A STUDY ON MAGNETO RHEOLOGICAL FLUIDS AND THEIR APPLICATIONS

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Abstract - ***Magneto rheological fluids have received widespread attention as smart materials due to their tunable properties. A magneto rheological fluid consists of three key components including, soft magnetic particles, carrier liquids and additives. This paper details the characteristics, composition, and rheological principle of magneto rheological fluids, working principle of magneto rheological fluid devices, and their applications in other engineering arenas. The aim is to provide a basic understanding of magneto-rheological components and technology to the readers.***

Key Words: *Magneto Rheological Fluid, MR Dampers, Off State Viscosity, Thixotropic Additives, Carbonyl Iron Particles etc.*

1. INTRODUCTION

Magneto rheological fluids commonly known as MR fluids are suspensions of solid in liquid whose properties changes drastically when exposed to magnetic field. It is this property which makes it desirable to use in different vibration controlling systems.

Magneto-rheological fluids consist of micron sized polarizable particles in a liquid. Application of a magnetic field changes MR fluid from a liquid state to a semi-solid state, proportional to the strength of the field applied. Magneto-rheological fluid has the extremely widespread application prospect in many fields including aerospace, automotive industry, hydraulic transmission, biotechnology and medical because of its characteristics of continuous, reversible, rapid and easy control [6].

1.1 Principle of Operation

Applying a magnetic field to magneto Rheological Fluids causes particles in the fluid to align into chains. Micro particles are magnetized to produce orderly movement when an external magnetic field is applied, this movement generating at the beginning of micro particles are magnetized and finishing until reaching a relatively stable state, forming a fixed structure.

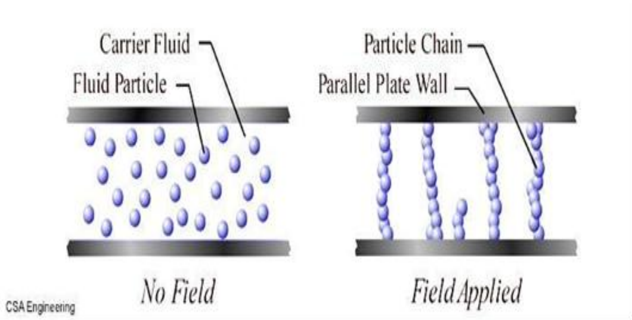

Fig 1. Behavior of MR fluid under Magnetic Field

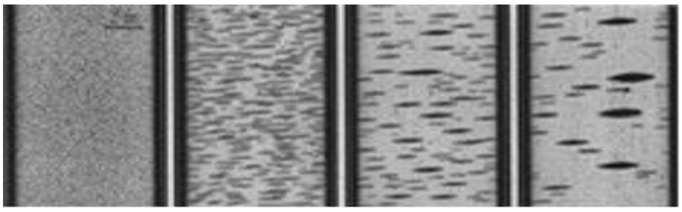

Fig 2. Behavior of MR fluid under Alternating Magnetic Field

The structure of particles in an MR fluid gradually changes when an alternating magnetic field is applied. The leftmost picture shows an MR fluid after 1 second of exposure to a fast-changing magnetic field. The suspended particles form a strong, fibrous network. The pictures to the right show the fluid after 3 minutes, 15 minutes and 1 hour of exposure. The particles have formed clumps that offer little structural support.

2. Selection Criteria for MR Fluid Components

The change in one or more components or in their properties influences the MR effect. The selection criteria for different MR fluid components are given below:

2.1. Liquid carrier

For the highest MRF effect the viscosity of the fluid should be small and almost independent of temperature [1]. Carrier liquid is the major constituent of MR fluids (50-80 per cent by volume) [1]. The commonly used carrier liquids are:

2.2 Mineral and Synthetic oil

The rate of change of viscosity with respect to the temperature is more in case of mineral oil. Hence, this limits the use of mineral oils as a carrier fluid in MR fluid for low temperature applications. Synthetic oil possess some important properties like higher flash point, does not thicken at high temperatures, lower friction, high shear strength and high viscosity index.

