Magnetorheological Fluids and Its Applications: Current Scenario and Future Prospects

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MAGNETORHEOLOGICAL FLUIDS AND ITS APPLICATIONS: CURRENT SCENARIO AND FUTURE PROSPECTS

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Abstract: Magnetorheological (MR) fluids are a kind of smart materials whose properties can be controlled by changing an external magnetic field. This peculiar behavior can be used in the developing novel technologies. The MR fluids have proven to be commercially viable and well suited for many applications. The MR fluids offer solutions to many engineering challenges. The success of MR fluid is apparent in many disciplines, ranging from the Automotive, Civil and Biomedical Engineering Community. The application of MR fluid based devices has grown rapidly in Civil Engineering, Safety Engineering, Mechanical Engineering, Transportation, and Life Sciences. Especially devices like MR fluid dampers are widely used in bridge construction, vehicle suspension and cancer detection tools. This paper presents a review on the development of magnetorheological fluids and its applications in future technology.

Keywords: Smart Materials, MR Fluid, MR Fluid Damper.

Introduction: MR fluids were first discovered in the 1940's by John Rabinow at the U.S. National Bureau of standards. The advantage of the MRF over conventional fluid is control of its viscosity upto desired magnitude within fraction of seconds [8]. A magnetorheological fluid is one of the controllable smart fluids. On the application of magnetic field it changes its viscosity till it becomes viscoelastic solid. MR fluid and a magnetic field are essential factors of MR fluid technology for controlling the viscosity property of the fluid.

The word magnetorheological is derived from two words Magneto- which based on the applied magnetic field and Rheology- branch of physics that studies deformation and flow of matter. MR fluids are composed of soft ferromagnetic or paramagnetic iron particles dispersed in a carrier fluid. When iron particles exposes to the external magnetic field, they acquire dipole moment with respect to external field which causes the particles to form linear chain parallel with that field. This effect is called magnetorheological effect. By studying rheological properties and their respective applications various mechanical models can be designed [7].

MR fluids are non-colloidal suspensions of polarizable particles having a size of the order of few microns. Transmission of force through fluid can be controlled with the help of electromagnet which enables us to it in many control based applications.

Micrometer or nanometer scale magnetic particles are suspended randomly within the fluid. On account of application of magnetic field the microparticles align along the line of magnetic flux. Material properties are dependent on the magnetic field applied to the fluid which reaches to a maximum point by increasing magnetic flux density. In the absence of the magnetic field it behaves like Newtonian fluid. Essential MR fluid components are base fluid, metal particles and stabilizing additives. The base fluid is an inert fluid which carries the metal particle suspended in it. It should not vary with temperature. Commonly used base fluids includes hydrocarbon oil, mineral oil, hydroxyl irons particles(DT-50), grade A silicon oil and nanometer-sized spherical silica. Metal particles used are very small of the order 1 micrometer to 7 micrometer.[1]

Additives like stabilizers and surfactants added to MR fluid for controlling its properties. The MR fluid acts reversible as magnetic field removed and the fluid returns to its original condition. MR fluid can bear the applied force because it can readily modify their aggregation states changing from a viscous free-flow fluid to a quasi solid state under the application of strong magnetic field. It's viscosity can be increased by more than two times that of magnitude of applied magnetic field in very short time(milliseconds).

An MR fluid is used in three different modes of operation, these being flow mode, shear mode and squeeze-flow mode. Yield stress of MR fluid is directly proportional to the applied magnetic field as magnetic field increases yield stress increases and vice versa. Usually behaviour of MRF commonly represented by Bingham plastic having relative yield strength with respect to magnetic field.Properties of MR Fluid: A MR fluid are suspensions of mainly micron sized particles avoid gravitational settling and support particles to be in stable conditions.

