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Investigation on the Performance of MR Damper with various Piston configurations

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Abstract- In recent year's semi-active dampers utilizing smart fluids like magneto-rheological (MR) fluid have attracted attention of the researchers. These devices have found varied applications like control of vibrations in seat suspension systems, rotary braking systems, prosthetics, seismic systems etc. The performance of MR damper depends on its magnetic and hydraulic circuit design. This paper deals with a design of MR damper for which mathematical model is developed. A finite element model is built to examine and investigate the 2- D axi-symmetric MR damper. Six different configurations of MR damper piston are simulated in order to investigate how the shape of the piston affects the maximum pressure drop that the damper can provide. The piston velocity and the input current to the coil are varied to evaluate the resulting change in magnetic flux density (B) and pressure drop(ΔP). The simulation results of the different configuration of damper piston show that the performance of single coil with filleted piston ends is better than that of other configurations for the same magnitude of input current and piston velocity.

Index Terms- Magneto-rheological (MR) fluid, MR damper, Magnetic flux density, magnetic field intensity.

I. Introduction

Magneto- rheological (MR) fluid, which is known as a functional fluid, changes its rheological characteristics upon the application of a magnetic field. The rheological properties of MR fluid are rapidly and reversibly altered when an external magnetic field is applied. The suspended particles in the MR fluid become magnetized and align themselves like chains, with the direction of the magnetic field. The formation of these particle chains restricts the movement of the MR fluid, thereby increasing the yield stress of the fluid. The fluid causes the maximum yield stress of about 50 to 100kPa and responds within milliseconds. The magnetic field dependent shear strength of MR fluid depends on several factors including the size, composition, volume fraction of the particles and the strength of the applied magnetic field . Designs that take advantage of MR fluids are potentially simpler and more reliable than conventional electromechanical devices. Maher Yahya Salloom and Samad [1] designed an MR valve for which simulation was carried out by magnetic finite element software (FEMMR). Sodeyama and Suzuki et.al [2] have developed and tested an MR damper which provided maximum damping force.of 300kN. H.yoshioka, j.c. Ramallo et.al.[3]constructed and tested a base isolated two-degree freedom building model subjected to simulated ground motion which is effective for both far- field and near- field earthquake excitations. Jansen and Dyke [4] evaluated the performance of number of semi active control algorithms that are used with multiple MR dampers. Spancer and Dyke et.al. [5] Proposed a new model to effectively use as semi-active control device for producing a controllable damping force portraying the nonlinear behavior of MR fluid damper. N.Seetaramaaiah and Sadak et.al. [6] have designed a small capacity MR fluid damper which acheived the requirements of dynamic range and controllable force. Lai and W.H Liao [7] have been found that MR fluids can be designed to be very effective vibration control actuators. Butz,T and Von Stryk[8] have given overview on the basic properties of electro and magnetorheological fluids and discussed various phenomenological models for devices . Laura M, Jansen and Shirley J. Dyke[9] presented the results of a study to evaluate the performance of a semiactive control algorithms for use with MR dampers.

The main objective of this paper is to evaluate the six different models of MR damper using ANSYS 11 software.

Nomenclature

A_p	: Piston cross section area
d	: spool length
d_{cyl},d_{sh},	: diameters of the cylinder and shaft respectively
e	: house thickness
H	: fluid viscosity in the absence of the Field, C
I	: current supplied to the coil
L, g, W	: length, gap and width of the flow channel between the fixed poles
N	: number of turns of the coil
Q	: volumetric flow rate
V_p	: velocity of the piston
τ	: shear stress,
τ_y	: field-dependent yield stress,
ΔP_η	: Viscous component of pressure drop
ΔP_τ.	: Yield stress component of pressure Drop
$\dot{\gamma}$	: fluid shear rate

