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"EXPERIMENTAL INVESTIGATION OF LABORATORY-PREPARED MAGNETO-RHEOLOGICAL FLUIDS AND A PROTOTYPE MR FRONT-FORK DAMPER FOR MOTORCYCLE SUSPENSION"

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ABSTRACT

Two magneto-rheological (MR) fluids were prepared by dispersing Fe_2O_3 (fluid-1) and Fe_3O_4 (fluid-2) particles of about 50 µm in silicone oil with AP3 grease as stabiliser, and a prototype MR damper for a motorcycle front fork was fabricated and tested on a vibration rig. The magnetic field in each fluid rose almost linearly with coil current, from 0 to 42 G (fluid-1) and 40 G (fluid-2) at 1.8 A, with slopes of 22.9 and 22.1 G/A. With fluid-1 in the damper, piston displacement under excitation fell from 46 mm at zero current to 1.7 mm at 1.8 A at an exciter length of 550 mm; for 250 and 400 mm the falls were from 36 to 0.2 mm and from 42 to 0.7 mm. At 400 mm the mean vibration amplitude fell from 5.7 to 3.9 mm (32%) when the damper was energised, and the dominant frequency fell from 122.30 to 55.884 Hz (54%). The results show that current alone gives continuous control of damping in a fork-scale damper. The limits of the data, including low field levels and single-run readings, are stated.

Key Words: *Magneto-rheological fluid; MR damper; front fork; Fe_2O_3; Fe_3O_4; vibration; experimental analysis.*

I. INTRODUCTION

The telescopic fork of a motorcycle combines spring and damper in one light and inexpensive unit, but its damping is fixed by orifices and cannot respond to changes in road, load or braking. A fork tuned for comfort wallows under braking, and one tuned for control passes road shocks to the rider. Semi-active dampers that change their force quickly with an electrical signal remove this compromise [1], [2].

MR fluids, suspensions of magnetisable particles in oil, change from a free-flowing liquid to a semi-solid in a magnetic field and back in a fraction of a second [3], [4], [5]. Used in the annular gap of a damper piston, they let the damping force be set by the coil current [6], [7]. Modelling and design studies are numerous [6], [7], [8], [9], [10], but reported work on compact fork dampers and on low-cost fluids prepared in an ordinary laboratory is limited [11].

II. PROBLEM IDENTIFICATION

The effect of the particle type and of the coil current on a fork-scale MR damper is rarely reported with matched field and displacement data. Two iron-oxide particles, Fe_2O_3 and Fe_3O_4, are used in laboratory fluids, but their comparison in the same carrier and recipe is not documented. It is also unclear how much the vibration of a rig-mounted fork damper is reduced by the field. This study addresses these questions experimentally.

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III. Research Objective

The main objectives of the present study are as follows:

- To prepare two MR fluids with Fe_2O_3 and Fe_3O_4 particles and compare the field they develop as current increases.
- To fabricate a prototype MR damper for a motorcycle front fork.
- To measure piston displacement against coil current at three exciter lengths.
- To compare vibration amplitude and frequency with and without the energised MR damper.

IV. MR Fluid Preparation And Damper Design

4.1 MR fluids

Silicone oil, which has good thermal stability, was used as the carrier, and AP3 grease was added to slow the settling of the particles [3], [11]. The recipe is 68 ml of silicone oil, 112.32 g of iron-oxide particles of about 50 µm and 6.75 g of AP3 grease. The oil and grease were measured into a beaker and stirred with a mechanical stirrer, left for one hour so that the grease dissolved, and the particles were then added and stirred for 15 to 20 minutes. Fluid-1 contains Fe_2O_3 and fluid-2 contains Fe_3O_4. Table 4.1 compares them with a normal fork fluid.

Table 4.1: Properties of MR fluid-1, MR fluid-2 and normal fork fluid

Property	MR fluid-1	MR fluid-2	Normal fork fluid
Particles	Fe_2O_3	Fe_3O_4	–
Density (g/cc)	3	2	1
Stability	Good	Average	Poor
Working temperature (°C)	−50 to 150	−40 to 150	−25 to 125
Viscosity ($N{\cdot}s/m^2$)	1.0	0.8	0.1

4.2 Prototype damper

The prototype is a mono-tube, flow-mode damper in which the fluid passes between the lower and upper chambers through grooves on the periphery of the piston. A coil of 150 turns is wound on a circular core inside the piston, and its leads run out through the hollow piston rod; when current flows, the flux crosses the fluid gap and the particles form chains that resist the flow [6], [11]. The coil is rated at 2 A maximum. The casing is aluminium alloy, the rod is coated carbon steel, and core and flux return are mild steel for permeability. The damper holds 68 ml of fluid; the cylinder diameter is 31.4 mm, the extended length is 608 mm and the stroke is ±25 mm. The pole span is 23 mm, the piston radius 23 mm, the piston-cylinder clearance 1 mm and the piston-rod radius 6 mm.

