

FEM Analysis of Plate Type Magneto-Rheological Brake



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ABSTRACT

Brake is an important element in power transmission system. The existing mechanical brakes exhibit some of the problems like wear and tear of component, poor response time and maintenance issues. The said problems can be overcome by employing appropriate configuration of brake like Magneto-rheological brake. In this work, practical design criteria such as material selection, viscous torque generation, applied current density, and MR fluid selection are considered to select a basic automotive MR brake configuration. Through the present work attempts are made to design and analyze the performance of plate type magneto-rheological brake. Finite Element Approach (FEM) is employed for analysis.

Keywords— FEM, Magneto-rheological, MR-Fluid, Plate Type MR Brake.

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I. INTRODUCTION

Magneto-rheological (MR) fluids consist of stable suspensions of micro-sized, magnetizable particles in a carrier medium such as silicon oil or water. When an external magnetic field is applied to the MR fluid, the polarization induced in suspended particles which gives the result in the MR effect (change of viscosity and shear strength) of the MR fluids. The MR effect directly influences the mechanical properties of the MR fluids. The conventional MR brake is obtained by a single magnetic pole structure. The disadvantages of this structure is insufficient active fluid area and the non-flexibility in applied magnetic field [1].

The propose brake is a magnetorheological brake (MRB) that has some performance advantages over conventional hydraulic brake (CHB) systems. A CHB system includes the brake pedal, hydraulic fluid, transfer lines and brake actuators (e.g. disk or drum brakes). When the driver presses on the brake pedal, the master cylinder provides the pressure in the brake actuators that squeeze the brake pads onto the rotors, generating the useful friction forces (thus the braking torque) to stop a vehicle. However, the CHB has a number limitations, including,

- (1) They have delayed response time (200–300ms) due to pressure build up in the hydraulic lines.
- (2) Bulky size and heavy weight due to its auxiliary hydraulic components such as the master cylinder,
- (3) Brake pad wear due to its frictional braking mechanism,
- (4) low braking performance in high speed and high temperature situations [2].

II. LITERATURE REVIEW

Edward J. Park, Dilian Stoikov, Luis Falcao da Luz, Afzal Suleman [1] studied that MRB is a pure electronically controlled brake system that uses the use of different techniques like using the bytes and amperes instead of bars and compressed brake fluid, due to that it is better to easy for implementation of advanced braking control system with less no. of components. A sliding mode controller was designed to get an optimal wheel sleep control which is feature of an ABS.

Kerem Karakoc, Edward J. Park, Afzal Suleman [2] studied that a magnetorheological brake (MRB) design has been introduced as a viable alternative to the current conventional hydraulic brake (CHB) device. Since the MRB is an electromechanical device, it has several advantages over the CHB, such as reduced actuation delay, ease of

software control implementation and lower system weight. The design process was started with an analytical model of the MRB. Then, the MRB device was designed with a focus on magnetic circuit optimization and material selection. A 3-D CAD model of the optimum MRB design was generated and a MRB prototype of the optimum design was manufactured.

Yaojung Shiao, Quang-Anh Nguyen [3] studied that the new MR Brake operation concept and structure are different from conventional MR brake. The multiple-pole structure analyzed to figure out the optimal design with maximum torque while maintaining acceptable input power. The optimum torque is obtained with 25.1 Nm is achieved with the using of AISI 1018 steel, 0.5 mm MR fluid layer and MRF-140CG MR fluid from Lord Company. Specific explanations have been given for simulation results based on characteristics of each material and structure. The results give a complete pack of materials with related dimension of the new MR brake for future research and applications.

J. Huang, J.Q. Zhang, Y. Yang, Y.Q. Wei [4] studied that the geometric design method of a cylindrical MR fluid brake is investigated theoretically. It includes the braking torque developed by the MR fluid within the brake with different magnetic field strength conditions has been analyzed. The engineering design calculations such as volume, thickness and width of the annular MR fluid within the brake are derived. The parameters such as thickness and width of the fluid in the brake calculated from the equations obtained, when the required mechanical power level, the rotational speed of the rotor, and the desired control torque ratio are specified.

Deepak Baranwal, Dr. T.S. Deshmukh [5] studied that The magneto-rheological fluid is smart fluid whose properties gets varies and controlled by magnetic field and metal particles. Also these fluids has property to transmit the force in the presence of magnetic field. There are many areas where the application of MR fluid occurs e.g. dampers, journal bearings, brakes, clutches, aerospace etc.in which electrical input is required to get a mechanical outputs.He conclude that magnetorheological fluid has wide scope in coming areas.This technology is mostly useful in where controlled fluid with varying viscosity is required.The main features of MRF technology is fast response, simple interface between electrical input and mechanical output and intelligent controllability.

