Study for Design of Magneto Rheological Damper

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Abstract**—**Semi-active isolation system have received attention over the active and passive isolation system for vibration, mitigation of vibration in industrial application is the essential development. Magneto rheological damper quick response to sudden maneuvers with less power consumption leads to many research and design of MR damper for different design parameters and variable current input, in this present work designed a MR damper with all the requisite design parameter information compiled from earlier work., number of coils required to generate the effective magnetic flux field has been calculated to design the magneto rheological damper and to arrive maximum magnetic flux density vs dc current with proper proportion percentage of ferrite particles in MR fluid which further leads to calculate shear stress and damper force can produce by the designed MR damper at variable current input.

Keywords*-MR damper,MR fluid,damping force.*

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1. INTRODUCTION

Newly emergent semi-active control device,magneto rheological (MR) damper, shows greatpromises for shock absorption in the fields such as civil engineering, aerospace engineering, automotive engineering and so on. Some issue should be fully studied to make MR dampers use extensively inengineering, such as design of MR dampers, performance tests and mathematical model forMR dampers.

The regular methods used for the optimal design of MR damper are done through optimizing the geometric and parameters of the electromagnetic circuit [1].In an MR device, magnet assembly plays a very important role in device overall characteristics. Electromagnet design affects both fluid flow and magnetics. Since the gap is also part magnetic circuit, it affects the magnetic performance parameters such as flux density and time response.so following are the objectives of magnet assembly design for MR device [2].

- Design a low reluctance magnetic circuit that guides the magnetic flux lines into a region where MR fluid needs to be energized (usually an annulargap in the range of 0.5–2 mm).
- Minimize weight and cost of the electromagnetby using minimum core material and selectingsimple to build components.
- Select coil parameters, e.g., the number of turnsand wire gauge, to provide the requiredmagneto-motive force with minimum ohmicresistance. A constraint is the total space availableto accommodate the coil.

Gavin et al. [3] has discussed the two major design goals for theMR devices. First, the dampers must havelow electrical power utilization. Second, the force in the device must response rapidly to changes onthe electrical command signal. Aydar et al. [4] has designed and fabricated a small MR damper, whichcan be potentially applied to a horizontal axis, front-loading washing machine. Lee et al. [5] has consideredthe integrated design method of a large-scale MR damper and electromagnetic induction system and hasalso considered a smart passive control system for reducing stay cable responses in this investigation.Taking into consideration that most MR dampers have annular magnetically active area, Chooi et al. [6] has designedand fabricated a double-tubeMR damper based on the annular solution and on the compressibility ofMRfluid inside the chambers. Jorge et al. [7] has proposed an approach to find out the training inputs fordetection of a MR damper, which has the characteristics of reduction of overuse of the damper,number of experiments and configurations of training inputs. A more recent study by Ding et al. [8] hasalso designed and fabricated two MR dampers with full-length effective damping path and a series oftests have been performed to obtain the force–displacement curves and the force–velocity curves ofthe damper.

In this paper considering all parameters established by earlier work considered to deign low force MR damper and analysis is carried out for variable current from 0.1A to 1.0A for maximum magnetic flux density. Based on resulted Maximum flux density shear stress computed and also computed the damping force generated by the designed model.

2. MAGNETO RHEOLOGICAL DAMPER DESIGN PROCESS

The MR damper design process consists of material selection, geometry design and magnetic circuitdesign. One of the goals for materials selection is to choose a kind of MR fluid that has low apparentviscosity and appropriate magnetic saturation yield strength. Another goal for materials selection is tochoose the materials of the cylinder and piston, in which the saturation induction density should behigher than the magnetic field intensity when MR fluid achieves magnetic saturation yield strength,so that the MR fluid can be used fully. The task of geometry design is to choose an appropriate gap, valuable cross-section area of piston head and an active pole length to satisfy the designrequirements. The objective of magnetic circuit designis to determine the number of the coils, so that the magnetic induction density in the annular flowpath generated by magnetic circuit is more than the magnetic field intensity when MR fluid achievesmagnetic saturation yield strength.

