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Research Article

Magnetorheological Fluid and its Applications

Pranav Gadekar*, V.S.Kanthale and N.D.Khaire

Mechanical Department, MITCOE, Pune University, Pune, Maharashtra, India

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Abstract

A Magneto rheological Fluid (MRF) is a Smart fluid whose viscosity can be varied by application of magnetic field. The MR Fluid has vast applications in various engineering as well as day to day life. There is huge potential that this revolutionary material will provide many leading edge applications. The fluid has applications in various fields such as automotive industry, household applications, prosthetics, civil engineering, hydraulics, brakes and clutches, etc. Also there is a possible application of the fluid in reducing the effect of Gun Recoil. This paper will describe these applications and working of proposed application.

Keywords*: MR Fluid, Viscosity, Dampers, Prosthetics, Gun Recoil.*

1. Introduction

Rheos is a Greek word to Flow. Rheology is the science if material flow under external load conditions. The word Magnetorheological Fluid means fluid whose apparent viscosity increases, with application of MAGNETIC field. Also known as MR fluids, these fluids have magnetisable particles suspended in the base fluid. The base fluid is a type of oil. The MR fluid change from liquid state to solid state when exposed to magnetic field in a fraction of second. This property enables a quick response interface between mechanical systems and electronic components. Magneto-rheological fluid has the very versatile application opportunities in many fields including aerospace, automotive industry, hydraulics, fields such as medical.

2. Composition and Properties of MR Fluid

Typical magneto rheological fluids are the suspensions of micro magnetic particles (ferrous) suspended in an appropriate carrier liquid such as mineral oil, synthetic oil, water or ethylene glycol. The MR fluid is composed of three main components:

1) Base (Carrier) fluid,
2) Magnetizable Metal particles and
3) Stabilizing additives.

1) Base fluid

The base fluid is non-magnetic carrier fluid in which the metal particles are suspended. The base fluid is natural lubricant and has shock absorbing properties. To take full advantage of MRF technologythe base fluid must have a low viscosity and it should be constant with temperature. This is required for variation due to applied magnetic field to be more effective than natural viscosity. The presences of suspended particles make base fluid thicker. Commonly used base fluids are mineral oils, hydrocarbon oils, and Silicon oils.

2) Metal particles

For this technology to be useful, the suspended particles should be affected by the magnetic field quickly. For this, magnetizable metal particles are used. Metal particles used in the MR- technology are very small, approximately of the order of 1μm to 7μm. Usually metal particles used are carbonyl iron, powder iron and iron cobalt alloys. Ferrous particles of these materials possess the ability to saturation of high magnetism which leads to form a solid magnetic chain. The particles can be up to 50% in the base fluid.

3) Additives

Certain additives are added to MR fluid for controlling its properties. These additives include surfactants and stabilizers. Surfactants lower the rate of settling of the metal particles. The functions of additives are to maintain friction between the metal particles, keep the viscosity of the fluid in control and to reduce the rate of settling of particles making the fluid thick due to long term use of the fluid. Thus additives also increase the working cycles of the MR fluid. Commonly used additives are lithium stearate and ferrous oleate.

The MR behavior of the fluid is determined by these three components. Varying any one component will

*Corresponding author: **Pranav Gadekar**

result in variation ofthe Controlling and MR properties of the fluid. A proper combination of amount of these components is necessary to define the properties of the fluid.

Table 1: General Properties of MR Fluid

Property	Typical value
Work Temperature	(-50) to (150) ^{0}C
Initial Viscosity	0.2 -0.3 Pa-s (at 25 ^{0}C)
Magnetic Field Strength	150-250 kA/m
Density	3 -4 g/cm3
Reaction Time	Few milliseconds
Yield Point	50-100 kPa
Typical Voltage	2-25 V
Current Intensity	1-2 A

3. Behavior of MR Fluid

The properties of MR fluid can be controlled in the presence of magnetic field. In the absence of magnetic field, the MR fluid is similar to the base liquid except that it is slightly thicker due to the presence of metal particles.

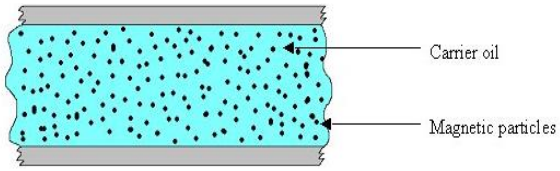

Fig. 1: MR Fluid in absence of Magnetic Field

In the external magnetic field MR fluid changes its properties, it transforms from thick liquid to solid. This effect results from the change of fluid structure: the ferromagnetic particles gain a dipole moment directed along the lines of external magnetic field and under its influence form linear chains.

