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Modeling and semi-active fuzzy control of magnetorheological elastomer-based isolator for seismic response reduction

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ABSTRACT

In this paper, a magnetorheological elastomer (MRE) based isolator was investigated to mitigate excessive vibrations in structures during seismic events. The primary objectives of this research are to propose a numerical model that expresses viscoelastic behaviors of the MRE and predict operation process of the MRE-based isolator for future design of isolator systems for various technical applications. Despite the simplicity in parameter definition in comparison to the conventional models, the proposed model works efficiently in a wide range of frequencies and amplitudes. The model consists of the following components: viscoelasticity of host MRE, magnetic field-induced property, nominal viscosity as well as high stiffness in low excitation frequency that are modeled in analogy with a standard linear solid model (Zener model), a stiffness variable spring, and a smooth Coulomb friction, respectively. Furthermore, a semi-active fuzzy controller was designed to enhance the performance of the isolator in suppressing structural vibrations. The control strategy was built to determine the command applied current. The controller is completely adequate for handling the nonlinearity of the isolator and works independently with the building structure. The efficiency of the MRE-based isolator was evaluated by the responses of the scaled building under seismic excitation. Numerical and experimental results show that the isolator accompanied with a fuzzy controller remarkably reduces the relative displacement and absolute acceleration of the scaled building compared to passive-off and passive-on cases.

1. Introduction

Magnetorheological elastomer (MRE) is a class of smart materials that mainly generate a slightly magnetic field dependent variable stiffness. MREs have attracted significant interest for application in the field of intelligent devices, such as vibration absorbers and isolators [1,2]. Recently, MREs have been used effectively for base isolation of structure to protect structures from seismic vibrations [3,4]. The MRE-based isolators have the ability to govern the transmissibility by adjusting their properties such as stiffness and damping.

In order to design MRE-based isolator systems for various technical applications, a numerical model is necessary to represent dynamic behaviors of MRE. Unfortunately, these behaviors are strongly nonlinear functions of magnetic flux density

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and displacement amplitude, and they are also affected by changes in frequencies to some extent [5]. Therefore, modeling of the MRE properties is a substantial challenge, particularly in vibration control technology. Recently, different viewpoints of MRE modeling were considered. Li et al. [6] proposed a micromechanics-based viscoelastic model with chain structure that predicted magnetic-field-dependent dynamic shear stiffness and damping of MRE. Li et al. [7] developed a four-parameter viscoelastic model for MRE. In this model, a spring element is in parallel with the standard Kelvin-Voigt model that predicts the viscoelastic properties of MRE under harmonic loadings. However, the strain amplitude is not above 10% and frequency is less than 10 Hz. Eem et al. [8] developed a nonlinear dynamic model that combined the Ramber-Osgood model and the Maxwell model. Simple algebraic equations are used to represent hysteretic nonlinearity. However, its parameters are independent of displacement and frequency. The use of Bouc-Wen (1976) model to represent the nonlinear hysteresis is well known in MR fluid model. The Bouc-Wen model is well acceptable in MRE modeling in recent years [9]. However, one of the major problems in the model is the need for identification of its seven parameters. Norouzi et al. [10] proposed a modified Kelvin-Voigt viscoelastic model for MRE-based isolator, whose coefficients are calculated by nonlinear regression technique. This model only works effectively in the low-frequency range.

The MRE-based isolator is one of the semi-active devices that require an efficient controller. Because of nonlinearity in the model, not many control algorithms exist that could effectively operate MRE devices. The on-off algorithm is widely used [11,12]. Opie et al. [13] developed a clipped-optimal controller for an MRE-based isolator. Behrooz et al. [14] used Lyapunov algorithm in seismic control. Du et al. [15] applied a sub-optimal H-∞ strategy to suppress the vibration of a vehicle seat suspension. In these algorithms, the command applied current has only two options: either zero or the maximum value. Consequently, fast switching produces periodical acceleration and jerk peaks that result in negative effects on the quality of structures. Choi et al. [16] developed a semi-active fuzzy algorithm for seismic response of three story building using MR damper. The command voltage is completely based on the structural first-floor velocity and the third-floor velocity. The semi-active fuzzy algorithm has advantages over the algorithms mentioned above and effectively reduces the building structural responses.

In this study, a MRE-based isolator was investigated to mitigate the seismic performance. The dynamic viscoelastic model of MRE was developed to simulate the dynamic behavior of MRE. The developed model works efficiently in a wide range of frequencies and amplitudes. A procedure was proposed that can determine the parameters in the model. A semi-active fuzzy controller was designed for seismic protection of building with an MRE-based isolator. The applied current is generated according to the relative displacement, the relative velocity, and the ground acceleration. The developed controller is successful in reducing the relative response as well as the absolute acceleration response.

2. Dynamic model of MRE

2.1. Properties of MRE

The elastomer properties of MRE are depicted by force-displacement loops as shown in Fig. 1. Three displacement amplitudes are considered: small amplitude, 0.4 mm; medium amplitude, 1.0 mm; and large amplitude, 1.4 mm. Measurements are performed for two levels of frequency: low frequency, 1 Hz; and medium frequency, 15 Hz. As can be seen in Fig. 1(a), there is an existence of the hysteresis loop at low frequency. The loops maintain their shape if the excitation frequency is relatively low, and therefore present a nominal viscous behavior in MRE. The slope of the hysteresis loops increases as the excitation amplitude decreases, thus the equivalent stiffness increases in small amplitude. The nominal viscosity as well as the increasing stiffness in small amplitude are similar to frictional behaviors. It is shown in Fig. 1(a) that the tangent of the

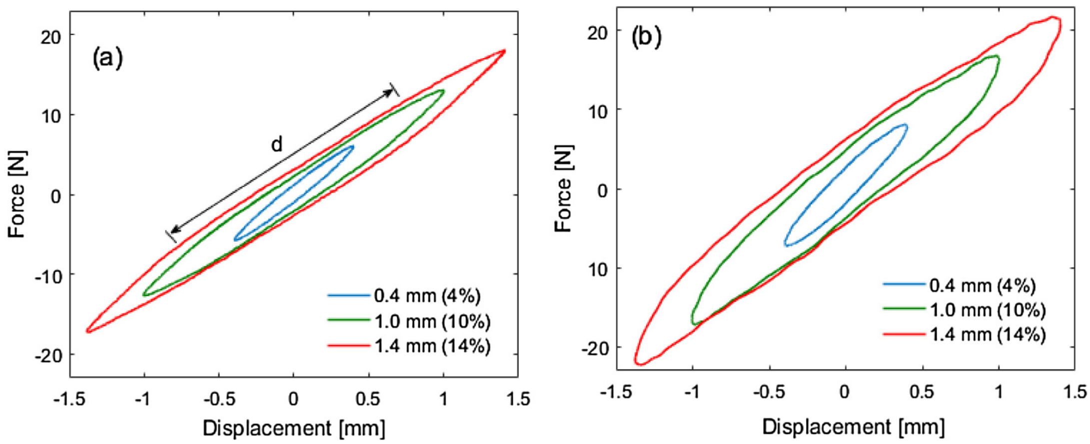

Fig. 1. Force-displacement response for MRE to harmonic excitations: (a) low frequency (1 Hz), (b) medium frequency (15 Hz).