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DAMPING CHARACTERISTICS OF MR FLUIDS IN LOW MAGNETIC FIELDS

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ABSTRACT

The cluster structure is visualized and the physical properties of new two types of nano MR fluids are measured in the applied magnetic fields. Correlating to these measurements, the damping characteristics of an oscillating flat plate immersed in two types of nano MR fluids such as damping amplitude, phase difference, viscous damping coefficient and viscous drag force acted on a flat plate are experimentally clarified, comparing with those of commercial magnetic fluid from the fluiddynamic points of view. It is shown that the resonance of damping amplitude and phase difference are very sensitive to the applied magnetic field, and further the damping effect of MR fluid is about ten times stronger than that of the commercial magnetic fluid even in low magnetic fields of 50-100 Gauss due to the robust cluster formation.

1. Introduction

Magnetorheological fluids are one of the representative functional fluids[1], since they have controllable yield stress, controllable large viscosity change due to the robust cluster formation and strong magnetic fore due to the high magnetization in the applied magnetic field[2,3]. These characteristics are superior to those of commercial magnetic fluid which is a colloidal dispersion of ultra fine magentic particle in the water or kerosin. It is expected that MR fluid has stronger damping effect than that of magnetic fluid even in a low applied magnetic field. But the particles of μm size in MR fluid can not be stably dispersed in the liquid because they sedimentate due to the gravitational force. The application of clutch, damper, shock absorber and polishing have been extensively developed for MR fluids[3,4]. In these applications, it is very important to utilize functions of MR fluids in a low magnetic field from saving electrical energy points of view, which results in the further development in near future. The authors have been investigating magnetic fluid damper[5] and oscillatory magnetic fluid flow[6]. Recently one of the authors has reported the advanced magnetic fluid damper using FeN magnetic fluid[7].

In the present study, two types of nano MR fluids are prepared. The viscosity and magnetization characteristics are clarified experimentally correlating to the visualization of the cluster formation in the applied magnetic field. Finally, to verify the functional advancement of MR fluids, the damping characteristics of an oscillating flat plate immersed in two types of nano MR fluids such as damping amplitude, phase difference, viscous damping coefficient and viscous drag force acted on a flat plate are experimentally analyzed, especially in low magnetic fields, compared with those of a magnetic fluid damper.

2. Experimental Apparatus and Procedures

Figure 1 shows the experimental set-up. There is MR fluid in the rectangular vessel (50 mm × 110 mm × 9 mm) in which a flat plate of titanium (30 mm × 30 mm × 3 mm, m = 56.84 g) is immersed connecting to the shaft, spring (k = 1,500 N/m) and vibration exciter.

When the magnetic field is imposed by the electromagnet, a flat plate immersed in a MR fluid, is oscillated vertically by the exciter and its oscillation is suppressed. The temperature of working fluid is 298 K and the range of frequency is up to 50 Hz. The movement of the displacement index was detected by the displacement analyzer. Then the amplitudes z_g, z and phase difference ϕ of the vibration exciter and vibrating flat plate were evaluated respectively by a FFT analyzer. The experimental study was conducted in the case of small amplitude oscillation within the framework of the linearization.

As the preparation of two types of nano MR fluids, iron particles of 10 nm, 1,000 nm diameter coated with a surfactant are dispersed by mixing in alkylnaphthalene oil. The mass fraction of particle are 43 and 73 wt.% respectively. Some gravitational sedimentation of iron particles was observed for 1,000 nm MR fluid. The commercial magnetic fluid (W-40) is prepared by dispersing 10 nm magnetic particle with surfacant in water for comparison.

The visualization of thin film of MR fluid column in the vertical magnetic field was conducted by using micro scope. The magnetization was measured by using a magnetic balance and further the viscosity was measured by using a cone-plate type rotational viscometer respectively[8].

