# Magneto Static Analysis of Mr Fluid Brake

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***Abstract***- *This paper mainly concentrating on the Magnetic flux density distribution in fluid flow gap at different current, because the braking torque is highly depending on the magnetic flux density developed in the gap. Different proportions of MR fluid has been prepared and evaluate the Rheological properties under different magnitude of current. MR brake model has been developed and analyzed the flux distribution in the flow gap. Results show that, magnetic flux density increases with increase in current.*

***Keywords***- Magneto rheological fluids, Rheometer, FE analysis, Magneto rheological brake

## I. INTRODUCTION

The disc in the conventional brake systems used in vehicles is wears out and the brake pollutes the environment. Brake pad dust is reported to be the largest source of environment pollution. To particles emanating because of wear of the brake pad pollutes the environment. In addition to pollution cause by wear particles, the friction induced noise between the brake pad and the disc is also a major concern. Also, the localized heating occurs in a conventional disc brake. To tackle these problems, conventional disc brake can be replaced with magneto-rheological fluid brakes.

The friction between the stator and the rotor increases and fulfills the braking function, which means that magneto-rheological fluids can be used as a brake friction material. A magneto-rheological brake consists of a rotating disc immersed in a magneto-rheological fluid and enclosed in an electromagnetic casing. The torque characteristics of the magneto-rheological brake in the shear mode are controlled by regulating the yield stress of the magneto-rheological fluid. An increase in the yield stress increases the braking torque, which means that, the higher the yield strength of the magneto-rheological fluid, the better is the performance of the magneto-rheological brake. An ideal magneto-rheological brake should exert a zero-frictional torque in the off-state condition and a controllable frictional toque in the on-state condition.

Chiranjit Sarkar and Harish Hirani [1], *this* paper describes the electromagnetic action in magneto rheological (MR) brake (MRB) system using finite element method.

Mangal and Vivek [2], this paper presents an experimental set up comprising of an electromagnet capable of generating 2.0 Tesla for an air gap of 18 mm has been designed to determine magnetic flux density values. Karakoc [3], in this paper the development of a novel electromechanical brake (EMB) for automotive applications is presented. Such brake employs mechanical components as well as electrical components, resulting in more reliable and faster braking actuation. The proposed electromagnetic brake is a magnetorheological (MR) brake. Kumar et al.,[4], the aim of present research work is to develop a finite element model to investigate the effect of disc material and magnetic saturation (by inserting B-H curve) on magnetic flux density. Thanikachalam, et al.,[5],this paper presents Prepration of MR fluid and improved MRB design is made, taking into account the temperature effects .Kumbhar et al.,[6], in this paper various electrolytic and carbonyl iron powder based MR fluids have been synthesized by mixing grease as a stabilizer, oleic acid as an antifriction additive and gaur gum powder as a surface coating to reduceagglomeration of the MR fluid. Edward et al.,[7 ], this paper presents the development of a new electromechanical brake system using magnetorheological (MR) fluid. The proposed brake system consists of rotating disks immersed in a MR fluid and enclosed in an electromagnet, where the yield stress of the fluid varies as a function of the magnetic field applied by the electromagnet

## II. MAGNETO RHEOLOGICAL (MR) FLUID PREPARATION:

MR fluids are smart fluids and it experience remarkable changes in physical properties due to the influence of magnetic field, the fluid greatly increases its apparent viscosity to the point becoming a viscoelastic solid. They exhibits maximum yield strength of 50- 100 kpa.

MR fluids mainly have three components i.e., the magnetizable particles, the carrier liquid and additives (stabilizer),The pure carbonyl iron powder(iron particle) of density 7.86 $kg/m^3$is selected for preparation of MR fluid

samples in the laboratory. The primary function of the carrier fluid is to provide a low permeability and non–magnetic base liquid in which the magnetically active phase particle remains suspended. In order to keep the off-state viscosity low, silicon of 350 cst is used for the preparation of fluid samples. Additives used in fluid preparation for prevention and minimization of sedimentation, coagulation of
the particles, maintain a coating on the particles in order to enhance the re-dispersibility and to enhance anti-oxidation.

For preparation of MR fluid following accessories are required i.e., a mechanical stirrer, beaker, weighing scale and with above constituents.

