Design, Development and Performance Evaluation of Semiactive Control Device: Magnetorheological Damper

Nitin. P. Sherje, S. V. Deshmukh

Abstract*—Vibration mitigation with semi-active control device has recently received considerable attention, because of its strong potential to control devices without imposing heavy power demands. This paper presents a design and development of Magnetorheological damper for commercial vehicles and performance evaluation experimentally. Semi-active control devices includes: Magnetorheological (MR) fluid dampers, semi-active stiffness dampers, semi-active tuned liquid column dampers, and piezoelectric dampers. In the last few years, a number of MR fluid-based devices have been researched all over the world. It has become popular in various applications like civil, automobile, biomedical, space shuttle etc. because of its advantages, high strength, Good controllability, wide dynamic range, fast response rate, low energy consumption and simple structure. Hence the work is focused on design and development of Magnetorheological damper considering the commercial vehicle and testing the performance experimentally. It has been observed that the designed damper had wide dynamic range and response. The performance of damper is tested using three different fluids MR1, MR2 and MR3. These fluids are composed by using different carrier fluids, carbonyl iron powder (5 µm) size and additives. The carrier fluids used are low viscosity paraffin oil, silicon oil, synthetic oil and additives used are AP3 Greece and Arosil.

Keywords: MR damper, magnetic potential, magnetic coil.

I. INTRODUCTION

The applications like machines, civil structures and vehicle undergo multiple sources of vibrations. The control of these vibrations is still to be a flourishing field for researchers as it may hamper the integrity of structure, lead to misalignment and noise in case of machines and loses comfort in case of vehicles.

Generally three types of controls are used for an automobile suspension system, passive, active and semi-active. Passive is one which provides the constant damping, in active control a force actuator is used which requires a high external power and provides a variable damping and semi-active requires a very power as compared to active but provides the same effect. Hence, the semi-active control has received a significant attention of the researchers. Different types of semi-active control devices are MR damper, ER damper, piezoelectric damper etc. Both MR and ER damper contain fluids whose properties are changes in presence of magnetic and electric field respectively. MR and ER fluids were initially developed independently in the 1940s [5] [6].

Initially the ER fluids have attracted the attention, but eventually it has been observed that it is not well suited for most of the applications. In non-activated mode ER and MR, both MR and ER fluids typically have similar viscosity, but MR fluids in activated mode exhibit a much greater increase in viscosity, and therefore yield strength, than their electrical counterparts. For ER fluid, the maximum yield stress is about 10 kPa; but for MR fluid, the maximum yield stress can reach about 100 kPa [7]. Hence MR fluid is used in most of the applications. The MR damper magnetic coil has been explained by many authors using different approaches, **Honghui Zhang et. al.** has been discussed the procedure for MR damper design and have done the FEM analysis for determining magnetic saturation. Optimization procedure was developed based on the finite element method in order to find the optimal geometry of MR valves constrained to a specific volume and satisfies a required pressure drop with minimal power consumption by **Quoc-Hung Nguyen and choi**. **B. F. Spencer has** proposed a mechanical model of MR damper to study the nonlinear behavior of MR Damper. It predicts the response of Damper accurately over a wide range of operating conditions.

II. DESIGN OF MR DAMPER COIL1

2.1 Length of groove

The following standard dimensions are selected while designing the coil of MR damper

Cylinder inner diameter = 40 mm
Piston rod diameter = 20 mm
Cylinder length = 192 mm
Stroke = 50 mm
Damping force = 2000 N (Maximum)
Velocity (V) = 100 mm/s
(velocity was chosen such that it is split between low & high velocity)
Length of piston (L_p) = 70 mm

To calculate viscous force Mean circumference of annular flow path (W), Effective cross section area of piston (A_A), Flow rate (Q) are necessary to calculate.

Mean circumference of annular flow path,

Manuscript published on 30 August 2016.
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$$W = \pi\left(\frac{InnerCylinderDiameter}{2} + \frac{PistonDiameter}{2}\right) \quad (1)$$

$$W = 122.46 \text{ mm}$$

Effective cross section area of piston,

$$A_a = \frac{\pi}{4}(PistonDiameter)^2 - (PistonRodDiameter)^2 \quad (2)$$

$$A_a = 819.54 \text{ mm}^2$$

Q = Rate of flow

$$Q = Aa \times V$$

Viscosity (η) = 0.3 Pa-S

The viscous force is given as

$$Viscousforce(f_\eta) = \left(1 + \frac{WhV_d}{2Q}\right)\frac{12 \times \eta \times Q \times L \times A}{Wh^3} \quad (3)$$

Where,

h= Depth of Groove

Assume Force of Friction (F_f) = 250N

Damping force is given as,

$$DampingForce = F\eta + F_f + F\tau \quad (4)$$

Hence, shear stress is found out to be

$$ShearForce(F\tau) = 1600\,N$$

By thumb rule dynamic range should be greater than 3

Thus,

$$DynamicRange = \frac{F_d}{F_\eta + F_f} = 5 \quad (5)$$

Yield stress of fluid (τ_B) = *20 Kpa* at current of 1 amp.

