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Study of Magnetorheological Fluid and its Applications

Abhijeet Gaikar[1], Shreekant Kshirsagar[2], Aniket Magar[3]
[1, 2, 3]Department of Mechanical Engineering, Savitribai Phule Pune University

Abstract: This paper exemplifies the introduction to the Magnetorheological fluid and its key properties. Magnetorheological fluids (MR) is very promising intelligent material and it can rapidly be changed from a liquid state to a solid state in a magnetic field. MR fluids are materials that respond to an applied field with a dramatic change in their rheological behaviour. The essential characteristics of these fluids is their ability to reversibly change from a free flowing, linear, viscous liquid to a semisolid with governable yield strength in milliseconds when exposed to a magnetic field. Magnetorheological fluid technology has been successfully employed already in numerous low and high volume applications. Rheological properties are presented and discussed in following report. A structure based on MR fluid might be the next generation in design for products where power density, accuracy and dynamic performance are the key features. Aspects of this technology, direct shear mode, valve mode, are studied and application of valve mode in damper is discussed. Excellent features like fast response, simple interface between electrical power input and mechanical power output, and precise controllability make MR fluid technology attractive for many applications.

Keywords: MR fluid; viscosity; force; damper

I. INTRODUCTION

Magnetorheological (MR) fluids are materials that retort to an applied magnetic field with a change in rheological behaviour. Naturally, this change is exhibited by the development of a yield stress that monotonically surges with applied field. Interest in magnetorheological fluids arises from their capability to provide simple, quiet, rapid response interfaces between electronic controls and mechanical systems. MR fluids have the potential to radically change the method to design electromechanical devices. The magnetorheological reaction of MR fluids effects from the polarization induced in the suspended particles by application of an external field. The interface between the resulting induced dipoles causes the particles to form columnar structures, parallel to the applied field. These chain-like structures resist the motion of the fluid, thereby increasing the viscous characteristics of the suspension. The mechanical energy required to yield these chain-like structures increases as the applied field increases ensuing in a field dependent yield stress. In the deficiency of an applied field, MR fluids reveal Newtonian-like behaviour. Thus the behaviour of controllable fluids is frequently represented as a Bingham's plastic having adjustable yield strength (Phillips, 1996). In this model, the flow is administered by Bingham's equations.

$$T = T_y (H) + \eta . \gamma, \qquad T \geq T_y \qquad \text{….(1.1)}$$

At stresses T above the field dependent yield stress T_y (at strain of order 10^{-3}), the material behaves visco-elastically:

$$T = G \gamma, T < T_y \qquad \text{....(1.2)}$$

Where G is the complex material modulus. It has been observed in the literature that the complex modulus is also field dependent. While the Bingham plastic model has proved useful in the design and characterization of MR fluid based devices, true MR fluid behaviour exhibits some significant departures from the simple model. Perhaps the most significant of those departures involves the non-Newtonian behaviour of MR fluids in the absence of a magnetic field.

II. RHEOLOGICAL PROPERTIES OF OF MR FLUIDS

Rheology is the study of flow and deformation. Flow capability and deformation, which is either elastic or plastic, have common features and study of both subjects must overlap. For a conventional application with a conventional liquid i.e. a hydraulic pump or a damper, the most important property is the viscosity and it changes with temperature. For this purpose only, temperature cannot be considered as a controlling feature.

Two ways of expressing the viscosity-

Dynamic viscosity:

$\eta = \tau / \gamma^o$, where, τ = shear stress (N/mm^2),

γ^o = shear rate (1/s), η (Pa s) ....(2.1)

Kinematic viscosity:
$\upsilon = \eta / \rho$, where, ρ = density (kg/m^3)

η (Pa s), υ (m^2/s, 10^4 Stokes, 10^6 cSt) ....(2.2)

