Experimental Investigation on Magnetorheological Damper for Seismic Resistance of Structures with Nano Fe_3O_4 MR Fluid

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Abstract

Semi active control system such as Magnetorheological (MR) damper has drawn significant attention in various fields. Magnetorheological dampers consist of MR fluid which is suspensions of magnetically polarizable particles with a few microns in size dispersed in a carrier liquid as silicone oil. In this study various factors which affect the magnetic flux density are being studied analytically using Finite Element Method Magnetics (FEMM) software. Then Fe_3O_4 Nano Iron particles are sonicated with silicone oil as 40-60 ratios by weight. This MR Fluid is used to the MR Damper which fabricated and mounted diagonally in the Reinforced concrete frame with and without MR damper for cyclic load test to know the behavior of MR Damper for seismic resistance. The energy dissipation capacity 45% increased and displacement reduced by 43 %.

Key words: MR damper, MR fluid, Magnetic flux density, Optimal design, RC Frame

I. INTRODUCTION

Magnetorheological dampers are semi active control system. Semi active control systems use a very less external power source and use the motion of structure to develop the control forces. MR damper uses MR fluid to produce damping force.MR fluid is composed of oil and different percentages of iron particles. When there is no magnetic field is present in the fluid act as ordinary oil. In the presence of magnetic field, the fluid rapidly increases its apparent viscosity due to the dispersed iron particles align themselves to form chains and become like semi solid material and then produce a damping force.

Many studies have been carried out considering different number of coil, different piston shape, etc. Guoliang Hu et al [1] optimized MR damper using finite element analysis for different configurations of MR damper piston, MR fluid gap, and Dampers housing. [2] studied about the performance of MR damper with various piston configuration and found single coil with fillet end gave better result. Mohammed et al. [3] investigated the design, manufacturing, and testing of a large capacity MR damper and found some discrepancy between measured and tested result. Khan et al. [4] developed a new concept for MR damper which combined shear and squeeze working modes. Alan Sternberg et al [5] studied about the optimal design of double coil MR damper for various pistons and compared with experimental results and found it to validate the result. Parlak et al.

In this study various factors which affect the magnetic flux density are being studied and thus the MR damper which gives optimized result is being found. FEMM software was used to analyze the magnetic field generated by electromagnetic circuit of the MR damper.

II. MR Fluid:

Magnetorheological (MR) fluids are materials that respond to an applied magnetic field with a change in rheological behavior. Typically, this change is manifested by the development of a yield stress that monotonically increases with applied field. Interest in magnetorheological fluids derives from their ability to provide simple, quiet, rapid-response interfaces between electronic controls and mechanical systems. That magnetorheological fluids have the potential to radically change the way electromechanical devices are designed and operated has long been recognized.

The magnetorheological response of MR fluids results from the polarization induced in the suspended particles by application of an external field. The interaction between the resulting induced dipoles causes the particles to form columnar structures, parallel to the applied field.

These chain-like structures restrict the motion of the fluid, thereby increasing the viscous characteristics of the suspension. The mechanical energy needed to yield these chain-like structures increases as the applied field increases resulting in a field dependent yield stress.

In the absence of an applied field, MR fluids exhibit Newtonian-like behavior. Thus the behavior of controllable fluids is often represented as a Bingham plastic having a variable yield strength.

The Magnetorheological Fluid used for the below experiments are the mixture of silicone oil and Fe_3O_4 Nano iron particles. 60 % of Iron particles and 40 % of Silicone oil by weight was used for sonication.

In the SEM Analysis test conducted it was observed that the Fe_3O_4 sample is Nano in size with 0.5 μm.