Hence, the length of groove found out be,

$$Lengthofgroove(L_G) = \frac{CL_P \tau_B A_A}{h} = 42.5mm \quad (6)$$

2.2 Magnetic Potential:

The first step of the magnetic circuit design is to select proper magnetic material. Good magnetic design is also determined by magnetic structure design. The magnetic field form a loop in the magnetic material, if the magnetic loop get saturated anywhere, it will stop the continual increase of the whole loop. At the same time, the magnetic structure must ensure the accomplishment of structure function.

2.1.1 Magnetic Reluctance:

Permeability of low carbon steel = 2000 μ_0

Permeability of free space = $\mu_0 = 4\pi \times 10^{-7}$ H/m (Henries per meter)

Permeability of MR fluid (μ_r)= 6 μ_0

As shown in fig 1 piston is divided in three parts to calculate magnetic potential. First of all, the magnetic reluctance on these three parts i.e, R_{m1}, R_{m2} and R_{m3} has been calculated and then the magnetic reluctance on the whole piston surface is obtained.

The magnetic reluctance at three parts are given below,

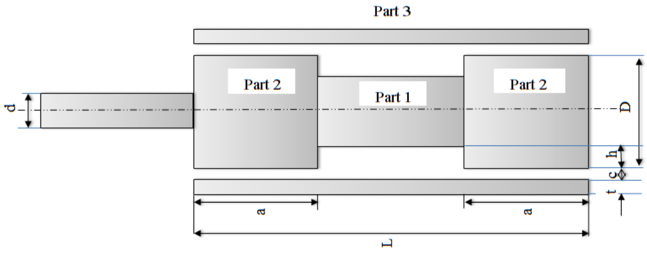

Fig: 1 Piston Design

Reluctance in part 1 is

$$R_{m1} = \frac{l}{\mu_0 \mu_r S} = \frac{L - 2a}{\mu_0 \mu_r \frac{\pi}{4}[(D-2h)^2 - d^2]} = 55.438\text{H}^{-1} \quad (7)$$

Reluctance in part 2 is

$$R_{m2} = \frac{l}{\mu_0 \mu_r S} = \frac{(D-d)/2}{\mu_0 \mu_r \pi Da} = 3.3346 H^{-1} \quad (8)$$

Reluctance in part 3 is

$$R_{m3} = \frac{l}{\mu_0 \mu_r S} = \frac{L - b}{\mu_0 \mu_r \pi (D + g + \frac{t}{2})t} = 34.1979\text{H}^{-1} \quad (9)$$

From equations (7), (8) and (9)

Total Reluctance

$$R = R_{m1} + R_{m2} + R_{m3} = 96.305 H^{-1}$$

The magnetic flux should be constant in the typical magnetic loop illustrated in Fig. 1 The force of MR damper must ensure the normal operation of vehicles, so we can get a reasonable gap width g according to the fluid dynamics. And, from the formulation of concentric cylindrical magnetic pole, we can formulate the Magnetic Permeance as,

Magnetic Permeance

$$A_g = \frac{2\pi\mu l}{\ln(\frac{R}{r})} = \frac{2\mu_0 \mu_{MR} \pi a}{\ln(1 + \frac{2g}{D})} = 0.012924 \text{ (Wb A}^{-1}\text{)} \quad (10)$$

Total Magnetic Potential is given as

$$F = \Phi(R + \frac{1}{A_g}) = \Phi(Rm_1 + 2Rm_2 + Rm_3 + \frac{\ln(1 + \frac{2g}{D})}{\mu_0 \mu_{MR} \pi a}) \quad (11)$$

$$= 347.35 Amp$$

$$\Phi = MagneticFlux = 3\text{weber (Wb)}(Assumed)$$

According to whole magnetic potential we can determine the upper limit of excitation current & number of turns

