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Vibration Suppression of a Cantilever Plate using Magnetically Tuned-Mass-Dampers

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***Abstract*—For a few decades various methods to suppress the vibrations of structures have been proposed. The objective of the present study is to propose and exploit an effective method to suppress the vibration of cantilever plates like the solar panels of a satellite. Magnetically Tuned Mass Damper (mTMD) is a Tuned Mass Damper (TMD) with Eddy Current Damping (ECD). The present study used magnetically tuned mass dampers to suppress the vibration of the plate. The parameters of a mTMD are designed based on the parametric study of the theoretical model. The results show that the present method is simple but effective in suppressing the vibration of the plate.**

***Keywords*—TMD, mTMD, ECD, Vibration, Suprression, Cantilever Plate**

I. Introduction

Eddy currents are generated when a moving conducting material intersects a stationary magnetic field, or vice-versa. The relative motion induces the eddy current within the conducting materials. These eddy currents induce their own magnetic field with the opposite polarity of the applied field that causes a resistive force. These currents dissipate due to the electrical resistance and this force will eventually disappear. Hence, the vibrating energy will be dissipated. Since the resistive force induced by eddy currents is proportional to the relative velocity, this eddy current damping can be allowed to function as a form of viscous damping.

Bae et al. [1] developed a theoretical model of an ECD constructed by Kwak et al. [2]. Using this theoretical model, they investigated the damping characteristics of an ECD and simulated the vibration suppression of a cantilever beam with Kwak's ECD. Sodano et al. [3-5] proposed a new concept using the eddy currents induced in a conductive plate to suppress the vibration of a cantilevered beam. Bae et al.[6] proposed the concept of magnetically tuned-mass-damper (mTMD) to improve the damping performance of a conventional TMD by using an eddy current damping (ECD). They showed that their method could significantly increase the damping effect of the TMD by simulations and experiments.

The objective of the present study is to investigate the effectiveness of mTMD for the vibration suppression of a cantilever plate. The design parameters of a mTMD are presented based on the parameter study. The vibration analyses of a TMD, mTMD, and a cantilever plate with mTMD are performed. The results are verified with experiments and the performance of a mTMD is discussed.

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II. Theoretical Analysis

A. *Theoretical Modeling of a Multi-Mode TMD*

The schematic of a Multi-Mode TMD with damping in both the base and adaptive mass system is showing in Fig. 1. The degree of freedom (DOF) is four. x_b and θ describe the bending mode and torsion mode of the plate, respectively. Using Lagrange's equations the equations of motions of Figure 1 can be obtained by

$$\begin{bmatrix} m_b & 0 & 0 & 0 \\ 0 & J_b + m_1 y_1^2 + m_2 y_2^2 & 0 & 0 \\ 0 & 0 & m_1 & 0 \\ 0 & 0 & 0 & m_2 \end{bmatrix} \begin{Bmatrix} \ddot{x}_b \\ \ddot{\theta}_b \\ \ddot{x}_1 \\ \ddot{x}_2 \end{Bmatrix} + \begin{bmatrix} c_b + c_1 + c_2 & -c_1 y_1 + c_2 y_2 & -c_1 & -c_2 \\ -c_1 y_1 + c_2 y_2 & c_t + c_1 y_1^2 + c_2 y_2^2 & c_1 y_1 & -c_2 y_2 \\ -c_1 & c_1 y_1 & c_1 & 0 \\ -c_2 & -c_2 y_2 & 0 & c_2 \end{bmatrix} \begin{Bmatrix} \dot{x}_b \\ \dot{\theta}_b \\ \dot{x}_1 \\ \dot{x}_2 \end{Bmatrix}$$
$$+ \begin{bmatrix} k_b + k_1 + k_2 & -k_1 y_1 + k_2 y_2 & -k_1 & -k_2 \\ -k_1 y_1 + k_2 y_2 & k_t + k_1 y_1^2 + k_2 y_2^2 & k_1 y_1 & -k_2 y_2 \\ -k_1 & k_1 y_1 & k_1 & 0 \\ -k_2 & -k_2 y_2 & 0 & k_2 \end{bmatrix} \begin{Bmatrix} x_b \\ \theta_b \\ x_1 \\ x_2 \end{Bmatrix} = F \quad (1)$$

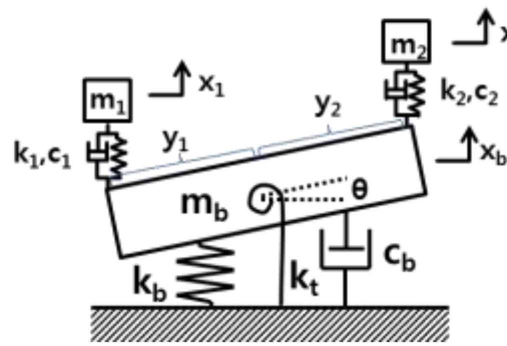

Figure 1 Schematic of a multi-mode TMD (4-DOF)

B. *Parameter Study and Optimization*

Using the 4-DOF model of Equation 1 the parametric study of a TMD is performed for both the bending mode and torsion mode. The important parameters of a TMD are k_1, k_2, m_1, and m_2. The first and second natural frequencies of the plate are 20.09 Hz and 45.34 Hz, respectively. Figure 2 shows the effect of frequency ratio, β, on the frequency response function (FRF) when the mass ratios, m_1/m_b and m_2/m_b , are

