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# Experimental Investigation of Using MR – Fluids in Automobiles Suspension Systems

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**Abstract:** In recent years, a flurry of interest has been shown for a relatively old technology called magneto-rheological fluids, or MR fluids. Multiple types of devices have been designed to implement this versatile fluid, including linear dampers, clutches, work-piece fixtures, and polishing machines. The devices have been used in automobiles, washing machines, bicycles, prosthetic limbs, and even smart structures. This paper focuses on another application of MR dampers, involving automobile suspension, and introduces using of MR dampers and automobile suspensions, and why the two would be a good combination. An experimental investigation is carried out to show the efficiency of using such fluids on suspension systems of the automobiles. The MR dampers provided a more stable ride than that of the OEM dampers. By reducing suspension displacement, settling time, and suspension oscillations, the MR dampers were able to reduce suspension geometry instability. It is found that the efficiency of damper used in this study increases by using MR fluids, and this efficiency increases as the current applied on the MR damper increase.

**Key words:** Automobiles, dampers, MR-fluids, road grip, shock absorbers, suspension systems

## INTRODUCTION

Magneto-rheological fluids are fluids that exhibit a change in rheological properties when a magnetic field is induced through the fluid. Such fluid's flow characteristics, namely apparent viscosity, change. In the present work an experimental study on using MR-fluids in a shock absorber device and its relation with road grip value. The damping characteristics of such fluids will be studied, and also a relation between the road grip and the current applied will be investigated. MR fluids are quite similar to Electrorheological (ER) fluids and Ferro-fluids in composition: all three fluids are a non-colloidal suspension of polarizable particles. While MR and ER fluids usually contain carbonyl iron on the order of a few microns in size, Ferro-fluids use nanometer-sized iron oxide particles. Ferro-fluid particles are too small to demonstrate any yield strength; instead they tend to be only attracted to and flow toward a magnetic field. MR fluids, on the other hand, demonstrate very high yield strengths when a field is induced, usually on the order of 20 to 50 times the strength of ER fluids. With no applied magnetic field (off state), MR fluids behave with Newtonian-like characteristics. Applying an external magnetic field through the fluid activates MR fluids, causing the micron-sized particles to form magnetic dipoles along the lines of magnetic flux, as shown in Fig. 1, Carlson *et al.* (1955).

MR fluid also develops a yield stress based on the amount of mechanical energy required to yield the ferrous dipole chains. This behavior can be compared to a Bingham plastic with variable yield strength. MR fluids can be used in three principal modes of operation: pressure driven flow (valve) mode, direct-shear mode, and squeeze-film mode. In pressure driven flow (valve) mode, the two magnetic poles are fixed, and a pressurized flow of MR fluid moves between them. In direct-shear mode, the two magnetic poles move relative to each other, and the MR fluid is "sheared" between them. Squeeze-film mode involves a layer of MR fluid, which is squeezed between the two magnetic poles. Jacob Rainbow, who worked for the US National Bureau of Standards first, introduced MR fluids in the 1940s. In an early demonstration, Rainbow was able to suspend a 117-pound woman from a swing using the activated fluid. This experiment proved the strength and capabilities of the new MR fluid. For this experiment to succeed, the fluid's yield strength needed to be over 100 kPa, (Rabinow, 1951). In the early 1990s, Lord Corporation pioneered the use of MR fluids in the Motion Master Damper and began improving the MR solution characteristics.