Fig. 1. a) Fe_3O_4 Iron particles b) Silicone oil c) MR Fluid

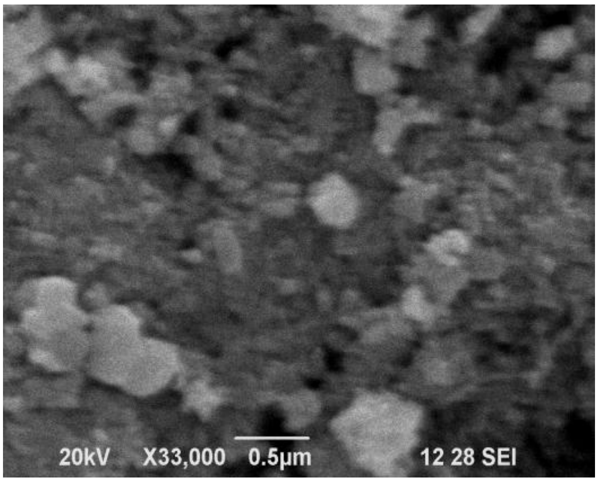

Fig. 2 SEM image of Fe_3O_4 Nano Iron particles

III. ANALYTICAL DESIGN OF MR DAMPER

The dimension of the MR damper taken for study about the magnetic field density is shown in Fig 1. The effect on MR damper due to various parameters was studied. The parameters studied are

(i) Number of turns of coil (ii) Current intensity (iii) Piston pole material (iv) Piston pole gap (v) Use of shear mode (vi) American Wire gauge (vii) Percentage filled in coil

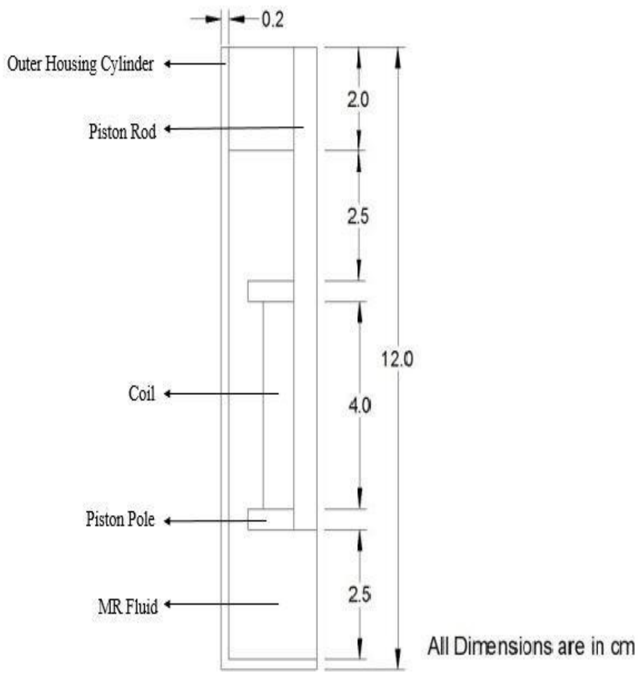

Fig. 3. Sketch of the design of MR damper

B-H Curve for Fe_3O_4

In this study Fe_3O_4 iron particles B H curve was considered as the MR fluid and analyzed. MR fluid formulated for general use in controllable, energy-dissipating applications.

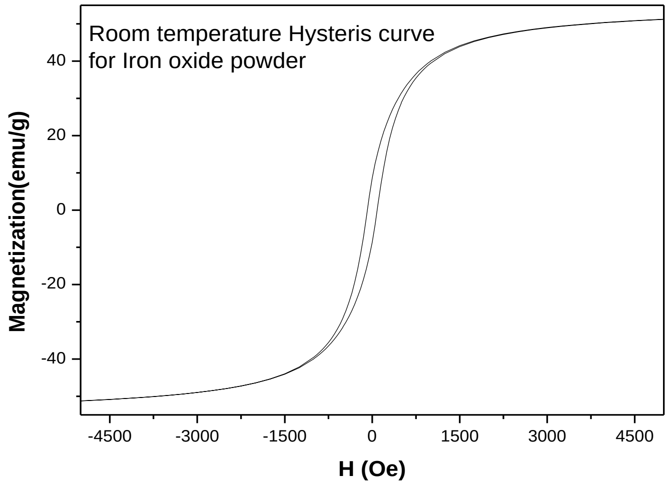

Fig. 4. B-H Curve for Fe_3O_4

Current & Coil Turns

This part of this study evaluates the performance of the damper to various operating current intensity. The current intensity was varied from 1, 1.5 and 2 Amp. It was found that as the current intensity increases the magnetic field strength increases. The magnetic flux density for different number of turns was studied. The percentage filled in the coil is 97.46% at 500 turns. Hence the number of turns was varied from 250 to 500 turns. Fig. 3 shows the graph obtained between magnetic flux density with respect to number of turns in coil

