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# Analysis of Magneto Rheological Fluid Damper with Various Piston Profiles

**Md. Sadak Ali Khan, A.Suresh, N.Seetha Ramaiah**

***Abstract – Control of seismic, medical and automobile vibrations represents a vast area of research that is growing rapidly. Magneto rheological (MR) dampers are a new class of devices that match well with the requirements and constraints of applications, including the necessity of having very low power requirements. The performance of MR damper depends on its magnetic and hydraulic circuit design. In this paper a finite element model is used to examine and investigate the 2- D axi-symmetric MR damper. Nine different configurations of piston for MR damper are simulated in order to investigate how the profile of the piston affected the maximum pressure drop that the damper could 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 piston show that the performance of single coil with filleted piston ends was 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

Magnetorheological (MR) fluids have been investigated by many scholars as their material properties can be modulated through an applied electro- magnetic field. Specially, they are capable of reversibly changing from a linear Newtonian fluid to a semi solid with in a fraction of the milli seconds and the yield strength of this semi-solid is controllable. The fluid causes the maximum yield stress of about 50 to 100kPa. 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. Systems that take advantage of MR fluids are potentially simpler and more reliable than conventional electromechanical devices. Sodeyama and Suzuki et.al [1] have developed and tested an MR damper which provided maximum damping force of 300kN. Maher Yahya Salloom and Samad [2] designed an MR valve for which simulation was carried out by magnetic finite element software (FEMMR).

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H.yoshioka, J.C. Ramallo et.al.[3]constructed and tested MR fluid based damper on 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 achieved the requirements of dynamic range and controllable force. Lai and W.H Liao [7] have 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 semi active control algorithms for use with MR dampers.Henri Gavin Jesse Hoagg et.al[10] have made a comparison between ER and MR devices in the context of electrical power requirements.

The present paper analyzes the force for vibration control by using nine different models of MR damper using ANSYS software. The main objective of the paper is to evaluate the nine different models of MR damper using ANSYS software.

## II. 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 |
| *L, g,W* | : | length, gap and width of the flow channel between the fixed poles |
| N | : | number of turns |
| Q | : | volumetric flow rate |
| $V_p$ | : | velocity of the piston |
| $\tau$ | : | shear stress, |
| $\tau_y$ | : | field-dependent yield stress, |
| $\Delta P_\eta$ | : | viscous component of pressure drop |
| $\Delta P_\tau$. | : | yield stress component of pressure drop |
| $\dot{\gamma}$ | : | Fluid shear rate |



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1P : one stage coil with plain ends
1C : one stage coil with chamfered ends
1F : one stage coil with filleted ends
2P : two stage coil with plain ends
2C : two stage coil with chamfered ends
2F : two stage coil with filleted ends
3P : three stage coil with plain ends
3C : three stage coil with chamfered ends
3F : three stage coil with filleted ends
MFD : Magnetic Flux density

## III. THEORETICAL ANALYSIS

The damper design is 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

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

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

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

$$Q = A_p V_p$$

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

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

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 change in pressure on either side of the piston within the cylinder, yield stress is required which is obtained from the graph of yield stress $v_s$ magnetic field intensity provided by Lord corporation for M.R. fluid -132 DG .

## IV. 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 contribution current to the coil is ranging from 0.2A to 2A which is the diffusion current for the standard MR fluid 132 DG. This paper presents analysis of a 2D axisymmetric MR damper for nine different configurations. In these models the proportions 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 design proposed of the MR damper consists of a steel path and an annular gap as shown in Fig. 1. Further the piston is considered with one, two and three stages in order to maintain two, three and four poles respectively as shown in Fig. 2 to 10.