**MR Dampers:** Magneto-rheological dampers are perhaps one of the most common applications for MR fluids. The fluid's adjustable apparent viscosity makes it ideal for use in dampers for vibration control. Real-time adjustable

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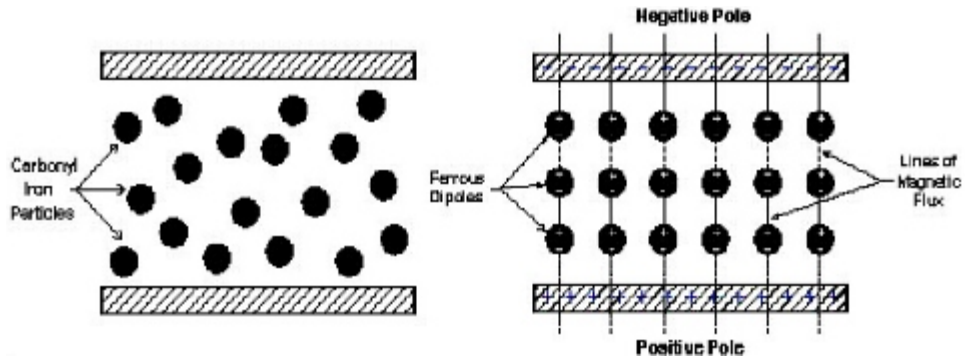


Fig. 1: Off-state MR fluid particles (left) aligning in an applied magnetic field (right)

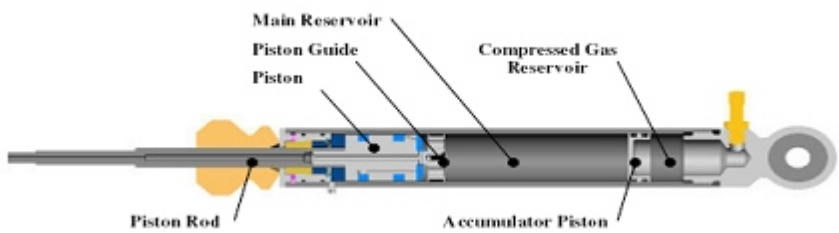


Fig. 2: Monotube MR damper, section view

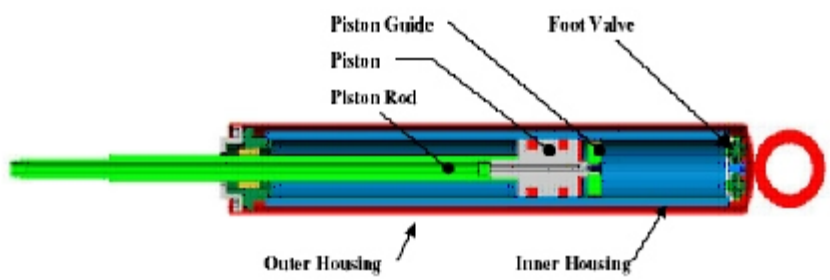


Fig. 3: Twin tube MR damper, section view

systems can be developed to change damping based on certain physical measurements, such as velocity or acceleration, in order to better counteract and control the system dynamics. Typically, MR damper applications use the pressure driven flow (valve) mode of the fluid or a combination of valve mode and direct-shear mode. Dampers that use only direct-shear mode tend to be used in applications that do not require much force from the damper. Linear MR dampers can be of three primary designs: monotube, twintube, or double-ended (also known as through-tube). The three design types reflect methods of adjusting the fluid volume to account for the volume of the damper shaft. Monotube designs are the most common damper design; they exhibit simplicity and compactness of design and with the ability to be mounted in any orientation (Fig. 2).

The twintube damper uses inner and outer cartridges to negotiate the changing volume of MR fluid, as shown in Fig. 3. As the piston rod enters the inner housing, the extra volume of MR fluid displaced by the piston rod is forced from the inner housing to the outer housing via the foot valve. When the piston rod retracts, MR fluid flows back into the inner housing, therefore preventing the creation of vacuum in the inner housing and cavitations of the damper. Drawbacks of this design include size and orientation – this damper must be mounted with the foot valve at the bottom to ensure no cavitations (Lampe, 1998).

Double-ended (through-tube) dampers use a third method to account for the piston rod volume. Fully extended, the piston rod protrudes through both sides of the damper housing, as shown in Fig. 4. This method of damper design retains a constant piston rod and fluid volume within the housing, thereby eliminating the need for a second housing or accumulator.