II. Theoretical Consideration

The damper design was done based on the following facts. The mechanical energy required for yielding increases with increase in applied magnetic field intensity which in turn increases yield shear stress. In the presence of magnetic field, the MR fluid follows Bingham's Plastic flow model, given by the equation

$$\tau = \eta \dot{\gamma} + \tau_y(H) \qquad \tau > \tau_y$$

The above equation is used to design a device which works on the basis of MR fluid. The total pressure drop in the damper is evaluated by summing the viscous component and yield stress component. which is approximated as

$$\Delta P = \frac{12\eta QL}{g^3 W} + \frac{C\tau_y L}{g}$$

$$\eta = 0.0006 \ \dot{\gamma}^{-0.6091}$$

$$A_p = \frac{\pi\left[(d_{cyl} - 2g)^2 - d_{sh}^{\ 2}\right]}{4}$$

$$Q = A_p V_p$$

$$W = \pi(d_{cyl} - g)$$

$$C = 2.07 + \frac{12Q\eta}{12Q\eta + 0.4Wg^2\tau_y}$$

the value of the parameter ,C ranges from a minimum of 2 (for $\Delta P\tau$ $\Delta P\eta$ less than ~1) to a maximum of 3 (for $\Delta P_\tau/\Delta P_\eta$ greater than ~100).

In order to calculate the pressure drop in the cylinder, yield stress is required which is obtained from the yield stress vs. magnetic field intensity curve provided by Lord corporation for M.R. fluid -132 DG in reference.

III. Finite Element Modeling of MR Damper

The MR damper consists of a copper coil which is wound on a piston. An annular gap of 0.4 mm is maintained between the piston and its housing. Mild steel is used for the piston due to its high relative permeability. The input current to the coil is varied from 0.2A to 2A which is the saturation current for the standard MR fluid 132 DG.

In the present research work, six different configurations are considered to analyze a 2D axisymmetric MR damper. In these models the dimensions of the piston, number of turns of the coil and annular gap are kept constant while different shapes of piston with plain, chamfered and filleted ends are considered. The new design proposed MR damper consisting of a steel path and an annular gap with disk gap as shown in Fig. 1. Further the piston is considered with single and three stages in order to maintain two and four poles respectively as shown in Fig. 2 to Fig. 7.