From equation (11),

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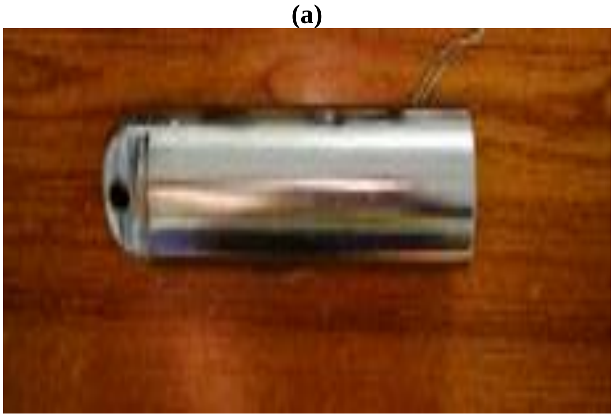
Number of Turns of Coil

$$N = \frac{MagneticPotential(F)}{I_{\max}} = 348 turns \quad (12)$$

III. DEVELOPMENT OF MR DAMPER

The MR damper has been developed using the dimensions mentioned in the design. The groove is made on piston surface for coil and piston rod is made hollow to incorporate the wires to connect with coil. The clearance between piton and cylinder is provided to transfer from one chamber to another chamber.

(a)



(b)

Fig 2: MR Damper Parts

A. *Magnetorheological Fluid*

The Magnetorheological fluid required for MR damper has been prepared by using carrier fluids, carbonyl iron powder and additives to avoid sedimentation. The carrier fluids used are paraffin oil, silicon oil and synthetic oil whereas additives used are Arosil 200, AP3 Greece. Three compositions are prepared MR1, MR2 and MR3. The article on preparation of MR fluid is published.

IV. TESTING OF MR DAMPER

The damper is tested using the experimental set up as shown in fig 2. The set up contains a shaker, load cell, LVDT, damper controller and data acquisition system. The shaker is used in this set up to produce excitation for damper and load call is provided to sense the damping force under different conditions. The LVDT is provided to measure the displacement of damper. The current controller is provided to regulate the current in the coil. The set have both the arrangements, if the button is shifted to manual mode one can change the current in the coil manually and if it is shifted to auto mode the current passes through the controller. During the experimentation the shaker is driven with sinusoidal signals at fixed frequency of 10 Hz keeping the amplitude of the damper equal to 10 mm. The damper response is checked at different current levels 0 A, 0.5 A, 1 A, 1.5 A and 2 A.

(a)

(b)

(c)

Fig 3: Test Set up

It has been observed that, as the current increases from 0 A, the damping force also start increasing. The plots are drawn between damping and displacement, damping force and time, damping and velocity for different current as shown in fig 3 and fig 4 respectively. The damper is tested for three different fluids MR1, MR2 and MR3.

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V. RESULTS

The fig 4 to fig 12 shows the responses of damper in terms of damping force verses displacement, time and velocity. The plots are obtained for current inputs in the step size of 0.5 Amp. The current is varied from 0 Amp to 2 Amp keeping the frequency and amplitude constant. The fig 4, fig 5 and fig 6 is drawn between damping force and displacement for MR1, MR2 and MR3 whereas fig 7, fig 8 and fig 9 is between damping force and time. The fig 10, fig 11 and fig 12 are drawn between damping force and velocity.

MR1, MR2 and MR3 are the fluids prepared using paraffin oil, silicon as a carrier fluids and AP3 grease and Arosil as an additive. It can be clearly observed from the figures shown below that the damping force increases with increase in the current. The viscosity of oil increases with increase in the current which in turn increases the damping force. For MR1, the damping force is 225 N at 0 Amp which is raised to 1250 N at 2 Amp. Similarly, for MR2 it is 235 N at 0 Amp which is raised to 1225 N at 2 Amp and for MR3 it is 296 N at 0 AMP and 1276 N at 2 Amp. The damping force at 0Amp for all MR fluids and that of at 2 Amp also is different. It is changes with respect to time as shown in fig 7, fig 8 and fig 9. The properties of MR1, MR2 and MR3 are different because of use of different carrier fluids and additives which influences the damping force.

