2010

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Publication Details

Zhou, Y., Li, W. & Hadi, M. (2010). Performance comparison between an MRF damper and an MRE isolator incorporated with a building structure. In International Conference on Engineering Design and Optimization, ICEDO 2010, 28-30 Oct 2010, Ningbo. Applied Mechanics and Materials, 37-38 862-865.

Applied Mechanics and Materials Vols. 37-38 (2010) pp 862-865
Online available since 2010/Nov/11 at www.scientific.net
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doi:10.4028/www.scientific.net/AMM.37-38.862

Performance Comparison Between an MRF Damper and an MRE Isolator Incorporated With a Building Structure

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Keywords: MR elastomers, MR Fluid, Viscoelastic, Four parameters solid model

Abstract. As an important member of smart materials, magnetorheological elastomers (MREs) exhibit characteristics that their modulus can be controlled by an external magnetic field. Based on these experimental results, a viscoelastic solid model with four parameters was proposed to predict the performance of MRE. A building model, three stories high, was constructed using MATLAB SIMULINK to evaluate the performance of an MRE device in structural control. In addition, the performance of an MRF damper and an MRE device in structural control, where the resultant peak force was selected as a criterion in the evaluation process, was compared and discussed. Two controllers, passive on and passive off control strategy were used to compare the response of structure. The effectiveness of an MRE bearing in structural control was well justified.

Introduction

MRE material consists of suspensions of polarised particles in a non-magnetic solid or gel-like matrix. These polarised particles can be arranged in chains in polymer media such as silicon rubber and natural rubber [1-3]. When a magnetic field is applied MRE materials can perform a controllable shear modulus with the magnetic field. Although many mathematical models for applications of MR materials [4-6] have been developed, they have not often been used to express the character of MRE materials. In this study, a four-parameter phenomenological model was proposed to investigate different approaches to modeling MRE materials based on experimental results. Then, a comparison between an MRF damper and MRE device in structural control was outlined. The resultant peak force was selected as a criterion in this evaluation process. The structural response including displacement and acceleration, were evaluated when an MRF damper and an MRE device were incorporated into a three storied building. Two controllers, passive on and passive off control strategy were used in comparison to evaluate the performances of MRF damper and an MRE isolator in structural control.

Study of An MRF Damper

According to Dyke et al [7], an MR fluid damper is one of a number of effective devices which are used to control the structural response in displacement and acceleration. This damper can generate various control forces due to changes of the external magnetic flux density. These sorts of control forces play very important roles in controlling structures. A Bouc-wen phenomenological model was developed to simulate the characteristics of MR effects for MR fluid dampers [7]. A typical Bouc-wen model with a simple mechanical idealisation is shown in Fig.1. The related equations governing the control force f predicted by this model are given by

$$\begin{aligned} f &= c_1\dot{y} + k_1(x_d - x_0), \\ \dot{z} &= -\gamma\left|\dot{x}_d - \dot{y}\right| z\left|z\right|^{n-1} - \beta(\dot{x}_d - \dot{y})\left|z\right|^{n1} + A(\dot{x}_d - \dot{y}), \\ \dot{y} &= \frac{1}{c_0 + c_1}\left\{\alpha z + c_0\dot{x}_d + k_0(x_d - y)\right\} \end{aligned} \quad (1)$$

where z is an evolutionary variable that accounts for historic dependence of response. Model parameters depend on voltage v to the current driver as follows, u is output of the first-order filter

$$\alpha = \alpha_a + \alpha_b u, \quad c_1 = c_{1a} + c_{1b}u, \; c_0 = c_{0a} + c_{0b}u, \quad \dot{u} = -\eta(u - v) \quad (2)$$

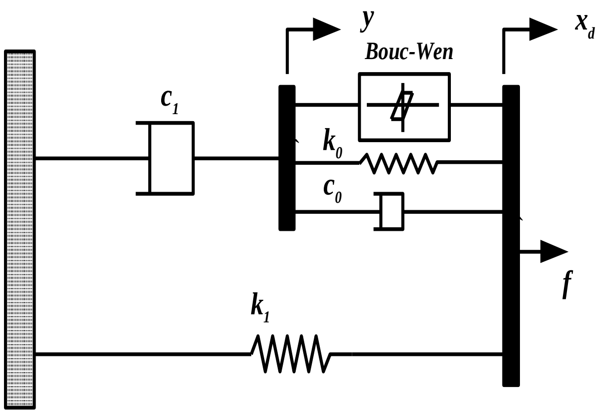


Fig. 1. A simple model of an MR damper [7]