The temperature dependency of a conventional fluid i.e. silicon oil or a mineral oil is determined by the approximation:

$$\eta(T) = A \,.\, e^{b/(T+273)} \quad ....(2.3)$$

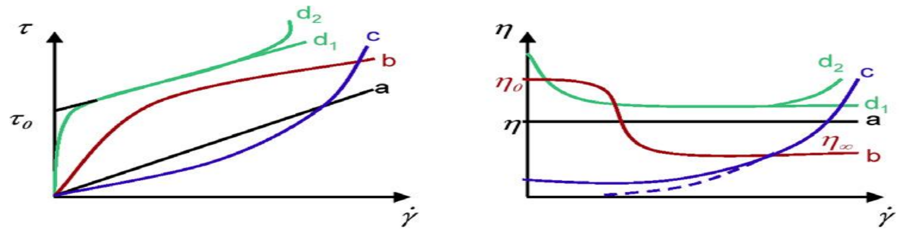

Fig.1 Different types of fluid behaviour

The factors A and b are experimentally defined for specific liquids. Newton estimated the relationship between shear stress and shear rate for various materials. For water it is linear and common name for such fluid is Newtonian fluid, which have constant viscosity value. Typical relationship between shear stress and shear rate is shown in Fig.1.
The correlation between the shear stress, viscosity and shear rate depends on the fluid type. As shown in Fig.1.1 the curve (a), is the fluids which can be recognised as Newtonian fluid. The viscosity does not vary despite different shear rate values, and the shear stress has a linear relationship with the shear rate. The representative fluid with this behaviour is water. In the case of curves (b) and(c), the shear stress has a reducing (b) or increasing (c) dependency with shear rate. There is analogous relationship between viscosity and shear rate, fluids with these behaviour are ketchup, tooth paste, etc. The curve (d) represents the behaviour of MR fluids, where no magnetic field is present, is very similar to the pattern of the carrier fluids, except that the metal powder content of the MR fluid makes the liquid slightly ‘thicker’. Fig.2. shows the typical relationship between shear stress and shear rate for a Bingham fluid and compares this with Newtonian fluid. It is recognised that the Bingham model is effective for use in explaining the rheological features of an MR fluid. When magnetic field is not present MR fluid behaves like a Newtonian fluid. When a magnetic field is present, the MR fluid displays a characteristic of Bingham fluids. At zero shear rate there is little resistance to flow. The force results in a plastic deformation, but there is no continuous movement. In this state, the maximum stress, which can be applied without triggering continuous movement, is the yield stress and this is a function of the magnetic field strength. For MR fluid, the yield stress can be steered, increasing or decreasing with the strength of the magnetic field.

A. Composition of MR fluid

A typical MR fluid consists of 20%–40% by volume of relatively pure, soft iron particles, typically 3–5 microns, suspended in a carrier liquid such as mineral oil, synthetic oil, water, or glycol. An assortment of restrictive added substances like those found in commercial lubricants are regularly added to demoralize gravitational settling and advance particle suspension, improve lubricity, adjust consistency, and hinder wear. MR fluid is different from a Ferro fluid, in which the particles are much smaller. MR liquid particles are fundamentally on the micrometer scale and are unreasonably thick for Brownian motion to keep them suspended. Ferro fluid particles are primarily nano-particles that are suspended by Brownian motion and generally will not settle under normal conditions. As a result, these two fluids have very dissimilar applications. Some of commercial fluids are MRX-126 PD, MRX-140 ND, MRX-242 AS, MRX-336 AG.

Table 1: Basic composition and density of commercial MR fluids

Commercial MR Fluid	Percent Iron by Volume	Carrier Fluid	Density (g/ml)
MRX-126PD	26	Hydrocarbon oil	2.66
MRX-140ND	40	Hydrocarbon oil	3.64
MRX-242AS	42	Water	3.88
MRX-336AG	36	Silicone oil	3.47

III. WORKING PRINCIPLE

Applying a magnetic field to magnetorheological liquids makes particles in the liquid adjust into chains. At the point when some low-thickness MR liquids are presented to quickly substituting magnetic fields, their inner particles bunch together. After some time they subside into an example of shapes that look somewhat like fish viewed from the highest point of a tank. Such clumpy MR liquids don't solidify as they should when polarized. The fish tank design is delicate and takes around an hour to completely develop.