2.3 Silicone Oil

Silicone oil has good temperature-stability and good heat-transfer characteristics, oxidation resistance, very low vapor pressure, and high flash points. But, Silicone oil is very difficult to seal. There is little change in physical properties over a wide temperature span and a relative flat viscosity temperature slope and serviceability from-40 to 204°C. The different properties of these carrier fluids are evaluated in Table 1.

Table 1. Properties of Carrier Fluids [1].

Properties	Mineral Oil	Synthetic Oil	Silicone Oil
Viscosity @ 40 °C (Pa-s)	0.028	0.1068	0.1100
Flash point°C	171 – 185	230	>300
Fire point°C	260 – 330	350	~ 500
Specific gravity	0.818 – 0.95	0.817	0.9124
Density at 25°C (kg/m^3)	825	873-894	760
Pour point°C	-25to -50	-30 – 50	-50
Cloud point°C	-15	-20°C	-20
Market cost/ litre (Rs.)	~ 80	~800	~900

2.4 Magnetic Particles

The size of magnetic particles is approximate of the order of 1μm to 10μm [1]. As the size of magnetic particle increases, the attainable force also increases but at the cost of increased off state viscosity (The viscosity without the magnetic field) of MR fluid. The concentration of magnetic particles in base fluid can go up to 50% [6]. Low coercivity, high saturation magnetization, high permeability, small remnance and small hysteresis loop are other characteristics of magnetic materials used for the chemically pure and the particles are mesoscale and spherical in nature in order to eliminate the shape anisotropy.

2.5 Additives

Highly viscous materials such as grease or other thixotropic additives are used to improve settling stability. Ferrous naphthanate or ferrous oleate can be used as dispersants and metal soaps such as lithium stearate or sodium stearate as thixotropic (The property exhibited by certain gels of becoming liquid when stirred or shaken) additives [1]. Magnetic particles are coated with some materials like polystyrene (PS), gaur gum etc. to prevent Carbonyl Iron(CI) particles from coming in contact with each other and to decrease the CI particle density to improve the sedimentation stability.

3. Modes of Operation

MR fluids can be used in three principal modes they are:

3.1 Direct Shear Mode:

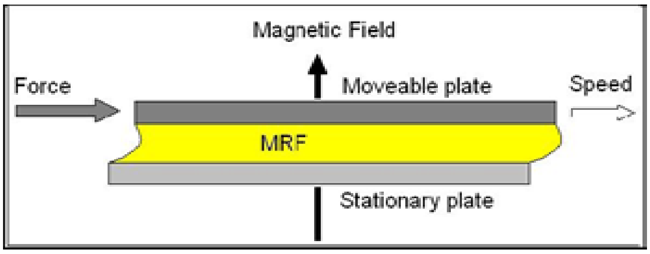

Fig 3. Direct Shear Mode

In direct-shear mode, the two magnetic poles move relative to each other, and the MR fluid is sheared between them. Operation in direct-shear mode requires that the two magnetic pole plates move relative to each other, thus shearing the fluid between them, as depicted in Figure 3. An applied magnetic field aligns MR particles perpendicular to the pole plates while the shearing motion attempts to bend the particle chains along the flux lines. Again, as the field intensity increases, the MR fluid's resistance to shearing increases. The direct-shear mode of MR fluids can be used in low force dampers.

3.2 Squeeze-Film Mode:

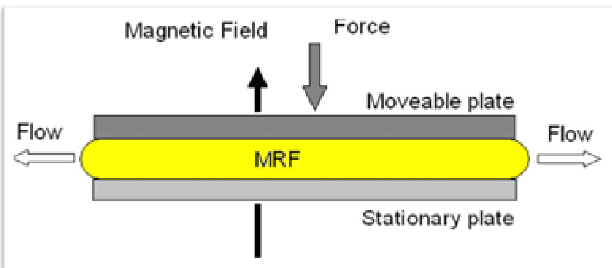

Fig 4. Squeeze Film Mode

Squeeze-film mode involves a layer of MR fluid, which is squeezed between the two magnetic poles as shown in the above Figure 4.
The application of force on the plates parallel to the direction of flux lines pressurizes the chain-like structures of MR fluid particles. The intensity of the induced field determines the ability of the MR fluid particle columns to resist buckling.