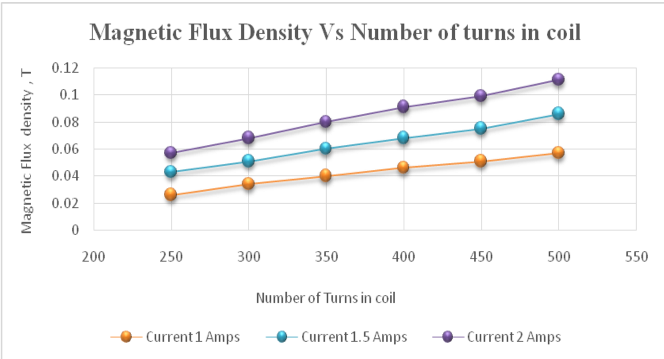

Fig. 5. Magnetic Flux Density Vs Number of turns in coil

Piston pole gap

The effect of piston pole gap size was studied for gap varying from 0.3 cm to 0.7 cm and for different current. The result so obtained is depicted in the graph shown in Fig.4.It was found that as the fluid gap increased, the magnetic flux density increased.

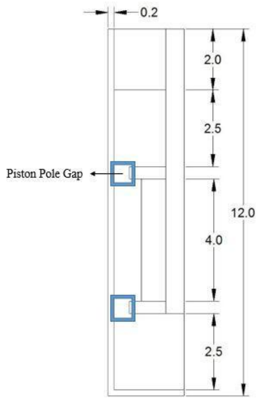

Fig. 6. Piston pole gap

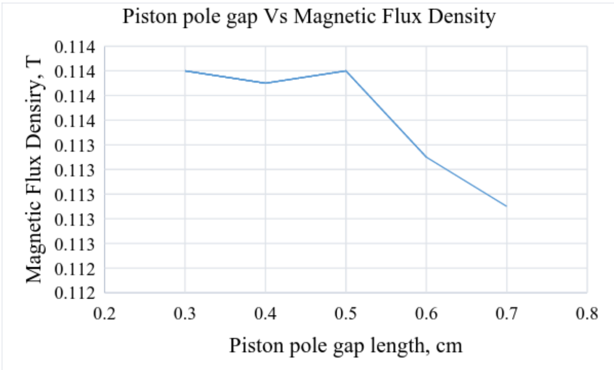

Fig. 7. Piston pole gap Vs Magnetic Flux Density

Piston pole Material

The effect of piston pole material was studied for gap various material as 416 stainless steel,430 Stainless steel, 455 Stainless steel and pure iron. The result so obtained is depicted in Fig. 6. It was found that pure iron material gives high magnetic flux density when compared to other material.

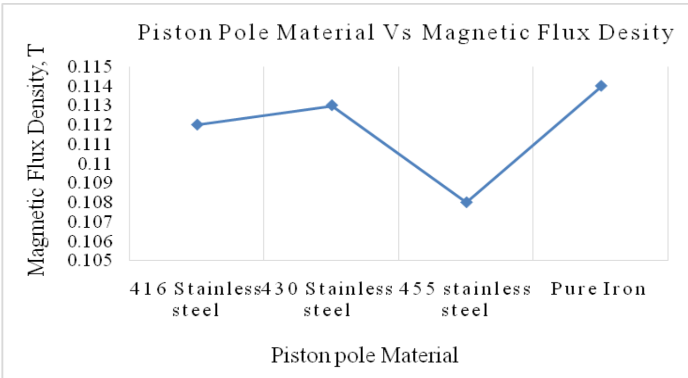

Fig. 8. Piston pole Material Vs Magnetic Flux Density

FEMM Meshing

Mesh generation is the practice of generating a polyhedral or polygonal mesh that approximates a geometric domain. The uses for rendering to computer screen as finite element analysis or computational fluid dynamics. Three-dimensional meshes created for finite element analysis need to consist of prism, pyramids, tetrahedral or hexahedra. Those used for the finite volume method can consist of arbitrary polyhedral. This mesh is otherwise a discretization of a domain existing in one, two or three dimensions.