Table 1. Properties of MR Fluid [5]

PROPERTY	TYPICAL VALUE
Initial viscosity	0.2-0.3[Pa.s](at 25◦C)
Density	3-4 [g / cm^3]
Magnetic field strength	150-250 [Ka/m]
Yield point	50-100 [Kpa]
Reaction Time	Few millisecond
Voltages and current Intensity	2-25V,1-2 A
Stability	Unaffected by most impurities
Work temperature	-50 to 150 [◦C]

The change in properties of the MR FLUID affected by size and size distribution under effect of magnetic field for MR material activation power of 50 W and voltage about 12-24V required.

The rheological properties of MR fluids preferably depends upon size, concentration ,density of particle ,additives, magnetic properties are also useful to determine the character and formation of particle structure within the fluid.

As the particle size increases, stable suspension of the MR fluid becomes difficult therefore particles with smaller size are used commercially e.g. carbonyl ions. Generally ferromagnetic particles as pigment particle used having size 30 nm in diameter.

In most of the engineering applications Bingham plastics is used for describing essential field dependent fluid characteristics. A Bingham plastic is a Non-Newtonian fluid whose yield stress must increase before beginning of flow for this, shear stress is directly proportional to shear strain. The total yield stress is given by,

$$\tau = \tau_0(H) + \eta\dot{\gamma}$$

Where,
τ_0= Yield stress caused by applied magnetic field [pa]
H = magnetic field strength[A/m]
$\dot{\gamma}$ = shear rate [/s]
η = plastic viscosity [pa .s]

Magnetorheological material are advantageous over electrorheological in some typical application. MR fluids more useful as they change their rheological properties large as ER fluids not so yield stress increases strongly. MR fluids can be used in dirty or humid atmosphere since they are less sensitive to moisture and contaminants. Power and voltage required as compare to ER fluid are less for MR fluid. MR fluid does not affected by surface chemistry of surfactant used.

Off-State Viscosity: The field independent viscosity is a important off-state property of MR fluid which affects velocity dependent force or torque of a given device when magnetic field is not applied. This viscosity also has importance in temperature dependence force or torque.
There are two factors which influences on the MR fluid viscosity.
1. the intrinsic viscosity of the carrier fluid
2. the particle volume fraction.

MR fluid viscosity is directly proportional to the particle volume fraction. MR fluid viscosity ranges from 50 to 200mPas at room temperature.[10]

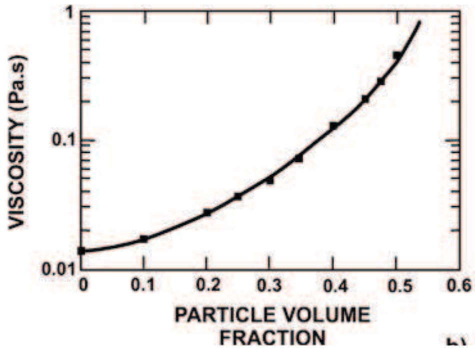

Figure 1: Viscosity Versus Particle Volume Fraction [10]

Yield Stress: Relative to applied magnetic field, maximum yield stress is a considerable property of MR fluid as it has effect on maximum output force or torque of given device.

Yield stress also depend on the material of the particles. Yield stress is directly proportional to saturation magnetization of the particles. Second important factor influencing maximum yield strength is volume fraction of the inserted particles and researchers have concluded that maximum yield strength varies non-linearly with growing particle volume fraction. Compare to yield stress, off-state viscosity increases two times with particle volume fraction. Another way to increase maximum yield stress by increasing the particle size distribution inside the MR fluid. In this technique viscosity can be reduced while maintaining the same particle volume fraction. A small increase in the proportion of small particles leads to substantial increase in yield stress.