4. MR Dampers

One of the areas where MR fluids find their greatest application is in linear dampers that effect semi-active control. These include small MR fluid dampers for controlling the motion of suspended seats in heavy duty trucks, larger MR fluid dampers for use as primary suspension shock absorbers and struts in passenger automobiles and special purpose MR fluid dampers for use in prosthetic devices In all of these devices one of the most important fluid properties is a low-off state viscosity. MR dampers offer an attractive solution to energy absorption in mechanical systems and structures and can be considered as "fail-safe" devices [3].

4.1 Types of MR Dampers

4.1.1 The Mono Tube Damper:

It is the most common since it can be installed in any orientation and is compact in size. A mono tube MR damper, shown in Figure 5, has only one reservoir for the MR fluid and an accumulator mechanism to accommodate the change in volume that results from piston rod movement. The accumulator piston provides a barrier between the MR fluid and a compressed gas (usually nitrogen) that is used to accommodate the volume changes that occur when the piston rod enters the housing.

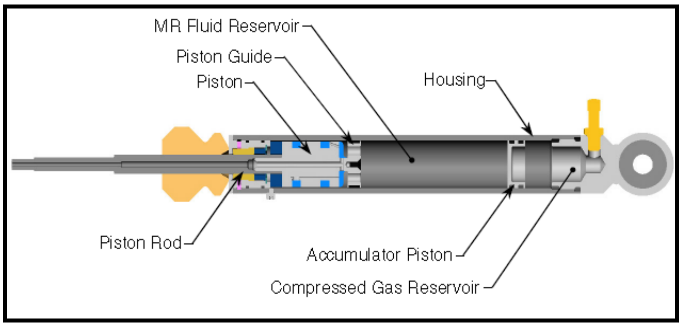

Fig 5. The Mono Tube Damper [11].

4.1.2 The Twin Tube Damper:

The twin tube MR damper is one that has two fluid reservoirs, one inside of the other, as shown in Figure 6. In this configuration, the damper has an inner and outer housing, which are separated from each other by a foot valve. The inner housing guides the piston rod assembly, in exactly the same manner as in a mono tubes damper. The volume enclosed by the inner housing is referred to as the inner reservoir and the space between the inner housing and the outer housing is referred to as the outer reservoir. The inner reservoir is filled with MR fluid so that no air pockets exist.

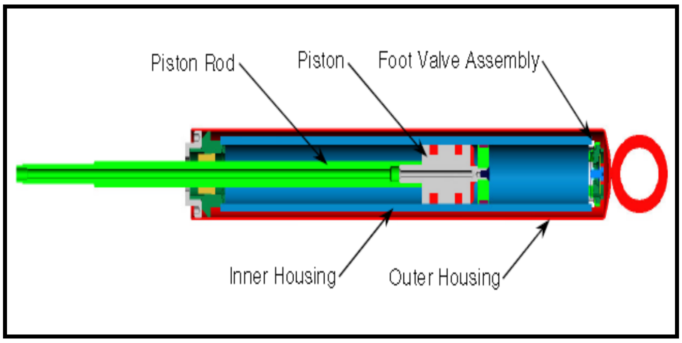

Fig 6. The Twin Tube Damper [11].

4.1.3 The Double Ended Damper:

In the double-ended damper a piston rod of equal diameter protrudes from both ends of the damper housing. The Figure 7 illustrates a section view of a typical double-ended MR damper.

Since there is no change in volume as the piston rod moves relative to the damper body, the double-ended damper does not require an accumulator mechanism. Double ended MR dampers have been used for gun recoil applications, bicycle applications, and for controlling building sway motion caused by wind gusts and earthquakes.