Following are the steps for fluid preparation,

- First step is to take the low viscosity silicon oil and add grease with correct quantity in a beaker.
- Stir this improper mixture of low viscosity silicon oil and grease with the help of mechanical stirrer for proper mixing.
- Then wait for 2 hours so that grease get completely soluble in silicon oil. After that add iron particle of 3-12 microns size in above mixture and again stir it with the help of mechanical stirrer for 15 to 20 minutes for proper mixing.

Three different proportion MR fluids are prepared( MRF1, MRF2, MRF3) and evaluate Rheological properties at different current levels.

Figure.1 shows the prepared fluid and Table.1 shows the composition of materials.


**Figure.1 MR fluid samples**

**Table.1 COMPOSITION OF SAMPLES**

| Sample MR fluid | Carbonyl iron powder | Silicon oil + Grease |
|---|---|---|
| MRF1 | 78.6gms (10%) | 90ml +2gm |
| MRF2 | 117.9gms (15%) | 85ml +2gm |
| MRF3 | 157.6gms(20%) | 80ml +2gm |

## III. CHARACTERIZATION OF MR FLUID

The rheological characterization of MR fluid was carried out by using Figure.2 rotational type rheometer (Anton paar MCR 320 model) with parallel plate configuration and magneto rheological device (MRD) cell attached to it. The experimental set up consists of three main parts, i.e., measuring plate, MRD attachment cell and software for user interface. In the MRD attachment, it has a magnetic yoke which monitors and maintain the parallel plate temperature. The magnetic field lines flow from bottom plate to upper plate from electromagnetic coil which is placed in the bottom position of the rheometer. Normally the samples are placed between the two plates and then the torque is applied on the top plate which exerts a rotational shear stress on the sample then the signals from the load cell are recorded in the system for analysis.

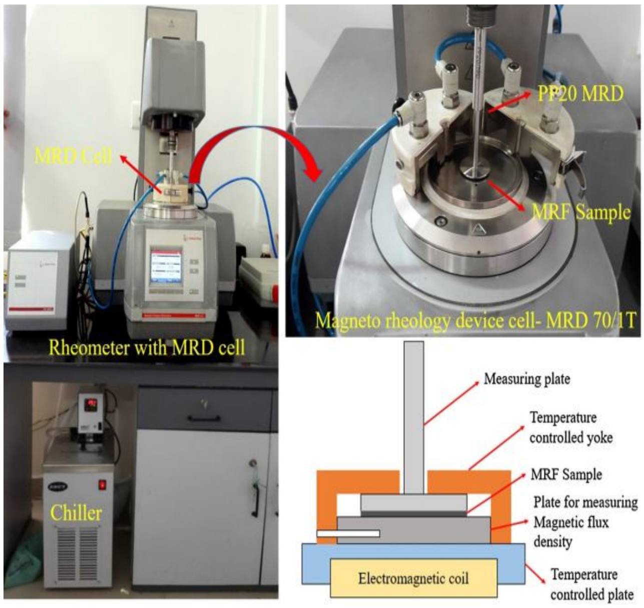


**Figure 2 Rheometer**

The experiment is conducted to study the responses of the MR fluid samples along the field direction. The samples of MR fluid were stirred thoroughly before measurement. The small quantity of MR fluid was taken onto the lower plate by using the spatula for the measurement. Then the samples were subjected to constant shear rate for varying current i.e., 0A, 0.5A, 1A, 2A. 1mm gap is made between the two plates in which the fluid was placed. After placing the samples the pre -shearing was produced by revolving the upper plate with $2.2s^{-1}$ was applied to the MR fluid for 3min to get good dispersion of the fluid. At the beginning, the readings for the load cell under no field and zero shear strain conditions were recorded for few seconds. Then the desired load was applied for required data and the readings were recorded in the system. Recorded data has been tabled in Table 2.

- The shear stress for various samples was plotted The shear stress for various samples was plotted against varying shear rate for varied current which is shown in Figure 3. From the graph it is seen that the shear rate increases as shear stress goes on increasing. This makes the fluid to offer resistance to the rotation of the fluid to offer resistance to the rotation of the disc with increase in shear rate.