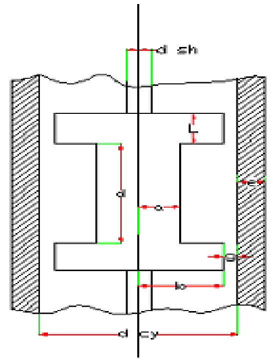

Fig.1 schematic diagram showing nomenclature of MR damper

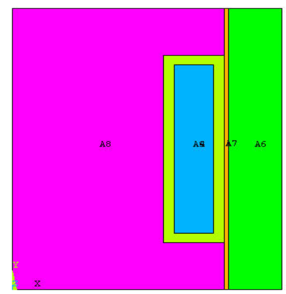

Fig.2. Piston with plain ends

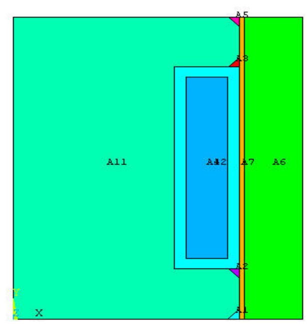

Fig.3. Piston with chamfered ends

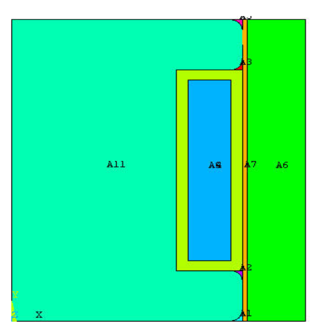

Fig .4. Piston with filleted ends

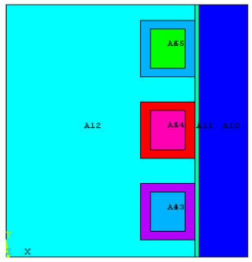

Fig.5. Piston with plain ends

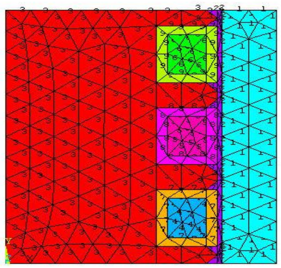

Fig.6. Piston with chamfered ends

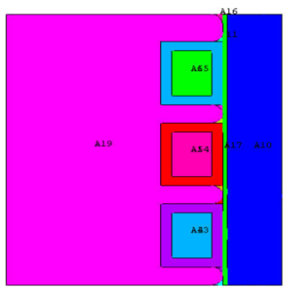

Fig .7. Piston with filleted ends

These models are analyzed to study the variation of magnetic field intensity and magnetic flux density with respect to the input current to the coil. Analysis is carried out using ANSYS 11 software. The variation of 2D flux lines, magnetic flux density and magnetic field intensity for the different models at 2 amperes are shown in Fig.8 to Fig.12

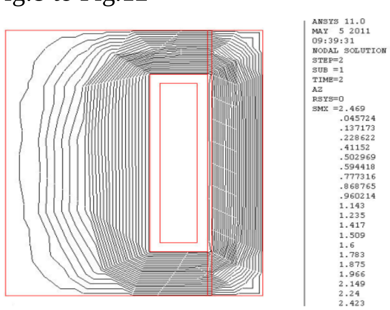

Fig.8. Flux lines around the coil

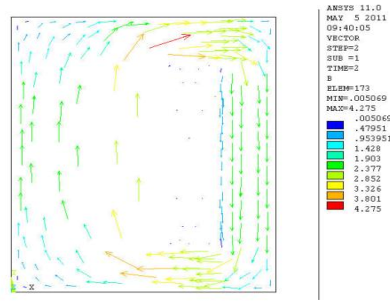

Fig.9:Magnetic flux density vectors

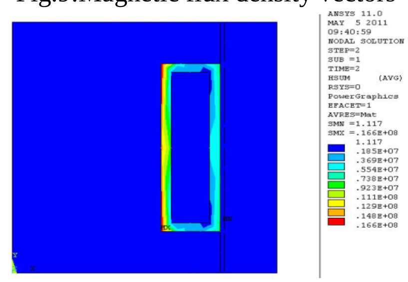

Fig.10.Magnetic field intensity

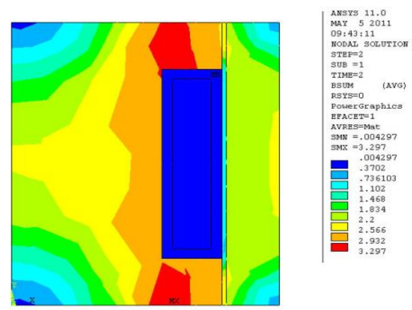

Fig.11.Magnetic flux density vector sum

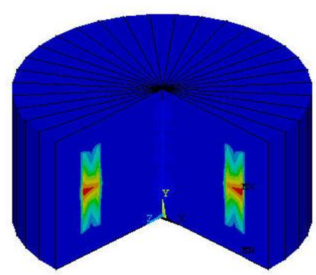

Fig.12. 3-D axisymmetric view of MR fluid Damper

4. Simulation results and analysis

The simulation results of pressure drop with respect to magnetic flux density for a variation in piston velocity from 0.04 m/s to 0.2 m/s and constant gap of 0.4 mm for various models are shown in fig 13a to 13e.

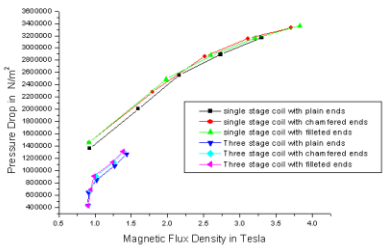

Fig.13a. Variation of Pressure Drop with Magnetic Flux Density for a Piston Velocity of 0.04 m/s

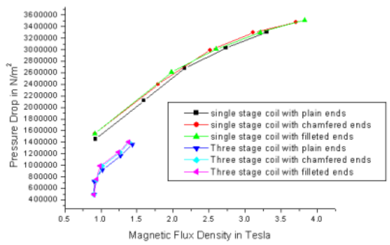

Fig.13b. Variation of Pressure Drop with Magnetic Flux Density for a Piston Velocity of 0.08 m/s