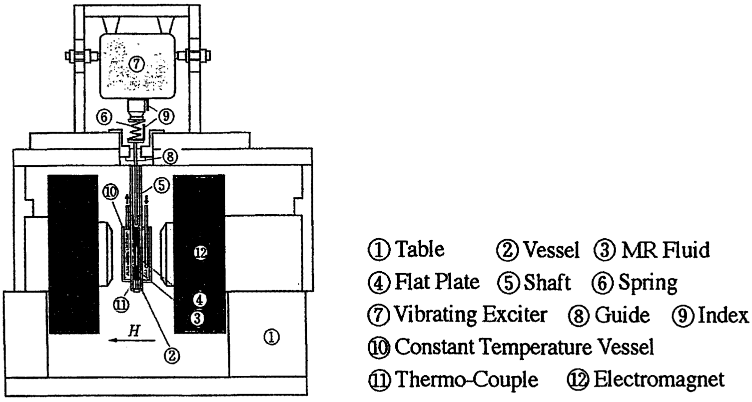

Fig.1 Experimental set-up

3. Experimental Analysis

The governing equation of a flat plate motion immersed in a MR fluid as shown in Fig.1 is given neglecting the synmetrical magnetic force under the assumption of small amplitude[7].

$$m\frac{d^2z}{dt^2}+k(z-z_g)=D \tag{1}$$

where D : drag force, k : spring constant, m : mass of flat plate, t : time, z : displacement of flat plate, z_g : displacement of exciter

If the oscillation amplitude is small and MR fluid can be regarded as a newtonian fluid especially in a low magnetic field for simplicity, the viscous drag force acted on a flat plate is given by

$$D=-C\frac{dz}{dt}-m_A\frac{d^2z}{dt^2} \tag{2}$$

where C: viscous damping coefficient, m_A : added mass

Now the displacements of exciter and flat plate are given respectively by

$$\begin{aligned} z_g &= \Delta z_g \sin(\omega t) \\ \omega &= 2\pi f \end{aligned} \tag{3}$$

$$z=\Delta z\sin(\omega t-\phi) \tag{4}$$

where f: frequency, ϕ : phase difference

Then, substrituting Eqs.(2) $\sim$ (4) into the Eq.(1), viscous damping coefficient and added mass can be given by

$$C=\frac{k}{\omega}\frac{1}{a}\sin\phi \tag{5}$$

$$m_A=\frac{k}{\omega^2}\left(1-\frac{1}{a}\cos\phi\right)-m \tag{6}$$

where

$$a=\frac{\Delta z}{\Delta z_g} \tag{7}$$

The amplitude ratio of a and phase difference ϕ are determined by the experimental measurement in Eqs.(5) and (6). Finally root mean square of viscous drag force is given by

$$\frac{\sqrt{\overline{D^2}}}{V_0}=\sqrt{\frac{1}{2}C^2+\frac{1}{2}m_A^2\omega^2} \tag{8}$$

where $V_0=\omega\Delta z$.

4. Experimental Results and Discussion

4.1 Fluid Structure and Physical Properties

Figure 2 shows the top view of column structure of MR 1000 observed in a veritical magnetic field of 150 G compared with no magnetic field. The column distance becomes narrow with increase in the magnetic field intensity under the balance of the dipolar repulsive force inside each column and the surface tension of the column[9,10]. This may result in the drastic increase in the effective viscosity.

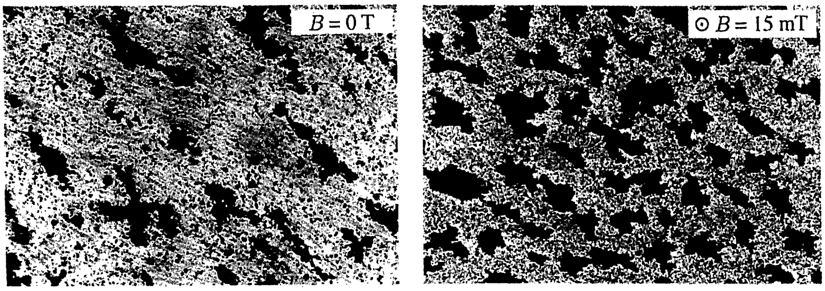

Fig.2 Top view of column structure of MR 1000 50μm

Figure 3 shows the flow curves of MR 10, MR 1000 and MF 10 in the diffrent magnetic field intensities. Since there exists very small yield stress for the magnetic field intensity less than 100 Gauss, both MR 10 and MR 1000 are assumed to be a newtonian fluid in the low magnetic field intensity. At larger magnetic field intensity than 120 G, the shear stress and the yield stress for MR 1000 are considerably larger than those for MR 10.

Figure 4 shows the magnetization curves of MR 10, MR 1000 and MF 10. It is clearly shown that the magnetization of MR 1000 is considerably larger than that of MR 10, depending on particle size and mass concentration.