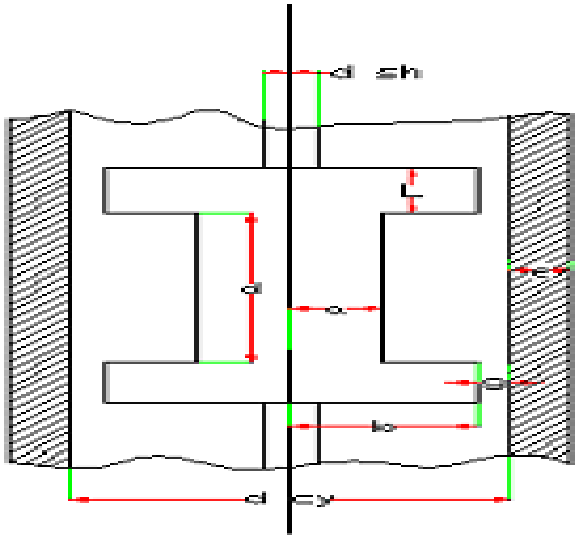


Fig.1 Schematic shows the design and dimensions of MR damper

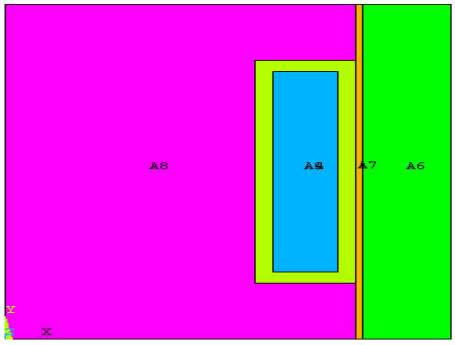


Fig.2. One stage coil with plain ends

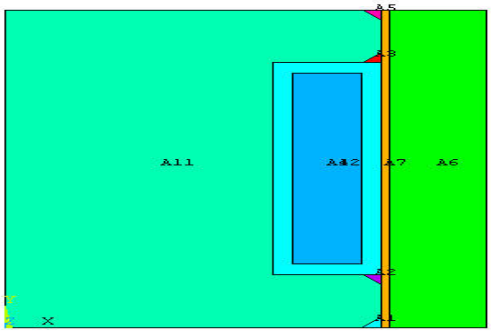


Fig 3. One stage coil with chamfered ends


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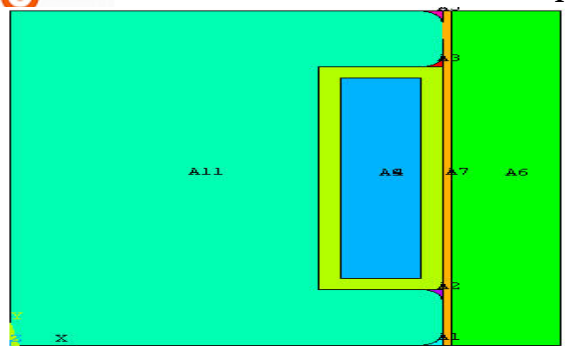


