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Multi-Modal Passive-Vibration Control of Bridges under General Loading-Condition

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Abstract

Application of TMD systems are observed for mitigation of excessive vibration of bridge-structures targeting either wind loading or vehicle loading. Usually, dominant modes in one direction (commonly vertical) are taken in account for such passive control using TMD systems. However, considering modes dominant in one direction may not be considered as a robust practice while any bridge structure is having dominant modes along both the transverse and vertical directions and the same bridge structure is subjected to loading along both the directions. An approach for simultaneous control of major horizontal, vertical and torsional modes is presented in the present study targeting robust vibration control under general loading condition. A modal frequency response function (FRF) based strategy is proposed using the traditional mode-wise control approach. The proposed modal FRF based approach is applied to an existing important large truss bridge (Saraighat Bridge) to carry out an analytical design of TMD system considering general loading conditions. A Good control-performance is observed based on this proposed design methodology under various simulated general loading conditions.

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1. Introduction

In the field of passive vibration control of structural systems, the tuned mass damper (TMD) is considered as amongst the oldest passive vibration control devices in existence. One of primary reporting of TMD devices is observed as dynamic vibration absorber (DVA) problem [1] where TMD system is connected with a single degree

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of freedom (SDOF) primary system. A performance study of TMD system with uncertain parameters was carried out by Jensen et al. [2]. In an introductory work regarding multiple TMD (MTMD) system, Xu and Igusa [3] considered a main structure supporting a large number of substructures having closely spaced natural frequencies. Abé and Igusa [4] studied the characteristics of TMD systems for response control of structures with closely spaced natural frequencies. Jangid and Datta [5] investigated the dynamic response behaviour of a simple torsionally coupled system with MTMD system. Rana and Soong [6] explained the design of MTMD system targeting a particular mode of MDOF structural systems. Various works on optimal design of TMD systems in frequency domain are found in literature using/minimizing H∞ norm e.g. [7, 8]. Moreover, many interesting investigations regarding the wind-induced vibration control of bridge structures using TMD devices are found in literature considering various vibration mechanisms: (a) buffeting (e.g. [9]) (b) flutter (e.g. [10]) (c) vortex-induced vibration (i.e. [11]). Another area of major investigations on TMD devices for bridge structures are found to control vibration under moving loads e.g. [12].

From the literature survey, it is observed that the design of TMD systems for bridge structures is carried out usually considering wind loading or vehicle loading. In those studies, modes dominant in single direction (commonly vertical) are taken into account for design of the TMD system. However, such design may not be considered as robust against general loading conditions effective in both horizontal and vertical directions. Very limited works on design of TMD systems considering generalized loading for simultaneous control of vertical, horizontal as well as torsional modes are reported in the literature. In the present work, a control-strategy targeting general loading-condition is proposed using modal frequency response function (FRF) and the traditional mode-wise control-approach with simultaneously controlling the major horizontal, vertical and torsional modes.

2. Design of MTMD system: a modal FRF based approach

In case of designing of TMD device for a MDOF structural system, it is possible to design the TMD device separately targeting any mode in a similar way of designing TMD device for single degree of freedom (SDOF) structural system, if the corresponding mode shape is normalized in an appropriate manner [6]. Finally, the MTMD systems individually designed for various target modes are attached to the primary structure in the respective designed locations to work as multi-modal control device. This approach, usually considered as a fundamental modal framework for TMD design, is used in the present study to propose a novel modal FRF based TMD design strategy simultaneously controlling both the horizontal (transverse) and vertical modes.

2.1. Modal FRF Associated to a target mode

Equation of motion of the MDOF structural systems can be expressed as:

$$[M]\{\ddot{x}\}+[D]\{\dot{x}\}+[K]\{x\}=\{F\} \tag{1}$$

where, $[M]$, $[D]$ and $[K]$ represent mass, damping and stiffness matrices, while $\{F\}$ represents the force vector. With the assumption of proportional damping and using a mode shape matrix $([\Phi])$ based transformation as $\{x\}=[\Phi]\{Q\}$, Eq. (1) can be transformed into n (system size) uncoupled equations in modal coordinates (Q_i). An uncoupled equation associated to the i^{th} mode can be expressed as follows.

$$M_i\ddot{Q}_i+D_i\dot{Q}_i+K_iQ_i=\{\Phi_i\}^T\{F\} \tag{2}$$

where, M_i, D_i, K_i, Q_i and $\{\Phi_i\}$ represent the modal mass, modal damping coefficient, modal stiffness, modal coordinate and mode shape associated to the i^{th} mode. If , mode shape for i^{th} mode, is scaled or normalized such that the modal deformation along a DOF (suppose j) connected to the MTMD becomes unity (i.e. Φ_{ij} = 1), then it becomes feasible to individually design an MTMD device targeting the i^{th} mode of an MDOF structural system [6].