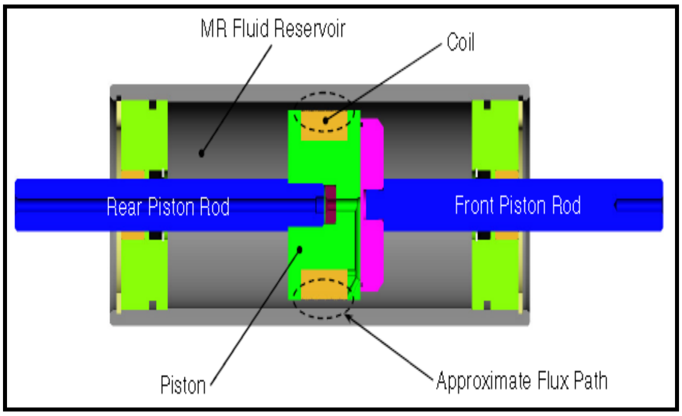

Fig 7. The Double Ended Damper [11].

5. Components of MR Fluids

Although the formulation of MR fluid depends on the needs of the application, MR fluid typically contains the basic components as shown in the Figure [1].

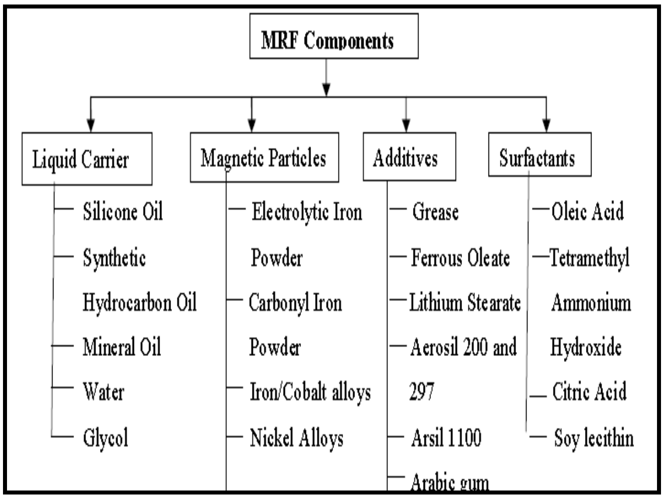

Fig 8. Components of MR Fluid

6. Typical Applications of MR Fluids

6.1 Semi-Active MR Damper for Seats

In early 1998 a real-time, semi-active vibration control system became available for use in the seats of Class 8 (Eighteen Wheeler) trucks (Lord 1998). Manufacturers of premium large trucks such as Western Star and Freightliner offer the MR fluid based Motion Master System as a standard option. A complete semi-active vibration control system including MR fluid damper, sensor, microprocessor, current driver and ancillary cables. Today, over 5000 MR fluid based semi-active vibration control systems are in use in heavy-duty, over-the-highway trucks in the United States. These systems receive high praise from the drivers who experience them. They routinely deliver many hundreds of thousands of kilo- meters of service [8]. Their robustness is illustrated by the fact that there have been no failures in the field.

Fig 9. MRF in Seat Suspension

6.2 MR Fluid Shocks for Racing Cars

Late in 1998, MR fluid based adjustable shock absorbers for oval and dirt track racing automobiles were introduced by Carrera (Anderson 1998). A MagneShock by Carrera is shown in Figure 10. Race-car operators are today able to purchase MagneShock cockpit controlled primary suspension dampers for about $500. A set of four of these controllable MR fluid dampers eliminate the necessity of maintaining the usual stable of perhaps dozens of different passive hydraulic shock absorbers [8]. Car operators no longer need to physically change shock absorbers to optimize their vehicle for the conditions of the track, weather or tire condition. Rather, they need only perform a few test laps while adjusting the cockpit controls for the MR fluid dampers. A single set of four MR shocks may replace dozens of passive hydraulic dampers. The driver can easily and quickly optimize the left-to-right and fore-to-aft damping in order to optimize car performance on the track.