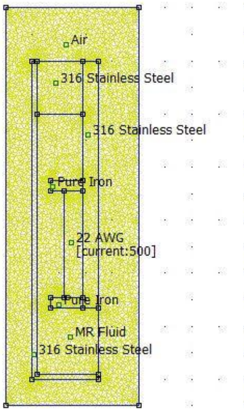

Fig. 9. Meshing

FEMM result of Optimum Design

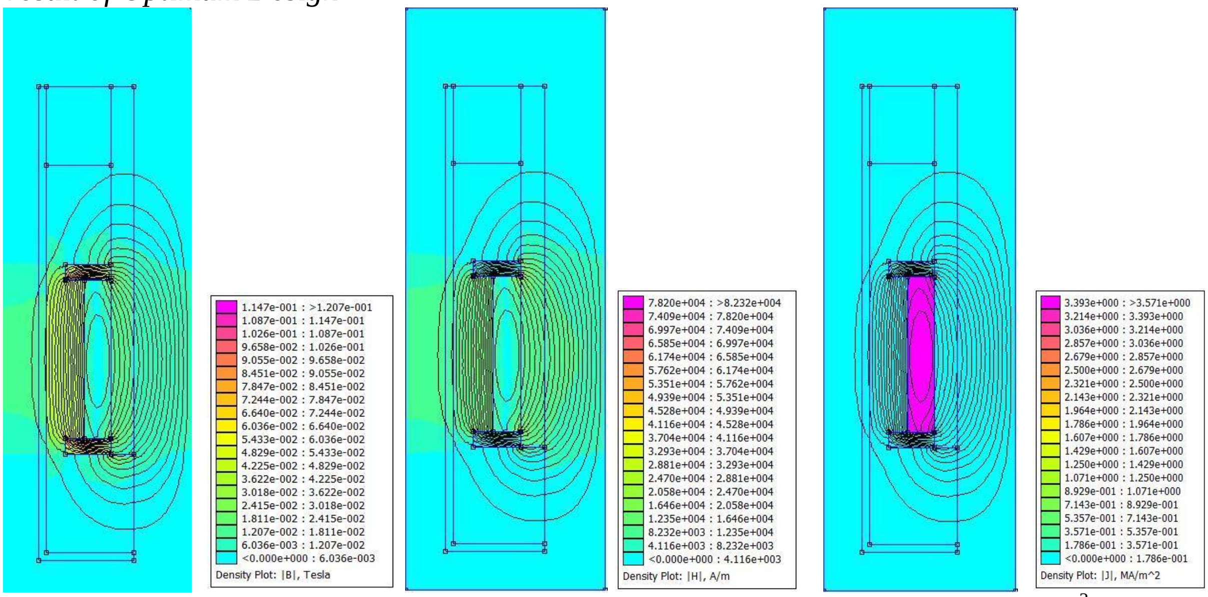

Fig. 11. a) Flux Density, Tesla b) Magnetic field Intensity, Am c) Current Density, MAm^2

MR Damper Fabricated

As per the FEMM which gives the better result the sizes were optimized and fabricated.

Fig. 12 MR Damper

Fig. 13. Coil with piston cap

IV. CYCLIC LOAD TEST

Capacity of the loading frame is 50kN

Table.1 Specimen Details

Grade of the concrete	M25
Reinforcement details	
Beam	8mm
Column	8mm
Stirrups	3mm
Grade	M25
Cement	OPC 53
Size of aggregate	10 mm
Minimum cement content	310 kg/m^3
Slump value	50-75 mm
Specific gravity of cement	3.15
Specific gravity of fine aggregate	2.605
Specific gravity of coarse aggregate	2.88
Support condition	Fixed
Mix ratio	1: 1.8: 1.7

Fig. 14. Casted RC Framed Specimen

Single Bay Frame without Damper

This specimen was designated as the reference frame to compare its performance against frame with damper. Ten displacement cycles were applied to the frame. First cracks were observed at a load of 6 kN and the corresponding displacement was at 9. 583 mm.