Fig 4. One stage coil with filleted ends

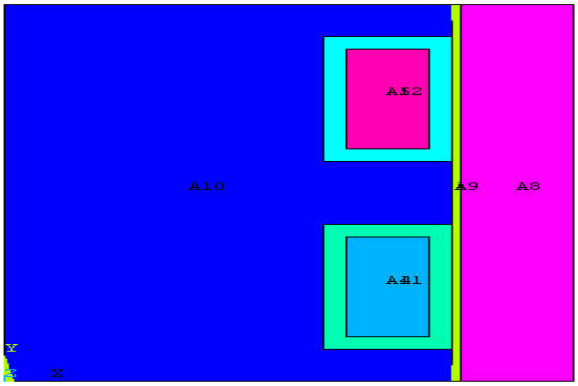


Fig 5. Two stage coil with plain ends

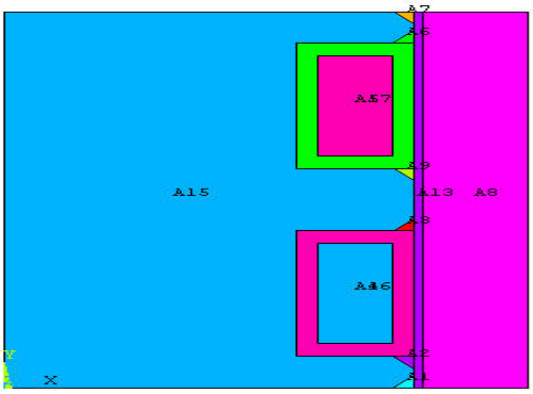


Fig 6. Two stage coil with chamfered ends

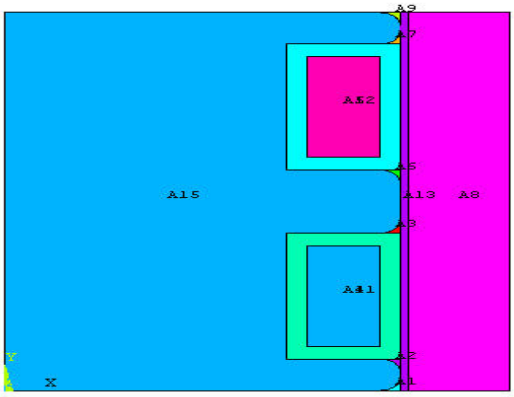


Fig 7. Two stage coil with filleted ends

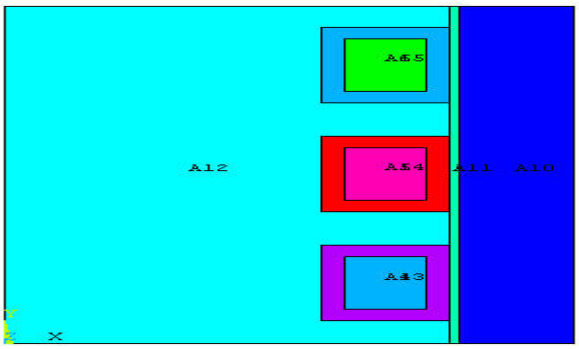


Fig 8. Three stage coil with plain ends

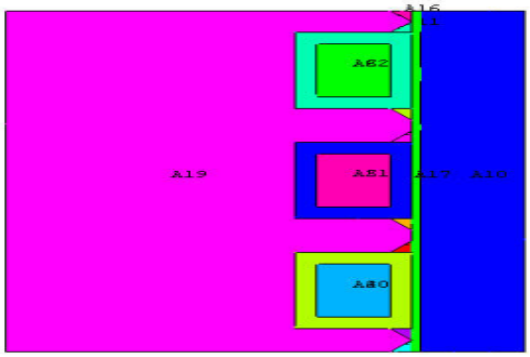


Fig.9. Three stage coil with chamfered ends

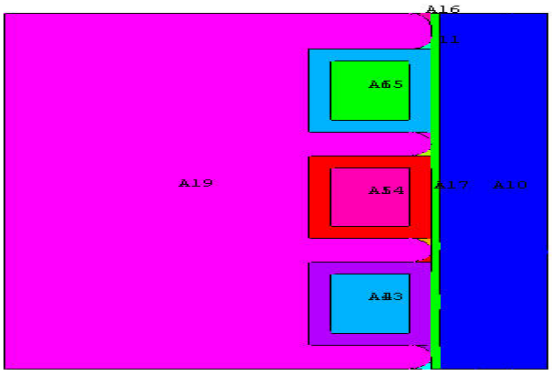


Fig 10. Three stage coil with filleted ends

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 [R] 11 software. The variation of 2D flux lines, magnetic flux density and magnetic field intensity for the different models at a current of 2A are shown in Fig.11 to Fig.24

It can be observed from fig.11 and fig.13 that the flux lines are continuous loops in case of one and three coils .There are two separate loops in case of three coils model since it has even number of poles whereas in case of two coils model (Fig12) the flux lines form a single loop due to odd number of poles. There is a concentration of flux lines near the MR fluid gap.


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Moreover, the flux lines shift their path when they reach the MR fluid gap, since the properties of MR fluid are different from that of piston and cylinder.