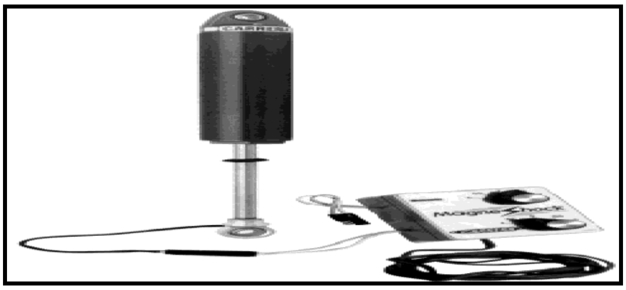

Fig 10. MR fluid based controllable shock absorber for NASCAR racing automobiles

6.3 Advanced Prosthetics

Perhaps the most exciting of all of the new MR fluid developments is that of real-time controlled dampers for use in advanced prosthetic devices. The idea here is to use a small MR fluid damper to control, in real-time, the motion of a prosthetic knee. The benefit is a more natural gate that can automatically adapt to virtually any condition. The HIP or High Intelligence Prosthesis is an above the knee prosthesis that has been introduced by Biedermann Motech this year (Matthis 2000, Carlson 2000, Jones 2000). The basic elements of the system are shown schematically in Figure 11. A group of sensors determines the instantaneous state of the knee: knee angle, swing velocity, axial force and moment.

A microprocessor-based controller determines the current needed to be applied to the MR fluid damper to allow for proper motion or locking of the artificial knee based on the instantaneous action being carried out by the user [8]. Once calibrated to a specific user the system automatically adapts in real-time to the users walking speed, stairs or inclination. The HIP system allows the user to move without having to consciously control what is going on with the prosthesis. As shown in Figure 11, all of the electronics are integrated into the mechanical structure of the prosthetic knee along with the MR damper and battery pack. The entire system operates from a rechargeable battery that provides about two-days of operation between charges. The HIP system with a MR fluid damper provides superior gait control over a wider range of activity than does servo-motor controlled systems costing many time much.

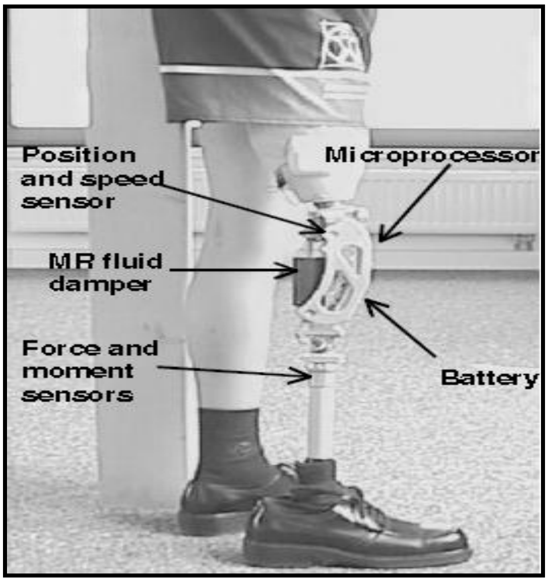

Fig 11. Above-knee prosthesis with real-time gait control provided by MR fluid damper

6.4 MR Fluid as Robot Blood

Astronauts onboard the International Space Station are studying strange fluids that might one day flow in the veins of robots. MR fluids are liquids that harden or change shape when they feel a magnetic field.

Fig 12. MRF as a Robot Blood

7. CONCLUSIONS

This paper presents the current status of MR devices and their applications in mechanical engineering [5]. There is great potential that this revolutionary material might open up many new frontiers of applications. The development of smart materials will undoubtedly be an essential task in many fields of science and technology such as information science, microelectronics, computer science, medical treatment, life science, energy, transportation, safety engineering and military technologies [3]. Beginning of the commercialization of MR technology was year 1995 and use of rotary brakes in aerobic exercise equipment. From this moment application of magneto- rheological material technology in real-world systems has grown steadily. MR technology has moved out of the laboratory and into viable commercial applications for a diverse spectrum of products [3]. Applications include automotive primary suspensions, truck seat systems, control-by-wire/tactile-feedback devices, pneumatic control, seismic mitigation and human prosthetics.

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