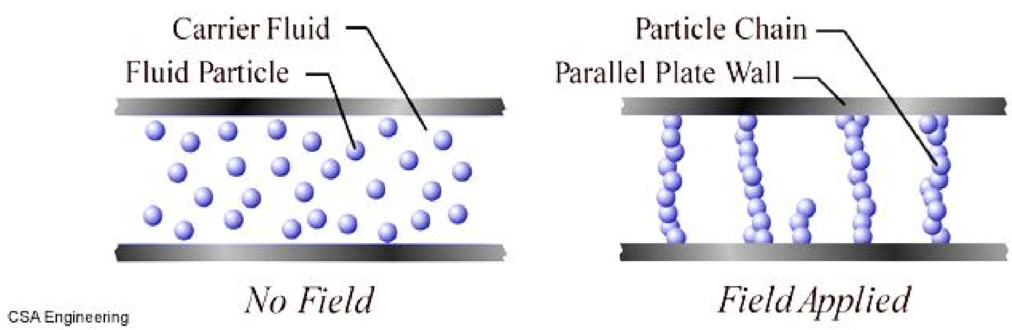

Fig.2 Magnetic particles arranged themselves after magnetic field is applied.

It doesn't happen in MR fluids that are always blended and agitated, as in a vehicle's suspension, however it could demonstrate troublesome in different circumstances. The structure of particles in a MR liquid step by step changes when a rotating magnetic field is connected. The picture shows an MR fluid after of exposure to a fast changing magnetic field. The suspended particles form a strong and fibrous network.

A. Modes of Operation

A MR fluid is utilized in one of three principle methods of operation, these are flow mode, shear mode and Squeeze-flow mode. These modes include, separate liquid streaming because of pressure gradient between two stationary plates, liquid between two plates moving with respect to each other and liquid between two plates moving toward the path perpendicular to their planes. In all cases the magnetic field is perpendicular to the planes of the plates, in order to resist liquid flow towards the path parallel to the plates.

1) *Flow Mode:* Flow mode can be utilized in dampers and shock absorbers, by utilizing the development to be controlled to compel the liquid through channels, crosswise over which a magnetic field is connected. The opposition of the fluid can be controlled by controlling the force of magnetic field. This method of MRF innovation is also applicable in the automotive industry.

$$\sum P = \Delta Pv + \Delta Pm \qquad \text{....(3.1)}$$

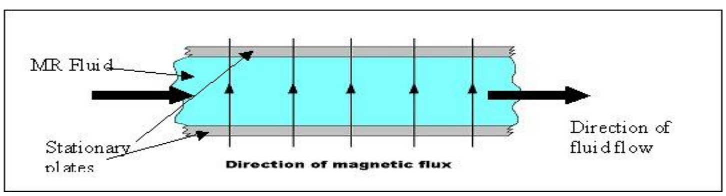

Fig. 3 Flow mode

2) *Shear Mode:* In this mode, the liquid streams between surfaces having relative movement and a magnetic field is applied perpendicular to the motion of stream. Shear mode of MRF technology is utilized in different sorts of brakes and clutches of the vehicles.

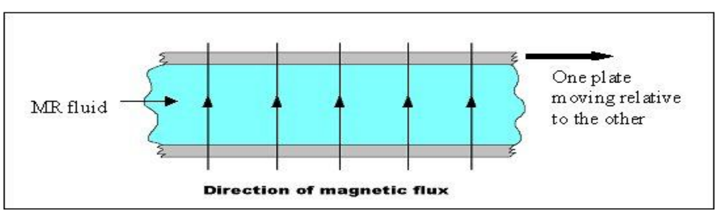

Fig.4 Shear mode

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In this mode, the resultant shear force created is a summation of the force developed because of the thickness of the liquid (Fv) and the force developed because of the magnetic field (Fm).

$$\sum F = Fv + Fm \quad \text{….(3.2)}$$

3) *Squeeze Mode:* This mode is utilized for slow motion and high power applications. This mode is a recent development as contrast with the other two. In this method of MR fluid technology externally applied force is absorbed with the assistance of MR fluid. The yield stress created through this mode is approximate ten times of the stress created in either valve or shear mode.