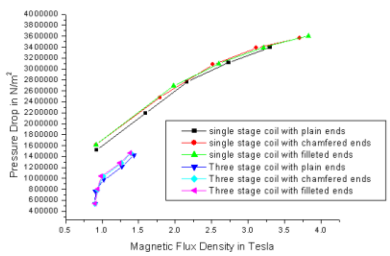

Fig.13c. Variation of Pressure Drop with Magnetic Flux Density for a Piston Velocity of 0.12m/s

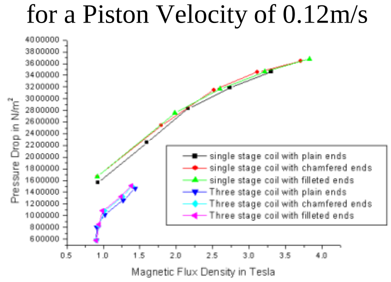

Fig.13d. Variation of Pressure Drop with Magnetic Flux Density for a Piston Velocity of 0.16 m/s

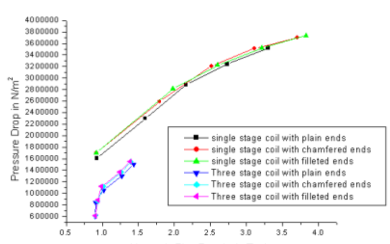

Fig.13e. Variation of Pressure Drop with Magnetic Flux Density for a Piston Velocity of 0.2 m/s

The simulation results of pressure drop with respect to flow rate for a variation in current from 0.4 amp to 2 amp and constant gap of 0.4 mm for various models are shown in fig 14a to 14e.

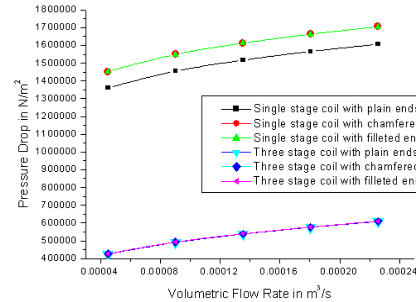

Fig.14a. Variation of Pressure Drop with Volumetric Flow Rate for a Current of 0.4 A

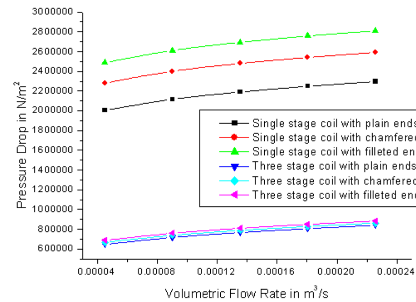

Fig.14b. Variation of Pressure Drop with Volumetric Flow Rate for a Current of 0.8 A

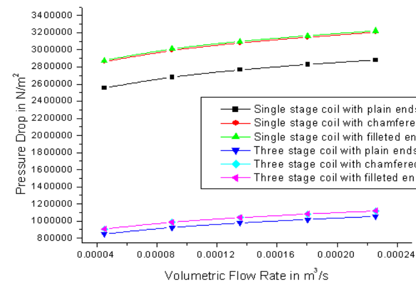

Fig.14c. Variation of Pressure Drop with Volumetric Flow Rate for a Current of 1.2 A

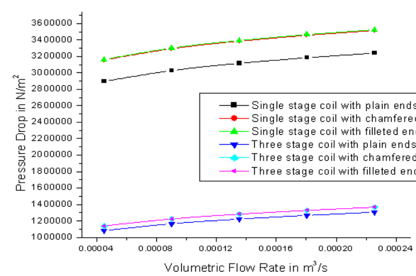

Fig.14d. Variation of Pressure Drop with Volumetric Flow Rate for a Current of 1.6 A

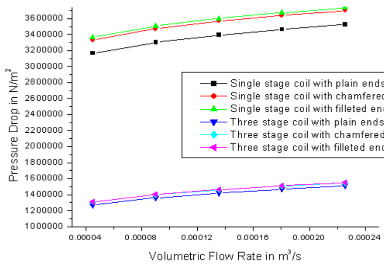

Fig.14e. Variation of Pressure Drop with Volumetric Flow Rate for a Current of 2 A

It is observed from figures 13a to 13e that magnetic flux density increases with increase in current and pressure drop increases with increase in magnetic flux density in case of single and three stage piston configurations. It is also observed that the pressure drop increases with increase in the velocity of the piston. Maximum pressure drop is observed in case of single stage with filleted piston end model. The figures from 14a to 14e show that the pressure drop increases with increase in flow rate of MR fluid. The maximum pressure drop with respect to flow rate is also found to occur in case of single stage with filleted piston end model.