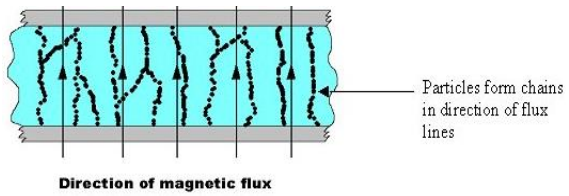

Fig. 2: MR Fluid in presence of Magnetic Field

When the external magnetic field disappears, the magnetic fluid will regain its initial properties due to dispersion of particles as a result of thermal motion. This dispersion time is in order of few milliseconds. As the strength of magnetic field increases, the stresses of linear ferromagnetic particle chains increase which leads to the larger viscosity of the MR fluid. This property enables to control the fluid viscosity by use of external magnetic field. In the absence of magnetic field, the MR fluid behaves like a Newtonian fluid which has same characteristics as that of carrier fluid with higher density due to the magnetic particles.

The yield stress which can be applied in steady conditions is in proportion to the magnetic field strength. Hence MR fluid is controlled resistive fluid. The yield strength also varies with the magnetization properties of the metal particles which is a function of the concentration and nature of metal particles.

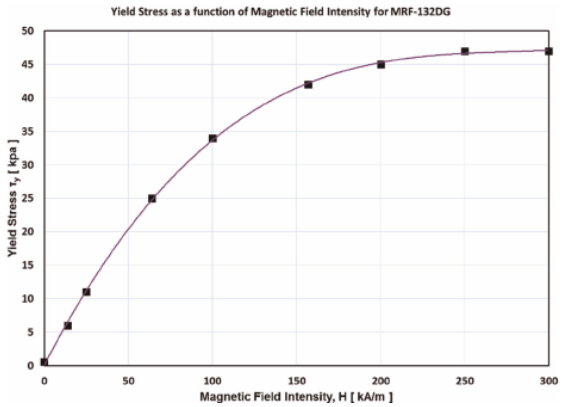

Fig. 3: Yield stress as a function the magnetic field strength

4. Applications

A] MR Dampers

The semi-active control is affected by linear dampers which is a major application of the MR fluid. In these devices a low-off state viscosity is a important property. MR dampers give us a new window to problem of energy absorption in various systems and structures and hence are considered as fail-safe devices. A notable application is small MR fluid damper which is used to control the motion of suspended seats. Larger MR fluid dampers are used as primary suspension in heavy duty trucks also as struts in passenger automobiles. Special purpose MR fluid dampers in prosthetic devices are also used. MR Dampers can be used for various purposes. The various places where dampers find their application are:

1. Automotive Industry

Car Suspension

Advantage of MR fluid dampers as real time semi-active damping elements is taken by the industry. This system works in a different way than conventional suspension system. The magnetic field is applied with a help of an electromagnet. A controlled set of algorithm improves the shock absorbing capacity of suspension by varying viscosity of the MR Fluid. This system made its first debut in 2002, it now appears on more than a million vehicles from multiple automotive OEMs including Ferrari, GM,Audi, Land Rover and others.

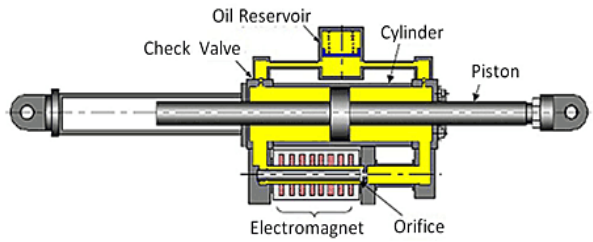

Fig. 4: A MR Fluid Suspension

Seat Suspension

First introduced in 1998, semi-active vibration control system was used in the seats of Eighteen Wheeler trucks (Lord 1998). A semi-active vibration control system includes MR fluid damper, microprocessor, sensor, current driver and auxiliary cables. Currently, more than 5000 MR fluid based semi-active vibration control systems are being used in heavy-duty trucks in the American highways. These systems are highly praised by the drivers who experience them. They are efficient for several hundreds of thousands of miles. The number of recorded failures in this field is virtually zero.