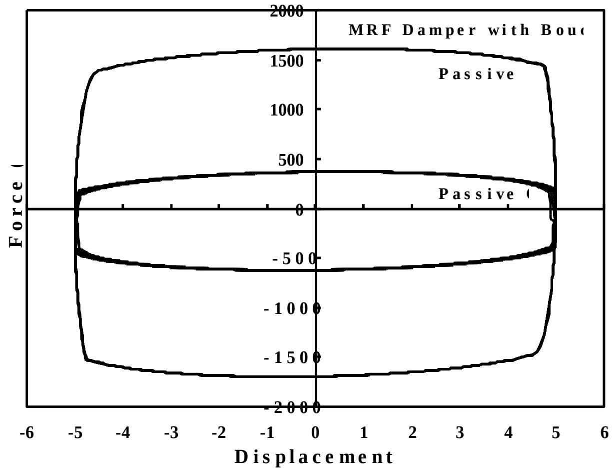


Fig. 2. Displacement and force for an MR damper

Eq. 2 is necessary to model the dynamics involved in reaching a rheological equilibrium and driving the electro-magnet in the MR damper [8]. A nominal set of parameters based on the response of the MR damper was obtained in a series of displacement-controlled tests. Then the optimised parameters required to fit the generalised model of the MR fluid damper to the experimental data were determined. By using one typical set of 14 parameters given in reference [7], the force-displacement curves were reconstructed and shown in Fig. 2, where the amplitude and frequency are 5mm and 2.5Hz, respectively. It was found that the peak control forces of the MR fluid damper are 624N at 0V and 1699N at 2.25V.

Experimental Study of MRE Isolator

In the experiment, a MRE isolator was fabricated. The dimensions are given in Fig.3. The bearing consists of 6-6mm thick MRE bearings. The bearing was ϕ90mm×43mm and had a 45mm diameter gap in the centre. Each layer was separated by a 1mm thick steel plate.

The experimental setup for the characterization of MRE bearing dynamic performances was shown in Fig.4. In the experiment the MRE device was installed in an electro-magnet (S&T 139802) which can generate varying magnetic fields. A force sensor (CA-YD-106 53317) was placed on the MREs device to measure any change in the force on it. A sensor (CA-YD-106 50798 & 50837) was used to measure displacement at different magnetic fields and an electro-magnetic shaker (SINOCERA JZK-5) was used to generate excitation to it. The electro-magnetic shaker was controlled by computer connected to a DAQ board (SCB-68). LABVIEW software was used to program the excitation interface and a Tesla-meter (IMADA HT201) to measure different magnetic flux.