2.1 MATERIALS SELECTION

For the cylinder and thepiston, the two parts are not only the part of magnetic circuit but also the main force deliverymembers of MR dampers. Therefore, Steel 1008less carbon content which have highmagnetic permeability and high saturation induction density, are adopted for manufacturing thepiston and the cylinder, respectively,

2.2 CONCEPT DEVELOPEMENT

Magneto-rheological damper design requires knowledge of fluid dynamics, electromagnetic principles, and basic machine design. The purpose of this section is todescribe the guidelines of designing and manufacturing MR dampers.

As a Semi active control device, MR damper have paid more attention and applied in many areas to mitigate the vibration, so suppression of vibration will be carried out in three ways as explained below.

The process of vibration suppression system is in different categories step by step Shows in fig. 1.

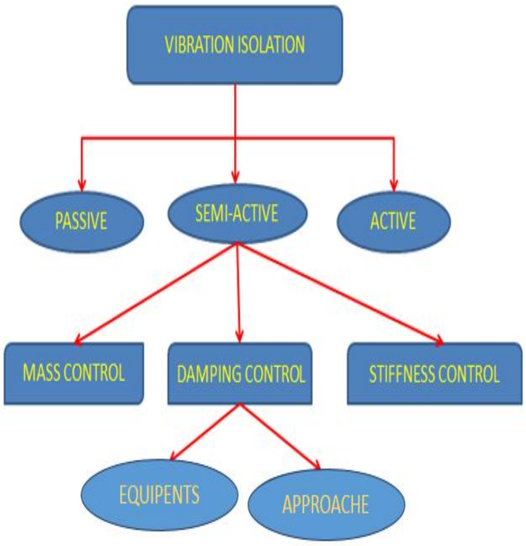


Fig.1 overview of Vibration Suppression

MR dampers are categorized as “semi-active”. This indicates that these dampers retain some oftheir damping properties even when there is no power supply, or even when the controller fails. In suchcases the damper reverts to a passive state, working as a passive damper. This property is a significantadvantage over similar systems which are not semi-active.

3. GEOMTERY DESIGN

MR dampers have been fabricated for various sizes, configurations and load requirements for specific load applications. Of the three modes of operation of MR fluid discussed above, MR damper operates in valve mode and for certain applications in combined (mixed) mode of valve and shear. Based on the construction method, MR dampers are classified into mono tube, twin tube and tri-tube devices. Mono tube is the widely-employed design due to its simplicity for design and fabrication. Twin tube designs are used for load intensive applications and tri-tube design is still in the laboratory research. The type of damper analyzed in this research work is mono tube damper construction. In principle, it is similar to a conventional mono tube damper with few modifications. In many cases, a high-pressure gas chamber is present with a floating piston separating the gas chamber and working fluid. For basic project analyses, the gas chamber design is excluded and limited to the main working fluid or spring can be used. A main piston is present, separating the working fluid into two chambers – compression chamber and rebound chamber. An annular is present in between the piston and cylinder. Few designs also incorporate the annular gap in the piston assembly itself. The figure 3 shows one such design.

The annular gap enables the working fluid to move between the chambers.

In many research works, instead of a single annular gap, rectangular ducts and multiple annular gaps have been employed. The type of flow geometry is decided based on the requirements of safe viscous damping at zero flux (no current flow in the coil) and highest possible damping value achievable at saturation magnetic field. This depends upon a variety of parameters such as type of MR fluid used, type of ferrous particles suspended in the carrier fluid, volume ratio of the ferrous particles, amount of flux in the magnetic circuit.

The current in the coil produces a magnetic flux. The magnetic flux passes through the magnetic circuit of which the piston, MR fluid gap, cylinder wall are the main components. The piston and cylinder are made of materials with high permeability. The magnetic flux crosses across the MR fluid flux as leakage flux. The initial design phase for an MR damper involves the magnetic circuit design incorporating theelectromagnetic properties of the piston material, cylinder material and MR fluid. This project work involves in the basic electromagnetic analysis of an MR damper.