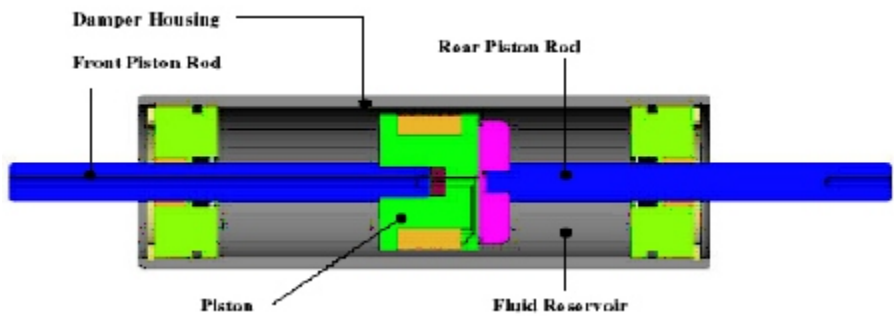


Fig. 4: Double-ended (Through-Tube) MR damper, section view

The twintube and double-ended damper provide a significant advantage over the monotube design. The pressurized charge in the accumulator of the monotube design adds a spring force to the damping rod, so not only does the damper have force vs. velocity characteristics, it also has a spring rate. The twintube and double-ended damper, however, do not demonstrate this trait, showing only force vs. velocity characteristics.

Many researches discussed the operation and applications of the MR fluids in shock absorbing, Ericksen *et al.* (2003), presented a theoretical and experimental investigations of a controllable, semi-active, fail-safe, Magneto-Rheological Fluid (MRF) shock absorber for the rear suspension of an off-road motorcycle. A fail-safe MRF damper is referred to a device that retains a minimum required damping capacity in the event of a power supply or electronic system failure. A theoretical fluid mechanics-based model was developed to predict the controllable damping force in terms of the physical parameters of the device, the magnetorheological fluid properties, the electromagnetic circuit parameters, and the input motion. It was found that the MRF damper emulated the original equipment manufacturer shock absorber performance in its passive off mode (i.e., no applied magnetic field) and provided controllable dynamic damping rebound and compression forces, when activated (Ericksen, 1999).

Magnac *et al.* (2006), presented a device-oriented test bench developed in order to characterize the magneto-mechanical properties of MRF such as the magnetization curve, the yield stress. It was based on a large electromagnet, which is able to produce a magnetic field into a tube containing the MRF sample. The magnetization curve is determined using the permeameter method. It allows designing the magnetic circuits for applications. The variable damping versus field was measured using a dynamic method. The yield stress is measured using various static loads. It allows designing devices with the right braking/holding forces in the applications.

Table 1: Damper specifications

| | |
|---|---|
| Maximum Input Power | 50W |
| Fluid Maximum Yield Stress | 35.87kpa |
| Max apparent Fluid Plastic Viscosity | 2.58 pa/s |
| Wire length, Diameter | 200 m, 0.7 mm |
| Coil Turns | 200 |
| Inductance (L) | 2.5 mH |
| Coil Resistance (R) | 2.75 Ω |

## MATERIALS AND METHODS

In this work The MR fluid damper, which was used, is the twintube damper shown in Fig. 3. The effective fluid orifice is the entire annular space between the piston outside diameter and the inside of the damper cylinder housing. Movement of the piston causes fluids to flow through this annular region. Table 1 shows the used damper specifications.

MR fluid used in this study is of an own composition. MR is composed of:

- Iron particles: iron powder is used as a magnetic particles which have less than 4 microns diameter and this range of size is considered perfect for MR fluids.
- Oil: the oil is needed to be used with lithium grease because it contains the additives that prevent iron particles from settling, hydrocarbon oil or the automotive oils cannot be used because it has high viscosity and the MR fluid will be MR grease rather than MR fluid. Also, the WD-40 oil can't be used too, although it has a low viscosity but it has a strong odor and it is more volatile and it evaporates quickly.
- Grease: The role of lithium grease, which contains some chemicals, is to prevent iron particles from settling; the viscosity is measured using the viscometer. The three immersion bodies have different factors giving different scale ranges. The viscometer can be used to measure both Newtonian and non-Newtonian liquids. The measured viscosity for the MR fluid is approximated as about 0.26 $Pa.s^{-1}$.