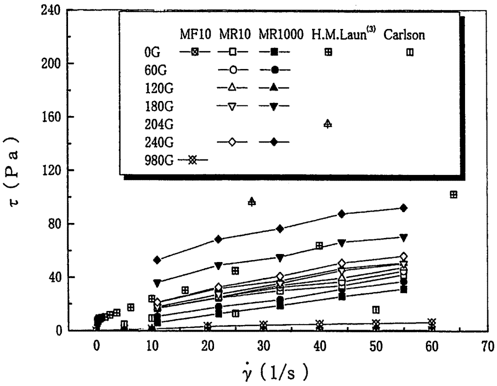

Fig.3 Flow curve

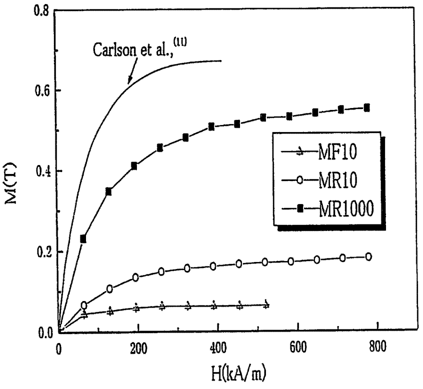

Fig.4 Magnetization curve

4.2 Damping Characteristics

Figure 5 shows the amplitude ratio of the flat plate displacement to the exciter displacement with the oscillation frequency as defined in Eq.(7). There is little effect of the applied magnetic field on the MF 10. On the other hand, the amplitude ratio decreases considerably even in a low magnetic field especially for MR 1000. The resonance frequency of the MR fluids shifts to the lower frequency with the increase in the magnetic field intensity.

Figure 6 shows the phase difference between the flat plate and exciter. There is very little effect of magnetic field on magnetic fluid. But there is a relative variation of phase difference for MR 1000 with the magnetic field intensity. The phase variation is the smallest for MR 1000 at 95 Gauss.

Figure 7 shows the ratio of viscous damping coefficient for MR fluids to the one for magnetic fluid. This ratio decreases gradually with increase in the oscillation frequency. The ratio of MR 10 lies between 8 and 14 due to the high volume concen-

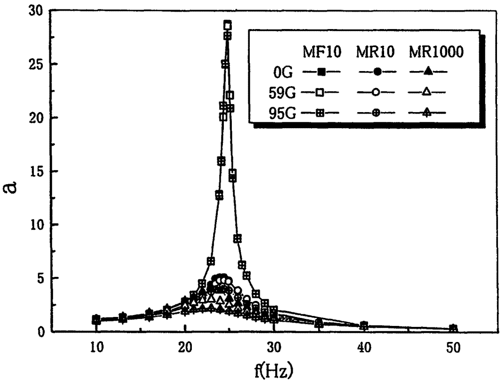

Fig.5 Amplitude ratio of the flat plate displacement to the exciter displacement

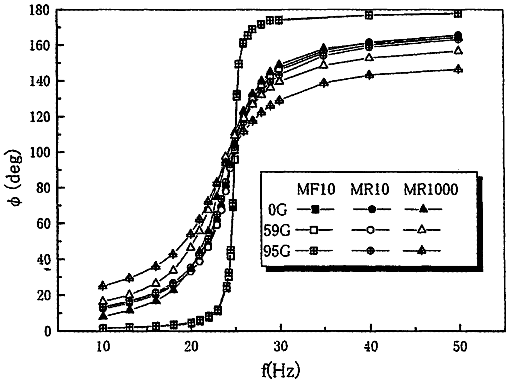

Fig.6 Phase difference between the flat plate and the exciter

tration. But the one for MR 1000 lies between 8 and 24 due to the robust cluster formation even in a low magnetic field intensity as shown in Fig.2. It clearly increases with increase in the magnetic field intensity.

Figure 8 shows the relative increase in viscous damping coefficient against the applied magnetic field for magnetic fluid, MR 10 and MR 1000. Although the relative increase in viscous damping coefficient for magnetic fluid and MR 10 are less than 0.2, the one for MR 1000 is more than 0.5 in the lower frequency than resonance frequency of about 25 Hz due to the robust cluster formation in a low magnetic field intensity.

Figure 9 shows the ratio of root mean square of viscous drag force for MR fluids to the one for magnetic fluid. The basic tendency of drag force ratio corresponds to the viscous damping ratio as shown in Fig.7. The viscous drag force ratio for MR 10 and MR 1000 lie between 6 to 15 at 59 Gauss and 95 Gauss in the frequency less than 25 Hz.