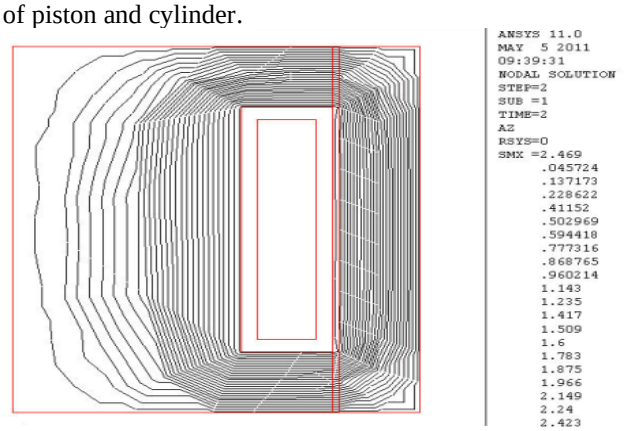


Fig 11. Flux lines around the one stage coil

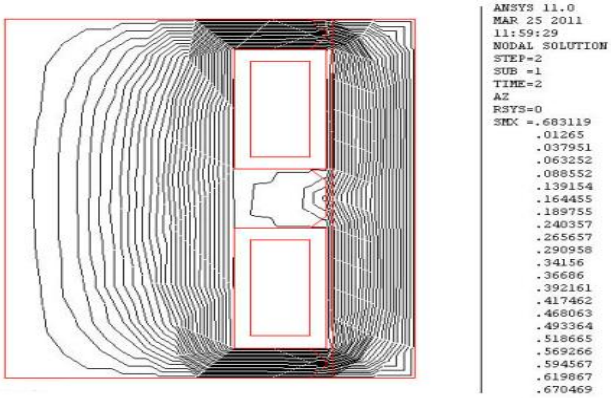


Fig 12. Flux lines around the two stage coil

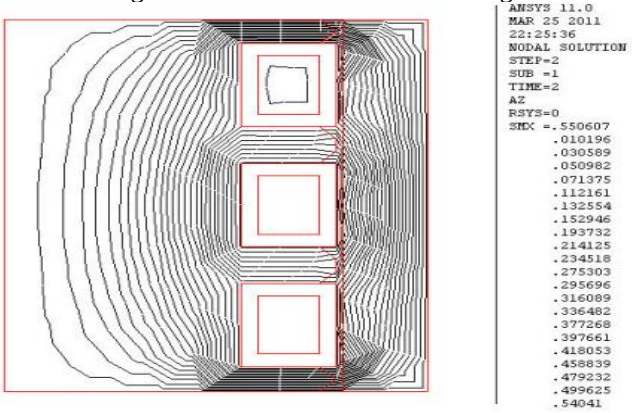


Fig 13. Flux lines around the three stage coil

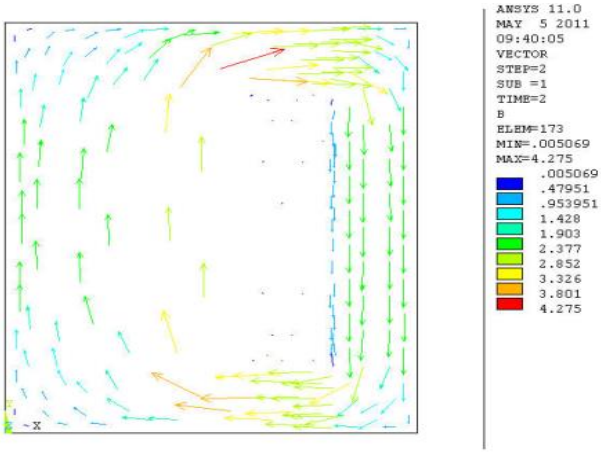


