Synthesis and Characterization of Mr Fluid for Damper in Vehicle Suspension System

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ABSTRACT

During the last 30 years, significant amount of research has been conducted on Magnetorheological fluid (MR fluid) and it's applications. MR Fluid is a smart fluid which when subjected to a magnetic field changes its viscosity and undergoes a change from liquid state to semisolid state. MR Fluid is basically a suspension of magnetic particles (Iron, Cobalt) in carrier fluids (silicone oil, vegetable oil, distilled water etc.) with certain additives (AP3 grease, Aerosil, Arabic gum). The properties which govern the selection of MR Fluid include viscosity, sedimentation ratio, yield strength etc. Out of these properties, sedimentation ratio is an important property which indicates the homogeneity and settling time of MR Fluid. MR Fluid has wide range of applications in various fields such as automotive, optics, aerospace, human prosthesis etc. MR damper is a semi-active control device that uses MR fluid to produce controllable dampers. This study focuses on the calculation of sedimentation ratio of different MR fluids using different carrier fluids and nanoparticles or micro particles or mixture of both. This work was further extended to design and testing of MR damper for vehicle suspension system. Customized piston was designed and manufactured with internal pressure control method and used in conventional damper. Performance evaluation was carried out on dynamic test rig and results were obtained.

Keywords:Magnetorheological Fluid,carrier fluid,additives, sedimentation ratio, Magnetorheological damper.

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1. INTRODUCTION

MR fluids are magnetic analogues to electro-rheological (ER) fluids and typically consist of micro-sized or nano-sized, magnetically polarizable particles dispersed in a carrier medium such as mineral or silicon oil.[1] Rheological fluids are non-Newtonian fluids which do not satisfy the Newton's law of fluid friction in which the coefficient of kinetic viscosity, η, is variable. [2] Ferromagnetic particles when randomly dispersed in oil or water, form a colloidal mixture in which some surfactants are added to avoid the settling of the suspended particles. The resulting mixture is like greasy heavy mud as the density of MR fluids is more than thrice the density of water. [3] The dispersed particles in carrier fluid form chains which are parallel in orientation to magnetic field when the magnetic field is applied. This results in an increase in shear stress which is perpendicular to the direction of applied magnetic field. [4]

The credit to the discovery of MR fluids goes to Jacob Rabinow in 1949.The MR fluids have wide range of viscosity values and their operational parameters remain unaffected by temperature. [5] However some properties like dynamic yield stress and viscosity of MR fluid were found to be decreased by 10% and 95% respectively when temperature was changed in the range 400 to 1500 C. [6] For an MR fluid the yield stress can be increased or decreased with the strength of magnetic field as shown below:

$$\tau = \tau_{y\,(H)} + \gamma\mu_p$$

Where, τ_y (H) is the yield stress due to the applied magnetic field H, μ_P is the constant plastic viscosity and γ is the shear-strain rate. [7] The properties like shear stress of an MR fluid depend on magnetic field as well as volume fraction and the size of particles. The volume fraction of iron particles should be in between 20% to 40% of carrier fluid to create complete chaining mechanism of MR fluids. [8].

The tendency of magnetic particles to aggregate and settle down is the frequent and inevitable problem. It influences properties of MR fluid by disturbing its homogeneity. It is because magnetic particles are denser than liquid carrier and settle under gravity to form a hard cake, which makes the impossible to disperse again. This gives rise to incomplete chain formation and restricts the response of MR fluids to magnetic field. This can cause the device containing MR fluid to fail in an extreme situation. As a result, it becomes important to calculate the sedimentation ratio (R). It is defined as a ratio of length of clear part to the sum of length of clear and turbid part.

$$R = \left(\frac{x}{x+y}\right) * 100$$

Where, R (%) is sedimentation ratio, 'x' is the length of clear part and 'y' is the length of turbid part. [5]

MR damper is basically a piston cylinder arrangement for absorbing vibrations by dissipating energy. MR fluid works in shear mode in which one plate is moving relative to the other. [9] When the piston reciprocates inside the cylinder, the MR fluid passes through the clearance, the kinetic energy of piston is converted into heat energy due to the viscosity of fluid. The damping rate can be controlled by controlling the viscosity which in turn is controlled by changing the magnetic field by changing the current.

There are mainly three types of MR damper namely single tube, double tube and through rod. The damper used in this study was single tube damper in which clearance was provided between piston and cylinder through which the MR fluid travels from piston side to rod end side and vice versa.

To change the rheology of the fluid, copper winding was provided on the piston with adequate number of turns. The parameters such as voltage, current were varied using electronic control system. Control systems can be classified into three types i.e. active control, semi active control and passive control.[9] MR damper under study uses semi active control system. It is also known as fail-safe system because if the controller fails, semi active system behaves as passive system. The advantages of semi active system over active system are lower implementation cost, lower power consumption, easy to control and install, simple in design.