. Figure 2 represents the magnetic circuit of the active working domain of the magneto rheological damper. The dotted line represents the flow of magnetic flux lines. The flux lines form a closed loop taking the lowest reluctance path in the active domain region. The amount of damping force generated from the damper depends up-on the activation of the MR fluid in the annular gap region through which MR fluid flows. The effectively of the damper depends upon the active volume of the MR fluid over which magnetic flux is acting.

3.1 MAGNETIC CIRCUIT OF THE MR DAMPER

The magnetic circuit (loop) for the flux flow is shown in Fig. 2. The dotted line represents the flux flow direction.

Dotted red line path shows the flow of magnetic flux when electromagnetic coils are active where outer cylinder and electromagnetic coil separated by fluid flow gap.

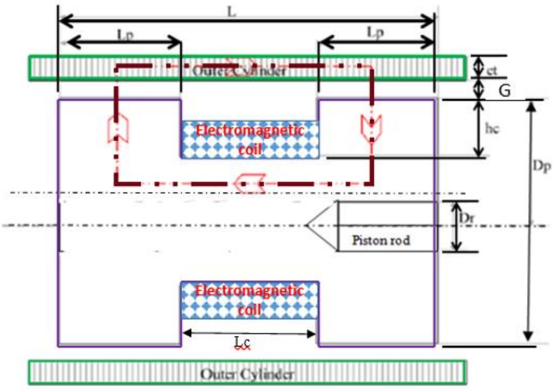


Fig.2 Magnetic flux flow circuit

3.2 GEOMETRIC PARAMETERS INVOLVED

The magnetic flux passes through various cross-sectional areas in the damper. The parameter for each of the flux area passage is found out and listed. The magneto rheological fluid flows in the annular orifice between the piston and cylinder, where the piston bobbin portion acts as a magnetic pole and the piston outer portion acts as the complementary magnetic pole. The fabricated MR damper is compared with LORD MR Damper 8040/1-0. The following dimensions are assumed for the fabricated MR damper.

Table.1 GEOMETRICAL PARAMETERS

Flux path portion	Geometricalparameter
Piston middle portion	Piston diameter (Dp) Piston rod diameter (Dr) Coil portion height (hc)
Piston bobbin portion	Piston diameter (Dp) Width of MR fluid gap (Lp)
Piston outer portion	Piston diameter (Dp) MR fluid flow gap (g) Cylinder thickness (ct)
MR fluid gap	Piston diameter (Dp) Width of MR fluid gap (Lp)

Table.2 DIMENSIONS

Geometrical dimension	Value (mm)
Diameter of the piston (Dp)	30
Diameter of piston rod (Dr)	9
MR fluid gap (g)	1

Pole width (Lp)	4
Total pole width (L)	34
Outer portion thickness (ct	3
Coil height (hc)	7.5
Coil Length(Lc)	26

Final design of ME damper explained under geometry design shown below fig.3 and section shown fig.4

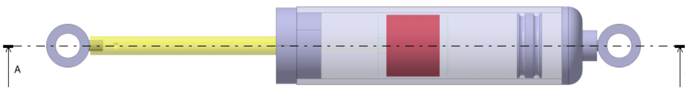


Fig.3 MR Damper (monotube MR damper with floating piston)

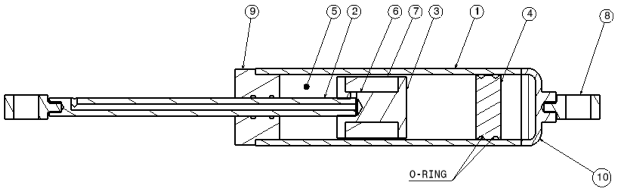


Fig.4 MR Damper section view A-A

The components identified with ballooned numbers are

1. Cylinder
2. Piston rod
3. Piston head
4. Floating piston
5. MR fluid chamber
6. Electric coil
7. MR fluid flow gap
8. Hold hook
9. Top Cover
10. Bottom Cover

3.3 MR FLUID CHAMBER

An MRF consists of micron-sized, magnetically polarized particles Suspended in a carrier fluid, Such as Silicon or mineral oils. MRFs are capable of responding to a magnetic field in a few milliseconds. The material properties of an MRF can be changed rapidly by increasing or decreasing the intensity of the applied magnetic field.