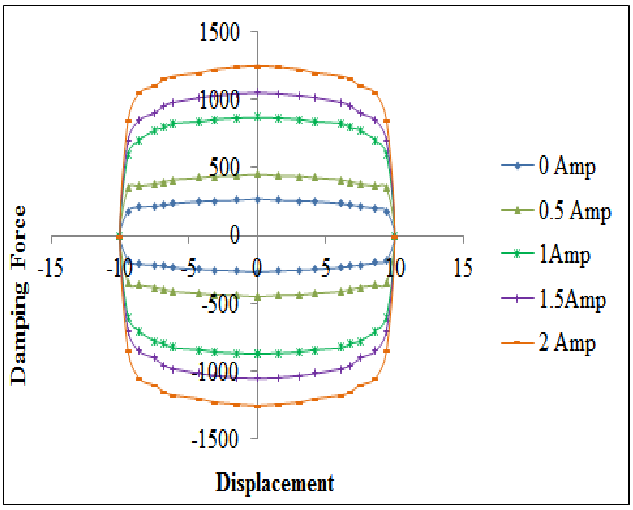

Fig 4: Damping Force Vs. Displacement (MRF1)

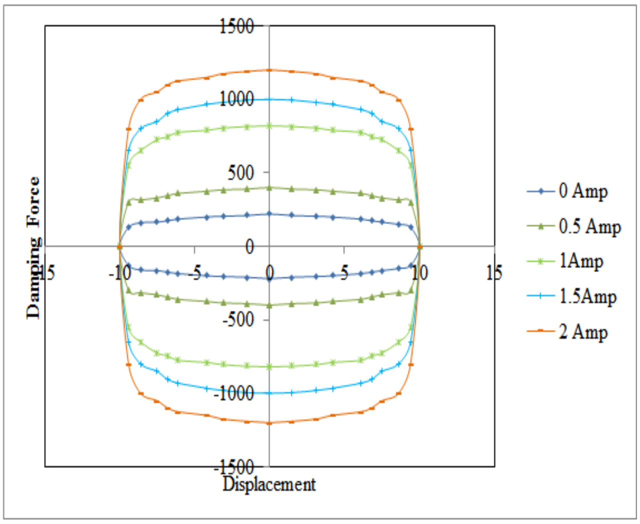

Fig 5: Damping Force Vs. Displacement (MRF2)

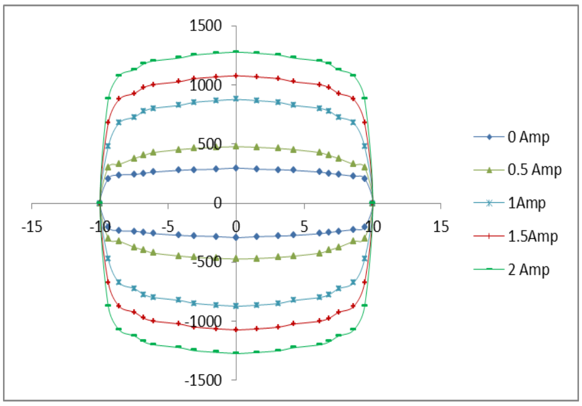

Fig 6: Damping Force Vs. Displacement (MRF3)

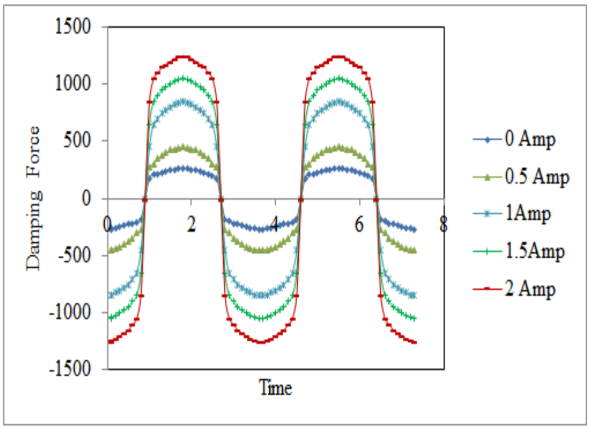

Fig 7: Damping Force Vs. Time (MRF1)

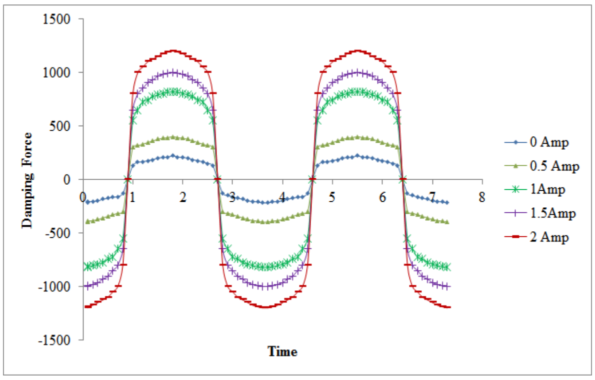

Fig 8: Damping Force Vs. Time (MRF2)