**Work procedure:** The laboratory testing was accomplished via the use of a Suspension system Test

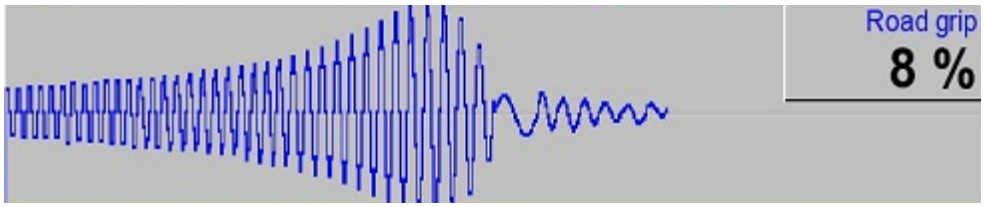


Fig. 5: Damping characteristic for MR damper at off-state

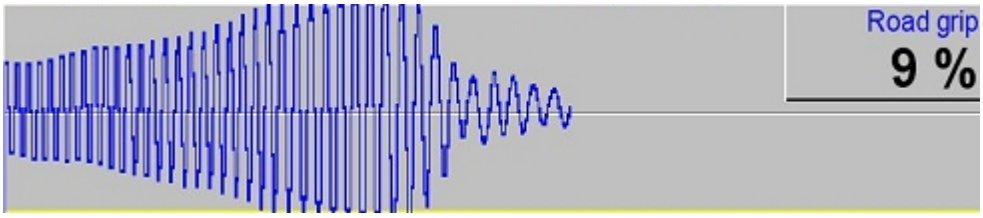


Fig. 6: Damping characteristic for MR damper at 0.5A

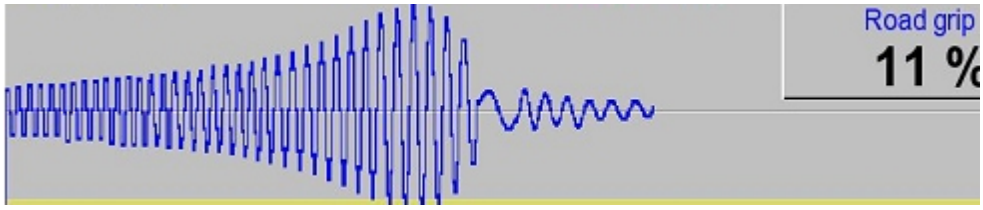


Fig. 7: Damping characteristic for MR damper at 1A

machine, which can provide a variety of types of displacement inputs from impulses and square waves to sinusoidal waves. The Suspension test machine was set to input a sinusoidal wave of a varying frequencies and displacement into the damper via a hydraulic actuator. The clamping system on the machine also incorporates a load cell, which outputs a voltage proportional to the force of the damper. Test procedure was kept the same for both the OEM and MR dampers. A sinusoidal displacement input was used to excite the dampers. Frequency of the sine wave was at 2-20 Hz, while the displacement was varied from 0 to 1.6 inch, providing a range of velocities at which to collect force data. Since the input is a sinusoidal wave in the form of Eq. (1), the maximum velocity can be determined via its derivative, as shown in Eq. (2):

$$X = A \sin \omega t \quad (1)$$

$$dx/dt = A\text{w} \cos \omega t \quad (2)$$

where x: is the damper displacement, dx/dt is the damper velocity, A is: the amplitude of the sine wave,ω : is the angular velocity, and t: is the time. The maximum velocity is Aω, and the maximum force is at that displacement setting is attributed to the maximum velocity.

**Road Grip:** The road grip is a concept used to give an indication about the efficiency of the damping system in the automobiles; it depends on the amount of obstacles or status of the road used by the automobile.