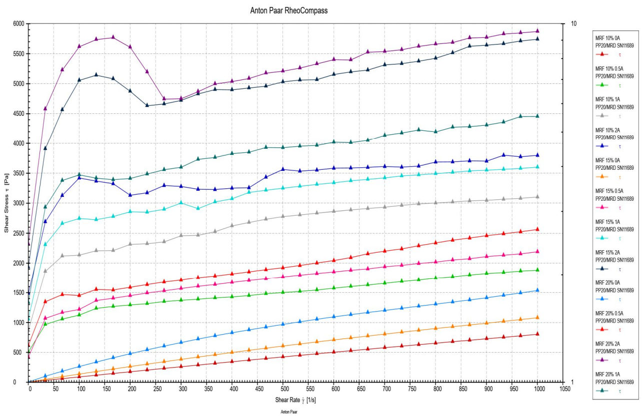


**Figure 3 Flow curve of MR fluid**

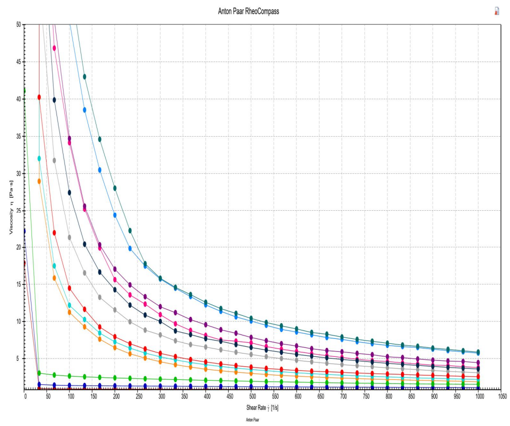


**Figure 4 Viscosity v/s Shear rate curve**

- Figure 4 represent the viscosity value of all MRfluids with shear rate. The viscosity value is measured in Pa sec. Here non Newtonian flow behavior is observed at zero magnetic field. Here, viscosity decreases with increasing shear rate. At low shear rate, the viscosity of MRF 3 is greater than other. At higher shear rate, the value of all three samples is nearly same. At higher shear rate the value of viscosity is equal to nearly 1 Pa sec. Shear thinning behavior of the MR suspensions observed.

**Table 2 Rheometer fluid test results**

| Fluid name | current | shear stress | shear rate | viscosity |
|---|---|---|---|---|
| | [A] | [Pa] | [1/s] | [Pa·s] |
| MRF 1 | 0A | 803.75 | 1000 | 0.80378 |
| | 0.5A | 1882.9 | 1000 | 1.8828 |
| | 1A | 3101.8 | 1000 | 3.1018 |
| | 2A | 3794.5 | 1000 | 3.7942 |
| MRF 2 | 0A | 979.4 | 1000 | 0.9794 |
| | 0.5A | 2189.9 | 1000 | 2.19 |
| | 1A | 3601.5 | 1000 | 3.6016 |
| | 2A | 5740.2 | 1000 | 5.7404 |
| MRF 3 | 0A | 1136.4 | 1000 | 1.1364 |
| | 0.5A | 2559.4 | 1000 | 2.5594 |
| | 1A | 4453.3 | 1000 | 4.454 |
| | 2A | 5872.5 | 1000 | 5.8727 |

Figure 5 Shows that as supplied current increases from 0-2 Amps gradually the viscosity of the flowing fluid will also increases.

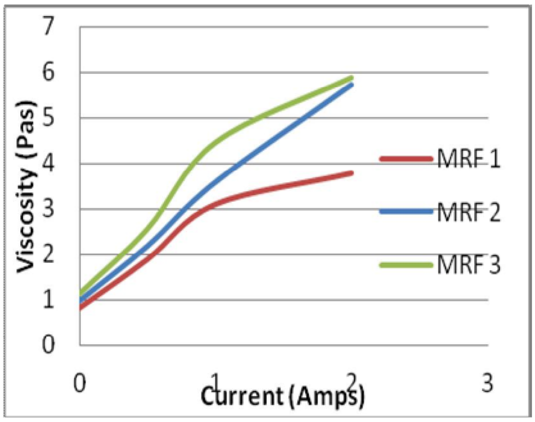


**Figure 5 Current v/s Viscosity**

## IV. FEM MODDELING AND STUDY OF MAGNETICFLUXDENSITY DISTRIBUTION

The geometry of MR fluid brake is symmetric about the axis, therefore it is analyzed as a 2-D axi-symmetric model as shown in Figure 6. Two dimensional axi-symmetric modeling drastically reduces the computational cost. In Figure 6 an axi-symmetric view of single disk MR brake has been shown. In this configuration it is assumed that rotating disk is mounted on the shaft with interference-fit and for FEA the shaft and rotating disk can be treated as a single component as single element for analysis.