Fig 14 MFD vectors for one stage coil

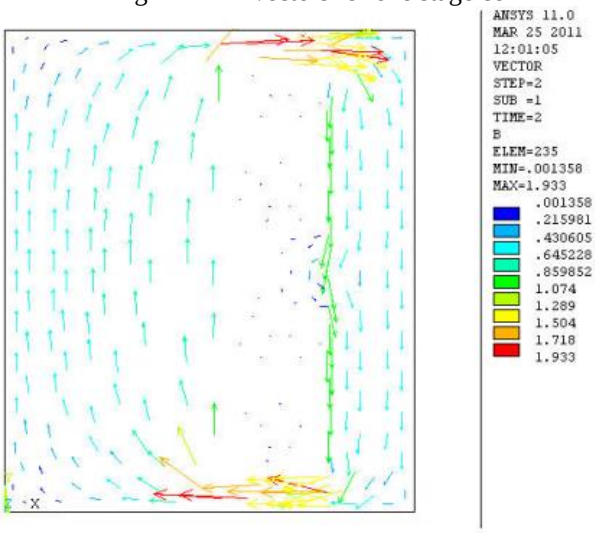


Fig 15. MFD vectors for two stage coil

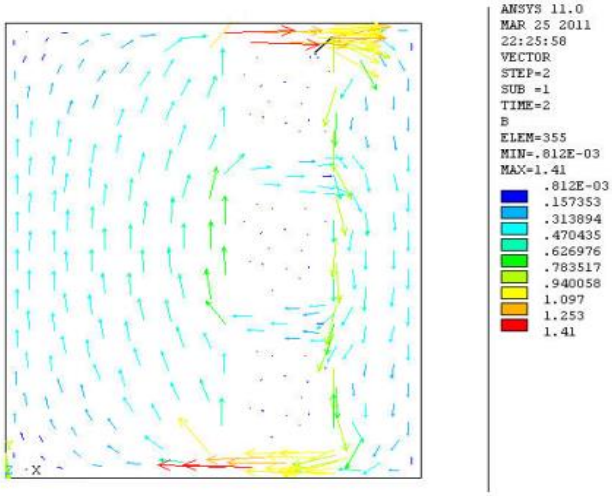


Fig 16. MFD vectors for three stage coil.



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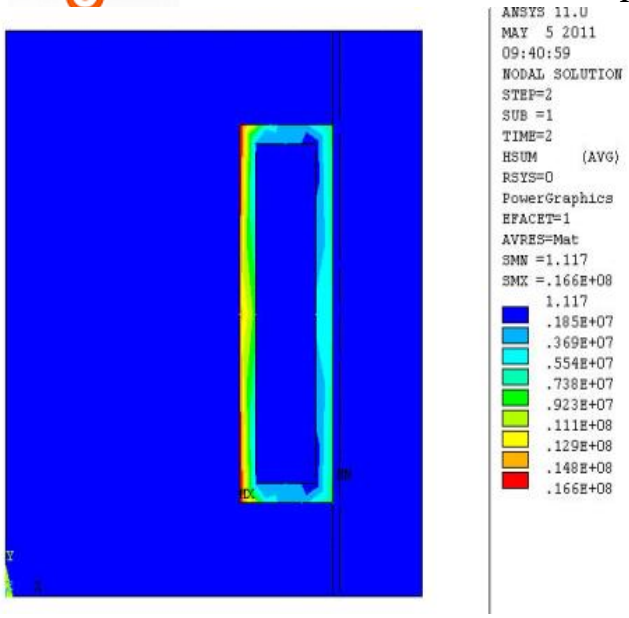


