Mechanical Systems and Signal Processing 25 (2011) 205–221

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/jnlabr/ymssp

Structural identification of a prototype pre-stressable leaf-spring based adaptive tuned mass damper: Nonlinear characterization and classification

Demosthenis Rizos *, Glauco Feltrin, Masoud Motavalli

EMPA, Swiss Federal Laboratory of Material Testing and Research, Structural Engineering Research Laboratory, Ueberlandstrasse 129, CH-8600 Duebendorf, Switzerland

ARTICLE INFO

Article history:
Received 27 October 2009
Received in revised form
29 June 2010
Accepted 2 July 2010
Available online 8 July 2010

Keywords:
Adaptive tuned mass damper
Pre-stressable leaf-springs
Nonlinear characterization
Nonlinear structural identification
Vibration mitigation
PZT stack actuators

ABSTRACT

The current paper focuses on a prototype adaptive TMD. Its design concept is based on pre-stressable leaf-springs that are controlled by piezoceramic (PZT) stack actuators. Experiments performed on the prototype showed that it is continuously tunable in a broad frequency range. Moreover, they revealed that the device exhibits structural nonlinearities. The current paper focuses on the structural identification of the prototype and attempts for the first time to characterize and classify the observed nonlinearities. Several experiments at different PZT voltage levels are performed. The results indicate PZT voltage dependent nonlinear softening and hardening stiffness. Based upon these observations, static experiments and proper data-pooling techniques, an effective "global" model for the nonlinear stiffness is derived. The estimated nonlinear model is finally validated upon static experiments as well as more realistic operational cases, that are vibrations of the prototype under typical ground excitation.

1. Introduction

A standard way of mitigating vibrations in structures, especially in bridges, is by installing Tuned Mass Dampers (TMDs). Their popularity lies mainly in their conceptual and implementation simplicity. Classically, a TMD is a single degree of freedom system consisting of a mass, a spring and a damper, which is attached on the primary structure. Conventionally, the design task includes the tuning of the TMD devices resonant frequency and damping to that of the structure, so that the mechanical energy can be effectively dissipated. Towards that direction, several design formulae have been developed, covering different load scenarios and optimality objectives [1–5].

Conventional TMD devices are passive and therefore cannot account for the structural modifications of the primary structure under control. This might be a severe limitation, especially in the case of lightweight and slender bridges, whose structural state is significantly effected by the fluctuating live loads. In essence, their resonance frequencies vary with time (see [6,7] for some characteristic demonstrations). The consequence is a dramatic decrease in energy dissipation efficiency, due to the conventional TMDs' mistuning [8]. Conventionally, this situation is tackled by using multiple TMDs, where the natural frequencies of the TMDs are distributed over a frequency range. Even though the current idea has been already used to suppress vibration in civil engineering structures [4], the device is not continuously tuned over the frequency

* Corresponding author. Tel.: +41 44 823 4989; fax: +41 44 823 4455.
E-mail addresses: dimosthenis.rizos@empa.ch, demosthenis.rizos@gmail.com (D. Rizos), glauco.feltrin@empa.ch (G. Feltrin), masoud.motavalli@empa.ch (M. Motavalli).

0888-3270/$ - see front matter
doi:10.1016/j.ymssp.2010.07.001

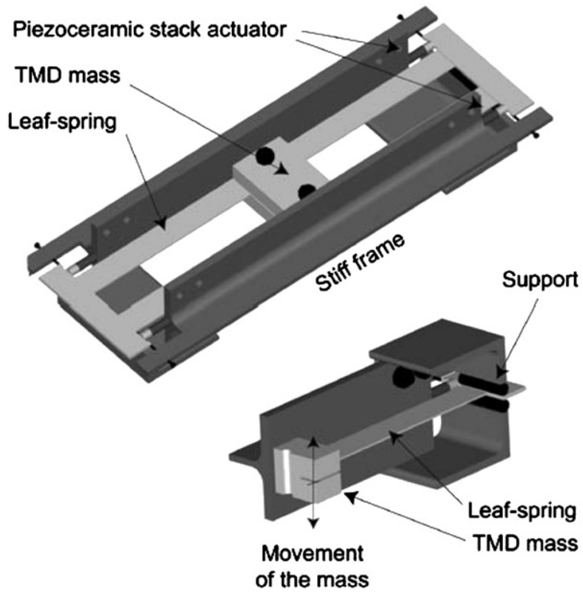

Fig. 1. The PLA-TMD device [27] (conceptional viewpoint).

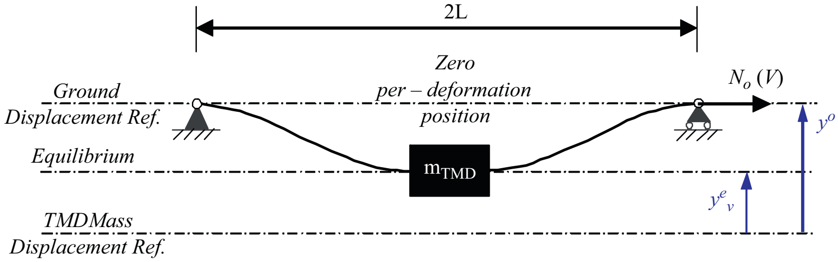

Fig. 2. The PLA-TMD device (operational viewpoint).

range, but over a discrete number of frequencies. This limitation has been recently mitigated by considering the concept of the adaptive TMDs. The underlying idea is to construct devices with continuously tunable characteristics and to develop effective adaptive strategies for mitigating vibrations [9,10].

In general, adaptive TMD designs can be classified into those that employ variable geometries in order to adjust the TMD characteristics to the structural modifications [11–17] and those that employ smart materials for achieving the same goal [18–26].

The current work focuses on the latter category and especially on a prototype Pre-stressable Leaf-spring based Adaptive TMD (*PLA-TMD*—Fig. 1) proposed by Gsell et al. [27]. The tunable characteristics of the PLA-TMD are achieved by four embedded piezoceramic (PZT) stack actuators, which are capable of providing different axial loading $N_o(v)$ (pre-stress) to the leaf-springs (Fig. 2). Thus, modifying the excitation voltage of the PZT stack actuators, the leaf-springs' stiffness can be externally controlled. Therefore the PLA-TMD resonant frequency can be tuned close to the resonant frequency of the primary structure under control.

Among the main advantages of the specific device is its conceptual simplicity, as well as its capability to be continuously tunable in a broad frequency range [27]. These characteristics make the PLA-TMD device quite promising for elaborating an effective adaptive vibration mitigation strategy. However, an analytical “global”[1] model for connecting the applied PZT voltage with the PLA-TMD resonant frequency is still pending. Such a development would have been comparatively easy, if some preliminary experiments had not indicated that the PLA-TMD's resonant frequency is a function of the vibration amplitude [27]; a clear indication of nonlinear dynamics [28, p. 41].

A practical way of finding this functional relationship between the PZT voltage, the PLA-TMD resonant frequency and the amplitude of vibrations is to apply nonlinear structural identification techniques [28]. However, this task is bound to failure if the nonlinear dynamics involved are not well determined and understood [29, pp. 538–539]. The main goal of the

[1] Global in the sense of covering the whole operational range of both the vibration amplitude and PZT voltage level.