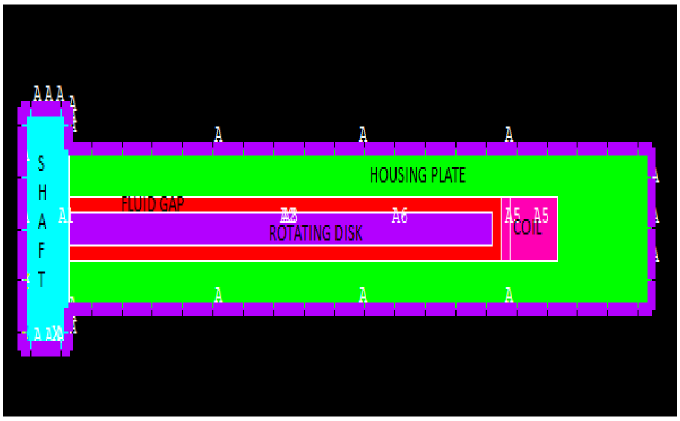


**Figure 6. 2D Single disk MR brake**

In order to predict the effect of magnetic field strength, Magneto static analysis has been carried out. Current was supplied to copper coil in order to get the magnetic effect at the disc, housing and MR fluid. PLANE 13 element having four nodes with each nodes having four degree of freedom was used to mesh the geometry. PLANE 13 element have provision to insert B-H curve and Relative permeability for prediction of magnetic flux effect on magnetic field strength. The KEYOPT (3) option was selected to use axisymmetric simulation. All other input parameter as current (0-2 amp), number of coils (500), cross sectional area of coil (0.016 m2). The MR fluid gap was acts as a torque arm and kept as 3 mm. EMUNIT command was used to maintain the SI units throughout the analysis. It was assumed that there is no leakage from housing to environment. The Materials used and values of relative permeability assigned to materials of various MR brake components are listed in Table 3 and BH curve plots of iron material is showed in Figure7

**Table 3 Materials used and its relative Permeability values.**

| PARTS | MATERIALS | RELATIVE PERMEABILITY |
|---|---|---|
| Shaft | Stain less steel | 1 |
| Coil | copper | 0.9996 |
| Rotating disk | Carbon steel/Iron 99.8% pure | 100/5000 |
| Housing plate | Carbon steel/Iron 99.8% pure | 100/5000 |
| MR fluid | MRF 1,2,3 | 3.684 |

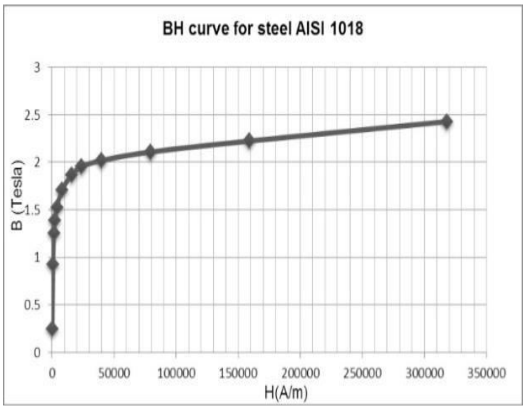


**Figure 7 B-H curve of iron material**

In this analysis assumption of zero leakage from housing to the surrounding environment was made. To impose this constraint of parallel direction of the magnetic flux on boundaries of housing was used. 2D magnetic static analysis was performed to find the distribution of magnetic flux lines flow within the brake housing. Figure 8 shows the 2 D flux flow lines in complete path MR brake. The values of maximum flux flow lines (SMX) are 1267.38.When supplied current is 2Amps and selected disk and housing plate material is iron 99.8% pure. It is interesting to note that flux lines are passing through the shaft. As torque is calculated along the disk, magnetic field concentration should be around the disk plate and magnetic field in the shaft should be as low as possible. Hence the shaft material should be non-magnetic material i.e. stain less steel.

