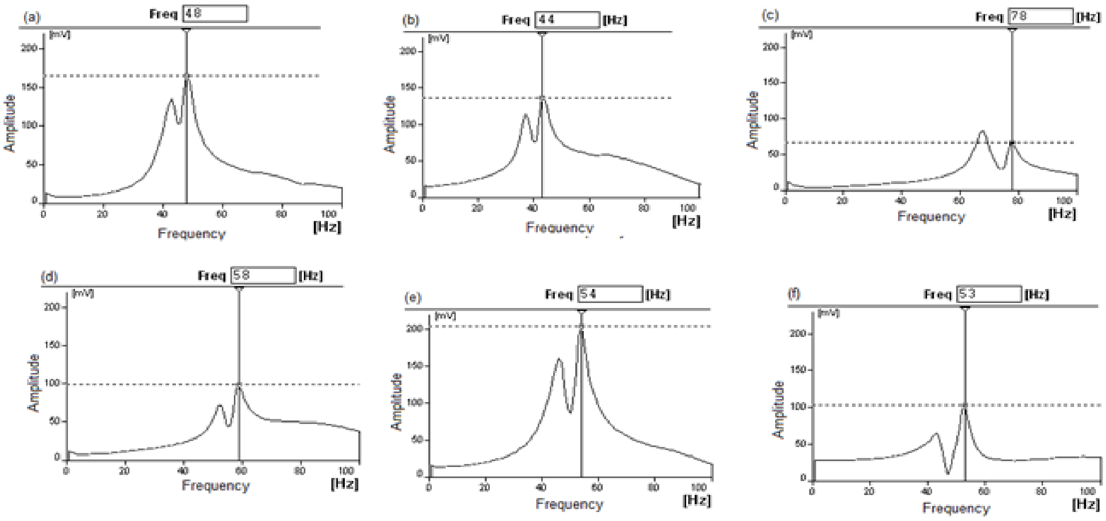

Figure 3. Frequency responses of neutralizer by experimental modal analysis when neutralizer is tuned to impose node at, (a) 1L, (b) 0.9L, (c) 0.7L, (d) 0.6L, (e) 0.5L, and (f) 0.4L for $\omega_e = 22\sqrt{EI/(\rho L^4)}$.

It is also revealed by the steady state response of beam for imposing node at 0.4L that the region of beam from 0L to 0.4L has fewer vibrations compared to beam without absorber. Therefore it is not required to impose node at 0.1L, 0.2L and 0.3L along the beam locations.

It is worth commenting that, even if damping in the neutralizer and beam is small it affects the vibration suppression at node location on the beam. Consequently although node is the point at which the displacement is zero, practically there is some amount of displacement due to presence of the damping.

IV. Conclusion

The enforcing node method technique investigated in this work offers new ways of using variable stiffness vibration neutralizers in eliminating unwanted vibrations from certain part of a beam structure in order to improve their performance in the vibration isolation. It is observed from single node steady state responses that all curves pass through a common point when same neutralizer is used to impose node at different locations on beam for constant harmonic excitation.

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