## RESULTS AND DISCUSSION

MR-fluids performance depending actually on two parameters: the value of the applied current, and the composition or ratios of added materials to the oil. In this study the effects of applied current is investigated at some specific value of road grip and the damping characteristics will be drawn to show the best current offer the best damping and road grip.

The Motor scan suspension tester mod.2210 was used to incorporate the required results. Motor scan suspension tester is used to test the suspension of the cars objectively and quicker than that was until now. The suspension is put into a vibration of 25 Hz. At the moment that this frequency is reached, the engine is stopped and the frequency will slowly go back to 0 Hz. Figure 5 shows the damping characteristics for off-state of the MR-damper. It is clear that the road grip at this condition is about 8%.

Figure 6 shows the road grip of about 9% when a current of about 0.5 A affects on the MR damper, it is also clear that the efficiency of the damper has been improved.

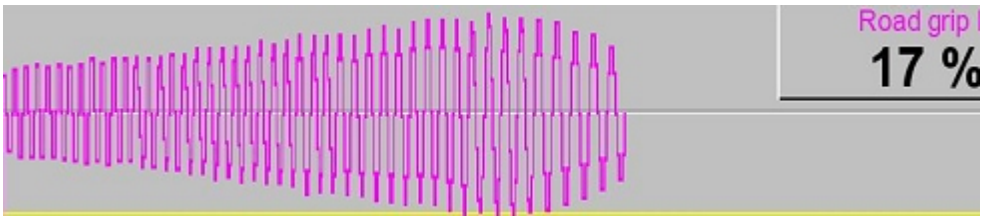


Fig. 8: Damping characteristic for MR damper at 1.5A

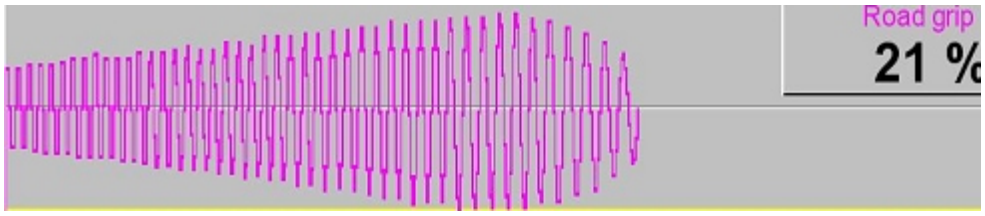


Fig. 9: Damping characteristic for MR damper at 2A

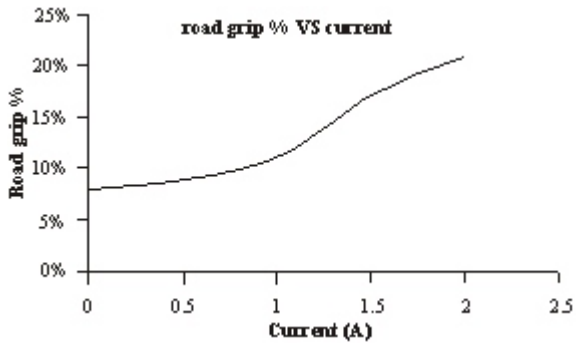


Fig. 10: Road grip vs. current applied on the MR damper

Figure 7 - 9 show the damping characteristics of the MR damper status with different values of applied currents. Also the road grip of the damper is increased proportionally with the applied current, it reaches about 21% at 2 A current.

Road grip is proportional to the current applied on the MR damper as shown in Fig. 10.

## CONCLUSION

The damping ratio $\zeta$ is considered as an indication of the system characteristics and the system behavior, if it's under, critically, or over damped. The best characteristics of a second order system as the present system are about 0.7. The steady state response was shown in both sinusoidal displacement and velocity, which varies with the applied current and attain its maximum value when the applied current is zero and increases as the current in the coil increases. The experimental results have shown that the damper sinusoidal response using PWM voltage has a very fast response about 7 ms, using the low carbon steel.

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