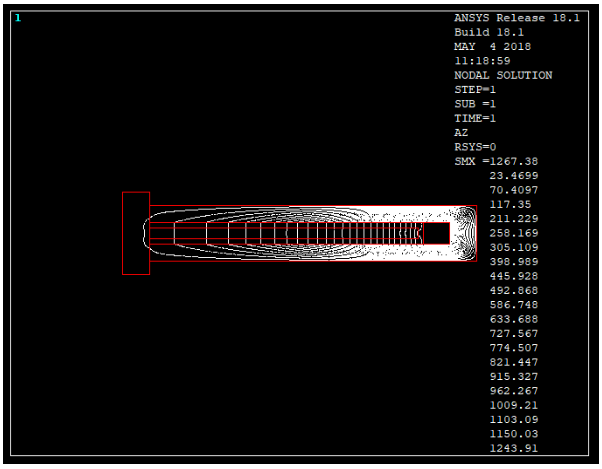


**Figure 8 2D flux flow lines inside the brake**

Table.4 Indicates that with increase in the magnetic flux density for two different , and graphical representation is also showed in Figure 9. The vector plot of magnetic flux density distribution within the MR fluid brake is shown by using nodal solution Figure 10 and Figure 11, which shows the magnetic flux distribution MR brake models. It shows that Iron 99.8% pure has maximum magnetic flux density (SMX) of 4.68 Tesla in fluid flow gap at maximum current of 2Amps compare to low carbon steal which produces 1.28 Tesla maximum at current 2Amps.

**Table 4 Estimation of Magnetic flux density of Materials**

| Current, I (Amp) | Low Carbon steel | Iron 99.8% pure |
|---|---|---|
| 0 | 0 | 0 |
| 0.2 | 0.287 | 0.519 |
| 0.4 | 0.384 | 1.038 |
| 0.6 | 0.499 | 1.456 |
| 0.8 | 0.543 | 1.848 |
| 1 | 0.606 | 2.214 |
| 1.2 | 0.715 | 2.730 |
| 1.4 | 0.855 | 3.148 |
| 1.6 | 1.032 | 3.396 |
| 1.8 | 1.114 | 4.161 |
| 2 | 1.287 | 4.681 |

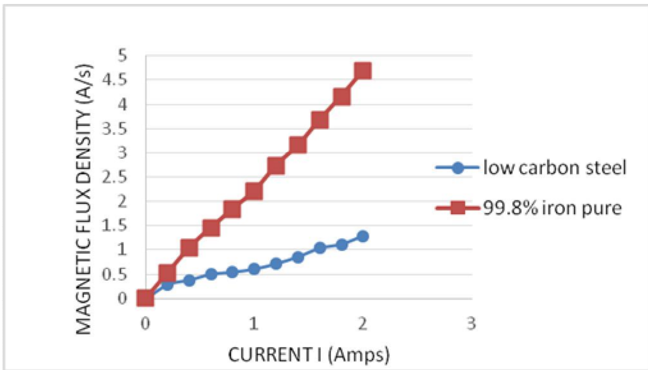


**Figure 9 Current v/s Magnetic flux density**

It is compulsory to understand the material requirement for MR brake housing. Low permeability of material is required to minimize the leakage of magnetic field. However, higher permeability of material is required to transmit magnetic field from housing to rotating disks. To understand this, the simulation was carried on two materials: low carbon steel (relative permeability 100) and iron 99.8% pure as housing stationary plate (relative permeability 5000).

