Design, Development, Performance and Testing of Magnetorheological Fluid Damper

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Abstract— Magnetorheological fluid is type of smart fluid in a carrier fluid, usually a type of oil containing magnetic particles. When subjected to magnetic field then the magnetic particles behave like dipoles and aligning along the flux thus fluid greatly increase its apparent viscosity. Objective of work is to design, develop Magnetorheological damper and evaluate performance and testing, also prepare blends of fluid based on the weight fraction of oil to iron particle. Damper and fluid tested on vibration test rig set up and evaluate various performance curves. Damping resistance increases with current. Magnetorheological damper is more efficient for blend sample having 35% iron particles.

Keywords: Magnetorheological fluid, Magnetic field, Damper, Blends of fluid, Testing on test rig setup

I. Introduction

A. Magnetorheological fluid:

A magnetorheological fluid contains mineral or silicone oil that carries magnetic particles. These magnetic particles may be iron particles that can measure 2-20 microns in diameter. When magnetorheological fluid is subject to a magnetic field the iron particles behave like dipoles and start aligning along the constant flux, shown in Fig.1. When the fluid is contained between the dipoles, its movement is restricted by the chain of the particles thus increasing its viscosity. Thus it changes its state from liquid to a viscoelastic solid. Controllable fluids exhibit a change in their rheological behaviour (mainly their apparent viscosity) which depends upon the application of an external magnetic or electric field. Such fluids are respectively called magnetorheological (MR) fluid. The particle chains are parallel to the field direction and restrict the fluid flow. 1,2Mechanical Engineering, Flora Institute of Technology, Pune, India,

B. Paper Objective:

To design suspension system which has maximum force range for current up to 2A (used to control damping force) and working temperature range 0-750c. Tests were performed on shock absorbing test rig for various blends of MR fluid.

C. Paper scope:

Develop electronic feedback system to control the system vibration so that the system will automatically adjust the coil current. Also provide air, water or nitrogen cooling system to avoid heating of damper and get better result.

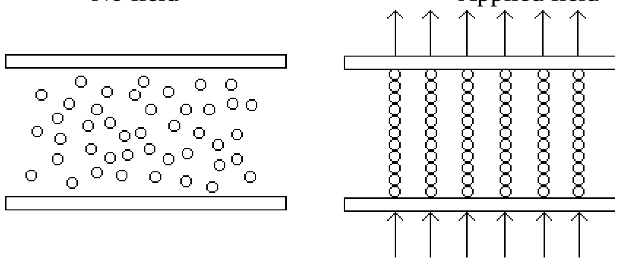

Fig. 1: Chain like structure formation in controllable fluid

II. Literature Survey

Fundamentals of Vehicle Dynamics, Thomas D. Gillespie.[1] From this book studied various excitation source, basic mechanics of vehicle vibration response. MR-fluid brake design and its application to a portable muscular rehabilitation device, More Thomas Avraam.[2] From this paper studied the various MR-fluids composition, preparation method of MR fluid and properties of MR fluid. Compositions are Magnetisable particles, Carrier fluid, Additives, Properties of MR-fluids are Off-state viscosity, Yield stress, B-H relationship. Design, modeling and control of magnetorheological fluid-based force feedback dampers for telerobotic systems. Farzad Ahmadkhanlou, The Ohio state University 2008.[3] From this paper studied Fluids, piston-cylinder arrangement and testing of MR fluid, also various calculations for magnetic circuit design. Characteristics of ferro fluid. Satish B. Purohit, S. R. Lapalikar, Sachin Pare and Vikas Jain, Mechanical Engineering Department, SGS Institute of Technology and Science, Indore-452002, India [5] From this paper studied preparation of MR Fluids, focuses on the synthesis and characterization of ferromagnetic fluid.

III. Design of MR Fluid Damper

Following parts of MR fluid damper are designed
1) Cylinder
2) Piston with coil
3) Piston ring
4) Connecting rod

At the time of designing considered some assumptions such as factor of safety.

A. Design of Cylinder[4]:

According to space requirement
l/D = 1.5
L = 102 mm
102/D = 1.5
D = 68 mm
Maximum speed of rotating motor: Nmax = 1500 rpm
Eccentric weight = 200 gm
Total eccentric weight = 2 × 0.2 kg = 0.4 kg

Exciting force due to rotating eccentric mass = mrw2 sin ɵ
= 0.4 x0.052 (2π x 1500/60)2 sin (90)
= 513.27 N
Weight of motor with plate = 24.88 x 9.81
= 244.07 N
Total force acting (Fmax) = 513.27 + 244.07
= 757.29 N
Pressure = Fmax /Area
= 575.29 / [(π/4)682]
= 0.2085 MPa

Considering multiplying factor of safety is 1.5 (with gap is blocked) to calculate maximum pressure:

Pmax = 1.5 x 0.2085
= 0.31275 MPa

Selecting material gray cast iron (brittle material as cylinder material FG200)

