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Study of Passive Vibration Absorbers Attached on Beam Structure

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Abstract. Structural vibration is undesirable, wasting energy and possibly leading to excessive deflections and structure and machine's failure. In order to reduce structural vibration, one of the common way is considering vibration absorber system attach to the structure. In this study, a vibration absorber is developed in a small scale size. The host structure selected for the study is a fixed-fixed ends beam. The effectiveness of vibration absorbers attached to a beam is investigated through experimental study. In prior to experiment, a finite element analysis of Solidworks® and analytical equations of Matlab® are produced in order to determine the structural dynamic response of the beam, such as the natural frequency and mode shapes. The preliminary results of finite element analysis demonstrate that the first five natural frequency of fixed-fixed end beam are 17Hz, 46Hz, 90Hz, 149Hz and 224Hz, and these results are in agreement with the beam's analytical equations. However, there are slight discrepancies in experiment result due to noise and error occurred during the setup. In the later stage, the experimental works of beam are performed with attached vibration absorber. Result shows that the attachment of vibration absorber produces better outcome, which is about 45% vibration reduction. It is expected that by adding more vibration absorber to the structure, the vibration attenuation can significant.

Introduction

The structural vibration phenomenon is a natural source, which occur from structure movement that is repetitive, and involves external forces acting on it [1-3]. In general, vibration is not needed in everyday life. This is because the vibration causes distress to the user. On top of that, it results in damage to the components inside the machine. This undertaking aims to ensure that the amplitude of vibration on the machine can be reduced by attached vibration absorbers onto structure, which could indirectly benefit the consumer as well. In this study case, vibration analysis of fixed-fixed ends beam system is selected as it is important to explain and help to analyse a number of real life systems such as used in building, automobile frames, machine frames and other mechanical structure.

In general, common techniques used for vibration control can be classified into two categories. There are active vibration control (e.g. ref. [4,5]) and passive vibration control (e.g. ref. [6-8]). Although these techniques have been widely used for feasible solutions to vibration control problems, significant limitations are still encountered. Basically, active vibration control methods require additional power to be introduced into a system through a series of control inputs or secondary sources. The details on the application of active vibration control have been covered extensively in the textbooks of Fuller et al. [1] and Hansen and Snyder [9]. Though it is shown that active vibration control methods performed well at low frequencies, their application at higher frequencies, are still limited due to the drastic increase in the computational load and requirement for adding more sensors and actuators [10].

The latter approach using passive vibration control is more sound and has significant advantage as it do not require any power sources, inexpensive and easy to implement. However, their performance is limited to the middle and high frequency range. This limitation is based on the restraint most systems have for the addition of excess mass and volume [11,12]. This research study aims to develop a strategy using multiple passive vibration absorbers to tune with a flexible beam, in such a way to reduce the vibration across the structure globally. The properties of the absorbers are adapted in order to minimize the vibration level of the structure.

Theoretical Equations

A beam is a structural component that has the ability to maintain the shape under bending load. For a fixed-fixed ends beam [1], the equation of motion is given as in Eq. (1).

$$EI\frac{\partial^4 w}{\partial x^4} + \rho A\frac{\partial^2 w}{\partial t^2} = F(x,t) \tag{1}$$

The total normal response of beam is given by the superposition of the individual eigen solutions, or modes as shown in Eq. (2).

$$w(x,t) = \sum_{n=1}^{\infty} W_n \cdot \psi_n e^{j\omega_n t} \tag{2}$$

where W_n is the modal amplitude, ψ_n is the mode shape of a fixed-fixed ends beam, ω_n is the natural frequency and n is the mode number. The structural mode shape ψ_n is given by [13]:

$$\psi_n = \cosh(k_n x) - \cos(k_n x) - \beta_n\left[\sinh(k_n x) - \sin(k_n x)\right] \tag{3}$$

where β_n and k_n are obtained in the respective Eqs. (4) and (5).

$$\beta_n = \frac{\cosh(k_n L) - \cos(k_n L)}{\sinh(k_n x) - \sin(k_n x)} \tag{4}$$

$$\cosh(k_n L) \cdot \cos(k_n L) - 1 = 0 \tag{5}$$

The natural frequencies of the *n*-th mode of a clamped-clamped beam can be calculated from:

$$\omega_n = k_n^2 \sqrt{\frac{EI}{\rho A}} \tag{6}$$

where E is the Young's modulus, I the area moment of inertia, ρ is the density, L is the length of a beam, A is the cross-sectional area of a beam. By neglecting the exponential time varying term in Eq. (2), the total response of beam incorporating the viscous damping ζ is simplified as:

$$w(x,t) = \frac{F}{\rho AL}\sum_{n=1}^{\infty}\frac{\psi(x_i)\psi(x)}{\omega_n^2 - \omega^2 + j2\zeta\omega\omega_n} \tag{7}$$