Silicon oil with suspended carbonyl iron powder of 30% of volume is used for the designed damper in this project.

Components are all applied of magnetic steel to accommodate easier flow of MR fluid and effective activation when the current flow through the electric leads to the electromagnetic coil, electromagnetic coil induces magnetic field which passes through the ferromagnetic particles suspended in the MR fluid intern due to magnetic flux flow the ferromagnetic particles become active state and solidifies the state of MR fluid in active portion and resist the movement of piston.

Referring to FIGS. 5 and 6, a conventional MRF damper has an I-shaped magnetic circuit a formed of a ferrous material. Windings of electric wires “b” produce a magnetic flux “c” in the magnetic circuit. However, a Small gap “d” is formed in the magnetic circuit “a” through which the MRF flows according to the displacement of the piston E In this manner, the magnetic flux “c” is directed through the MRF to the cylindrical housing “f” to complete the magnetic circuit path. In the presence of a magnetic field, the ferrous particles in MRP form chains “h” perpendicular to fluid flow through the passage. Accordingly, increased damping results from the particle chain's resistance to Shearing.

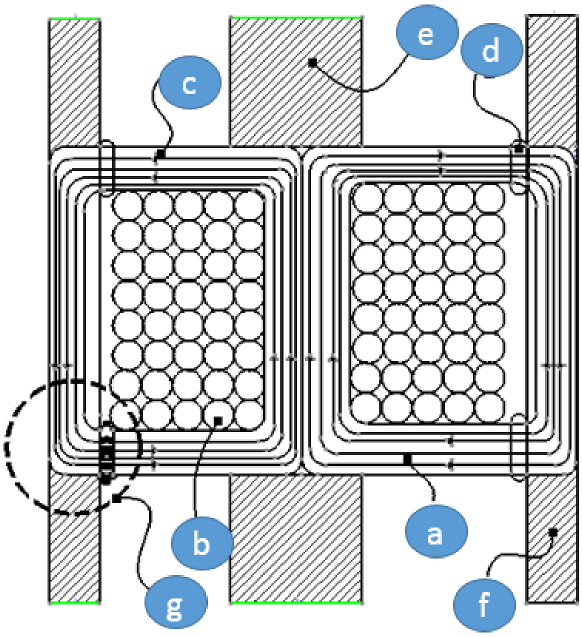


Fig.5 Magnetic Flux flow at piston assembly

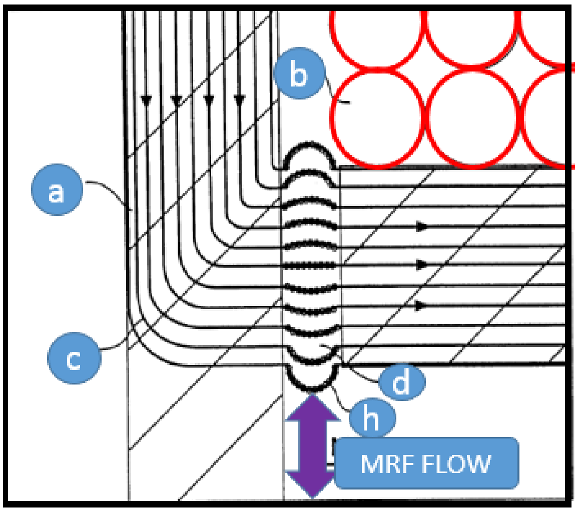


Fig.6 Detail view of chains formed from Magnetic rheological particles

However, conventional MRF damper designs have significant limitations. For example, the magnetic path must be formed of ferrous materials. As illustrated in Fig. 5 and 6, the piston consists of an I-shape magnetic circuit. The magnetic flux lines that are formed only inside the ferrous magnetic circuit activate the MRF at the gaps, thereby creating a chain-like formation of MRF particles across the gap to resist the motion of the piston.