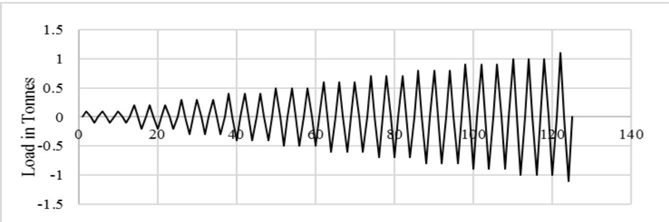

Fig. 15. Loading history

The maximum cracks opening was obtained as 1.0 mm. The ultimate load carrying capacity of bare frame is 19 kN.

Fig. 16. Bare frame without Damper

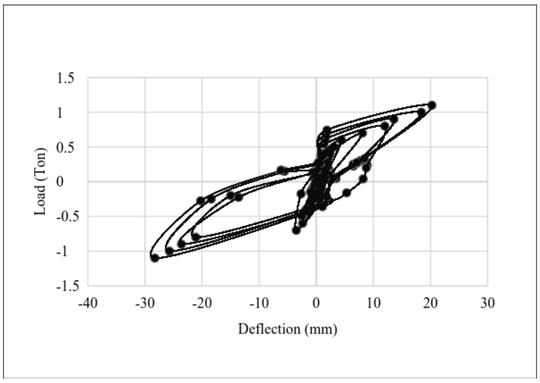

Fig. 17 Load Vs Deflection for bare frame

Frame with Damper

Sixteen full displacement cycles were applied to the frame. First cracks were observed at a load of 8 kN and the corresponding displacement was at 5.463 mm. The maximum crack opening was obtained as 1.0 mm. The ultimate load carrying capacity of bare frame is 37.7 kN.

Fig.18 Single bay frame with Damper

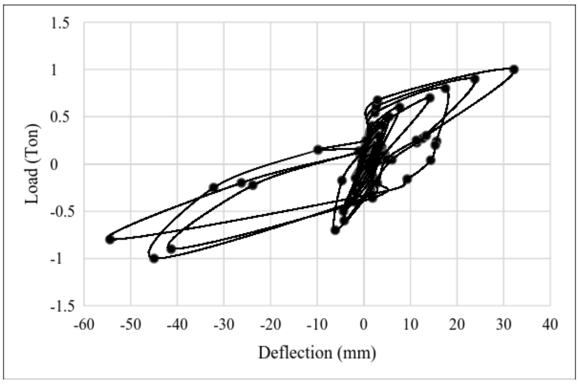

Fig. 19 Load Vs Deflection for bare frame with MR Damper

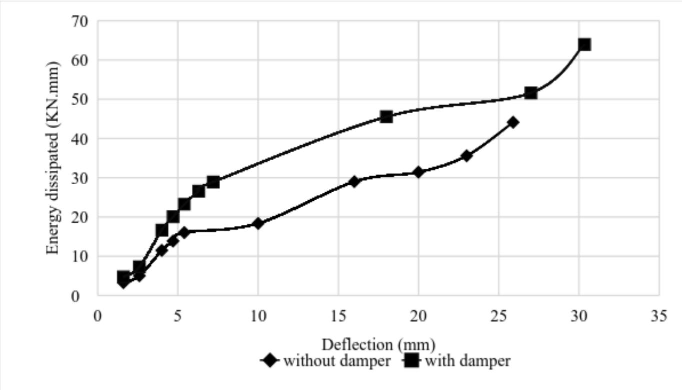

Fig. 20 Energy dissipation Vs Deflection

IV. CONCLUSIONS

In this research it was observed that MR damper is highly controllable. Maximum vibration reduction for Shear mode MR damper is proved in Cyclic Load test where the displacement reduced by 43 %. The MR Damper is designed as per the analytical result in Finite Element Method Magnetics (FEMM). Fe_3O_4 is Nano in size proved by SEM Image. As for as the carrier liquid is concerned silicone oil is used. From this experimental study the cyclic load test bare frame without Damper first crack was observed at 6 KN whereas with damper the first crack at 8 KN. The specimen failed at without Damper at 17 KN, the specimen with Damper Loaded till 37.7 KN. After the cracking widening of cracks did not occur & failure was not observed. Ultimate load carrying capacity 55% increased. The energy dissipation capacity 45% increased when compared to bare frame.

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