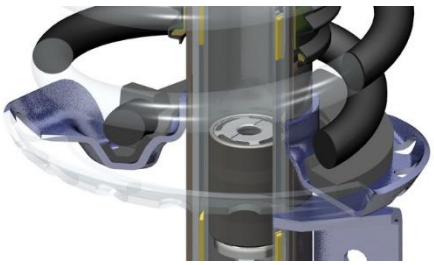

Fig. 5: MR Fluid dampers in Seat Suspension

2. Seismic Protection of Buildings

The MR Dampers can be used as Seismic dampers which will operate under the resonance frequency of the building by absorbing shock waves and oscillations that can cause harm, within the structure. This makes the dampers able to make any building earthquake proof.

Fig. 6: A MR Seismic Damper Test sample

3. Cable Stayed Bridges

MR fluid dampers are used to control the vibrations induced by the string winds. They are also used to avoid the seismic action. The Dongting Bridge is a cable stayed bridge which crosses Dongting Lake where it meets the Yangtze River in south central China. The Dongting Bridge is the first cable-stayed bridge to use MR dampers for absorbing rain and wind induced vibrations. The results are a very significant reduction in vibrations of the bridge structure.

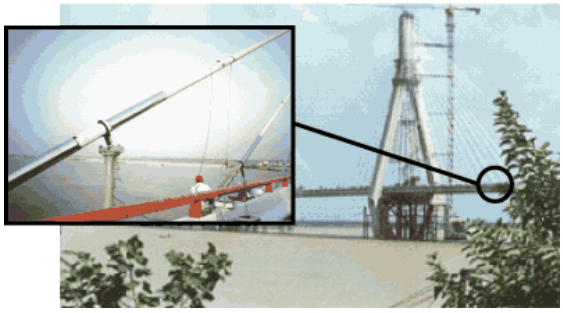

Fig. 7: The Dongting Bridge with MR Dampers.

4. Household Application: Washing Machine

The MR fluid damper is used in the washing machine to reduce vibrations during spin. The application of semi active control in household applications is still a long way journey; the discussions are only in those areas where the research is primarily about tub dynamics at low spin, about the main drum's resonance frequency. Instead, this work mainly focuses on the vibrations induces due to high rotational velocity.

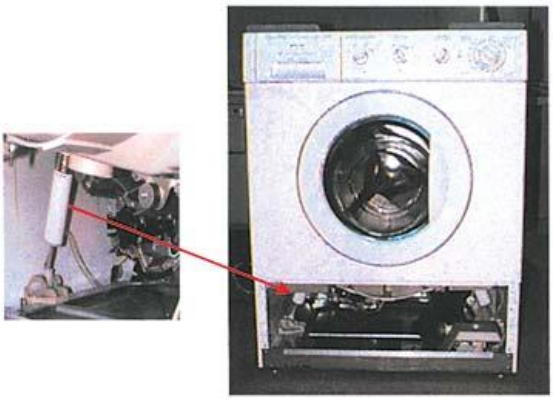

Fig.8: MR Fluid dampers in Washing Machine

5. Prosthetic Knee

The MR Dampers can be used in prosthetic knee to provide fast shock absorbing and make the user fell more natural feet. This is done using a small MR fluid damper to absorb the shocks due to the motion of a prosthetic knee. This gives a gate which is compatible to almost all conditions. BiedermannMotech (Matthis 2000, Carlson 2000, Jones 2000) introduced the HIP or

High Intelligence Prosthesis which is a prosthesis above the knee. A group of sensors determines the instantaneous state of the knee: knee angle, axial force, moment and swing velocity.

Fig. 9: MR Dampers in Prosthetics

6. Artificial Muscles

The MR Fluid is used to reduce vibrations produced during the use of artificial muscles. The robots are required to contact the humans safely. Hence there is a prime interest in artificial muscle based on pneumatics. This actuator is light, flexible, and power density is high. However, being flexible the artificial muscle has vibration problem under a high load. It requires the use of the magnetorheological (MR) fluid. Hence a control method of the MR brake which takes in accountenergy of the manipulator system has been proposed. Using this method, MR brake dissipates energy which gives us the desired effect.

B] MR Fluid other than Dampers

1. Hydraulic Valves

Under the control of MR valves, actuators operating by hydraulic system can use MR fluid as a working medium. This system consists of MR valve which is a proportional throttle valve with stationary parts. The valve can comprise a metal body with a magnetic core in which there is a hydraulic channel and an induction coil winding which is located between the inside of the body and the outside core. This is connected to a fluid inlet, outlet port. When MR fluid starts flowing through such valves the magnetic field is applied to the fluid which results an increase in viscosity. The inlet pressure in increased by the increased resistance to flow of the fluid which is an effect is increased viscosity.