Further, the MRF passages must be very small in order to generate a sizable damping force. As shown in Fig. 6, if the dimension of the gap through which the MRF flows is toolarge, the chain-like formation of the particles will produce smaller resistance forces. Thus, less resistance to the motion of the piston is obtaining, thereby resulting in Smaller damping forces. In contrast, if the gap Size is too small, it is difficult to achieve the necessary tolerance in manufacturing the individual components. Seals are provided at floating piston and top cap using O-ring to prevent leakage or contamination.

3.4 ELECTROMAGNETIC COIL

When designing a MR damper, usually a few of the design's dimensions are known or can be determined. Some of these dimensions include the wire conduit diameter, the bore diameter, the fluid gap, the coil recess length L, and the coil connector groove width and depth. The piston minor diameter must be solved for iteratively until a desired housing outer diameter or total piston length is determined.

Once the piston dimensions have been settled, the coil form dimensions can be calculated, and the maximum number of turns of different wires sizes can be determined.

Magnetic flux density is considered based on the input current values from 0.1amperes to 1.0 amperes and the numbers of turns coil, so to arrive the proper number of turns of coil based on the maximum input current value AWG 24 gauge copper is selected as an electromagnetic coil to wind on the piston head.

a. Wire diameter :

The n gauge wire diameter dn in inches (in) is equal to 0.005in times 92 raised to the power of 36 minus gauge number n, divided by 39:

$d_{n\,(\mathrm{in})} = 0.005\ \mathrm{in} \times 92^{(36-n)/39}$-------------------------------1

Wheren is =24,

$d_{n\,(\mathrm{in})} = 0.0201$ or 0.5106mm

b. Wire cross sectional area :

The n gauge wire's cross sercional area An in kilo-circular mils (kcmil) is equal to 1000 times the square wire diameter d in inches (in):

An (kcmil) =1000×dn^2 =0.025in^2 ×92(36n)/19.5………2

An (kcmil) = 0.404

The n gauge wire's cross sercional area An in square millimeters (mm2) is equal to pi divided by 4 times the square wire diameter d in millimeters (mm):

An (mm^2) =(π/4)×*dn*2 =0.012668mm^2 ×92(36*n*)/19.5……3

An (mm^2) = 0.204

c. Cross sectional area of electric coil winded area:

Cross sectional area of electrical coil winding area is as follow

Ae(mm^2) = height of winding area x length of pole……………..4

Ae(mm^2) = 7.5 x 26

Ae(mm^2) = 195

d. Number of turns coil :

Number of turns coil is requisite parameter to derive the magnetic flux density as follows

$$\text{No. of turns coil} = \frac{\text{Area of cross section of rectangular winding area}}{\text{Area of cross section of copper wire}}$$

$$N = \frac{An}{Ae} \qquad \text{----------------------5}$$

$$N = \frac{195}{0.204}$$

N = 956

4.FEM ANALYSIS OF MR DAMPER

The geometry is constructed in Ansys software as an axisymmetric design. The MR damper analyzed consists of an annular orifice with MR fluid gap of 1 mm. Fig. 7 shows the axisymmetric geometry of the damper in Ansys. The middle axis of the piston rod represents the vertical axis of symmetry for the domain.