Sut = 200 MPa
Assume Factor of Safety (FOS) = 4
σall = Sut / FOS
= 200/4
= 50 MPa
Cylinder wall thickness
t = (Pmax.D / 2σall) + 1.5
= (0.31275×68 / 2×50) + 1.5
= 1.71 mm
By empirical relation
t = 0.045D + 1.6
= 4.66 mm
Take t = 4.66 mm
Thickness of cylinder head
th = D √kPmax/√σall
= 68 √(0.162×0.31275/50)
= 2.1646 mm
Stress calculations:
σc = Pmax. D/2t
= 0.31275×68/2×4.66
= 2.282 MPa
σl = Pmax.D2 / (Do2 - D2)
= 0.31275 x 682 / (71.322 -682)
= 1.0678 MPa
Net stress (σc)net = σc - μσl
= 2.282 – 0.25(1.0678)
= 2.01505MPa
(σl)net = σl – μσc
= 1.0678 – 0.25(2.282)
= 0.4973 MPa

B. *Piston Design[4]:*

Thickness of piston head th

$$t_h = D\sqrt{3P_{max}/16\sigma_{all}}$$

Selecting cast iron as piston material
σall = Sut / 4
= 40 MPa
th = 68√(3(0.31275)/16(40))
= 2.604 mm OR
By empirical relation
th = 0.032D + 1.5
= 3.676 mm
Take th = 3.676 mm

C. *Piston Ring[4]:*

Selecting material gray cast iron
Radial pressure = 0.0252 to 0.042 MPa
Tensile strength of CI is 85 MPa
Limit of maximum axial thickness
hmin = D/10z
z is no. of rings
= 1.1333 mm

$$b = D\sqrt{3Pw/\sigma t}$$

= 2.618 mm
h = 0.7b
= 1.8326 mm
Gap between free ends
G = 3.5b to 4b .... Before assembly
= 0.002D to 0.004D ... After assembly in cylinder
Before assembly:
G = 3.5b
= 3.5 (2.168)
= 9.163 mm
After assembly:
G = 0.002D
= 0.002(68)
= 0.136 mm
Width of Top Land and Ring Land
Distance from the top of piston to the first ring grove h1
h1 = th to 1.2 th
= 3.676 mm
Distance between two consecutive ring grooves
h2 = 0.75h
= 1.3745 mm

D. *Connecting Rod:*

Cross section area = π/4d2
Material used for connecting rod is cast iron
σall = 35 MPa
Stress induced in rod = F/A
d=12 mm, thus A = $\frac{\pi}{4}(12)^2$
= 761.61/A
= 6.734 MPa
Stress induced < allowable stress so design is safe

E. *Fork oil specification [6]:*

Castrol fork oil	Kinematic viscosity	Viscosity index	Pour point	ISO viscosity ratio
5	3.74	150	-34	15
10	6.4	150	-34	32
15	8.2	150	-34	46
20	11.1	150	-34	68

Table 1: Specification of Fork Oil

Grade 5: Castrol fork oil 5 is used in MR damper as basic oil with following properties:
Kinematic viscosity (1000c) = 3.74 cP
Kinematic viscosity (150c) = 15 cP
Viscosity index (min) = 150
Pore point (0c) = -34
Iso viscosity index = 15

F. *Blending of MR Fluid:*

Sample 1. It contains 30% iron magnetic particles (20 μm) and 70% fork oil.

Sample 2. It contains 35% iron magnetic particles (20 µm) and 65% fork oil.

Sample 3. It contains 40% iron magnetic particles (20 µm) and 60% fork oil.

Sample 4. It contains 45% iron magnetic particles (20 µm) and 55% fork oil.

Fig. 2: Experimental set up

IV. RESULT

With the help of test rig following values gated.

Current (A)	Sample 1	Sample 2	Sample 3	Sample 4
0	2.03	2.03	2.03	2.03
0.1	1.11	1.22	1.62	1.62
0.2	1.11	0.813	1.22	1.62
0.3	1.11	0.813	1.22	1.62
0.4	0.813	0.813	0.813	1.22
0.5	0.813	0.813	0.813	1.22
0.6	0.813	0.813	0.813	1.22
0.7	0.813	0.813	0.813	1.22
0.8	0.813	0.813	0.813	1.22