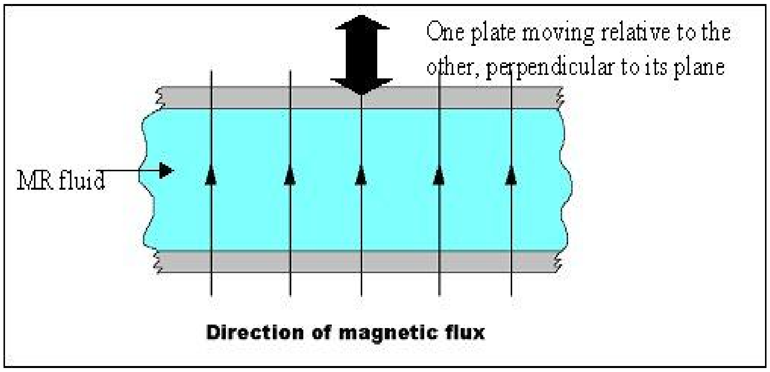

Fig.5 Squeeze flow mode

Working of the squeeze mode is clearly shown in the figure above. This technology is basic and includes less moving parts. Consequently MR fluid based products require less maintenance and have relatively longer life.

B. Application of MR fluid

1) *Damper and Shock absorber:* As motion control system turn out to be more refined, vibration attributes become progressively critical to a system's general structure and functionality. Most devices use MR fluids in a flow mode, direct-shear mode, or combination of these two modes to develop dampers and shock absorber.
2) *Military and Defence:* The U.S. Armed force Research Office is right now subsidizing investigation into utilizing MR fluid to enhance body protection. In 2003, researchers expressed they were five to ten years away from making the fluid bullet resistant. Also, Humvees, certain helicopters, and different other off-road vehicles utilize dynamic MR shock absorbers as well as dampers.
3) *Optics:* Magnetorheological finishing, a magnetorheological fluid-based optical polishing technique, has turned out to be highly precise. It was utilized in the development of the Hubble Space Telescope's corrective lens.
4) *Automotive and Aerospace:* If the shock absorbers of a vehicle's suspension are loaded up with MR liquid rather than plain oil, and the entire device encompassed with an electromagnet, the viscosity of the liquid can be fluctuated relying upon driver inclination or the load being conveyed by the vehicle or it might be dynamically changed so as to give stability control. This is as a result a Magnetorheological damper. The MagneRide attractive ride control is one such system which allows the damping factor to be balanced once every millisecond because of the conditions.
5) *Human Prosthesis:* Magnetorheological dampers are used in semi-dynamic human prosthetic legs. Much like those utilized in military and business helicopters, a damper in the prosthetic leg reduces the shock conveyed to the patient's leg while jumping, for instance. This outcomes in an expanded versatility and agility of the patient.

IV. CONCLUSIONS

Magneto rheological liquids are really astonishing magnetic fluids. MR fluid improvement is obviously a balancing act that is combined with MR device design. MR fluid sturdiness and life have been observed to be more noteworthy hindrances to commercial accomplishment than yield strength or stability. MR fluid sturdiness and life have been observed to be more noteworthy hindrances to commercial accomplishment than yield strength or stability. Significant use of MR liquid which is in dampers is being clarified with the goal that we can come to know how it really functions when utilized in a system. Challenges for future MR fluid advancement are liquids that work in the high shear routine, thus MR liquids can be considered as a superior method for controlling vibrations. The way to achievement in these usage is the ability of MR fluid to quickly change its rheological properties upon introduction to the applied magnetic field.