The coil is designed as homogenous multi turn coil and is copper wire AWG24-gauge diameter. Analysishas been done for 956 turns. Initially, the whole domain is assumed to be at zero magnetic vector potential.The domain is meshed with 92899 elements as shown in Fig. 8

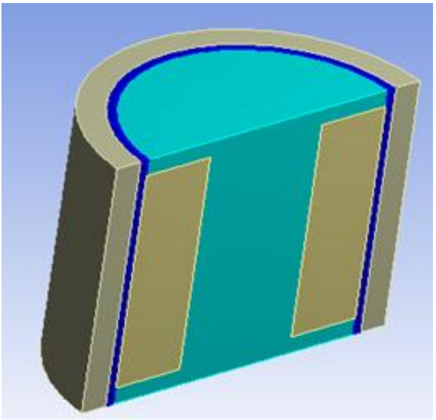


Fig.7 Symmetry design

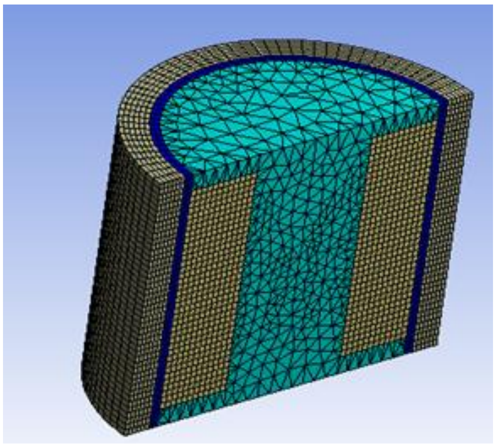


Fig.8 Mesh structure

The problem is solved for varying current values supplied to the coil ranging from 0.1 ampere to 1 ampere in steps of 0.1ampere with coil turns of 956 turns and 12V.

Boundary conditions applied for varying current are shown in table 5. Ansys FEA solver solves the problem in the electromagnetic domain and magnetic flux density values are obtained for all the conditions.The magnetic flux lines generated for a current value of 0.5 ampere and 956 turns with a pole width of 26 mm is shown in figure 9.

Table 3. Boundary conditions applied to obtain the Magnetic flux density

DC current(A)	Voltage(V)	Max. Magnetic flux density(T)
0.1	12	0.2814
0.2	12	0.4455
0.3	12	0.5086
0.4	12	0.5425
0.5	12	0.5699
0.6	12	0.5938
0.7	12	0.6151
0.8	12	0.6345
0.9	12	0.6522
1.0	12	0.6687

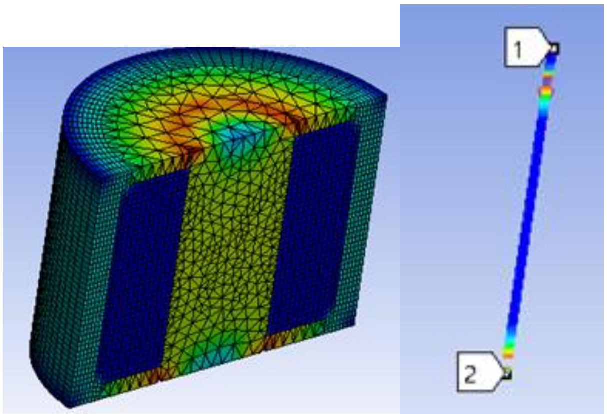


Fig 9- Magnetic flux density

Maximum flux density obtained at varying current of 0.5A and constant voltage of 12V with number of electric coil of 956 turns is 0.56996T.

Figure 9 show the magnetic flux density distribution for 956 turns, 0.5 ampere, 26 mm pole length conditions. The following combinations are implemented for simulating the magnetic flux density distribution. The current is varied from 0.1 ampere to 1.0 ampere in steps of 0.1 ampere. The numbers of turns of the coil are kept at 956 turns.

The magnetic flux density values for current values from 0.1 amperes to 1 amperes in steps of 0.1 amperes for 956 turns coil and a pole length of 26 mm is given in fig.10 along flow gap.

