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Critical magnetic field analysis of porous foam magnetorheological (MR) fluid damper

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In this paper, a new porous foam magntrorheological (MR) fluid damper is proposed. In the action of magnetic field, the metal foam is used to store and release the MR fluids. It is worthy to study the time MR fluids can be extracted and produce damping force. Therefore, the critical magnetic field intensity is investigated experimentally by a custom-made test rig. The experimental results show that when magnetic field intensity increased to a critical value, the MR fluids are extracted out from the porous foam into shear gap, and move with the piston, the shear damping force begin to change.

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Keywords: Critical magnetic field, Magnetorheological (MR) fluid, MR damper, Porous foam

1. Introduction

As a smart material, Magnetorheological (MR) fluids has been attracted lots of researchers during these years. It is composed of high concentration micron-sized carbonyl iron (CI) particles and water or oil and other additive. MR fluid devices have been employed in many applications for its unique advantages. In presence of a magnetic field, particles in the fluid form chains, and the suspension becomes like a semi-solid material in a few millisecond [1-2]. Under the magnetic field, an MR fluid behaves as a non-Newtonian fluid with controllable viscosity. However, if the magnetic field is removed, the suspension turns to a Newtonian fluid and the transition between these two phases is highly reversible, which provides unique feature of magnetic-field controllability of the flow of MR fluids.

In recent years, MR fluids have been widely used in many areas, among which Magneto-rheological damper (MR damper) have been widely used, such as civil engineering, vibrate control, and automobile suspension system, et al. Compared to the conventional passive ones, the relative higher cost is a key barrier to widespread commercial application of the device. Aiming at this problem, Calson [3-6] introduced the idea of using sponge as an absorbent matrix to contain MR fluids for MR damper. However, the repeatedly MR fluids under excited conditions would cause the drop of MR effect, and the friction of sponge used under high shearing conditions is also a question. Yao proposed a porous foam metal damper and researched its response time [7]. Liu proved that the porous foam metal can be used into MR damper [8-9].

2. Experiment setup and methods

2.1 Materials

The MR fluids and porous foam media copper used in this paper is the same as is the same as (Yao and Liu etc., 2013). Fig. 1 shows the magnetic characteristics of MR fluids. The porosity, initial permeability and thickness are 110 ppi, 1.5 and 2 mm, respectively.

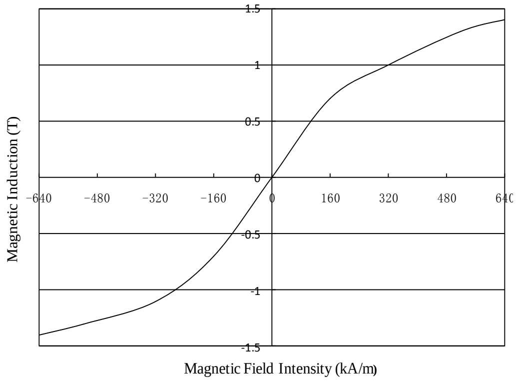

Fig. 1. Characteristic of MRF-J01T.

2.2 Porous foam MR fluid damper and test rig

Fig. 2 illustrates the sketch of the porous foam media MR damper. Compared with traditional MR damper, a layer of porous foam stuck on the surface of the working cylinder is used to store and release the MR fluids. Table 1 shows its dimensions. When extern magnetic field strength is zero (I=0A), MR fluids are stored in the porous foam media, and no MR fluids appearances in the gap; once the current is on, MR fluids stored in the pore of porous foams will be extracted and begin to fill the shear gap.

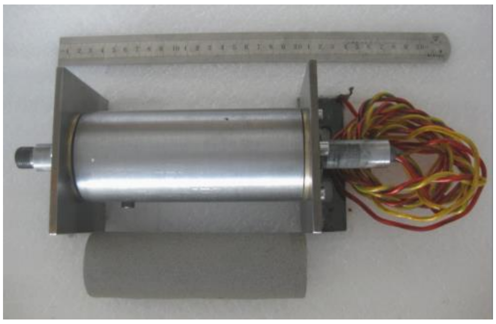

Fig. 2. Porous foam metal MR damper

2.3 Magnetic resistance of metal foam filled with MR fluids

As can be seen in Fig. 2, the equivalent magnetic resistance of metal foam as following:

Table 1. Main parameters of the foam damper

Maximum Stroke(mm)	± 60
Number of coils	1
Turns of coil	1635
Shear gap (mm)	1
Diameter of cylinder(mm)	44
Effective length of piston (mm)	90

$$\frac{1}{R_p} = \frac{1}{R_m} + \frac{1}{R_{mf}} \tag{1}$$

$$R = \frac{L}{\mu_0 \mu_r A} \tag{2}$$

Where R_p the equivalent magnetic resistance of metal foam is filled with MR fluid; R_m and R_{mf} are magnetic resistance of metal foam and MR fluid, respectively. R is the magnetic resistance, L length; μ_r relative permeability; μ_0 vacuum permeability. Finally, the relative permeability of metal foam filled with MR fluids is:

$$\mu_p = \mu_m S_m + \mu_{mf} S_{mf} \tag{3}$$

The magnetic resistance in metal foam MR damper, R, can be calculated as following.

$$R = R_1 + 2R_2 + R_3 + 2R_g + 2R_p \tag{4}$$

Where, R_1 and R_2 are magnetic resistances of piston; R_3 and R_g are magnetic resistances for cylinder wall and shear gap, respectively.