2. Brakes and Clutches

MR fluid-based brakes and clutches are operated in shear and flow mode, former being commonly used. The MR fluid rotary brake by Lord Corp. is a controllable rotary resistance system that is smooth acting, compact and consumes low power. They are used along with velocity feedback where the torque is controlled forcing the user to obtain a constant target velocity profile. They are simple and easy to control, which makes them a very cost efficientmodel for a wide variety of applications that ranges from controllable exercise equipment to precision active tension control.

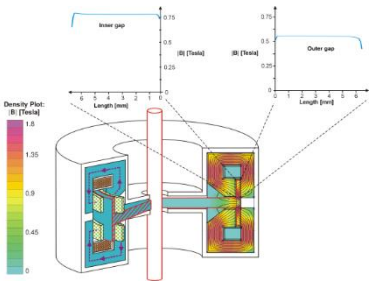

Fig. 10: MR Fluid-based brake

3. Polishing Devices

One of the most unexpected use of MR fluid is its use as a polishing agent. Optical surfaces are polished in a MR finishing slurry which is controlled by programs. Unlike the usual lap polishing, the shape and viscosity of the fluid can be controlled in varying the field. The computer algorithm predicts the final smoothness and form of the work piece.

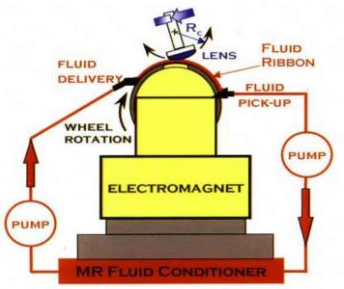

Fig. 11: Polishing Device using MR Fluid

4. MR Fluid as a Robot Blood

The smart fluids are studies on the ISS which may flow in robots as blood. MR fluids are liquids that change viscosity or change shape when are under a magnetic field.

Fig. 12: Artist's Impression of Robot having MR Fluid Blood

C] Proposed Application

MR Fluid as a Gun Recoil Protection

Newton's Third law states that every action has an reaction which is equal in magnitude and opposite in direction. Following this law, the gun produces recoil- which is backward transfer of momentum after firing.
The Recoil force of the gun after firing is very high. When a shotgun barrel or rifle is held against the shoulder, the recoil is directed almost straight back in a way causing the shoulder to absorb majority of that reactive force. The shooter's cheek may also absorb some of the recoil if he is pressing the weapon into the cheek piece firmly. The gun recoils upwards because of bending of the spine and hips but recoil is mainly straight back into the shoulder.

Many times it has adverse effects on the user. The effects include broken bones, tearing of tissue, internal blood leakage, etc. Body takes long time to recover from these injuries depending upon the extent of injury. These injuries are not desirable to soldiers in middle of the battlefield. These injuries can be fatal in rare cases if not attended properly.

Fig. 13: The adverse effects of recoil

Currently, shoulder pads made of thick foam are used, but they provide protection to certain extent and prove no use if used not in a correct way. Also they wear out after used several times. In order to overcome this problem the foam can be replaced by MR fluid.

The Fluid can be used as a Damper to reduce the effect of recoil. Compared to foam pads, these will last longer being much durable. The MR fluid can operate after thousands of cycles of "OFF" and "ON" states of phase changes which proves it is highly efficient. MR fluid has no effect over a large temperature range (-50^0C to 150^0C) hence it can be used in extreme conditions also, while the current foam pads seem to be ineffective in extreme temperatures.

The MR Fluid can be filled in pads instead of foam which can be attached around the shoulders of the person using the rifle as shown in the figure 13. Using the controlled timing algorithms, the MR fluid can be quickly converted to solid by applying external magnetic field as soon as there is a gunshot. This can prevent the user from getting severe injuries due to recoil. The phase change period of the MR fluid is in milliseconds, so it will be very convenient to change the phase of fluid from liquid to damping solid quickly. This will make the user safe from the hazard of gun recoil.

Fig. 13: Representation of using MR Fluid to reduce gun recoil

Conclusions

The MR fluid, whose viscosity is a function of the applied magnetic field will replace the conventional viscosity based mechanisms. It will also improve in cost reduction and functionality of the system. Quick response, non- complex relationship between electrical input and mechanical output, integration and controllability in complex mechanisms are the main features of the MR fluid.MR fluids and MR fluid devices have been advancing greatly in the last few years developing many commercial products. There is a large competition to develop the more friendly fluid in many developed countries.