Finite Element Analysis

A finite element (FE) model of fixed-fixed ends beam is simulated using Solidworks®. Fig. 1 shows the FE meshed model of the beam. The model was meshed using solid wedge 6-nodes element and the frequency modal analysis was solved over the frequency range from 0 to 300 Hz in order to determine beam's natural frequency.

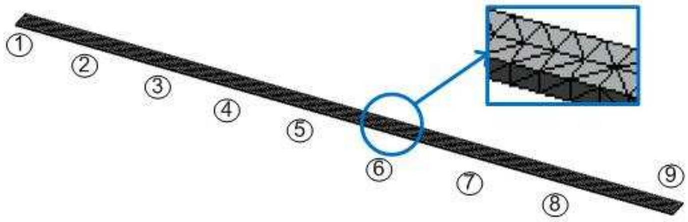

Fig. 1. FE meshed model of a beam

Experimental Vibration Testing

Three conditions were conducted in the study: (1) beam without attached vibration absorber, (2) beam with attached single vibration absorber, and (3) beam with attached dual vibration absorbers. Due to limitation of weight imposed on a beam, only up to two vibration absorbers were include in the investigation. Fig. 2 shows apparatus setup for the vibration test. The beam is divided into 9 points (refer Fig. 1) where in each point, the response is measured.

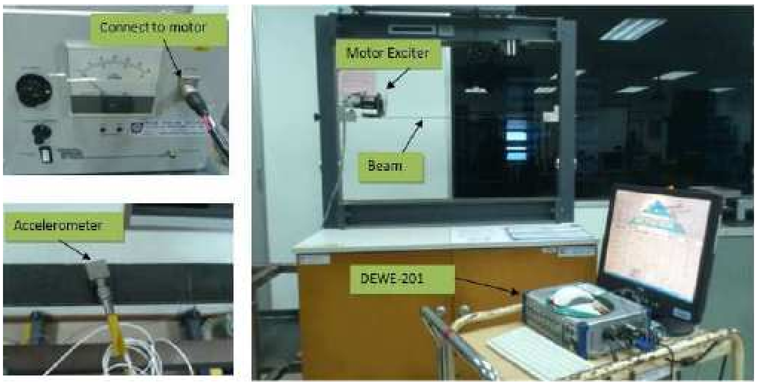

Fig. 2. Vibration apparatus setup

Results and Discussion

Modal analysis of a fixed-fixed ends beam. In preliminary stage, a dynamic characteristic of fixed-fixed ends beam was determined by three methods; mathematical equations by Matlab®, finite element analysis by Solidworks® and experimental test. Table 1 tabulates the results of first five natural frequencies of a fixed-fixed ends beam obtained from these approaches. It shows that all these approaches corroborated well, although there is a small discrepancy in the experimental result due to error and noise measured during testing. Meanwhile, mode shapes of the fixed-fixed ends beam are displayed in Fig. 3.

Table 1. Natural frequencies of beam in unit Hz

Mode	Matlab®	Solidworks®	Experiment
1	17	17	34
2	46	46	67
3	90	90	106
4	149	149	142
5	223	224	214

A beam with attached vibration absorbers. The next stage of analysis incorporates the attachment of passive vibration absorbers. The absorber's resonance frequency is tuned to the second natural frequency of the beam at 67 Hz in order to suppress the vibration. Figs. 4, 5, 6 and 7 show configuration of two absorbers on a beam, the superimpose result of the frequency response function of a beam at all points without vibration absorber, with attached single vibration absorber and with attached dual vibration absorbers, respectively.