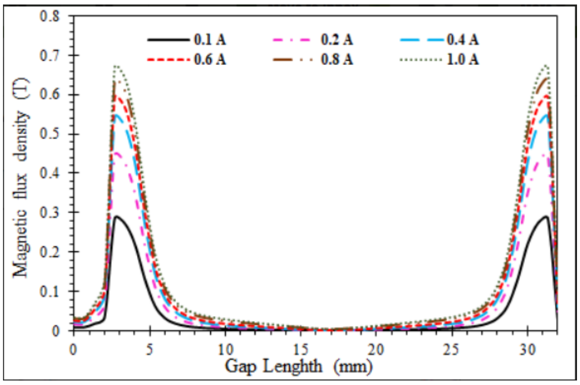


Fig.10 Variation of magnetic flux density along flow gap

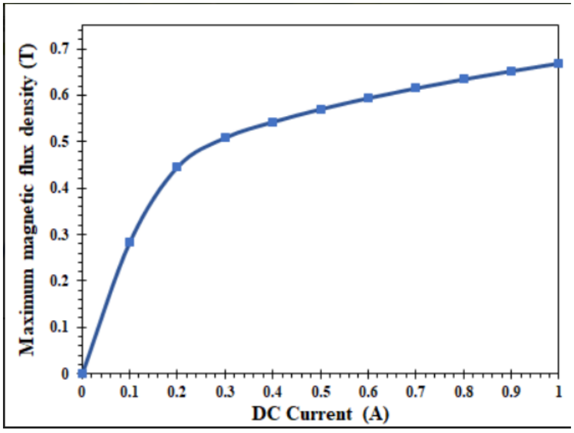


Fig.11 Magnetic saturation of magnetic coils

MRF (magneto rheological fluid) passages must be very small in order to generate a sizable damping force if the dimension of the gap through which the MRF flows is too large, the chain-like formation of the particles will produce smaller resistance forces and lower magnetic flux. Thus, less resistance to the motion of the piston is obtaining, thereby resulting in Smaller damping forces. Plot shows that at minimum gap length and maximum current of 1.0A can achieve magnetic flux density of 0.68T.

Similarly Magnetic saturation of magnetic coil analyses has been done for varying current. Higher the current higher will be the magnetic flux density. Saturation is the state reached when an increase in applied external DC current (A) cannot increase the magnetization of the material further.

Analysis values potted in fig.11 maximum magnetic flux density versus DC current shows that at the maximum current of 1A maximum magnetic flux density is 0.68(T) in which further increase of DC current will not increase the magnetization of the passing material intern there will be slight change in the maximum magnetic flux density.

5. Computation of damping force of MR damper

Shear valve mode is adopted and it has the merit of simple configuration and high damping force. Calculation of damping force of MR damper is based on damping Force developed in the flow mode type of MR damper isStated as detailed by Jolly et al. [9], Xu et al. [10],Gurubasavaraju et al.[1].

Figure 12 illustrates the parameters of damper designed in which "g" the fluid flow gap through the piston head, so the fluid flow mechanism is the flow mode as there is not relative motion in the annular gap in the piston head and also the requisite Dimension of the MR damper are depicted in the table 4.

The total damping force F produced by MR damper includes controllable damping force $F_{\tau,}$ a plastic viscous force $F_{\eta}$and a friction force F_f [11]

$$F = F_{f\tau} + F_{f\mu} \quad (1)$$

$$F_{f\tau} = \left(2.07 + \frac{12Q_f\mu}{12Q_f\mu + 0.4w\tau_b g^2}\right)\frac{c_f\tau_b L_t}{g}A_{fp} * Sgn(\acute{u}), \quad (2)$$

$$F_{f\mu} = \left(1 + \frac{wg\grave{u}}{2\grave{u}A_{fp}}\right)\frac{12\mu Q_f L}{g^3 w}A_{fp}, \quad (3)$$

$$A_{fp} = A_p = \frac{\pi}{4}[D_c^2 - \{(D+2h)^2 - D^2\} - d_0^2], \quad (4)$$

$$w = \pi(D+g); c_f = \left(2.07 + \frac{12Q_f\mu}{12Q_f\mu + 0.4w\tau_b g^2}\right), \quad (5)$$