Fig 17.Magnetic field intensity for one stage coil

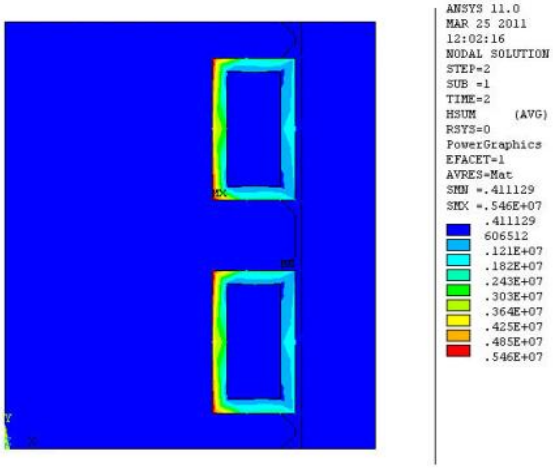


Fig 18.Magnetic field intensity for two stage coil

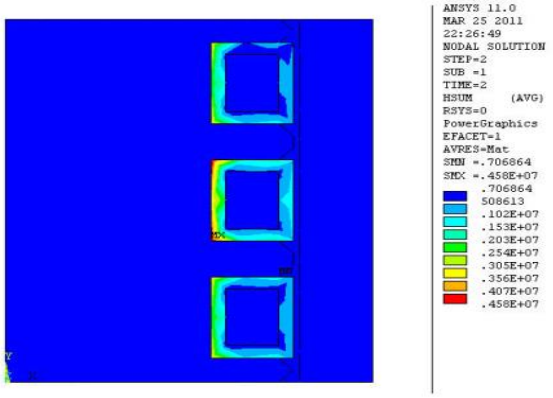


Fig 19.Magnetic field intensity for three stage coil

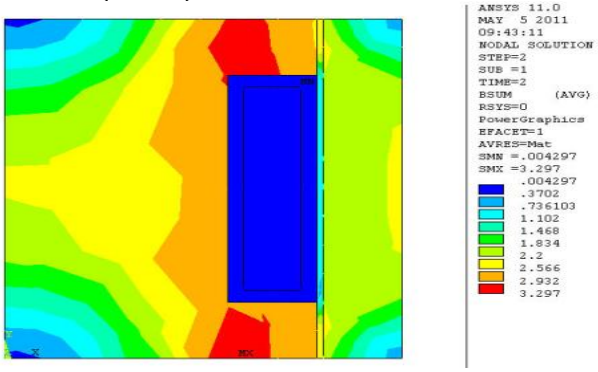


Fig 20. MFD vector sum for one stage coil

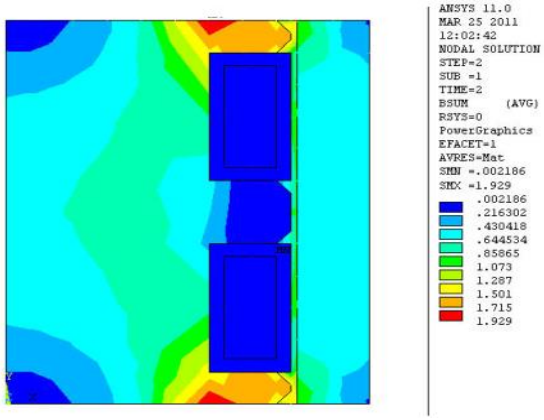


Fig 21. MFD vector sum for two stage coil

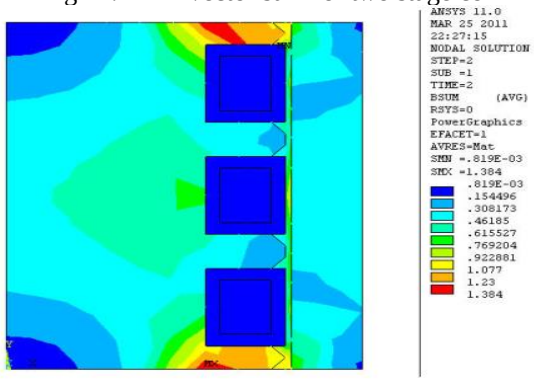


Fig 22. MFD vector sum for three stage coil

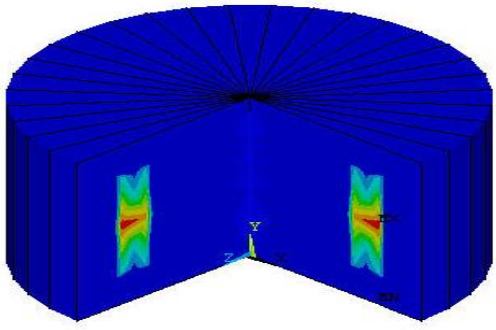

Fig 23. 3-D Axisymmetric view of MR fluid damper one stage coil


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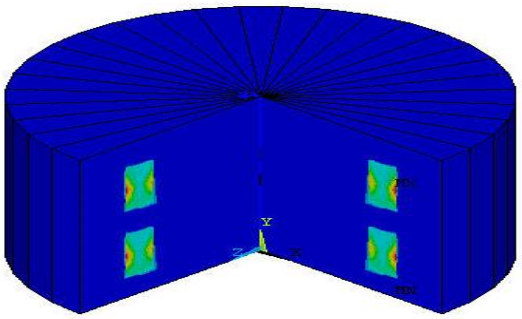

Fig 24. 3-D Axisymmetric view of MR fluid Damper two stage coil

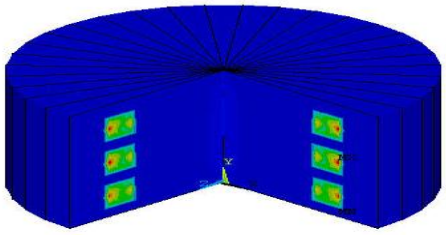

Fig 25. 3-D axisymmetric view of MR fluid Damper three stage coil

## V. 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. 26a to Fig.26

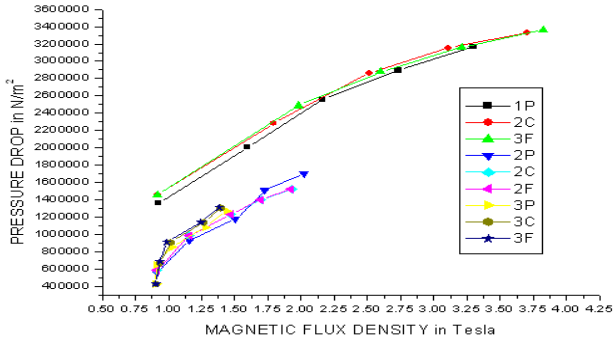


Fig 26 a. Variation of Pressure drop with Magnetic Flux Density for a Piston Velocity of 0.04 m/s