The proposed application of MR Fluid focuses on the protection of soldiers from the recoil injuries during rifle shooting. The MR fluid can be used as damper to reduce the recoil force from the gun. If followed the suggested procedure, the highly viscous "ON" state fluid can reduce the recoil of the gun which, if not prevented, can lead to serious injuries.

The MR fluid although being very much exciting, its use is limited due to the high cost of the fluid. Metal particles tend to set after long term use, fluid thickens due to prolonged use. The better quality fluid costs too much. Research needs to be done in this area to overcome these problems. The MR fluid if used in day to day life will provide a great solution to many maintenance problems as the fluid is resistant to water and dust contamination, also showing no effect on reduction in performance due to temperature variation in certain limits.

References

M. Kciuk, R. Turczyn,(2006)Properties and Application of Magnetorheological Fluids", *JAMME*, Volume 18, Issue 12, Pg no. 127-130.

Mark R J, Jonathan W B, Carlson J D.(1999) Properties and applications of commercial magnetorheological fluids[R]. *Thomas Lord Research Center Lord Corporation,*

Macosko C W.(1994)Rheology: principles, measurements, and applications[Book]. *New York: VCH Publishers Inc*.

Winslow W M.(1949) Induced vibration of suspensions *Journal of Applied Physics*, (20):1137-1140.

Carlson, J. D., Weiss, K. D.(1994), ―A growing attraction to magnetic fluids, *Machine Design*, Vol. 66, No. 15, p. 61-64,

A.K. ghorbani-Tanha, H. Salahshoor, s. Mohammadzadeh,(2009) "Semi-active vibration control of a washing machine using magneto rheological dampers"*3rd International Conference on Integrity, Reliability and Failure*, Porto/Portugal, 20-24 Paper Ref: S1510_P0339.

M. Kciu, R. Turczyn(2006), Properties and application of magnetorheological fluid, *Journal of Achievements in Materials and Manufacturing Engineering*,18 ,1–2.

V.P. Kolhe(2012), "Advanced Vibration Control Using Magneto rheological Fluid" *International Journal of Innovation in Mechanical and Automobile Engineering*, ISSN: 2249- 2968, ISSUE-II, pp. 115-121.

MUHAMMAD Aslam, YAO Xiong-liang, and DENG Zhong-chao(2006) Review of magnetorheological (MR) fluids and its applications in vibration control *Journal of Marine Science and Application,* Vol.5, No.3, pp. 17-29.

Harshal M. Bajaj, Gagandeep Singh Birdi, Bhushan A. Ugale(2014),application of magneto rheological (mr) fluid damper and its social impact, *International Journal of Mechanical And Production Engineering, ISSN: 2320-2092*, Volume- 2, Issue- 2, Feb.-2014

BogdanSapinski, (2009) "Magnetorheological Dampers in Vibration Control of Mechanical Structures", *Mechanics*, vol.28 No.1.Pg no. 18-25.

Huang, J.Q. Zhang, Y. Yang, Y.Q. Wei, Analysis and design of a cylindrical magneto-rheological fluid brake, J. *Journal of Materials Processing Technology* 129 002) 559– 562

Pinkos, A., Shtarkman(1993), E. and Fitzgerald, T(1993). An actively damped passenger car suspension system with low voltage electro rheological magnetic fluid.*SAE Technical Paper Series* 930268.

Deepak Baranwal, Dr. T.S. Deshmukh(2012), "MR-Fluid Technology and Its Application-Review", *International Journal of Emerging Technology and Advanced Engineering*, Volume 2, Issue 12, December 201

Lord(1998) Rheonetic linear damper [C]. Lord Corporation, [s. l.],.

J. David carlson what makes a good mr fluid?(2001) Presented at the 8th *International Conference on Electrorheological (ER) Fluids and Magneto-rheological (MR) Suspensions*, July 9-13, 2001.

D. Carlson, B. Marjoram, J. Toscano, D. Leroy, K. Burson, K. St Clair, A. Kintz(2008), Magneto-Rheological Technology and Applications,*LORD Corporation*

Kordonsky, W. (1993)Elements and devices based on magnetorheological effect. *J. Intelligent Mater. Systems and Struct.*, ,4(1), 65–69.

S. D. Jacobs et al.(1995), Magnetorheological finishing: A deterministic process for optics manufacturing, in Optical Fabrication and Testing ,Vol. 2576, pp. 372382