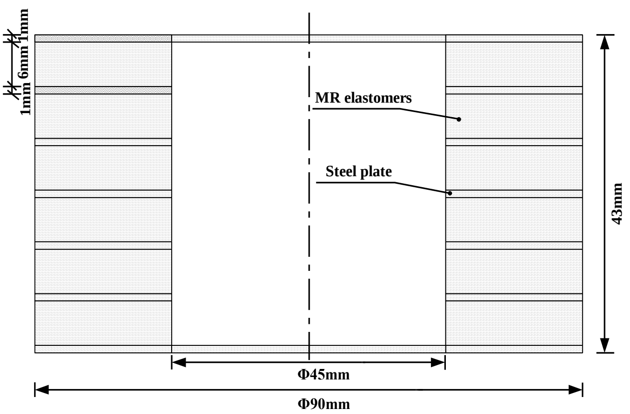


Fig. 3 Schematic cross-section of MRE bearing

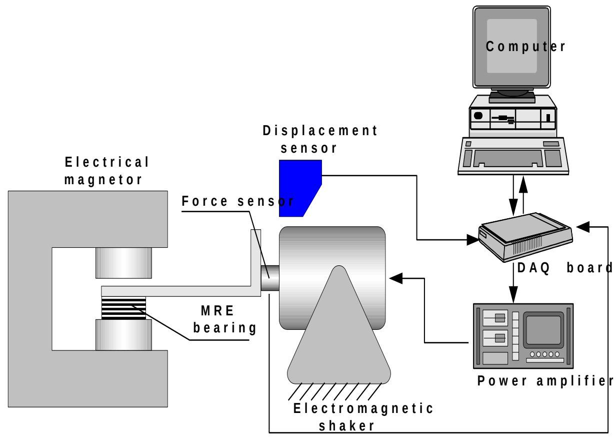


Fig. 4 Schematic of experiment setup

The force-displacement experimental results were shown in Fig. 5. As shown in Fig. 6, a four-parameter, including k_b, k_1, k_2 and c_2, was developed to study dynamic performances of MRE isolators. x^* and f^* are represented as inputs displacement and outputs force, respectively. The force-displacement relationship is given by

$$f^* = K^* x^* = (K_1 + iK_2)x^* \tag{3}$$

The real and imaginary parts of the complex stiffness K^* can be expressed as

$$K_1 = \frac{(k_1k_b + k_2k_b + k_1k_2)[(k_1+k_2)^2 + c_2^2\omega^2] + c_2^2\omega^2 k_1^2}{(k_1+k_2)[(k_1+k_2)^2 + c_2^2\omega^2]}, \quad K_2 = \frac{c_2\omega k_1^2}{[(k_1+k_2)^2 + c_2^2\omega^2]} \tag{4}$$

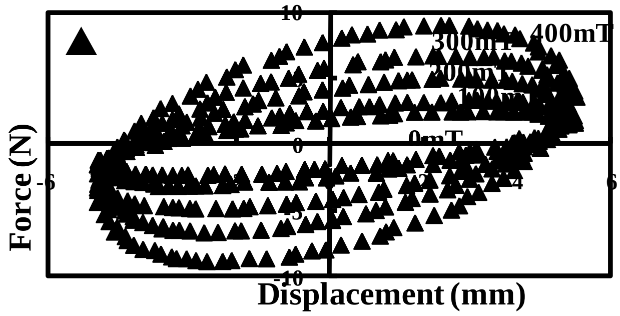


Fig. 5 Displacement and force for MRE devices

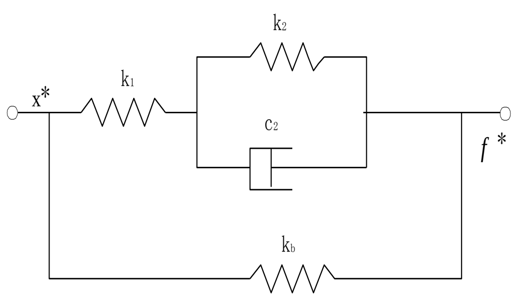


Fig. 6 Four-parameter viscoelastic model

Under a harmonic displacement input, the steady-state response can be obtained as

$$f(t) = x_0\sqrt{K_1^2 + K_2^2}\,\sin(\omega t + \phi) \tag{5}$$

where ϕ is phase angle between input and output, which can be calculated as $\phi = \tan^{-1}(K_2/K_1)$.

Comparison Between MRF Damper and MRE Isolator

The damping frequency of the MRF damper is 2.5Hz. To achieve the same frequency input on the MRE device, the curve fitting mathematical method was used to evaluate the related K_1 and K_2 at 2.5Hz frequency input. Linear exploration and the experimental data of 5Hz and 10Hz were used in this study to find the values of K_1 and K_2. The related value of K_1 and K_2 are listed in Table 1.