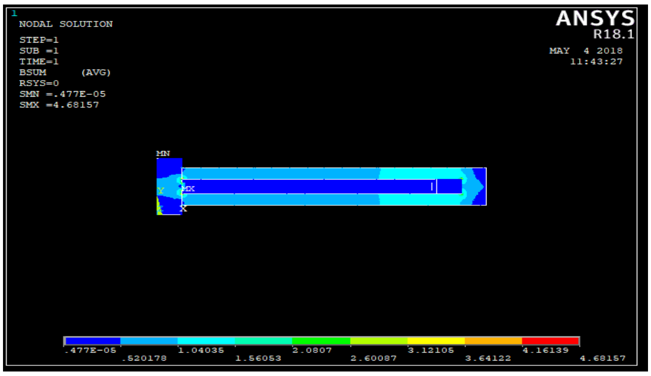


**Figure 10 Magnetic flux density of Iron 99.8% pure**

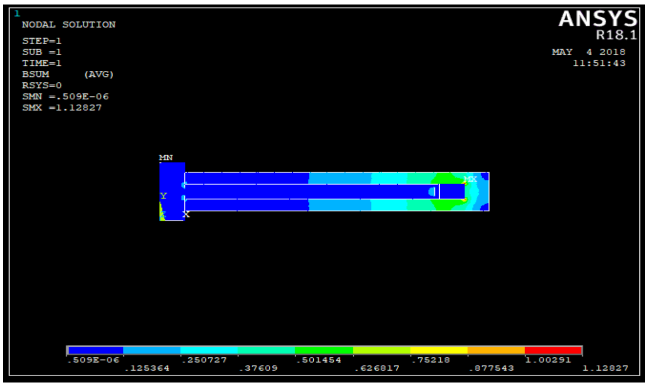


**Figure 11 Magnetic flux density of low carbon steel**

## V. ESTIMATING THE BRAKING TORQUE USING FINITE ELEMENT ANALYSIS

In this section, 2-D axi-symmetric analysis of a SINGAL disk MR brake has been presented. Torque, exerted by the brake has been presented as function of electric current supplied to electro magnet . In this brake arrangement ,all three MRF samples are considered . The maximum current supplied to electromagnet was kept as 2 amp

Torque of the MR brake assembly is estimated as function of MR gap ranging from 0.25mm to 3 mm, for this study 3mm gap is considered as constant . Rotary disk plats and housing of MR brake is made iron 99.8% pure having the relative permeability equal to 5000. Coil is made of copper wire (relative permeability = 0.999994)

Table 5 shows the increase in torque at the higher limit of current i.e. 2A, in different fluid samples. Figure 12 shows graphical representation of data in Table.5.

**Table 5: Estimation of torque at different currents where h=3mm constant for all calculation**

| Current I (Amps) | For MRF 1 Torque (Nm) | For MRF 2 Torque (Nm) | For MRF 3 Torque (Nm) |
|---|---|---|---|
| 0 | 5.860 | 7.801 | 11.103 |
| 0.5 | 13.602 | 15.820 | 18.493 |
| 1 | 22.408 | 24.727 | 32.168 |
| 2 | 21.415 | 41.465 | 42.477 |

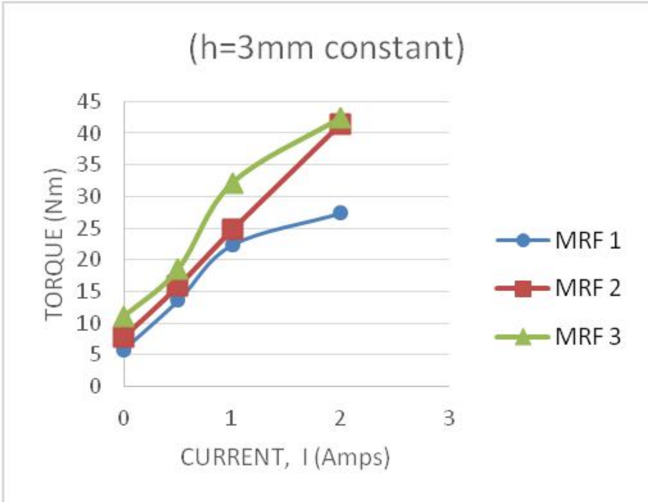


**Figure 12 Current v/s Torque**

## VI. CONCLUSION

This study has discussed the finite element analysis of the MR brake. The following conclusions can be made from the present study.

- In this study different proportion of MR fluids are prepared and its rheological properties are studied.
- Magneto static analysis of single disk MR brake is carried out by using ansys and studied the magnetic flux distribution in the fluid flow gap.
- Magnetic flux density of 2 D flux lines increases with increase in supplied current.
- Housing material with Iron 99.8% increases the braking torque as compared to carbon steel material because it produces max magnetic flux density.
- MRF 3 produces more braking torque, because high viscosity nature this fluid can be seen when max current of 2 amps is supplied.

## VII. ACKNOWLEDGMENT

We are thank full to Anton paar for allowing us to characterize the MR fluid samples.

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