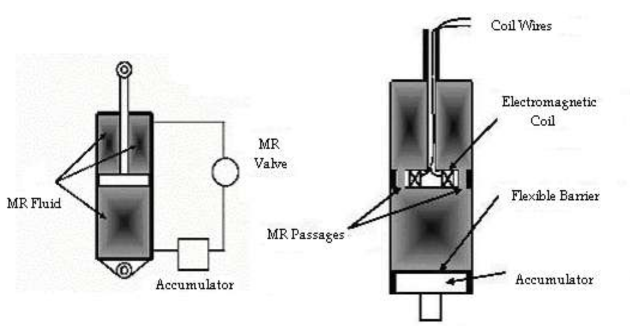


Fig.1. Semi active controlled MR damper

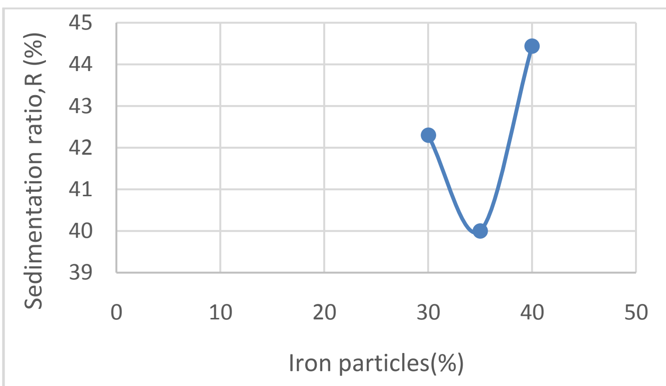
2. Experimentation

Six MR fluid samples have been synthesized using different carrier fluids such as silicone oil, soyabean oil and magnetic particles used were Fe_2O_3 nanoparticles and micro particles. From economical point of view, in-house synthesis of nanoparticles was carried out using 'Sodium Borohydride Reduction' method. The size of nanoparticles was found to be 19 nm. The combination of nano and micron sized particles was used in low cost and easily available carrier fluids in different proportions of weight percentage along with different additives for stabilization of the fluid to obtain an optimum fluid which has the minimum sedimentation ratio. Each sample was observed for 50 hours and sedimentation ratio of different fluid samples was calculated using the formula stated above. The details of the samples are given below:

Table 1. Composition of different MR fluid samples

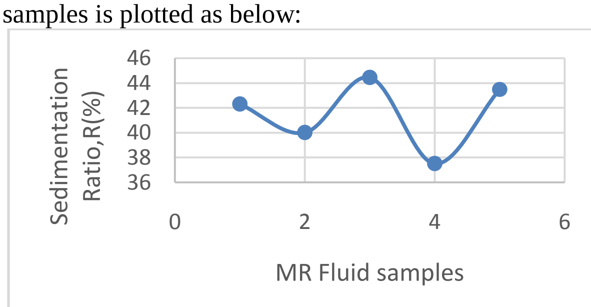
Sample	**Carrier Fluid**	**Additive**	**Additive % of carrier fluid**	**% of Iron Particles of carrier fluid**	**Sedimentation Ratio (%)**
MRF 1	Silicone Oil	AP3 Grease	8	30	42.30
MRF2	Silicone Oil	AP3 Grease	8	35	40
MRF3	Silicone Oil	AP3 Grease	8	40	44.44
MRF4	Silicone Oil	Aerosil	2	35	37.5
MRF5	Silicone Oil	Arabic Gum	6	35	43.47
MRF6	Soyabean Oil	Arabic Gum	6	35	-

As Arabic Gum was only partially miscible with Soyabean Oil, sedimentation ratio for *MRF6* could not be calculated.



Graph 1. Sedimentation Ratio vs. % of Iron Particles

It is observed that for 35% of iron particles, the sedimentation ratio was minimum and within acceptable range. So the samples *MRF4*, *MRF5* and *MRF6* were synthesized using composition of iron particles as 35%. The graph of sedimentation ratio for all the samples is plotted as below:



Graph 2. Sedimentation Ratio of Different MR Fluid Samples

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Amongst all the samples, Aerosil and Silicone oil yielded the minimum value of sedimentation ratio. Furthermore, all the samples were tested for viscosity and yield strength and their values were found to be comparable with the standard values.