Table 1 K_1 and K_2 of MRE device at 2.5 Hz frequency input

Case	K_1 (N/mm)	K_2 (N/mm)	Amplificatory Factor (K)
Passive Off	0.55	0.50	168
Passive On	1.45	1.76	149

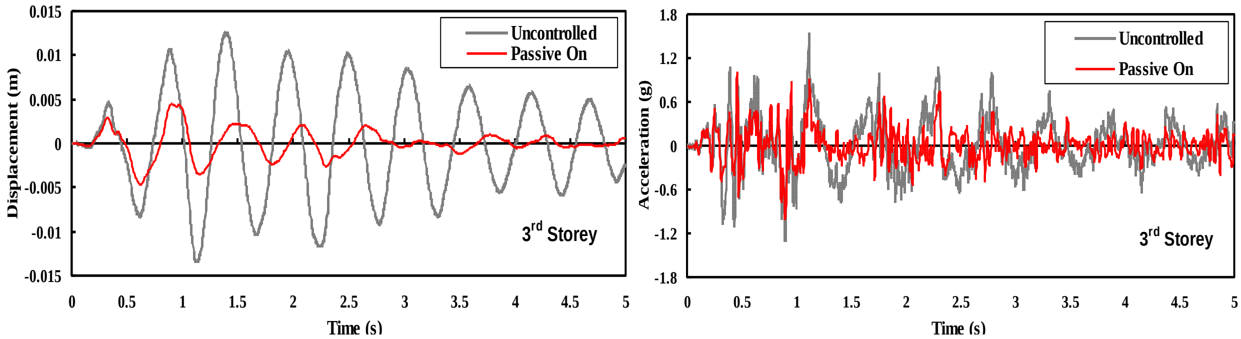
With these parameters, the relationship between displacement and force for an MRE Isolator with a frequency input of 2.5Hz are reconstructed. The control forces of the MRE device are 624N at 0A and 1699N at 1.75A. These two peak control forces are the same as that of the MRF damper.

Table 2 A comparison between the MRF damper and the MRE device

	Case		**MRF**	**MRE**	**Percentage**
x_i(mm)	Passive Off	1st	-66.2%	-63.4%	-2.8%
		2nd	-66.4%	-62.6%	-3.8%
		3rd	-64.8%	-61.6%	-3.2%
	Passive On	1st	-81.7%	-78.9%	-2.8%
		2nd	-71.0%	-68.2%	-2.8%
		3rd	-66.4%	-64.0%	-2.4%
$\ddot{x}_i$ (g)	Passive Off	1st	-24.4%	-20.0%	-4.4%
		2nd	-35.4%	-31.0%	-4.4%
		3rd	-46.4%	-43.1%	-3.3%
	Passive On	1st	+4.4%	-11.1%	+15.5%
		2nd	-27.4%	-22.1%	-5.3%
		3rd	-40.5%	-35.3%	-5.2%

Structural Responses Evaluation. According to Dyke et al. [7], the peak responses for a three storied benchmark building incorporating an MRF damper were listed in Table 2 where the external ground excitation selected was a 120% EI Centro earthquake. For an MRE device we also applied the same ground excitation and peak control forces generated by the MRE device were kept the same as those generated by an MRF damper. The displacement and acceleration in passive on case of the top floor are illustrated in Fig.7. The peak responses for a three storied building model incorporating an MRE device is listed in Table 2.

From Table 2, the control performances are between 2% to 5% less than the MRE device which demonstrates that the control performances of the MRE device has almost the same effect as those applied by the MRF damper. In addition, the MRE device controlled first floor acceleration better than the MRF damper when the passive on control logic was applied. First-floor acceleration increased by 4.4% when the passive on control logic incorporating MRF damper was operating, had a negative effect on building. However, a building that incorporates an MRE device can still reduce the acceleration on the first-floor by 11.1% by using the passive on control logic.



(a) (b)

Fig.7 (a) Displacement response of top floor. (b) Acceleration response of top floor.

Conclusions

This paper presented study of MRF damper and MRE isolator. A four-parameter phenomenological model was proposed to modeling MRE materials based on experimental results. Then, their performances in controlling the structure of a three storied building was compared and evaluated using the equivalent peak control force as the criteria. By applying related parameters in a viscoelastic model to the MRE device, the displacement and acceleration of a three storied building were compared with the responses of an MRF damper. Both the displacement and acceleration of a structure incorporating the MRE device are slightly inferior to the MRF damper. This comparison demonstrated the effectiveness of the MRE bearing in structural control.

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