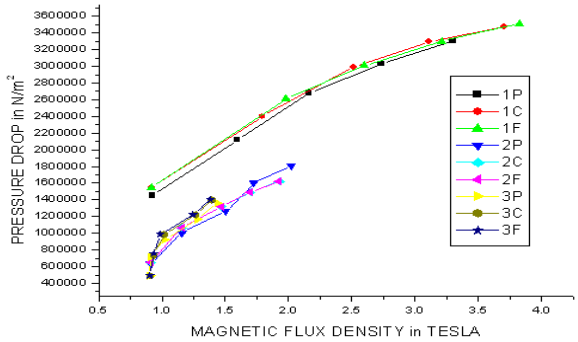


Fig 26 b. Variation of Pressure drop with Magnetic Flux Density for a Piston Velocity of 0.08 m/s

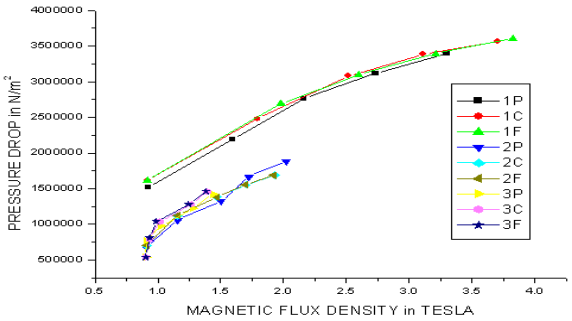


Fig 26 c. Variation of Pressure drop with Magnetic Flux Density for a Piston Velocity of 0.12m/s

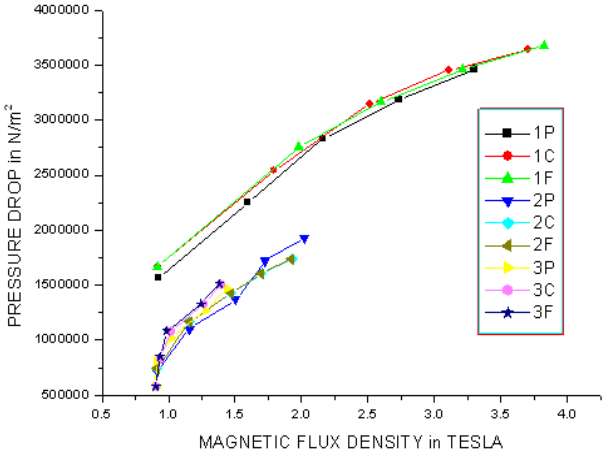


Fig 26 d. Variation of Pressure drop with Magnetic Flux Density for a Piston Velocity of 0.16 m/s

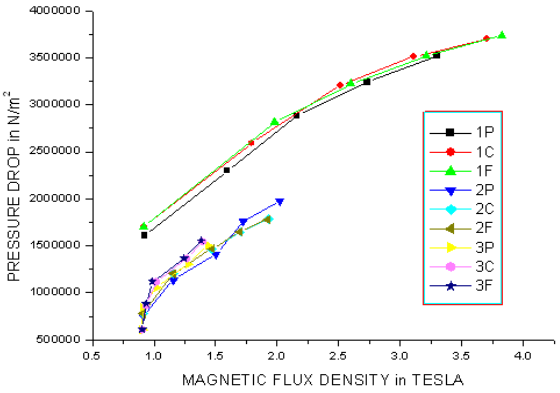


Fig 26e. Variation of Pressure drop with Magnetic Flux Density for a Piston Velocity of 0.2 m/s

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.


