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Active vibration suppression through positive acceleration feedback on a building-like structure: An experimental study

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A B S T R A C T

This work deals with the structural and dynamic analysis of a building-like structure consisting of a three-story building with one active vibration absorber. The base of the structure is perturbed using an electromagnetic shaker, which provides forces with a wide range of excitation frequencies, including some resonance frequencies of the structure. One beam-column of the structure is coupled with a PZT stack actuator to reduce the vibrations. The overall mechanical structure is modeled using Euler–Lagrange methodology and validated using experimental modal analysis and Fine Element Method (FEM) techniques. The active control laws are synthesized to actively attenuate the vibration system response via the PZT stack actuator, caused by excitation forces acting on the base of the structure. The control scheme is obtained using Positive Acceleration Feedback (PAF) and Multiple Positive Acceleration Feedback (MPAF) to improve the closed-loop system response. Some experimental results are included to illustrate the overall system performance.

1. Introduction

The study on structural control of mechanical vibrations in buildings has recently become a research topic of importance, especially in highly populated cities, where civil structures are usually affected by the presence of transportation systems and seismic phenomena [1–4]. Research on vibration control in buildings is generally focused on the use of passive, semi-active and active vibration control schemes [5,6]. Passive schemes, also summarized by the well-known *Tuned Mass Damper* (TMD), are limited in their response since they are designed to inject extra damping or minimize a certain frequency or a particular vibration mode on some structure. On the other hand, active schemes, also well-known as *Active Mass Damper* (AMD), can provide a feedback and/or feedforward controller for a wide range of frequencies or vibration modes. The AMD control scheme usually adds extra degrees of freedom and an actuator to the original model of the structure, which usually increases the complexity of the overall system dynamics. The suppression or damping of the vibration frequencies in the system is performed by computing a control force provided by an electrohydraulic or electromechanical actuator [5].

Recent technological innovations on smart materials provide new alternatives to implement real-time active vibration control schemes on civil and mechanical structures. In fact, the smart materials used as actuators can offer good

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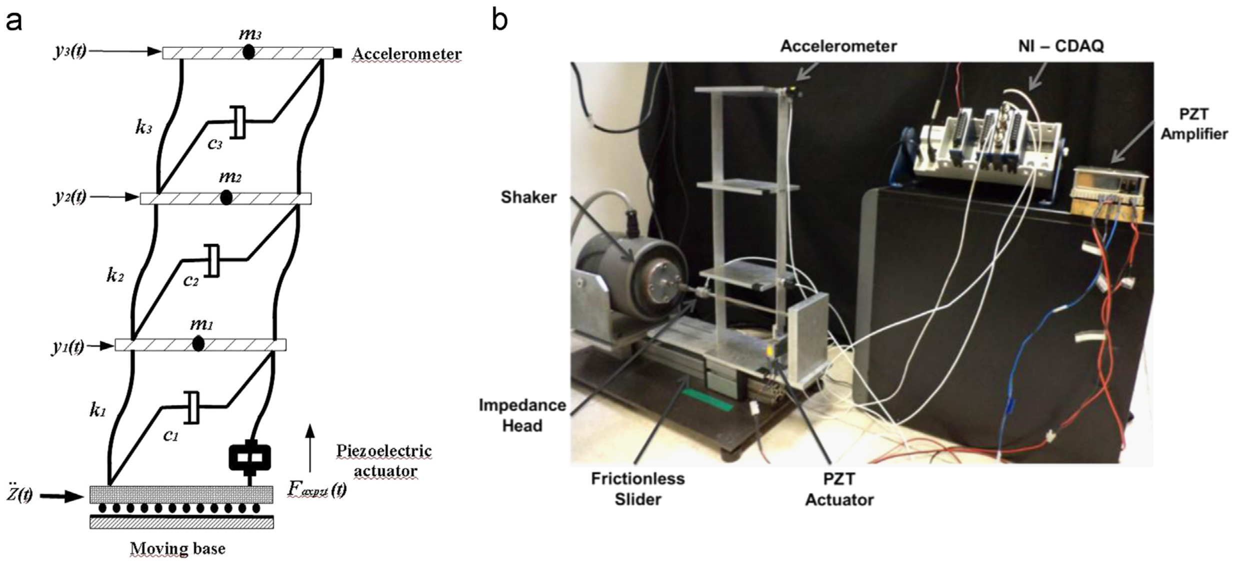