Regarding to the designed MR damper, μ_p is 3.54; R is 1.07×106 A/wb. By calculation, the relationship between magnetic induction and currents can be obtained:

$$B=0.591I \tag{5}$$

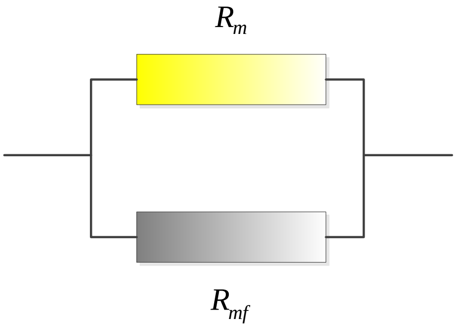

Fig. 3. Magnetic resistance model

2.4 Test rig

The entire test rig custom-made is shown in Fig. 3. The foam MR damper was fixed on the linear rail, one piston rod which was driven by a steady state-adjustable DC motor is fasten to a force sensor. It is driven with a DC motor whose speed can be adjusted by a controller with a speed encoder. A force sensor with an amplifier was used to measure the damper force delivered through the foam MR damper. The coil was activated by the power supply. The test signals in the system are gathered by a DAQ data acquisition, the data process and display are done by PC with LabVIEW software. A timer was designed to synchronize the start of the magnetic field application and the measurement starting point. The strength of the magnetic field can be adjusted by changing the current that flows through the coil.

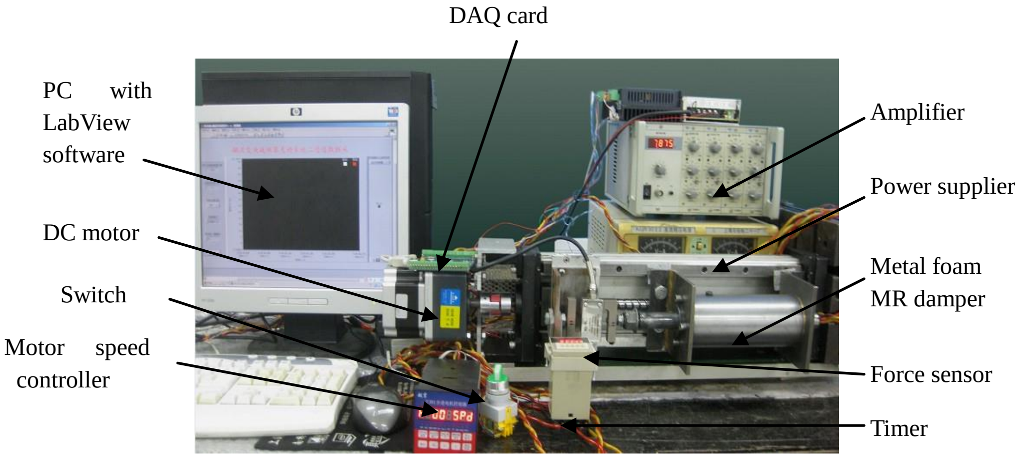

Fig. 4. Test rig of foam MR damper

3. Results and discussion

The shear velocity is 4mm/s, Fig. 5 presents the damping force when the current is off, that is, the extern magnetic field strength is zero. View from Fig. 5, the damping force is not zero for the friction between piston and cap, and the gravity of the MR damper, the damping force is $F_0 = 3.6N$ at zero magnetic field intensity. When current is on, the magnetic field intensity is not large enough, the MR fluids is still stay in porous foam metal, hence, there is not any change of damping force, as shown in Fig. 6. As soon as the current increases to 0.04A, here, the magnetic field strength are 4.55 kA/m, magnetic particles in MR fluids are extracted out of the porous foam metal to be chain-like. With movement of piston, it produces the MR fluid effect, the damping force is changed, and the magnetic damping force is $F_M = 0.5N$. The bigger the magnetic field strength, the larger the damping force changes. When current is 0.5A, that is, here, the magnetic field strength are 5.69 kA/m, the magnetic damping force is 7.3N.