V. Design Of The Experimental Set-Up

For magnetic characterisation, each fluid was placed in the field of an electromagnet supplied through a step-down transformer (230 V to 12 V), and the field was read with a gauss meter for currents from 0 to 1.8 A in steps of 0.2 A.

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For damper tests, the damper was mounted on a rig with a vibrator motor (maximum 1500 rpm, speed controller). The exciter length, the distance of the excitation point on the rig arm, was set to 250, 400 or 550 mm. The coil current was supplied through the transformer and a variable voltage unit and read on a multimeter. Piston displacement and amplitude were measured with an LVDT, an accelerometer was fitted to the damper tube, and the signal was recorded with a sound-card oscilloscope on a laptop that also gave the frequency (Figure 5.1). Fluid-1 was used in the damper tests. Three series were run: displacement against current at three exciter lengths, amplitude against exciter length with and without the energised damper, and frequency with and without the field.



Figure 5.1 Experimental set-up with MR damper, LVDT, accelerometer, vibrator motor and sound-card oscilloscope

VI. Result and Discussion

6.1 Magnetic field against current

Figure 6.1 shows that the field in both fluids rises with coil current. A straight line fits both sets closely (R^2 = 0.998 and 0.997), with slopes of 22.9 G/A for fluid-1 and 22.1 G/A for fluid-2. At 1.8 A the fields were 42 G and 40 G, so fluid-1 gave a field about 5% higher at the top of the range and a higher reading at every non-zero current.

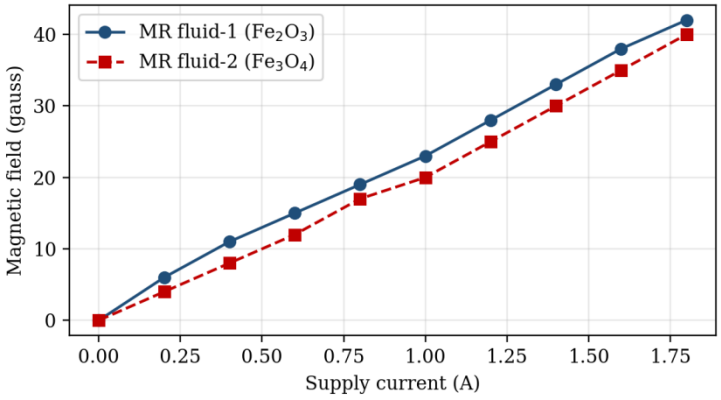


Figure 6.1 Magnetic field against supply current for MR fluid-1 and MR fluid-2

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6.2 Piston displacement against current

Table 6.1 and Figure 6.2 give the piston displacement with fluid-1. At 550 mm it fell from 46 mm at zero current to 1.7 mm at 1.8 A, a reduction of 96%; at 250 and 400 mm the reductions were 99% and 98%. Most of the fall occurs early: 0.2 A alone reduces displacement by 44%, 48% and 46% at 250, 400 and 550 mm, and the curves flatten above about 1 A. The displacement is larger for the longer exciter at every current, so the energised damper reduces the effect of a larger input but does not remove it.

Table 6.1: Piston displacement (mm) against current at three exciter lengths (fluid-1)

Current (A)	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
250 mm	36	20	9.6	5.3	4.5	3.6	2.2	1.1	0.6	0.2
400 mm	42	22	10.5	6.23	5.2	4.4	3.2	2.4	1.2	0.7
550 mm	46	25	12	8	7	5	3.5	3	2.5	1.7