3. Design of Damper:

The following standard dimensions are selected while designing the coil of MR damper:
Cylinder inner diameter (D_c) = 41 mm
Piston inner diameter (D_p) = 39 mm
Piston rod diameter (D_r) = 18 mm
Cylinder length (L_c) = 310 mm
Stroke (S) = 50 mm
Damping force (F) = 2000 N (Maximum)
Velocity (V) = 100 mm/s (Velocity was chosen such that it is split between low & high velocity)
Depth of groove (h) = 4.2 mm
Clearance (g) = 2 mm
Pole width (w) = 39 mm
Volume fraction (Ø) = 0.35
Permeability of free space (μ_0) = $4\pi*10^{-7}$
Magnetic field intensity (H_{steel}) = 200 A/m
Fluid viscosity(η) = 0.3 Pa.s
Constant (C) = depend upon the carrier fluid used for preparation of MR fluid (for hydrocarbons C=1).
Flow rate (Q) = $1.2566*10^{-5}$ m^3/s
Yield strength (τ_y) = 20 kPa
Variable for $\frac{\Delta P_\tau}{\Delta P_\eta}<1$ (c) = 2
Current (I) = 2 A

The force generated in the device, F, is the pressure drop times the piston cross section area and can be expressed as[10]

$$F = \Delta P * \pi * \left[\frac{\left(D_p + g\right)^2 - D_r^2}{4}\right]$$

For force $\mathbf{F = 2000N}$, Pressure drop accounted is **ΔP = 18.766*10^5 Pa**

The length of piston (L) was calculated using the formula [9]

$$\Delta P = \frac{12\eta Q L}{g^3 w} + \frac{c\tau_y L}{g}$$

L = 93.5 mm, **L = 95 mm (approx.)**

Using the following relation, the magnetic field strength of MR fluid (H_{mrf}) was calculated [11],[12]

$$\tau_y(H_{mrf}) = 271700C\phi^{1.5239}\tanh(6.33\times10^{-6}H_{mrf})$$

H_{mrf}= 60.358 kA/m

The magnetic flux (B) is given by, [13]

$$B = 1.91\phi^{1.133}\left[1-(\mu_0 e^{-10.97\mu_0 H_{mrf}})\right] + \mu_0 H_{mrf}$$
$$= 0.657\ \text{T}$$

The relative permeability (μ_r) is calculated by,

$$\mu_r = \frac{dB}{dH} = 20.95\phi^{1.133}\left[\mu_0 e^{-10.97\mu_0 H_{mrf}}\right] + \mu_0$$

$\mu_r = 4.74*10^{-6}$

ISSN: 2321-8169
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Finally, the number of turns (N) is calculated by using Kirchhoff's Law of magnetic circuits, [10]

$N*I = H_{mrf}*g + H_{steel}*L$

N = 164 turns

Fig.2. Creo model of piston

Fig.3. Actual piston with winding

4. TESTING OF DAMPER

The current for the MR damper coil is given by electrical circuit. The main use of electrical circuit is to vary current of electromagnet. The electrical circuit consists of step down transformer, rheostat, bridge rectifier and capacitor. The arrangement is as shown in figure. A DC variable speed motor is mounted on a rigid rectangular plate that is hinged along one side and is suspended by spring on opposite side. The motor is coupled to an exciter unit consisting of 2 discs and eccentrically mounted rollers. Speed of motor can be varied with the help of dimmers stat provided on control panel while speed of rotation is indicated with the help of optical sensor. The damper unit is to be connected to the rectangular plate. An arrangement is provided to vary the damping. A record of amplitude can be obtained with the help of paper feed arrangement. A DC supply of (0-3A, 12V) is given with the help of arrangement as shown in figure 4. This arrangement consists of Transformer, Bridge Rectifier, Indicating lamp and Rheostat.

Fig.4. Test setup for MR Damper

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OBSERVATIONS FOR MR DAMPER

Table 2: Displacement of damper for 250rpm motor speed

Current (Amp)	**Displacement (mm)**
0	46
0.050	25
0.100	12
0.150	8
0.200	7
0.250	5
0.300	3.5
0.350	3
0.400	2.5
0.450	1.7

Table 3: Displacement of damper for 270rpm motor speed

Current (Amp)	**Displacement (mm)**
0	49
0.050	34
0.100	17
0.150	15
0.200	9
0.250	8
0.300	5
0.350	3.5
0.400	3
0.450	2.5

Table 4: Displacement of damper for 300rpm motor speed

Current (Amp)	**Displacement (mm)**
0	47
0.050	27
0.100	13
0.150	11
0.200	9
0.250	7
0.300	6
0.350	5
0.400	3.5

CONCLUSION

Different types of MR fluid samples were synthesized using combination of nano and micron sized iron particles. The sedimentation ratio of each of the samples was calculated. The fluid yields the best result when 35% iron particles were used. The best combination amongst these samples was Silicone Oil and Aerosil.

MR damper was designed based on internal pressure control method and the required dimensions were calculated. MR damper was further tested by varying the motor speed. It was observed that as the current is increased the displacement of the piston goes on decreasing thereby increasing the damping effect.

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