Experimental Shock and Vibration Response of Magnetorheological Elastomer Isolator

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ABSTRACT

In this work the experimental design of a magnetorheological elastomer based on a silicone rubber matrix and carbon iron powder particles is detailed. The elastomer samples are intended for vibration and shock isolation purposes and are manufactured considering different concentration percentages for the carbon iron particles used. A magnetic field is generated and applied to the samples using an electromagnet in order to evaluate the resulting natural frequency of the samples for different values of the voltage supplied. Furthermore, vibration isolation characteristics are evaluated by the experimental measurement of impedance and transmissibility. It is found that it is possible to obtain large changes in the stiffness of the system up to 64% for the higher percentage of particles concentration. The paper provides an insight into the properties and applications of MRE samples for vibration isolation and future applications in active control.

Keywords: Magnetorheological elastomer, Vibration isolation, Vibration suppression.

INTRODUCTION

Magnetorheological elastomer (MRE) is a class of solid that consist of polymeric matrix with embedded ferromagnetic particles such as carbonyl iron. Since its mechanical properties change instantly by the application of a magnetic field, the MRE became a widely used material when it comes to controllable features. Kwon *et al.* [1] have recently published a comprehensive review paper on MRE. These properties make the MRE excellent for vibration control and suppression. Deng and Gong [2] developed an adaptive tuned vibration absorber (ATVA) by utilizing MRE as its smart spring elements, finding better performance in terms of shift-frequency and vibration absorption capability. Blom and Kari [3] utilised MR material in the form of rubber bushing, finding that the the stiffness of the bushing can be controlled over a large range of the applied magnetic field strength. In this paper an experimental analysis of the vibration isolation properties of MRE samples is presented, focusing on the effect of the voltage applied for different configurations, showing the effect of the stiffness and damping change in the frequency response.

MANUFACTURING

The MRE samples were manufactured using silicone rubber (MM288 by ACC Silicones Ltd) as matrix and carbonyl iron powder (CIP Type SQ by BASF SE) as ferromagnetic particles. These particles are spherical with an average diameter of 5 μm and with a 99.5% iron content purity, and have low remnant magnetisation, high permeability and high saturation. Silicone rubber is easy to use and has very good chemical and UV resistance in a wide temperature range. These properties result in high magneto-rheological effects. Samples with particle concentration of 0, 10 and 30% were manufactured in a cylindrical shape of 30mm diameter and a 12mm height. The mixture was placed into a vacuum chamber for degassing, and then the MRE mixture was poured into an aluminium mould. The rubber was cured at room temperatures for 24 hours.

EXPERIMENTAL PROCEDURE

Vibration isolation properties and mobility were measured in the MRE samples. An electromagnet (Magnetech opposite pole electromagnet OP-1212) was placed on top of the sample, acting both as an isolated mass and as the source of the magnetic field. The electromagnet was supplied with a DC voltage from a high current source. In order to increase the magnetic range of investigation one or two permanent magnets were also placed at the bottom and top of the sample. Three different configurations of the sample have been studied and they can be seen in Figure 1, and are defined as follows. Configuration A given by Figure 1(a) represents the MRE samples without any external effect, only the electromagnet at the top as payload mass. Configuration B, i.e Figure 1(b), is the MRE sample with the permanent magnet on the bottom of the MRE and the electromagnet at the top. Figure 1(d) shows a picture of the real sample in this configuration. Configuration C, i.e Figure 1(c), is the MRE sample with a permanent magnet on the bottom and one at the top. Both magnets were oriented with the same polarity. For each configuration the cases of no supplied voltage and ± 18 V were considered, to avoid overheating. The condition with the electromagnet turned off is considered the reference basis for the measurement and comparison. The MRE samples were secured to a LDS V406 shaker table via an impedance head PCB Piezotronics model 288D01. This configuration can be used to measure both their isolation (considering the electromagnet as the payload) by measuring the transmitted acceleration on top of the electromagnet with a miniature accelerometer PCB Piezotronics 352C22, and their absorption capabilities (considering the MRE sample and the electromagnet to act as a dynamic vibration absorbers). Hence, in order to asses the isolation and absorption properties of the 10 % and 30 % MRE samples, the impedance and transmissibility were measured for the different conditions described before. The samples were excited by a broadband random excitation up to 500 Hz through the shaker. The signals from the impedance sensor and the accelerometer were acquired through dynamic signal analyser Dataphysics QUATTRO.