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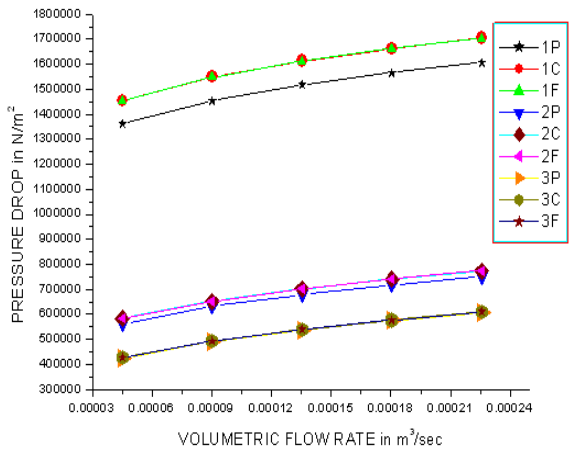


Fig 27a. Variation of Pressure drop with Volumetric Flow Rate for a Current of 0.4 A

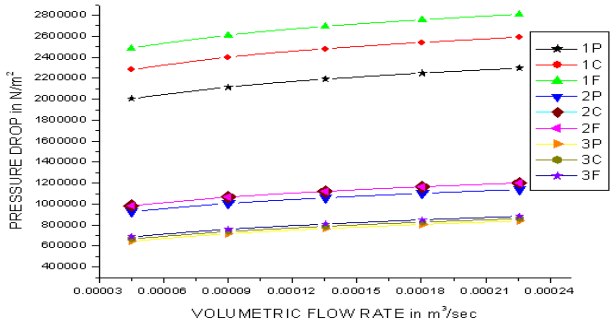


Fig 27b. Variation of Pressure drop with Volumetric Flow Rate for a Current of 0.8 A

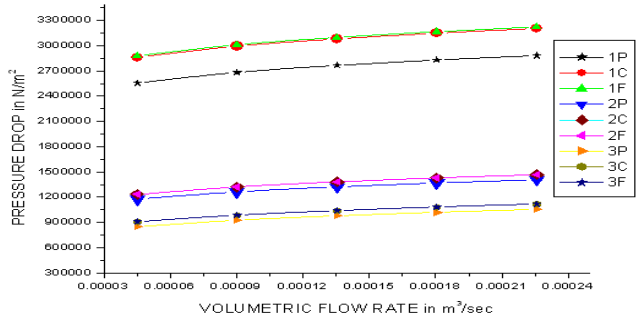


Fig 27c. Variation of Pressure drop with Volumetric Flow Rate for a Current of 1.2 A

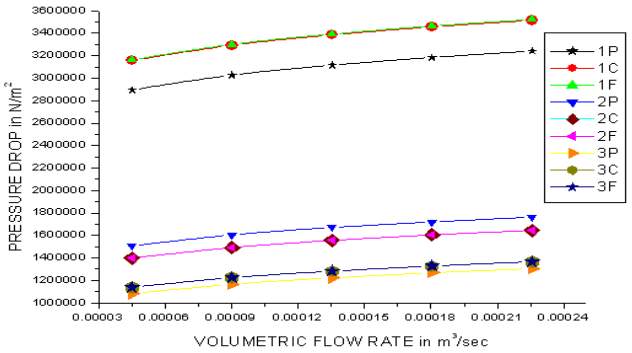


Fig 27d. Variation of Pressure drop with Volumetric Flow Rate for a Current of 1.6 A

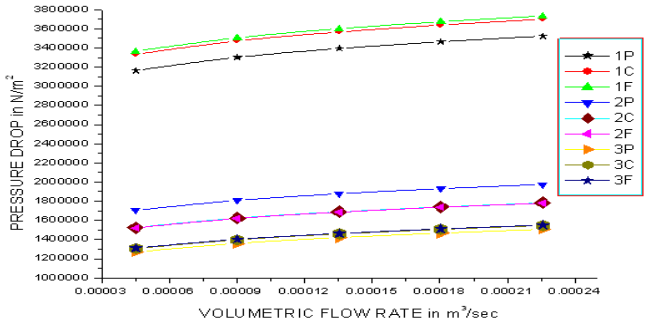


Fig 27e. Variation of Pressure drop with Volumetric Flow Rate for a Current of 2 A

It is observed from Fig. 13a to Fig.13e that as current increases, the magnetic flux density also increases which results in an increase in pressure drop. For a given current, the pressure drop increases with increase in velocity. This trend is observed for currents up to 1.6A. However at 2A current the pressure drop is less at lower velocities but it gradually increases at higher velocities to reach a maximum. 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 one stage model with filleted piston ends

## VI. CONCLUSION

In the present paper, the performances of an MR fluid damper with nine different configurations are studied. It can be concluded from the evaluation of the above models 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 small capacities.


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