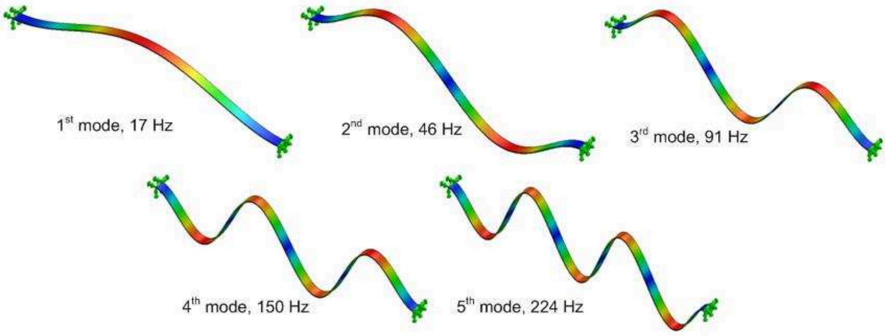

Fig. 3. Mode shapes of a fixed-fixed ends beam

From Figs. 5–7, it can be visually compared the effect of adding absorbers on the vibration amplitude of a beam. Obviously by attaching single and dual vibration absorber, the vibration of a beam structure was decreased, especially in the second mode predominant frequency. It is noticed that the vibration amplitude reduced significantly through the beam structure when dual vibration absorbers were used. The average global vibration reduction obtained with dual absorbers attachment is about 45%. In this case, the absorbers attachment was fixed at points 2 and 7 (refer Fig. 4) in order to counter the second bending motion of the beam as shown in Fig. 3.

Fig. 4. Configuration of dual absorbers

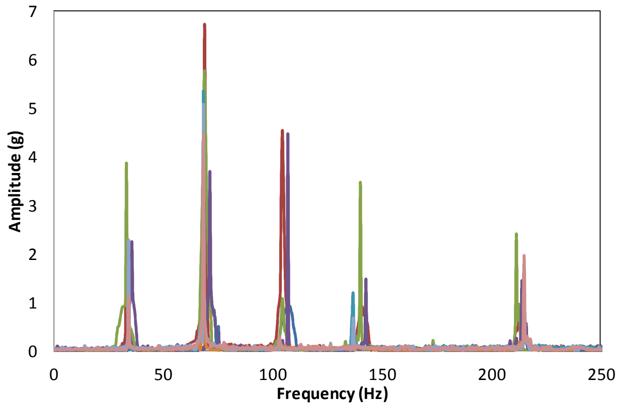

Fig. 5. Frequency response of a beam without vibration absorber

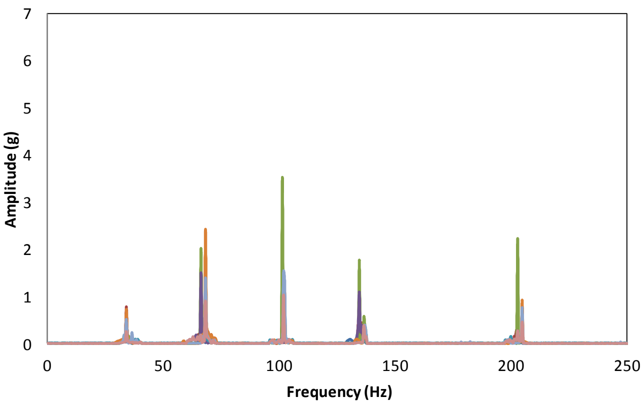

Fig. 6. Frequency response of a beam with single vibration absorber

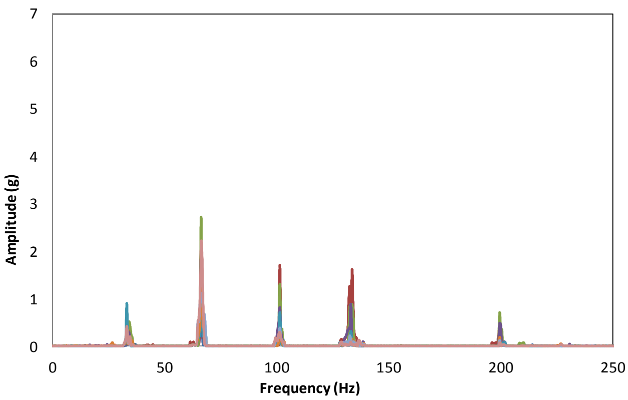

Fig. 7. Frequency response of a beam with dual vibration absorbers

Conclusion

The attachment of passive vibration absorber on a beam structure was successfully prepared in this study. A preliminary result of finite element analysis showed in agreement with mathematical modeling of Matlab® with error less than ±1.5%. As a result for experiment, the structural vibration of the beam is decreased with single vibration absorber and more with dual vibration absorber attachment. Overall, this study reveals that vibration absorbers attached on a structure prove to be more effective in vibration suppression.

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