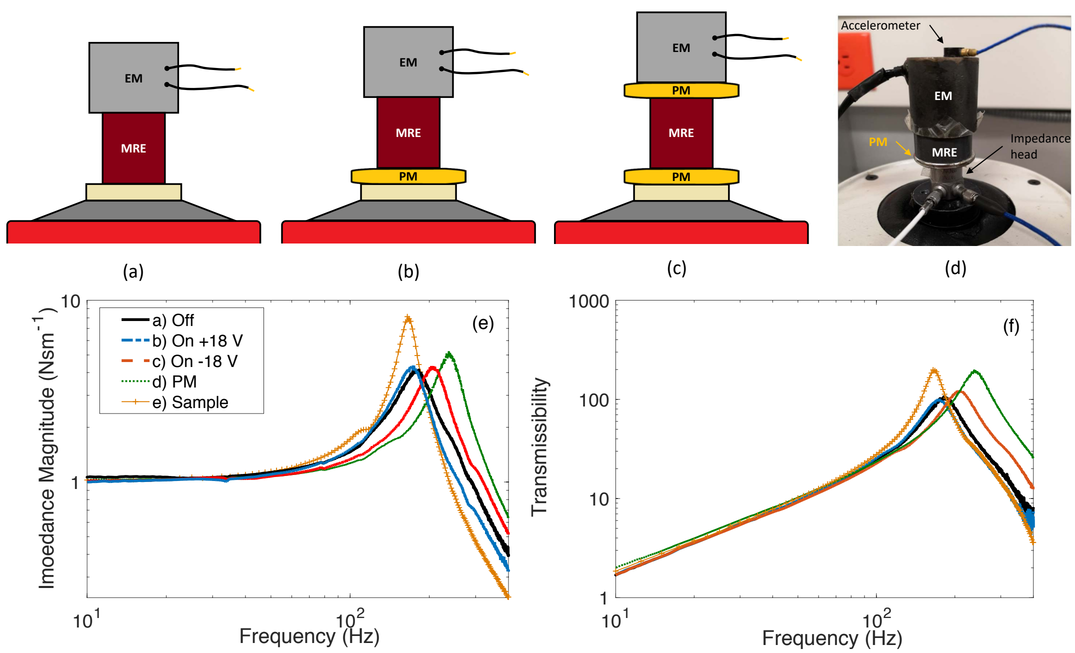

Figure 1: Configurations used in the experimental procedure and frequency response of the 30 % sample MRE isolator: (a) MRE sample between the electromagnet and the shaker table; (b) MRE sample with one permanent magnet at its base and electromagnet; (c) MRE sample with two permanent magnets; (d) picture of the actual experimental sample with one permanent magnet; (e) Absolute transmissibility; (f) Mechanical impedance.

Frequency response function results

In order to observe the largest frequency changes, some examples of the impedance and transmissibility functions are presented in Figure 1(e)-(f). For those voltages, the largest frequency changes are obtained whilst when the electromagnet is turned off the natural frequency falls in the middle. When the bottom permanent magnet is completely removed the resulting natural frequency

TABLE 1: Values of natural frequency, damping ratio, and stiffness change measured for the different configurations of MRE samples with 10 and 30% of concentration. PM: permanent magnet; V_{EM}: voltage supplied to the electromagnet.

Condition	B (T)	f_n (Hz)		ζ		% Δk	
		10%	30%	10%	30%	10%	30%
No PM, $V_{EM} = 0$V	0	98	168	0.1148	0.1309		
1 PM, $V_{EM} = 0$V	0.07	150	180	0.1105	0.1551	57.315	12.888
1 PM, $V_{EM} = 18$V	0.127	164	214	0.0945	0.0961	64.292	38.370
1 PM, $V_{EM} = -18$V	0.013	143	174	0.1065	0.0858	53.034	6.777
2 PMs, $V_{EM} = 0$V	0.14	175	247	0.1016	0.0801	68.640	53.737

is the lowest registered, effectively measuring the properties of the sample with no magnetic effect.

Table 1 presents the calculated values of natural frequencies and loss factor for the 10 % and 30% samples respectively. The data was processed using a circle fit of the impedance measurements, for the conditions described before, which are summarised on the table. The percentage of change in stiffness according to the change in the measured natural frequency of the different configurations is also presented. The stiffness change was estimated considering case A with the electromagnet turned off.

ANALYSIS OF EXPERIMENTAL FINDINGS

The impedance function and transmission ratio presented in Figure 3 show the effect of change in the natural frequency of the isolator sample. First, the effect of the particle percentage is clearly seen, as the sample without any magnetic effect has natural frequencies of 98 Hz and 168 Hz, resulting in a change of stiffness of approximately 66%. This obeys to the fact of increased stiffness due to the higher concentration of particles as expected. However, the main objective is to compare the effect of different magnetic fields applied to the sample. The value of initial stiffness value is considered when the bottom permanent magnet is in place and the electromagnet is turned off effectively acting as a payload. The effective natural frequency for this state is 150 Hz and 180 Hz for the the 10% sample and the 30% sample respectively. The frequency is increased to 164 Hz and 214 Hz in each sample when a positive voltage is applied. On the other hand, a negative voltage produces a decrease in the frequency, corresponding to 143 Hz and 174 Hz respectively. The actual stiffness change from minimum to maximum stiffness for each sample results in 24% and 34% for the 10% and 30% samples respectively. A limit of the electromagnets used on the experiments was the maximum voltage, current and time of operation. Due to the high current drawn at 18 V, they experienced a quick overheating. Thus it was not possible to sustain the tests for higher voltages and longer times. However, the feasibility of quickly changing the effective stiffness of the system was shown in the tests. In order to observe larger stiffness changes, permanent magnets were used. In this case, the maximum stiffness recorded were 175 Hz and 247 Hz and considering the initial sample with no magnetic effects as reference, the changes were 26% and 47% for the 10% and 30% samples respectively.

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