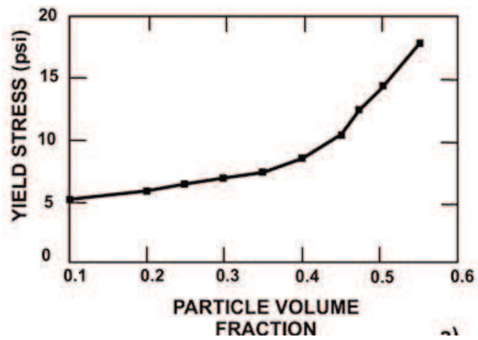

Figure 2. Maximum Yield Stress Versus Particle Volume Fraction [10]

B-H Relationship: In case of MR fluid, B-H curve is non-linear for the fluid provided by LORD but linear for ISC fluid. Very little or less hysteresis losses are observed in MR fluid BH curve this is only due to the effect of magnetically soft properties of the iron used for the particles as well as the mobility of these particles. A graph of the induction field (B) versus magnetic field (H) for the MR-fluids is shown below

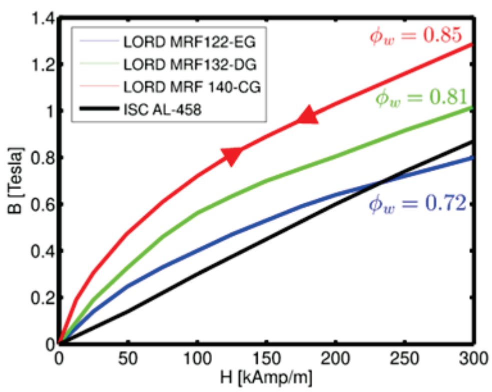

Figure 3. B-H Characteristic, For Various Fluid Formulations (ϕ_ω is The Particle Weight Fraction)[10]

Durability and In-Use-Thickening: First durability tests were carried on MR-fluid devices at the end of the 1990s. It is found that when MR fluid subjected to high stress and high shear rate over a long time it gets thicken. This process is called In-Use-Thickening(IUT). MR fluid changes its viscosity from low state to thick paste which makes it to be unstable in applications. IUT take place due to the breaking of iron particles into small pieces(for example carbonyl iron particles). It can be overcome by using particles exhibiting a higher hardness or using of anti-wear and anti-friction additives.

Applications: Due to rheological properties of the MR fluid, it is used in the applications where smooth suspension is required. By controlling the magnetic field the rheological properties can be changed. According to which fluid used in conventional application can be easily replaced by the magnetorheological fluid . There are following application as discussed below,

Mechanical Engineering:

Magnetorheological Dampers:

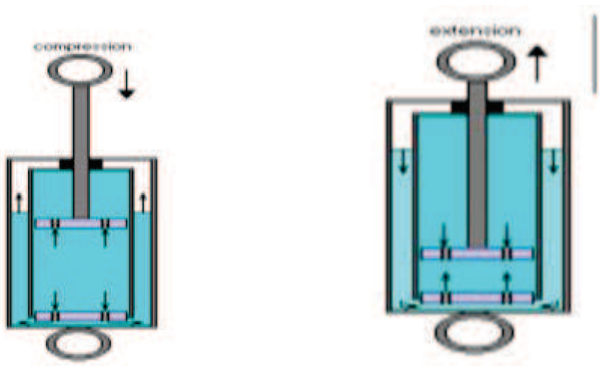

Figure 4: Conventional Damper [1]

In conventional dampers ,two cylinders are used when piston moves down fluid flow from inner to outer cylinder. Air and fluid present in the second cylinder. Air acts as compressing media and shows damping effect.

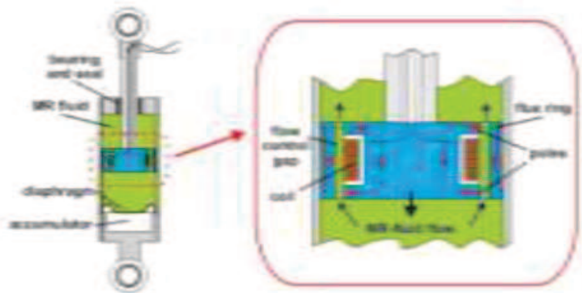

Figure 5: MRF Damper [1]

In MR dampers chambers are present. In contract to conventional dampers piston ,MR damper piston do not have fluid flow flowing through orifice from one chamber to another. During suspension coil get energized , current through which produces magnetic field. Due to magnetic effect, fluid in orifice behaves as semi-solid damper start to behave as shock absorbing system. [1]