Table 2: transmissibility for all samples

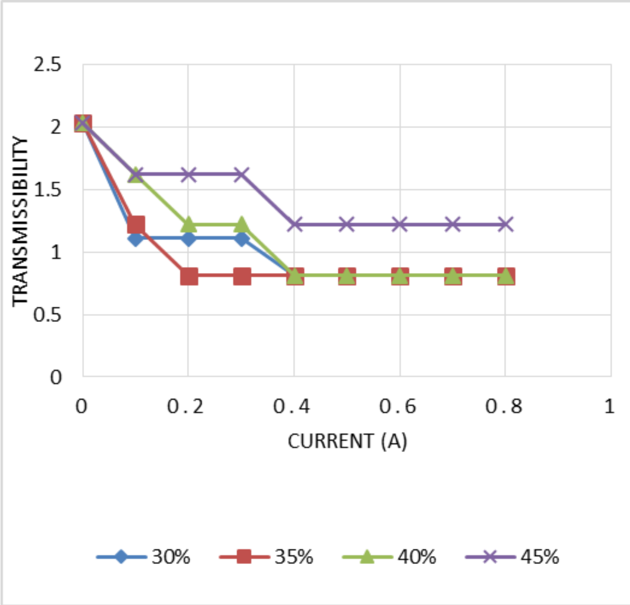

Fig. 3: Transmissibility v/s current

From above graph sample 2 (35% iron particles by weight) is most efficient for MR fluid damper.

Transmissibility of damper for sample 2

Speed(rpm)	Current(A)								
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
325	2.03	1.22	0.813	0.813	0.806	0.806	0.806	0.806	0.806
345	2.3	1.91	0.76	0.76	0.75	0.75	0.75	0.75	0.75
365	2.173	1.81	0.72	0.72	0.71	0.71	0.71	0.53	0

Table 3: Transmissibility of damper for sample2

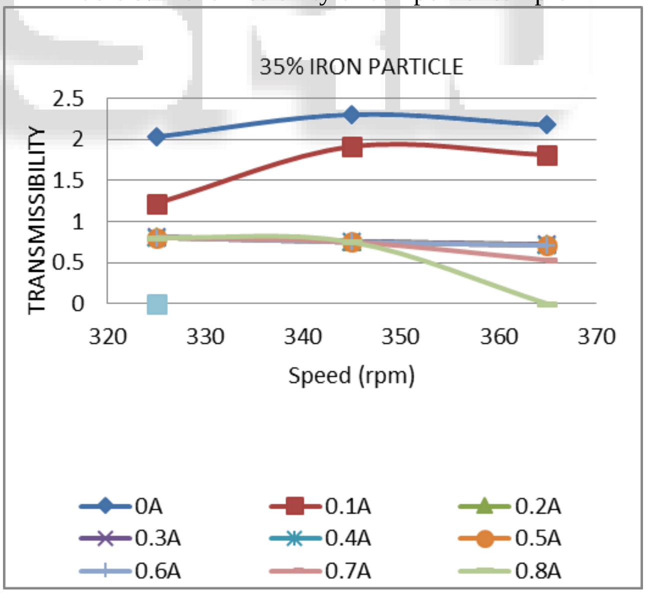

Fig. 4: Transmissibility v/s speed for sample 2

V. OBSERVATION

1) When current not supplied to coil then the transmissibility of damper is high. At resonance it is 2.30.
2) Current increases then the amount of damping provided by the MR damper goes on increases up to certain value. Thus transmissibility decreases from 2 to 1.2.
3) Because of sluggish response of a load cell some transmissibility curves overlap to each other i.e. curve for (0.2A and 0.3A), (0.4A, 0.5A and 0.6A).

4) There is no such effect when we increase current gradually , but significant effect on damping can be seen after sufficient increase in current (i.e. 0.3A step)

VI. Conclusion

The MR fluid damper is designed, manufacture and tested on shock absorber test rig. Performance of damper is observed for various blends of MR fluid.

1) When current not supplied to the coil then the transmissibility of damper is high. Transmissibility goes on deceasing as increasing current supplied to coil of damper up to damper magnetic saturation limit.
2) The transmissibility of damper at resonance for blend sample 2 (35% iron particle by weight) is very low which is 0.75 at 0.8 amp. Thus MR fluid with 35% of iron particles (20 µm size) is suggested for above configuration.
3) When current is supplied to the damper for long time (Approximately 30 min.) then the damper is heated considerably viscosity of base oil decreases which affects on damping capacity of damper.

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Nomenclature

D = Cylinder diameter (mm)
L = Stroke length (mm)
t = Cylinder wall thickness (mm)
Th = Thickness of cylinder head (mm)
th = Thickness of piston head (mm)
h = Height of piston ring (mm)
b = Width of piston ring (mm)
z = Number of piston ring
G = Gap between free ends of piston ring (mm)
h1 = Distance from top of piston to first groove (mm)
h2 = Distance between two conjugative ring groove (mm)
Nmax = Maximum speed of motor (rpm)
m = Eccentric mass (kg)
M = Total mass of motor assembly above damper (kg)
F0 = Exciting force due to rotating eccentric mass (N)
Fmax = Maximum force on damper (N)
Pmax = Maximum pressure in the damper (MPa)
σc = Circumferential stress (MPa)
σl = Longitudinal stress (MPa)
D = Diameter of piston (mm)
L = Length of piston (mm)
C = Clearance (mm)
t = Thickness of cylinder (mm)
d = Hole diameter of piston rod (mm)
g = Width of MR fluid working gap (mm)

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