M. Kciuk , R. Turczyn [6] studied that basic properties of the magnetorheological fluids (MR) and their development in recent years.They studied that replacement of the traditional devices with active, smart system.similarly shows that MR materials development and their application.They concluded that These fluids can reversibly and quickly change from a free-flowing liquid to a semi-solid with controllable yield strength when subjected to a magnetic field,while in the absence of magnetic field MR fluid behaves like Newtonian liquid.

Bhau K. Kumbhar, Satyajit R. Patil [7] studied that ,MR fluid technology is widely used for many industrial applications also MR fluids only exhibit a yield stress of 50-100KPa at a magnetic field of 150 -280 kA/m hence there is need of proper selection of fluid components like carrier, base fluid, additives etc. They conclude that Silicone oil can be used as a carrier fluid where MR fluid application demands broader temperature requirements. Carbonyl iron

powder appears to be the main magnetic phase of practical MR fluid compositions due to its high purity (~99.7%).also with the help of additives and proper coating of iron particles the MR effect can be increased.

From all above literature review it is concluded that Design of the MR brake configuration with solid and compact structure to enhance the magnetic field and its resulted braking torque, so attempts are made to design the appropriate rheological fluid capable of exhibiting the required properties also, current brake system does not deliver required torque this can be achieved by changing the no. of poles due to which we can obtain the required torque. similarly going to attempt compressing the fluid. After this we are going to analyse the design of Magneto-rheological brake using Finite Element Method. Finally we are also developing and testing of the performance of plate type Magneto-rheological brake.

III. WORKING PRINCIPLE OF MR FLUID TECHNOLOGY

The magnetic particles, which are typically micrometer or nanometer scale spheres or ellipsoids are suspended in the carrier oil are distributed randomly as below

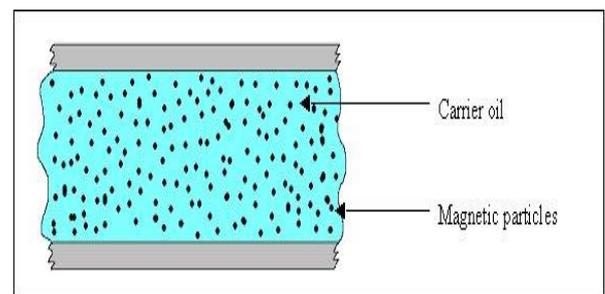


Fig.1-No magnetic field applied

When a magnetic field is applied, the magnetic particles (usually in the 0.1–10 μm range) gets align themselves along the lines of magnetic flux, as shown below fig2. When the fluid is present between two poles (typically of separation 0.5–2 mm in the most of devices), the resulting chains of particles produce an obstacle for the flow of fluid which is perpendicular to the direction of flux, effectively increasing its viscosity, mechanical properties of the fluid in its “on” state. Thus in designing a magneto rheological (MR) device it is necessary to ensure that the lines of flux are perpendicular to the direction of the motion to be restricted.

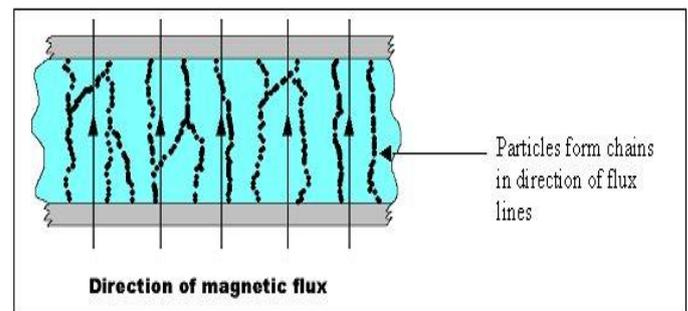
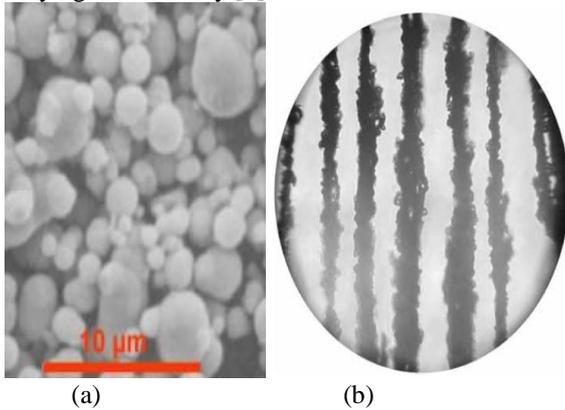


Fig.2-Magnetic field applied

The MR fluid is a smart fluid whose properties can controlled with the help of in the presence of magnetic field, alsoin the absence of magnetic field, the rheological properties of the MR fluid are similar to base fluid except

that it is slightly thicker due to the presence of metal particles.