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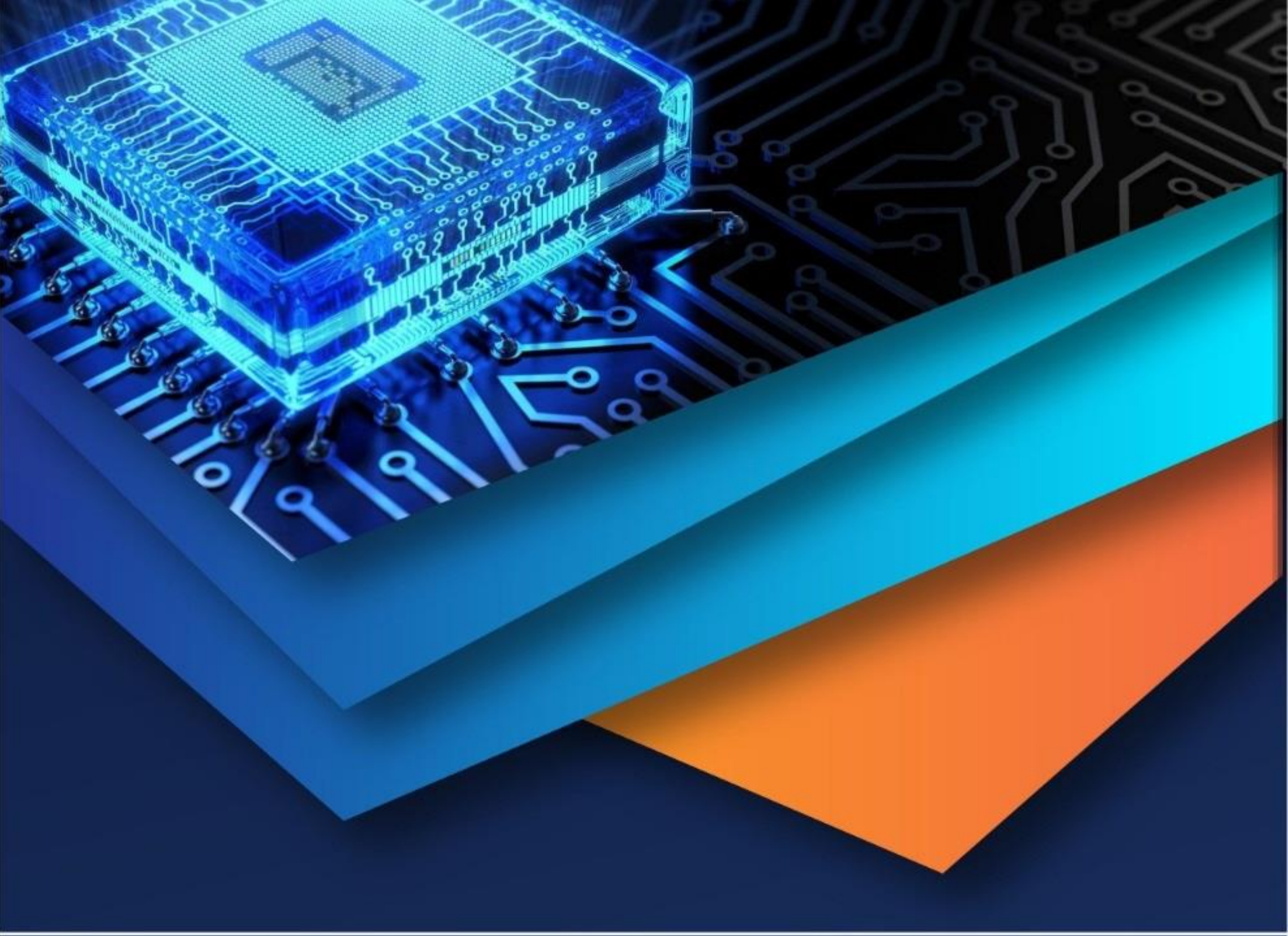

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