Fig. 1. Three-story building-like structure. (a) Schematic diagram, (b) experimental setup.

performance at an affordable cost [7–11]. Nowadays, there are piezoelectric (PZT) actuators that can be used to provide loads of several tons and these have already been applied in civil engineering [8,11].

In this work, the modeling, characterization and experimental validation of a small scale three-story building-like structure with a PZT stack actuator are considered for evaluation of an active vibration control scheme to compensate or reduce the overall vibration response under harmonic and seismic ground motion. The control scheme is based on Positive Acceleration Feedback (PAF) to attenuate a single mode of the structure and Multiple Positive Acceleration Feedback (MPAF) to simultaneously attenuate the first three dominant lateral modes of the structure.

2. Experimental setup of the building-like structure

The primary mechanical system consists of a small scale three-story building-like structure, which was designed and built in aluminum alloy with nominal stiffnesses $k_i = 12EI/L^3$, with Young's modulus E, moment of inertia I and total length L between floors, as described in the schematic diagram and overall experimental setup shown in Fig. 1 (see [11]). The maximum height of the structure is 450 mm with a rectangular base of $150 \times 100\ \text{mm}^2$. The building-like structure is assumed to have three degrees of freedom (y_1, y_2, y_3), describing the lateral motion of each floor and associated to the first three dominant lateral modes of the structure and characterized by three concentrated masses (m_1, m_2, m_3), each of them interconnected by two flexible beams in each mass represented by the equivalent stiffnesses (k_1, k_2, k_3), while equivalent (linear) viscous dampings (c_1, c_2, c_3) are considered on each interconnection.

The full structure is mounted on an anti-friction ball bearing rail and the moving base is connected directly to an electromechanical shaker, which is used to provide the ground motion with low-frequency harmonic components in a frequency sweep from 0 to 60 Hz as well as to emulate some realistic records from seismic events occurred at Mexico City.

The electromechanical shaker is a *Labworks*®ET-139 controlled via a linear power amplifier *Labworks*® PA-138. A *National Instruments*® NI-CompactDAQ data acquisition system, consisting of a NI-DAQ-9172 chassis and a NI-9133 module for accelerometers connected via USB to a PC running under *Windows 7*®. The accelerations on the ground and third floors are measured with accelerometers by means of another data acquisition system, connected via USB to the PC, to obtain and process the signals in *Labview*® and *Matlab/Simulink*®.

In addition, a PZT stack actuator is located on one of the beam-columns in the first floor of the three-story building type structure in order to actively attenuate the vibrations affecting the structure (see Fig. 2). The *Dynamic Structures & Materials*® FPA-0500E P-1036-150-SS-1M3 110 *Flextensional Piezoelectric Actuator*® was used. This actuator is embedded into a mechanical arrangement with springs to amplify the longitudinal motion from the transversal PZT material expansion. The nominal specifications of this PZT stack actuator are maximum displacement of $\delta_{pzt} = 523.7\ \mu\text{m}$, equivalent stiffness $k_{pzt} = 0.934\ \text{N}/\mu\text{m}$, (unloaded) resonant frequency of 440 Hz, blocking force about 375 N and asymmetric operation voltage from -30 to $+150$ V controlled from a power amplifier (peak output power 50 W and output voltage range from -100 to 400 V) and whose external control input (-2 to 8 V) is obtained from a data acquisition card installed into the PC, thus making possible the application of feedback and/or feedforward control schemes. To guarantee a symmetric actuation and protect its physical limits, the operating voltage applied to the PZT stack actuator is restricted to ± 30 V.

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