In the absence of magnetic field, these metal particles gets align themselves along the direction of flow however when a magnetic field is applied each metal particles becomes a dipole aligning itself along the direction of magnetic field. Thus a chain like structure is formed along the line of magnetic flux which offers mechanical resistance to the flow resulting in an increase in the viscosity of fluid. The MR effect is reversible. When the magnetic field is removed the fluid returns to its original condition. The fluid motion is controlled by varying its viscosity with the help of magnetization .The simpleness of MR fluid technology, the controllability and the quick response of the rheological properties makes it a smart fluid with application areas where fluid motion is controlled by varying the viscosity [7].



IV. RELATION BETWEEN SHEAR STRESS VS SHEAR RATE

In the absence of an applied magnetic field, the particles in MR fluid moves randomly in the carrier fluid. MR fluid flows freely through the working gap between the fixed outer casing and the disc plates. MR fluid obeys a Newtonian-like behaviour, where the shear stress of MR fluids can be described as,

$$\tau = \eta * \dot{\gamma}$$

in which τ is the shear stress, η the viscosity of the MR fluid when no applied magnetic field, and $\dot{\gamma}$ is the shear rate. When the magnetic field is applied, the behavior of the controllable fluid is represented as a Bingham fluid having a variable yield strength. In this model, the constitutive equation is derived by the least-squares method as follows,

$$\tau = \tau_B + \eta * \dot{\gamma}$$

where τ_B is the yield stress developed in response to the applied magnetic field. Its value is depends upon the magnetic induction field B, Fig 4. shows the relationship obtained from experiment between shear rate and shear stress, depending upon the applied magnetic field strength. It is observed that the MR fluids have a variable yield strength, as shear stress increasing with the applied magnetic field strength. The shear rate has small influence on the shear stress. This result indicates that the MR fluid exhibits Bingham behavior.

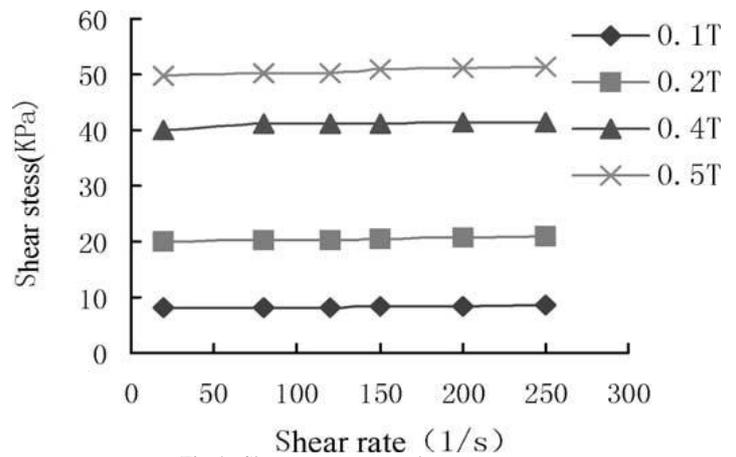


Fig.4 Shear stress versus shear rate.

V. PROPERTIES OF MR FLUID

The properties of typical MR fluid and its comparison with Electro-rheological (ER) fluids and Ferrofluids are as shown in Table 1.

TABLE 1.COMPARISON OF MRF, ERF AND FERRO-FLUIDS

Property	MR fluids	ER fluids	Ferro fluids
Particulate Material	Iron(Carbonyl/ Electrolytic), ferrites, etc	Zeolites, Polymers,Si O2	Ceramics, ferrites, iron, cobalt, etc.
Particle size	0.1-10μm	0.1-10μm	2-10 nm
Suspending fluid	Nonpolar and polar liquids	Oils	Oils, Water
Required field	~ 3 kOe	3 kV/mm	~1 kOe
Off viscosity (Pa.s)	0.1-1	0.05-1	0.002-0.5
Density (g/cc)	3 -5	1-2	1-2
Reaction time	15 - 25 milliseconds (ms)	Some ms	Some ms
Work temperature	-50 to 150° C	-25 to 125° C	-
Max. yield stress	50-100 kPa	2-5 kPa	10 kPa
Stability	Good	Poor	Good
Typical supply	2-25 V, 1-2 A	2- 5kV@1-10 mA	-
Device excitation	Electromagnets	High voltage	Permanent magnet

VI .SELECTION CRITERIA FOR MR FLUID COMPONENTS

The change in one or more components or in their properties influences the MR effect. The selection criteria for different MR fluid components are given below:

For the highest MRF effect the viscosity of the fluid should be small and almost independent of temperature. Carrier liquid is the major constituent of MR fluids (50-80 per cent by volume). The commonly used carrier liquids are Mineral and Synthetic oil having rate of change of viscosity with respect to temperature is more similarly synthetic oil have property like higher flash point lower friction, high shear strength with high viscosity index, in case of silicon

oil it has good temperature stability and heat transfer characteristics and high flash point, but it is very difficult to seal.