MRF Braking System: Below figure shows the MRF braking system. In consist solenoid coil. A two cylinders i.e. inner and outer. Outer is stationery and inner is rotating cylinder space between them filled with MR fluid when solenoid coil energises , magnetic field generators and fluid behaves as semi-solid .It after resistive torque to the rotating cylinder within milliseconds. Torque can be controlled by variation of magnetic field.[6]

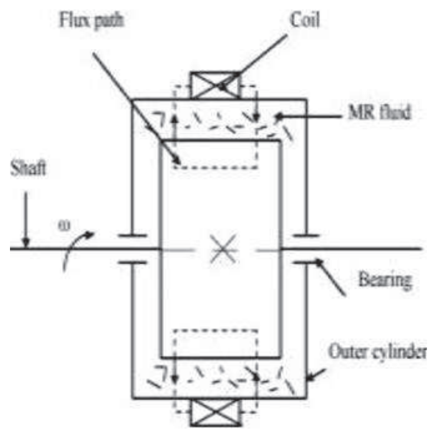

Figure 6: MRF Brake [1]

Advantages over conventional braking system:
1. Less requirement of power
2. Simple in construction
3. No hydraulic medium
4. Fast response
5. Easy control
6. No friction

Pneumatic Actuator Motion Control System: This system include pneumatic actuator controllable MR fluid resistance devices ,sensors and controllers. Pneumatic cylinder and linear resistance devices are placed parallel. The function of linear resistance device controlled by means of mid stroke positioning, velocity control and end- stop snubbing. Similarly, motion and velocity of pneumatic rotary actuator controlled by rotary resistance device based on MR fluid. Lord corp has manufactured commercial motion control system. [7]

Hydraulic Valves: MR fluid can be used in the hydraulic system as a working fluid for operating actuator by the control of MR valve(convertor). In this system MR valve is same as throttle valve with exception of moving parts. The valve consists a magnetic core with induction coil winding and a hydraulic channel. When fluid starts flowing through a valve magnetic field applied which increases it's viscosity. This change in the viscosity causes slowing or stopping of fluid flow by increasing pressure at the inlet. In contrast to conventional hydraulic valve MR valves are less expensive and don't wear out easily. At the first MR hydraulic system was proposed by Kordonsky et al as shown in following figure. When current flows through diagonally located MR valves(1,4 or 2,3), leads to decrease pressure in cylinder chambers and appropriate movement of piston.

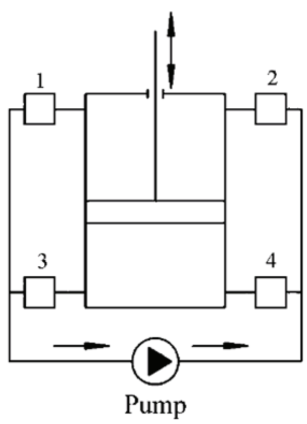

Figure 7: MR Hydraulic System[4]

Civil Engineering: ***Control of Seismic Vibrations in Structure:*** Large sized dampers are used in civil engineering application for the design, maximum damping force of 2,00,000 N (20 ton) were chosen, as shown in below fig.

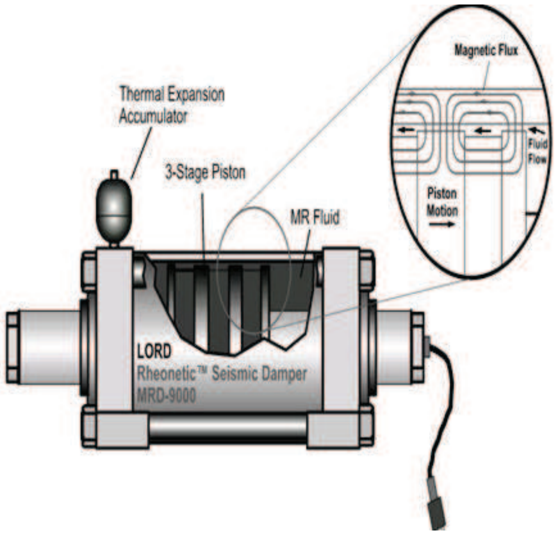

Figure 8: Schematic of MR Fluid Seismic Damper[2]

