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Linear and Nonlinear Analysis of Piezoelectric Based Vibration Absorber with Acceleration Feedback

S Mohanty*, S K Dwivedy

Indian Institute of Technnology Guwahati, Department of Mechancial Engineering, Assam, Guwahati, 781039, India

Abstract

In the present paper, analysis of a single degree of freedom spring-mass-damper primary system with a piezoelectric based dynamic vibration absorber (DVA) is carried out. The proposed DVA model consisting of a lead zirconate titanate (PZT) actuator which is connected in series with a spring. The analysis is done in two section by considering a static force and a harmonic force acting on the primary system respectively. In the first section linear stiffness is considered in the primary mass and in the second section cubic nonlinear stiffness along with the linear stiffness is considered. The voltage applied to the stack PZT actuator is considered to be proportional to the acceleration of the primary mass. Method of multiple scales (MMS) is used to obtain the system response in the nonlinear analysis and compared with linear analysis. For linear system optimum system parameters of the absorber are obtained using fixed point theory of optimization and Routh's stability criterion is used for stability analysis. Primary resonance condition is studied in the nonlinear analysis. In the proposed model as a spring is connected in series with PZT actuator for which force developed by the absorber to suppress the vibration of the primary system is not solely depend upon the voltage, so one can use small voltage to reduce the vibration of primary system.

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Keywords: Tuned mass damper, Piezoelectric actuator, Method of multiple scales, Fixed point theory.

1. Introduction

Dynamic vibration absorber (DVA) have been well researched over the past decades [1] showing various applications in the field of engineering systems. But still suppression of vibration by the DVA is an active area of research as large number of recent literature review papers [2-8] are available in this field. Various optimization techniques [9, 10] have been developed to minimize the peak amplitude of the primary vibrating system by attaching

* Corresponding author. Tel.: +91-9678436595;
E-mail address: siba.mech@gmail.com

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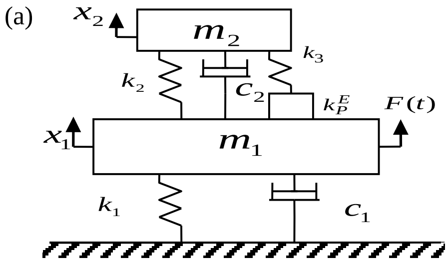
the tuned mass damper to the primary system. Different vibration absorption models [11-14] have been developed to reduce the peak and valley height of the frequency response curve and also maximum amplitude of the primary system. Many vibration absorber recently use various smart material like piezoelectric in stack and patch form to mitigate the vibration of the single degree of freedom (DOF) multi DOF and in continuous system and also harvesting energy from the system [15-17]. These vibration absorber are known as Active vibration absorber which uses sensor and actuator to provide counteracting force to the vibrating primary system to reduce to its vibration. Ji [18] used MMS for analyzing and studying different resonance condition of a nonlinear passive vibration absorber (PVA) with a nonlinear SDOF system vibrating with harmonic excitation. Nonlinear analysis of various absorber model with SDOF and MDOF are also studied in [19, 20] by considering multiple harmonic force and parametric excitation forces acting on the primary system. However the nonlinear analysis of the active vibration absorber with PZT actuator is not explored more. In the proposed model the PZT actuator is connected in series with the absorber by a spring which are not present in the previous literatures. So by this type of model one can use a higher order stiffness value for the absorber to produce more controlling force without much increase in the voltage provided to the actuator. This work will be an extension of [21] where linear analysis is carried out and nonlinear analysis with displacement feedback is done.

2. Mathematical Modelling

A non-linear single degree of freedom primary system to which an active DVA is placed is shown in Fig. 1. (a) The block diagram of the acceleration feedback on the primary system is shown in Fig. 1. (b). Here m_i, c_i and k_i denotes mass, damping and stiffness of the primary system and the DVA respectively for i =1, 2. k_3 and k_E^P denotes the stiffness of the absorber and piezoelectric actuator respectively. $F(t)$ is the force acting on the primary system. x_1 and x_2 are the displacement produced in the primary mass and absorber respectively.



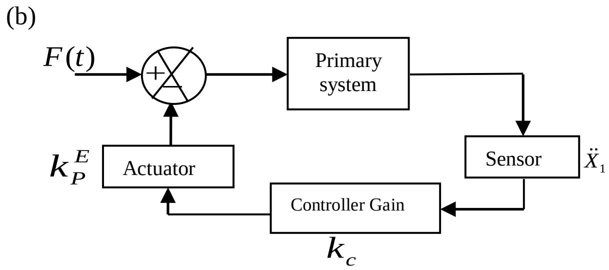


Fig. 1. (a) Piezoelectric stack actuator based Hybrid vibration absorber; (b) block diagram for acceleration feedback of the primary mass.

2.1. Linear system analysis

The equations of motion of the system in the Fig. 1. (a) can be compared with [9] but here as a spring of stiffness k_3 is attached in tandem with the PZT actuator of stiffness of k_P^E the actuating force developed will be different than [9]. So the modified equations of motion can be written as

$$m_1 x_1'' + k_1 x_1 + k_2\left(x_1 - x_2\right) + c_1 x_1' + c_2\left(x_1' - x_2'\right) = F\left(t\right) - k_r\left(x_1 + \delta_0 - x_2\right), \tag{1}$$

$$m_2 x_2'' + k_2\left(x_2 - x_1\right) + c_2\left(x_2' - x_1'\right) = k_r\left(x_1 + \delta_0 - x_2\right), \tag{2}$$

where $k_r = \left(k_P^E k_3 / \left(k_P^E + k_3\right)\right)$ and $\delta_o = n d_{33} v$

The nominal displacement of the stack actuator [10] is δ_o, where n is the number of wafer used in the stack actuator