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Smart tuned mass dampers: recent developments

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Summary. This special issue focuses on Smart Tuned Mass Dampers (STMD) that are either active or smart or semi-active in nature. Active tuned mass dampers or active mass dampers have found wide acceptance and have been implemented in many tall buildings and long span bridges. Recently researchers have developed a new class of smart tuned mass dampers using either variable stiffness and/or variable damping to effect the change in instantaneous frequency and damping. Since tuning plays a central role in STMDs it is of great current interest thus the topic of this special issue. Discussions of recent active and smart TMD implementations in tall buildings and bridges are also included.

Keywords: tuned mass damper; active; semiactive; smart; adaptive passive; tuning; instantaneous frequency

1. Introduction

Ormondroyd and Den Hartog were the first to theoretically investigate the tuned mass damper (TMD) (Ormondroyd and Den Hartog 1928). A TMD is a secondary mass attached using a spring and damper to a primary structure mass attached with a spring and damper to a fixed support. When the spring and damper, attaching the secondary massto the primary structure, have fixed properties then it is a classic tuned mass damper (Ormondroyd and Den Hartog 1928, Den Hartog 1956). If the spring and damper attaching the secondary mass to the primary structure have variable properties—either varied passively and thus called adaptive passive TMD, or varied semi-actively with sensing and appropriate feedback and thus called smart TMD (STMD)—they offer the capability to adapt the frequency and damping ratio of the secondary mass. The adjustment of stiffness and/or damping leads to tuning of the secondary mass frequency to match either the first mode of the primary structure or the excitation frequency—thus the name tuned mass damper. When detuning occurs due to the deterioration in the primary structure or due to other reasons, TMD loses its effectiveness, particularly in the absence of damping.

Optimum design of TMD's werefirst presented in the classic textbook by Den Hartog (1956). Since then, TMDs have been widely studied and many new types of TMDs have been developed and evaluated (Hrovat *et al*. 1983, Walsh and Lamancusa 1992, Abe and Igusa 1996, Pinkaew and Fujino 2001, Housner *et al*. 1997, Kareem *et al*. 1999, Spencer and Nagarajaiah 2003, Varadarajan and Nagarajaiah 2004, Nagarajaiah and Varadarajan 2005, Bonello *et al*. 2005, Nagarajaiah and

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Sonmez 2007, Nagarajaiah 2009, Sun and Nagarajaiah 2013, Weber 2013). Tuned mass dampers (TMD), active mass dampers (AMD) and hybrid mass dampers (HMD) have been widely applied for vibration control of tall buildings and bridges in the past decade (Kareem et al. 1999, Spencer and Nagarajaiah 2003). Recently, smart tuned mass dampers (STMD) have been developed Hrovat *et al*. 1983, Walsh and Lamancusa 1992, Abe and Igusa 1996, Pinkaew and Fujino 2001, Housner *et al*. 1997, Kareem *et al*. 1999, Spencer and Nagarajaiah 2003, Varadarajan and Nagarajaiah 2004, Nagarajaiah and Varadarajan 2005, Bonello *et al*. 2005, Nagarajaiah and Sonmez 2007, Nagarajaiah 2009, Sun and Nagarajaiah 2013, Weber 2013) to offer more adaptive capability than TMD's in reducing the response of the primary structure. Important aspect is the tuning of the instantaneous frequency of STMD using either variable stiffness or variable damping. It is more efficient to use variable stiffness to effect the change in instantaneous frequency rather than variable damping. Researchers have also developed combined variable stiffness and variable damper smart tuned mass dampers (Sun and Nagarajaiah 2013) which offer a wider range of capabilities for making the STMD adaptive and responsive to different types of structures and excitations. Researchers have shown that STMD can provide performance similar to AMD/HMD, but with an order of magnitude less power consumption. Recently variable length pendulum STMD and Adaptive TMD have been proposed (Nagarajaiah 2009) and found implementation in TV tower (Nagarajaiah 2009) and variable damping Magnetorheological damper (Spencer and Nagarajaiah 2003) based STMD has been tested in a bridge (Weber 2013).

The following papers included in this special issue on “Smart Tuned Mass Dampers” address these current topics of great interest; we summarize them briefly.

1. Arrigan *et al*. in their paper “A Frequency Tracking Semi-Active Algorithm for Control of Edgewise Vibrations in Wind Turbine Blades”, present the effectiveness of Semi-Active Tuned Mass Dampers (STMDs) in reducing the edgewise vibrations in the turbine blades. A frequency tracking algorithm based on the Short Time Fourier Transform (STFT) technique is used to tune the damper.

2. Pasala *et al*. in their paper “Adaptive-length pendulum smart tuned mass damper using shape-memory-alloy wire for tuning period in real time”, present a novel adaptive-length pendulum (ALP) damper. Length of the pendulum is adjusted in real time using a shape memory alloy (SMA) wire actuator. Effectiveness of the proposed ALP-STMD mechanism, combined with the STFT frequency tracking control algorithm, is verified experimentally on a prototype two-story shear frame.

3. Contreras *et al*. in their paper “Adaptive Length SMA Pendulum Smart Tuned Mass Damper Performance in the Presence of Real Time Primary System Stiffness Change” present the effectiveness of ALP-STMD on a primary structure whose frequencies are time varying experimentally. Significant performance improvement is illustrated for the stiffness modified system, which undergoes the re-tuning adaptation, when compared to the stiffness modified system without adaptive re-tuning.

4. Teng *et al*. in their paper “Design and implementation of AMD system for response control in tall buildings” present recently developed technologies pertaining to the design and implementation of Active Mass Damper (AMD) control system on a high-rise building in China subjected to wind load.

5. Sadhu *et al*. in their paper "Ambient Modal Identification of Structures Equipped with Tuned Mass Dampers using Parallel Factor Blind Source Separation", present a novel PARAllelFACtor (PARAFAC) decomposition based Blind Source Separation (BSS) algorithm for modal identification of structures equipped with tuned mass dampers.

6. Xu *et al*. in their paper "Active mass driver control system for suppressing wind-induced vibration of the Canton Tower", present field test results of AMD control that show the damping ratio of the first vibration mode increases up to 11 times of original value without control.

7. Jang *et al*. in their paper "Active mass damper system using time delay control algorithm for building structure with unknown dynamics", present numerical investigations of the feasibility of an active mass damper (AMD) system using the time delay control (TDC) algorithm for effectively suppressing the excessive vibration of a building structure under wind loading.

8. Sun *et al*. in their paper "Family of Smart Tuned Mass Dampers with Variable Frequency under Harmonic Excitations and Ground Motions: Closed-Form Evaluation", present closed-form solutions for the two types of STMDs under harmonic excitations and ground motions. Results indicate that a small damping ratio (zero damping being ideal) and an appropriate mass ratio can produce significant reduction when compared to the case with no tuned mass damper.

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