0.1. Figure 3 shows the effect of mass ratio on the FRF when the frequency ratios, β_1 and β_2, are 0.9.

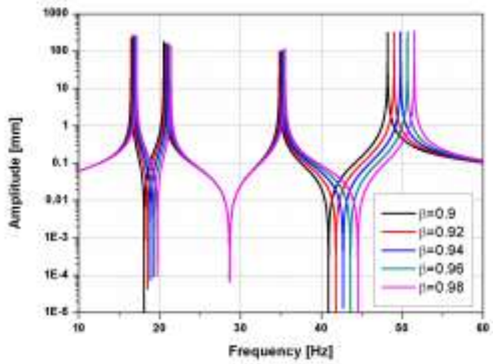

Figure 2 Effects of frequency ratio on FRFs

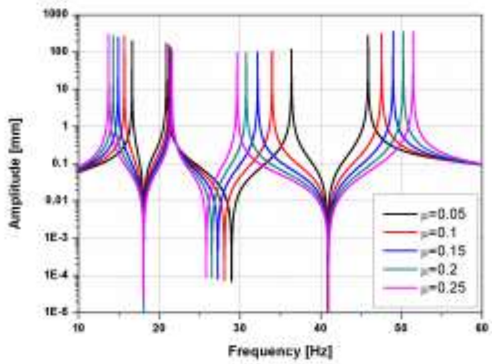

Figure 3Effects of frequency ratio on FRFs

From the weight requirements of a solar panel the mass ratio is fixed to be 0.1. The frequency ratio is optimized for the bending mode and torsion mode, respectively. The frequency ratio β_1 for the bending is 0.96 and β_2 for the torsion is 0.95. The frequency ratios β_1 and β_2 are optimized to be 0.91 and 0.92 for both the bending and torsion. Figure 4 shows the FRF of the plate with TMDs. The amplitudes of the bending mode and torsion mode considerably decrease due to TMDs,

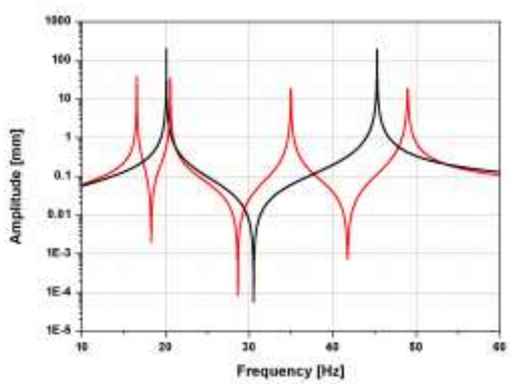

Figure 4 Optimization results of TMD

C. *Verifications with Experiments*

The experiments are performed to verify the performance of TMDs. Figure 5 shows the experimental setup of the cantilever plate with TMDs. Figure 6 shows the FRFs of the plate with TMDs. The frequency ratios β_1 and β_2 are 0.91 and 0.92, respectively. The amplitude of the bending and torsion decrease by 9.75dB~10.52dB and 14.05dB ~ 14.15dB, respectively.

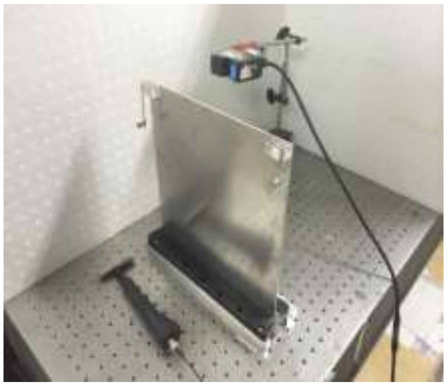

Figure 5 Experimental setup

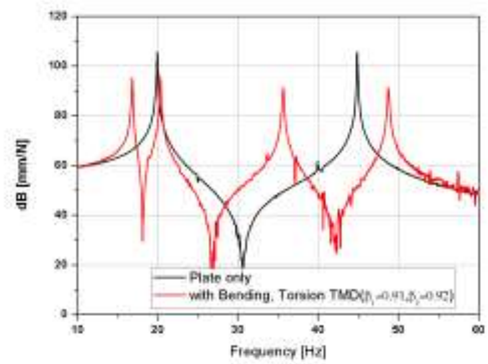

Figure 6 FRFs of plate with TMD

III. Magnetically TMD

ECD is introduced to the optimized TMDs to increase the damping performance. The gap size between a permanent magnet and the conducting plate is 1~5 mm. As gap size increase the damping performance decreases. From optimization process the gap sizes are 3 mm for the bending and 1 mm for the torsion. Figure 7 shows the FRFs of the plate with mTMD. The damping performance of mTMD is excellent for the three cases. When mTMD is applied for both bending and torsion its performance becomes to be maximum. The amplitude of the FRFs shown in Figure 7 decrease by 33.99 dB and 36.48 dB ~ 48.82 dB for the bending and the torsion, respectively.

IV. Conclusions

In the present study we apply the mTMD to attenuate the vibration of a cantilever plate. Although mTMD is very simple to be applied its damping performance is excellent. Using 4

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DOF model of the plate with TMD the parameters of TMD are designed, optimized and verified with experimental results. To increase the damping performance ECD is introduced to the TMD. The experimental results show that the damping performance of mTMD is excellent.

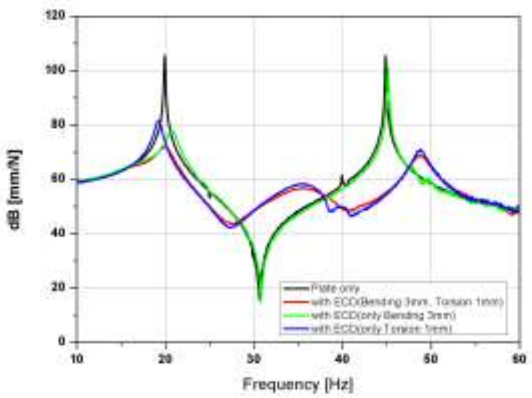

Figure 7 FRFs of plate with mTMD

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