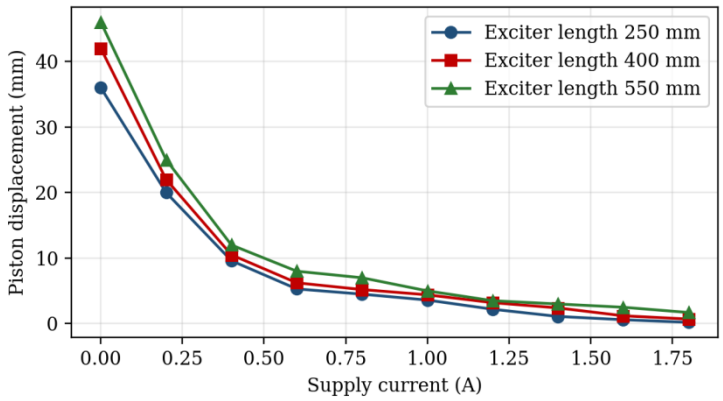


Figure 6.2 Piston displacement against supply current for three exciter lengths

6.3 Vibration amplitude and frequency

Table 6.2 and Figure 6.3(a) compare the vibration amplitude with and without the energised damper. The amplitude peaks at 400 mm in both cases: 5.7 mm without the damper and 3.9 mm with it, a reduction of 32%. At other lengths the reduction ranges from 23% (500 mm) to 40% (250 mm) and averages 30%. The dominant frequency recorded with the sound-card oscilloscope was 122.30 Hz without the magnetic field and 55.884 Hz with it (Figure 6.3(b)), a reduction of 54%.

Table 6.2: Vibration amplitude (mm) with and without the MR damper

Exciter length (mm)	250	300	350	400	450	500	550
Without MR damper	2.0	3.5	4.2	5.7	4.0	3.0	2.0
With MR damper	1.2	2.3	3.2	3.9	3.0	2.3	1.4
Reduction (%)	40	34	24	32	25	23	30

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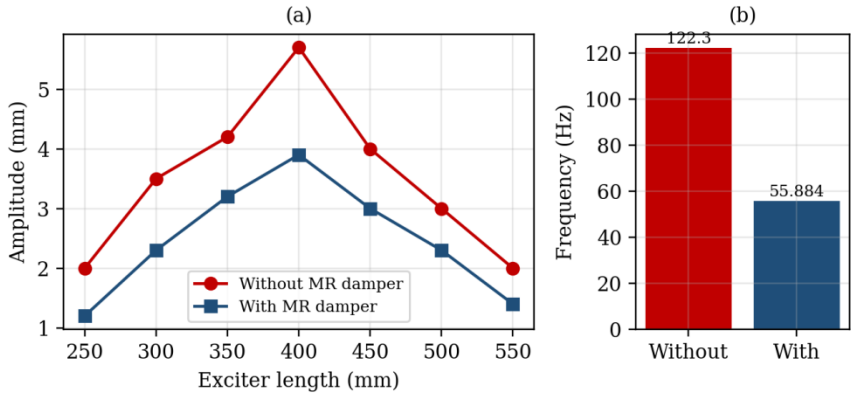


Figure 6.3 (a) Amplitude against exciter length with and without MR damper; (b) dominant frequency without and with the field

6.4 Discussion

The measurements agree with the MR mechanism: as the current rises the field in the gap rises, the particles align into chains, the resistance to flow through the piston grooves increases, and the piston moves less for the same excitation [3], [6], [7]. Because current is the only parameter changed in the displacement series, the decrease can be attributed to the field, and the monotonic response shows that damping can be set by the current, which is the basis of semi-active control [1], [2]. The fast initial drop followed by flattening is the usual pattern as particle chains approach their strength limit, but force and yield stress were not measured here, so this is not proved. Fluid-1 gave a higher field than fluid-2 at every current, by up to 5% at 1.8 A, and was rated more stable in Table 4.1; the margin is small, one set of readings was taken, and particle size and packing were not controlled, so the data do not support a general statement about the two oxides.

6.5 Limitations

The fields reached (up to 42 G, about 4.2 mT) are much lower than those used in commercial MR dampers and were measured in the electromagnet set-up, not in the damper gap. Damper force was not measured; displacement and amplitude are indirect indicators of damping. Each condition was recorded once, with no repeat tests or uncertainty estimates, and the amplitude values were read from graphs. Sedimentation over time and sealing life were not studied.

VII. CONCLUSION

Two MR fluids with Fe_2O_3 and Fe_3O_4 particles in silicone oil were prepared in the laboratory, and the field in both rises almost linearly with current, reaching 42 G and 40 G at 1.8 A. A fork-scale prototype damper (31.4 mm cylinder, 608 mm extended length, ±25 mm stroke, 150-turn coil) was fabricated and operated from 0 to 1.8 A. With fluid-1, piston displacement fell by 96% to 99% as current rose from 0 to 1.8 A at all three exciter lengths, most of it below about 1 A. At the 400 mm exciter length the mean amplitude fell from 5.7 to 3.9 mm (32%) and the dominant frequency from 122.30 to 55.884 Hz (54%). Future work should add force measurement, field measurement in the gap at higher currents, repeated tests, a computer-controlled current supply and on-road testing on a motorcycle.

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