TABLE 2 PROPERTIES OF CARRIER FLUIDS

Properties	Mineral Oil	Synthetic Oil	Silicone Oil
Viscosity @ 40 °C (Pa-s)	0.028	0.1068	0.1100
Flash point °C	171 – 185	230	>300
Fire point °C	260 – 330	350	~ 500
Specific gravity	0.818 – 0.95	0.817	0.9124
Density at 250C (kg/m ³)	825	873-894	760
Pour point °C	-25to -50	-30 – 50	-50
Cloud point °C	-15	-200C	-20
Market cost/ litre (Rs.)	~ 80	~800	~900

The size of magnetic particles is approximate of the order of 1µm to 10µm. If the size of magnetic particle increases, the force also increases but at the cost of increased off state viscosity of MR fluid. The concentration of magnetic particles in base fluid can go up to 50% low coercivity, high saturation magnetization, high permeability and small hysteresis loop are other characteristics of magnetic materials used for the formulation of MR fluid. Carbonyl iron (CI) is chemically pure Additives are highly viscous materials such as grease or other thixotropic additives are used to improve settling ,therefore it is conclude that Silicone oil can be used as a carrier fluid where MR fluid application demands broader temperature requirements (from -40°C to 204°C). As viscosity changes rapidly with respect to the temperature as in case of mineral oils, their use in the formulation of MR fluid is restricted to the applications where temperature extremes are low. Carbonyl iron powder appears to be the main magnetic phase of most practical MR fluid compositions due to its high purity (~99.7%).

VII. BASIC MAGNETORHEOLOGICAL BRAKE SYSTEM

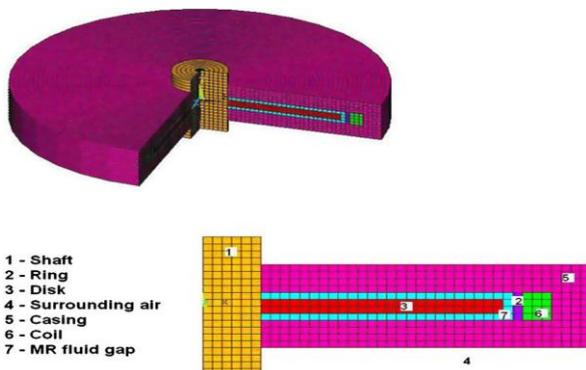


Fig.6 cross section of basic MR brake

A basic configuration of a MRB was proposed by Park et al. for automotive applications. As shown in Fig. In this configuration, a rotating disk (3) is enclosed by a static

casing (5), and the gap (7) between the disk and casing is filled with the MR fluid. A coil winding (6) is embedded on the perimeter of the casing and when electrical current is applied to it, magnetic fields are generated, and the MR fluid in the gap becomes solid-like instantaneously. The shear friction between the rotating disk and the solidified MR fluid provides the required braking torque.

The proposed CAD model for Plate type MR Brake is shown in fig. 7

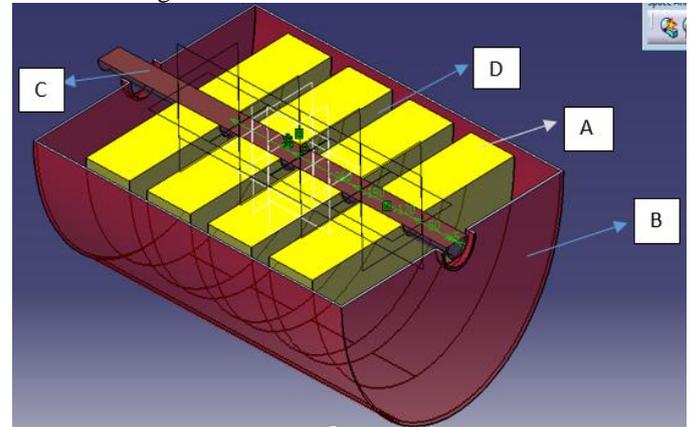


Fig 7. cross sectional view of multidisc MR brake.(where A-Disc Plates, B-Casing,C-Shaft, D-fluid gap between plates.)

VIII. CONCLUSION

The proposed MR brake configuration is as shown in above fig7. It contains brake configuration in which the disc plates as indicated by A are immersed in MR fluid which is indicated by D which are rotating in casing. The MR fluid is filled in casing indicated by B.

The FEA of CAD model is carried out in ANSYS software and we obtain the linear relationship between applied current, viscosity, shear rate and torque. If there is increase in current viscosity get increased, so there is increase in shear rate also takes place. Also we get the increase in braking torque with increase in current hence we get the required braking torque.

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