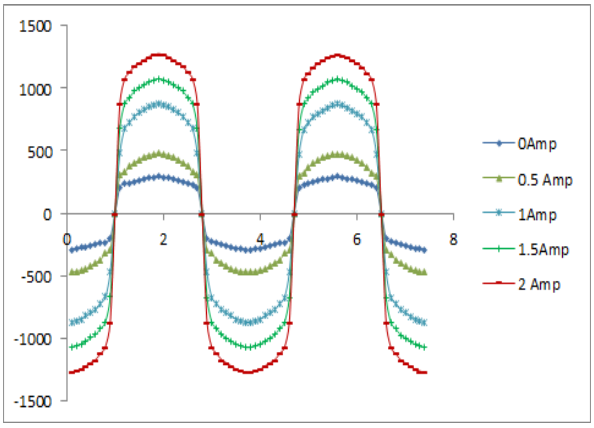

Fig 9: Damping Force Vs. Time (MR3)

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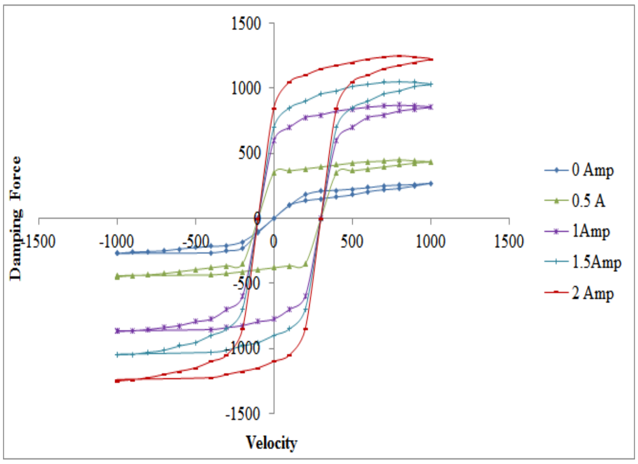

Fig 10: Damping Force Vs. Velocity (MRF2)

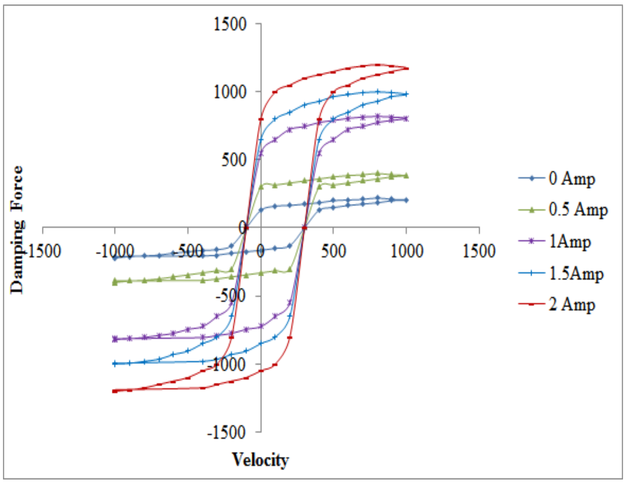

Fig 11: Damping Force Vs. Velocity

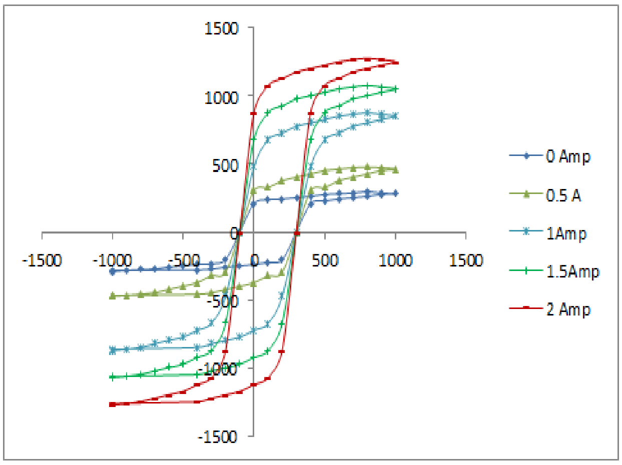

Fig 12: Damping Force Vs. Velocity

VI. CONCLUSION

It is observed that the proposed damper has provided good dynamic range and response. The damper is tested at an excitation frequency10 Hz (using electromagnetic shaker) by current step 0 Amp, 0.5 Amp, 1 Amp, 1.5 Amp and 2 Amp. From the results it is clear that there is a remarkable increase in the damping force with the increase in current. The MR is saturated when the current exceeds a particular limit, in the proposed damper it is 2 Amp. The damper had shown very good performance with all the fluids MR1, MR2 and MR3. The damping force is different at 0 Amp in these fluids. This is because of different initial viscosity of fluids. The viscosity changes according and gets the results for further increase in the current.

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