Shear Stress=$107356B^4 - 122177B^3 + 33803B^2 + 9941B - 65.907$ (6)

Where F = Damping force (N), $F_{f\mu}$ = Viscous damping force (N), $F_{f\tau}$ = Damping force due to shear stress (N),F_f= friction force,Q_f = Volumetric flow rate (m^3/s), l = Viscosity (Pa-s),τ_b = Field-dependent shear stress (Pa), A_{fp} = Area of piston head (m^2), g = Fluid flow gap, ù = Relative velocity (m/s), c_f = Flow rate-dependent coefficient, w = circumferential area (m^2).

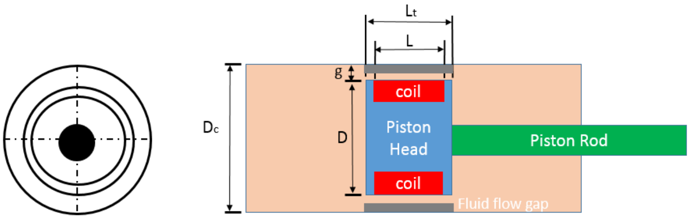
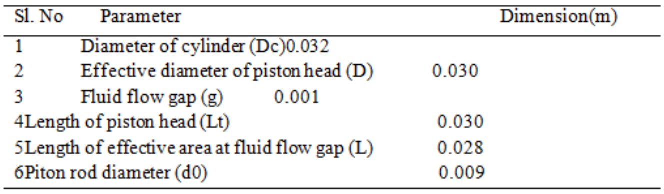


Fig.12 Diagram of MR damper

Table.4 Dimension of MR damper



Sl. No	Parameter	Dimension(m)
1	Diameter of cylinder (Dc)	0.032
2	Effective diameter of piston head (D)	0.030
3	Fluid flow gap (g)	0.001
4	Length of piston head (Lt)	0.030
5	Length of effective area at fluid flow gap (L)	0.028
6	Piton rod diameter (d0)	0.009

Shear stress computed by using the equation 7, the max. Magnetic flux density obtained by analysis are substituted to equation 7 and the enlisted equations are solved for obtained parameters and substituted to equation 1 for damping force of the designed MR damper.

The determined variables are enlisted in table.4, by substituting the parameters into equation 6.

$$F_{f\tau} = \left(2.07 + \frac{12 \ast 4.1 \ast 10^{-6} \ast 0.000296}{12 \ast 4.1 \ast 10^{-6} \ast 0.000296 + 0.4 \ast 0.097387 \ast 6631.933 \ast 0.001^{2}}\right) \ast \left(\frac{6631.933 \ast 0.0028 \ast 0.000643}{0.001}\right) \ast Sgn(0.006377)(6)$$

$$= 247.260\ kN$$

$$F_{f\mu} = \left(1 + \frac{0.097387 \ast 0.001 \ast 0.006377}{2 \ast 0.006377 \ast 4.1 \ast 10^{-6}}\right) \ast \left(\frac{12 \ast 0.000296 \ast 4.1 \ast 10^{-6} \ast 0.03 \ast 0.000643}{0.001^{3} {\ast} 0.097387}\right) \qquad (7)$$

$$= 0.002888\ kN$$

$$F = 247.260 + 0.002888 = 247.26\ kN$$

Maximum damping force achieved is 247.26 kN so damping force satisfy design requirement for low force damper applications.

6. SCOPE FOR FURTHER WORK

Based on present work the design of MR damper is completed and Analysis of damper at annular fluid flow gap magnetic flux density for varying current provides the maximum magnetic flux density at fixed voltage, so obtained maximum flux density(B) leads to calculation of shear stress and damping force of designed damper. Based on the achieved design dimensions the MR damper manufactured and tested for damping force.

7. ACKNOWLEDGMENT

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