Figure 10 shows the relative increase in drag force against the applied mag-

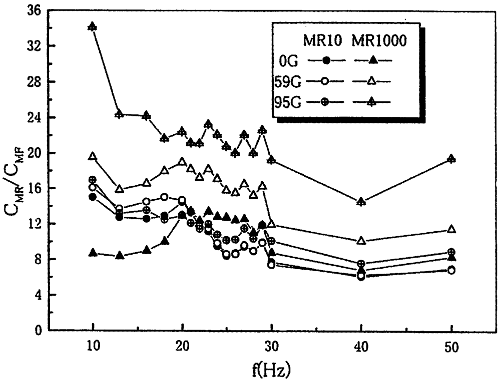

Fig.7 Viscous damping coefficient ratio of MR fluid to magnetic fluid

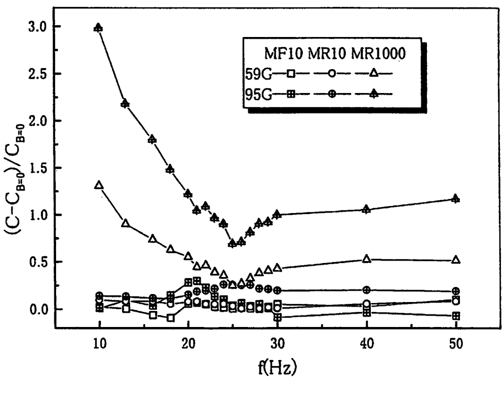

Fig.8 Relative increase in viscous damping coefficient against the applied magnetic field

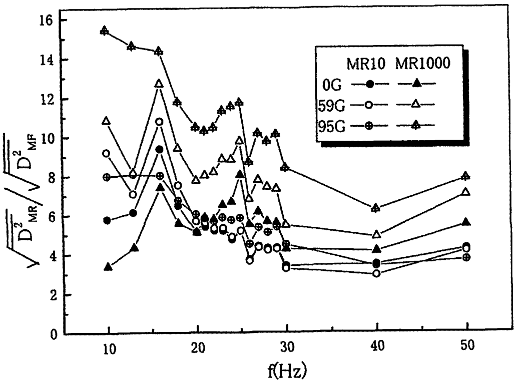

Fig.9 Drag force ratio of MR fluid to magnetic fluid

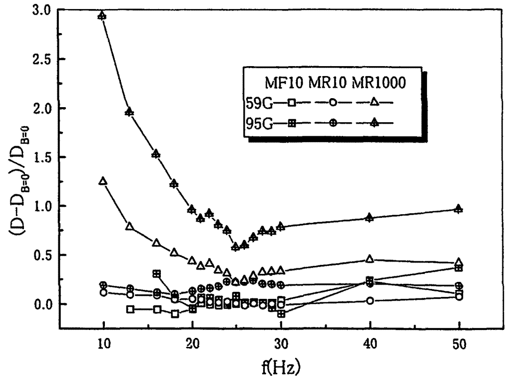

Fig.10 Relative increase in drag force against the applied magentic field

netic field. Although the relative increase in drag force for magnetic fluid and MR 10 are less than 0.2, the one for MR 1000 is between 0.4 to 3 in the lower frequency than the resonance frequency corresponding to the viscous damping coefficient as shown in Fig.8. This means that the MR 1000 shows sensitive damping effect both in low frequency and in a low magnetic field intensity.

5. Conclusions

Experimental investigations are carried out to clarify the effect of a low magnetic field on the damping characteristics of an oscillating flat plate immersed in the synthesized nano MR fluids as a basic study for the development of MR fluids viscous damper which has small load on the input electrical power, comparing with those of magentic fluid damper. The main results obtained in the present study are summarized as follows:

1. The analytical method is proposed to evaluate the effect of a low magnetic field on the damping characteristics of an oscillating flat plate immersed in MR fluids under the assumptions of small oscillation and newtonian fluid.
2. The cluster formation of MR fluid is observed in a low magnetic field intensity, correlating to the increase in the apparent viscosity. The viscous property and magnetization property of prepared MR fluids are clarified in the applied magnetic field.
3. Damping effect of oscillating flat plate and its sensitivity to the magnetic field is much better for large size MR fluid than that for magnetic fluid in the low-frequency range even in a low magentic field intensity due to the drastic increase in the viscosity induced by the robust cluster formation.

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