IV. Conclusion

In the present paper, the performances of a MR fluid damper with six different configurations are studied. It can be concluded from the evaluation of the above models of MR damper that, the model with filleted ends gives optimum pressure drop with respect to magnetic flux density as well as flow rate. This implies that higher loads can be carried by the damper even with a small capacity.

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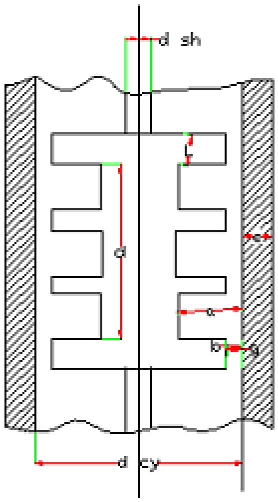
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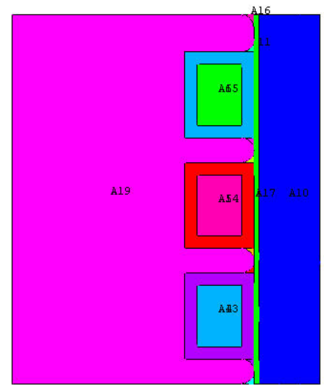
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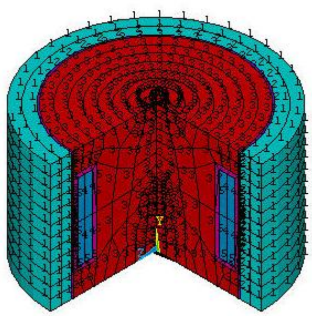

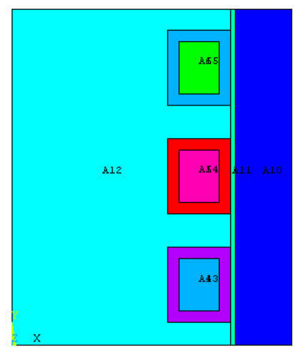
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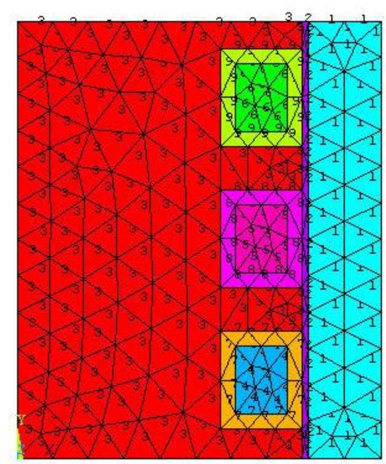

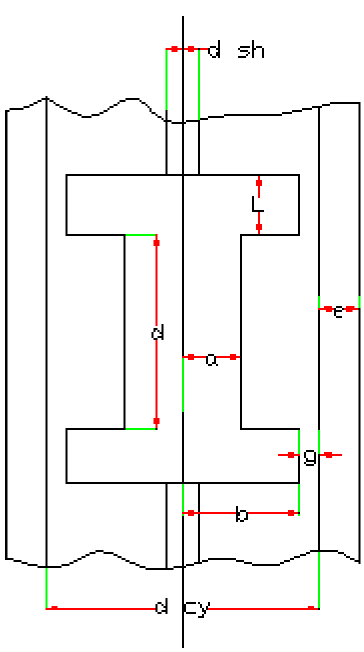
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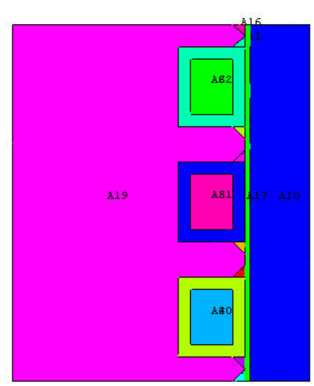
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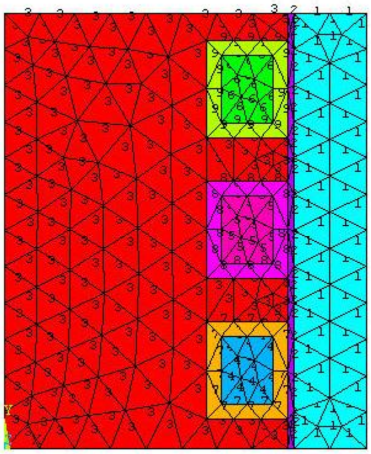

