Journal of Sound and Vibration 404 (2017) 47–57

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Experimental study of the novel tuned mass damper with inerter which enables changes of inertance

P. Brzeski, M. Lazarek, P. Perlikowski*

Division of Dynamics, Lodz University of Technology, Stefanowskiego 1/15, 90-924 Lodz, Poland

ARTICLE INFO

Article history:
Received 2 January 2017
Received in revised form
29 April 2017
Accepted 18 May 2017
Handling Editor: D.J Wagg

Keywords:
Inerter
Damping
Tuned mass damper
Prototype
Experimental investigation

ABSTRACT

In this paper we present the experimental verification of the novel tuned mass damper which enables changes of inertance. Characteristic feature of the proposed device is the presence of special type of inerter. This inerter incorporates a continuously variable transmission that enables stepless changes of inertance. Thus, it enables to adjust the parameters of the damping device to the current forcing characteristic. In the paper we present and describe the experimental rig that consists of the massive main oscillator forced kinematically and the prototype of the investigated damper. We perform a series of dedicated experiments to characterize the device and asses its damping efficiency. Moreover, we perform numerical simulations using the simple mathematical model of investigated system. Comparing the numerical results and the experimental data we legitimize the model and demonstrate the capabilities of the investigated tuned mass damper. Presented results prove that the concept of the novel type of tuned mass damper can be realized and enable to confirm its main advantages. Investigated prototype device offers excellent damping efficiency in a wide range of forcing frequencies.

1. Introduction

Tuned mass dampers (TMD) are widely used for damping of unwanted oscillations of mechanical and structural systems. The first record of TMD-like device can be found in the work by Watts [1] published in 1883. In 1909 Frahm described and patented the classic TMD [2]. His device is extremely effective in reducing the response of the damped structure only in the principal resonance. Den Hartog proposed to add a viscous damper to Frahm's system design [3] to expand its range of effectiveness. Thanks to that simple modification, the TMD can reduce vibrations of the main body in wide range of excitation frequencies around the principal resonance. Another way to broaden the range of TMD's effectiveness was proposed by Roberson [4] and Arnold [5] who interchange the linear spring of TMD by the nonlinear one (with the linear and nonlinear parts of stiffness). Recently there are many papers considering new or modified designs and applications of TMDs [6–10].

This paper is devoted to the examination of a novel design of TMD introduced in our previous publication [11]. Essence of the concept lies in the special type of an inerter. Initially inerters [12] were successfully applied in sports cars' suspensions [13,14]. Now we observe growing number of studies on other possible applications: in railway vehicles' suspensions [15,16], devices that absorb impact forces [17] or protect buildings from earthquakes [18,19]. In [20] authors study the influence of the inerter on the natural frequencies of vibration systems while in [21] we find the review of the effects of an inerter on the tuned mass absorber.

* Corresponding author.
E-mail address: przemyslaw.perlikowski@p.lodz.pl (P. Perlikowski).

http://dx.doi.org/10.1016/j.jsv.2017.05.034

In a very new papers [22–26] one can find the idea of usage of the inerter as a part of the TMD. Numerical results prove that optimally designed TMD with inerter outperforms classical TMDs. Still, to work efficiently, all considered devices have to be precisely tuned which can be hard to achieve or even impossible in some cases. Moreover proposed TMDs with inerters suffer from susceptibility to detuning. The above problems may be eliminated using the device equipped with an inerter that enables stepless and accurate changes of inertance that we proposed in 2014 [11]. The idea of inertance-changeable inerters was also considered for different applications by Chen et al. [27–29]. In [11] we prove that such a property can be achieved by using a continuously variable transmission (CVT) with gear-ratio control system. In [11] we describe the possible realization of the TMD that incorporates inertance-changeable inerter. Then, we perform numerical analysis of its properties. In this paper, we present the experimental investigation of the existing prototype of the device.

Although the mathematical model of the inerter is very simple its practical realizations do not follow the model strictly. It is mainly caused by factors like: internal motion's resistances, friction, play in gears and etc. Most of these effects are modelled using nonlinear functions that are much more complex than the formula proposed by Smith et. al. In our recently published paper [30] we present the analysis of the inerter nonlinearities on the performance of the TMD.

Aforementioned phenomena influence the response of the structure and the efficiency of a TMD. That is why in this paper we describes a series of experiments of prototype TMD performed on a unique experimental rig. Then, we compare experimental data with numerical results to legitimize the mathematical model of the examined TMD.

The paper is organized as follows. In Section 2 we present the idea that lies behind the examined TMD. Section 3 contains the description of the experimental rig and in Section 4 we present its physical and mathematical models. In Section 5 we present the data collected during the experimental tests of the prototype and compare it to results obtained from the numerical model. In Section 6 we summarize our results.

2. The idea behind the examined TMD design

The classical TMD introduced by Frahm [2] consists of mass on a linear spring. Such a device is extremely effective in suppressing oscillations of the main structure for the frequency equal to the natural frequency of the TMD. For the frequencies outside small range around its main resonance it increases the amplitude of the system's motion. Because of this disadvantage, the classical TMD has extremely small range of effectiveness and is hardly ever used. We can extend the range of effectiveness by adding a viscous damper, using a nonlinear spring instead of linear one etc. Still, the increase in the range of effective damping impairs damping properties in principal resonance (when vibrations frequency is equal to the natural frequency of the TMD). Therefore, we always have to face a tradeoff between the most effective mitigation of vibrations for given frequency or achieving the tolerable damping properties in a wide range of vibration frequencies. This problem can be minimized by novel types of TMDs which incorporates inerters or magnetorheological dampers that are intensively developed nowadays. Unfortunately, all of the devices are not as efficient as classical TMD for its tuned frequency.

The solution for the problems would be the TMD with as small damping as permissible (to secure best possible damping efficiency for natural frequency of the device) and controllable natural frequency. In our previous paper [11] we propose the new design of a TMD that meets both of these requirements. The device we propose is schematically presented in Fig. 1. It consist of inertial component (A) that is coupled via elastic link (B), inerter (C), and dashpot (D) to damped structure (E). The essential part of the proposed TMD design is the special type on an inerter (C). This inerter contains the CVT that allows

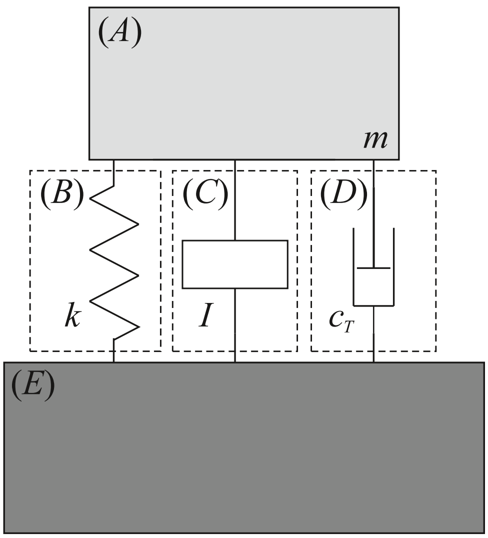

Fig. 1. Scheme of the proposed TMD model.