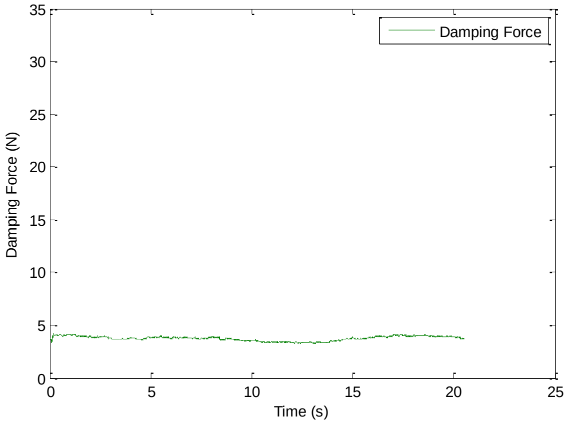

Fig. 4. Damping force (I=0A, $F_0 = 3.6N$)

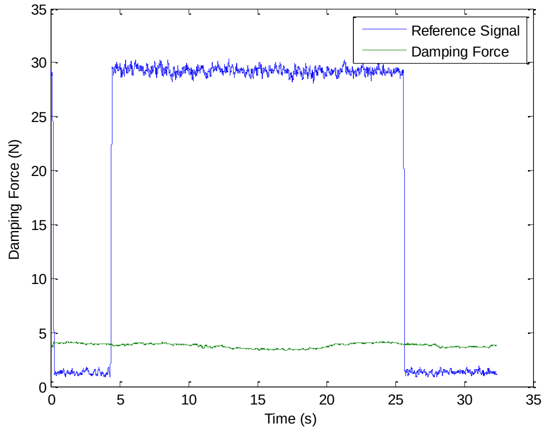

Fig. 5. Damping force（I=0.02A, $F_M = 0$)

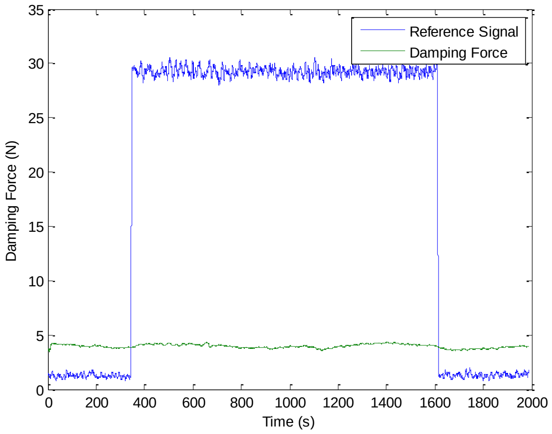

Fig. 6. Damping force（I=0.04A, $F_M = 0.5N$)

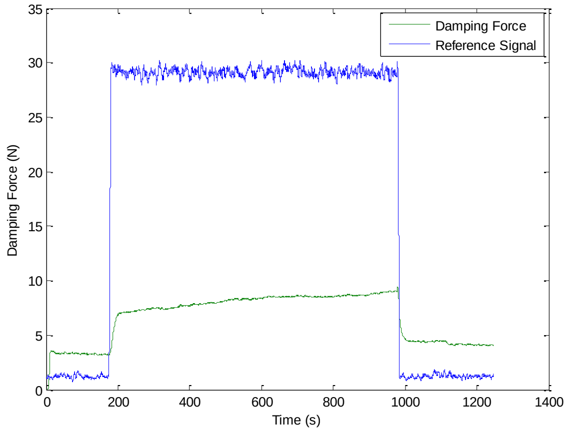

Fig. 7. Damping foce（I=0. 5A, $F_M = 7.3N$ *）*

Cowley and Rosensweig had shown the influence of density difference towards the surface instability with two type of fluid interface. Several works have been reported on the normal field instability behavior of the magnetic fluid [10–14]. The critical magnetic field strength, H_c is given by

$$H_c = \frac{1}{\chi}[\frac{2}{\mu_0}(\frac{2+\chi}{1+\chi})]^{1/2}(\rho g\sigma)^{1/4} \qquad (6)$$

Where χ is susceptibility of the fluid, ρ is its density, σ is its surface tension, μ_0 is the vacuum permeability and g is the gravitational acceleration.

Equ. (1) shows the relationship between the critical magnetic field strength and the susceptibility χ, the density ρ, the surface tension σ, and the gravitational acceleration. The experiment by Cowley and Rosensweig [10-11] also showed that the surface perturbation starts when the applied normal field, H, exceeds H_c. Further increase of H, would lead to a more violent perturbation, i.e. bigger amplitude of peaks and more peaks are formed. Liu [8] also proved the relationship between the volume of MR fluids and the current. The bigger the current, the larger the magnetic damping force.

4. Conclusions

A new porous foam MR damper is presented and the critical magnetic field intensity is also investigated experimentally in the paper. When the magnetic field intensity increased, the MR fluids stored in porous foam are drawn out from porous. The magnetic particles change into chain-like. With increasing the magnetic field intensity, the volume of MR fluids extracted also increase, the chains become longer, the magnetic damping force will be larger. Nevertheless, as to the shear damping force, the results show it has the obvious MR effect, and maybe the magnitude of shear damping force need improve. But compared with the sponge MR fluid damper, as provided by Carlson, the porous foam s have the advantages as wearable, which maybe provided the new methods for design the low-cost MR fluid damper.

Acknowledgment

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