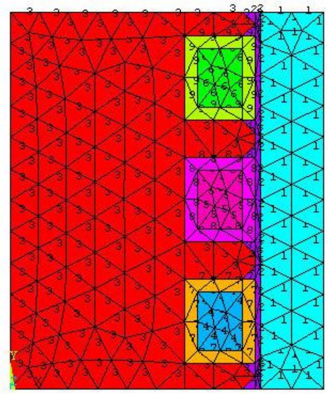

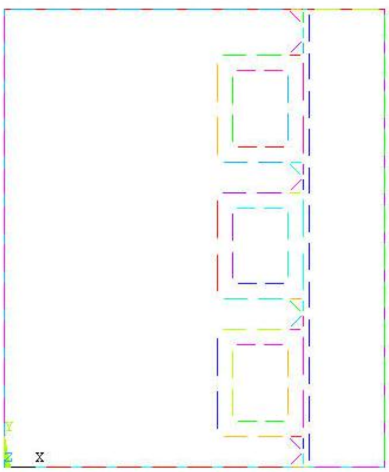

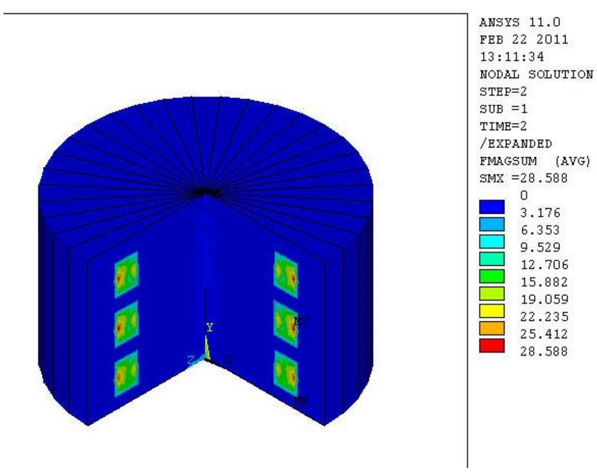
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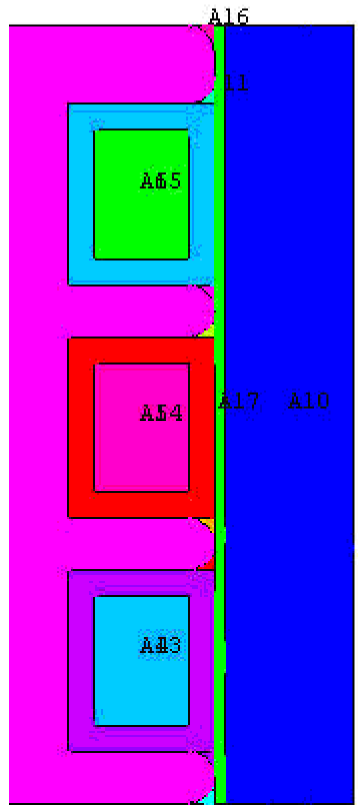
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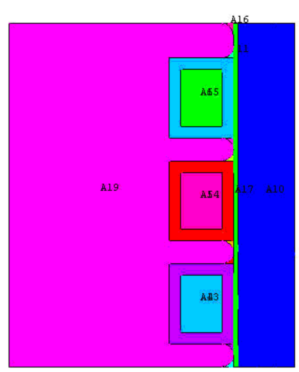
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