Outer cylindrical housing in seismic damper is part of magnetic circuit. The fluid orifice is the annular space between outside diameter of piston and inside of damper. As piston more the fluid flows through entire annular region. The inside diameter of piston is 20.3cm and stroke of ± 8 cm . piston supported by shafts on both sides. Electromagnetic coil is wound around the piston. The damper is of 1 cm long, 250 Kg mass approximately contains 5 litre of fluid. Fluid is energized by magnetic field.

Seismic dampers have more life span compared to vehicular seat dampers for many years. However seismic event it not occurred it should be able to function with same efficiency fluid should not be settle or separate for long period. One of fluid used in seismic damper is MRX-140ND.[2]

Industrial Shock Absorber With Magnetorheological Fluid: During the stopping process, in order to control the breaking force we prefer MR fluid in the industrial shock absorber as shown in figure 5. The absorber is based on double rod hydraulic cylinder in which chambers are connected by MR valve. MR fluid moves from one chamber to another when piston get pressed. Space between outside diameter of coil and inside diameter of valve is considered as fluid orifice.

Systematically installed shock absorber should safely dissipate energy by breaking forces and reduce loads and noises . Due to suddenly increase in mass on the piston rods, breaking forces rapidly increases as the rods are stable. The breaking forces decreases gradually. In case of passive shock absorber(curves 1, 2, 3), if the kinetic energy of the moving mass is high it suddenly stopped by hard impact and is bounces over absorber rod on the other hand if kinetic energy of moving mass is less , it stopped before reaching at the bottom. When MR fluid used in the absorber the forces can be maintained accordingly till the mass comes at the end(curve4). The required breaking forces can be established by electronic controller which element kinetic energy. As we can guess that the best stopping process can be obtained by the shock absorber with magnetorheological fluid.

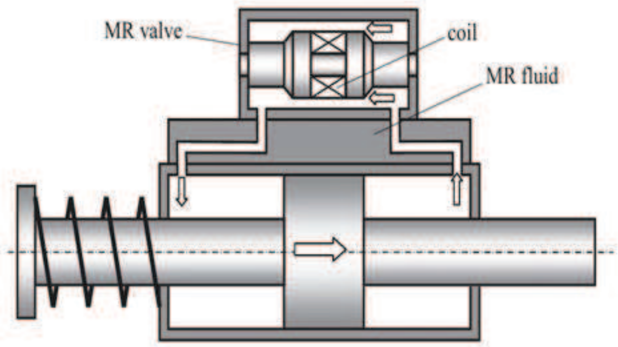

Figure 9. Design of MR Shock Absorber[9]

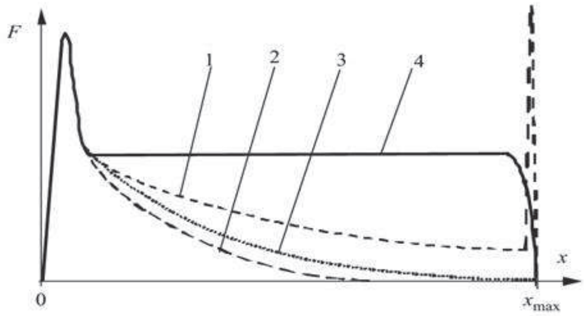

Figure 10: Different Braking Characteristics (Numbers Explained In The Text)[9]

Conclusion: Magnetorheological fluid has wide application in engineering and technology in upcoming years. This is very useful where smooth suspension. control and variation in the viscosity required. As the mechanical output is proportional to applied magnetic field by electric means , so it is found to be simple and efficient. Application based on MR fluid requires less maintenance and can be used for longer life span.

MR fluid is economically not fit for low cost application as its cost is high. It required to be replaced after prolonged used. As it become thick and its weight is high as it carries metal particles. It can be effectively used in military and defence, aerospace, human prosthesis, optics and automotive.

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