# Fluid Preparation and Analysis of Magneto-Rheological Brake in Automotive Applications

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***Abstract*— The aim of this work is to develop the brake system which overcomes the drawbacks of conventional hydraulic braking system. In this paper the new rotating disc design is proposed for rotor which immersed in a MRF as working medium enclosed by the coils wound. An effort has been made to synthesize the fluid preparation with various samples and volume fraction of base fluid, two different types of magnetic particles, and three different types of additives. The design procedure comprises the selection of materials for MRB, finding the characteristics of fluid by viscometer testing and SEM testing for iron particles is presented. The transient analyses of MRB conclude that the high braking torque is achieved when the brake temperature is lies in between the MRF working temperature range.**

***Keywords— MR-Fluid, MR-Effect, Driveby wire, Weight/Weight-ratio, MR-Fluid range.***

## I. INTRODUCTION

Smart materials are the materials that can be significantly alter one or more of their inherent properties owing to the application of the external stimuli in a controlled fashion such as stress, temperature, moisture, pH, electric or magnetic fields. Smart materials have properties that react to changes in their environment by an external condition. This change is reversible and can be repeated many times. Magneto-rheological fluid (MRF) is a type of smart fluid in a carrier fluid, usually a type of oil. When subjected to a magnetic field, the fluid greatly increases its apparent viscosity, to the point of becoming a visco-elastic solid. Importantly, the yield stress of the fluid when in its active state can be controlled very accurately by varying the magnetic field intensity.

In conventional hydraulic braking system there are some drawbacks such as delayed response in braking torque as 300-500 millisecond, huge weight & bulky size, low braking performance in high speed and high temperature situation. A magneto- rheological brake (MRB) is more efficient than conventional braking system in terms of weight reduction & fast response for braking. MRB works on the principle of direct shear mode operation. While applying the magnetic field, each magnetic particle forms north to south as perpendicular direction. Then the magnetic principle tells that opposite poles attracts each other to form strong bond between them which leads to increases in the yield strength of the MRF. This function opposes the shearing friction between the casing and the rotating disc which satisfies the braking operations. At the time of brake application the electromagnet which is built within casing is energized by the external DC voltage supply. Then the magnetic field is passed over the magneto- rheological fluid (MRF) its viscosity increases to produce MR-Effect which results in braking. Here the properties of LORD MRF 132DG such as viscosity, density magnetic field strength, reaction time and working temperature are compared with the MRF prepared in this work. Then the working temperature range of the fluid prepared in this work is analyzed with the MRB temperature occurring during the braking operation. The analysis results shows whether the brake temperature lies in between the fluid working temperature range.

## II. LITERATURE SURVEY

In the present work, research findings for fluid preparation and analysis of new rotor design for improving the brake efficiency in the magneto-rheological brake. Yaojung ciao and Quang-Anh Nguzen [1] introduces a new MR-Brake having multiple electromagnetic poles surrounded by several coils, which improves the brake torque by enlarging the magnetic field strength. Bhau K.Kumbhar and Satyajit R.Patil [2] synthesized the MR-Fluid by using various iron particles with additives and also use the sunflower oil as a carrier liquid. J.Wang and G.Meng [3] analyze the modes of operation of MRF and principles, characteristics and engineering application were presented. Yaojung Shiao and Quang-Anh Nguzen [4] proposed a multiple MR-Brake for motorcycle which is classified into inner-rotor structure & outer rotor structure to reach the target torque. Satyajit R.Patil and Kanhaiya P.Powar [5] made experimental investigation on bicycle in order to estimate the temperature rise of the MR-Fluid on account of braking man oeuvre. H.Shokrollohi [6] suggested the cobalt-ferrite particles are mixed with two various sized particles to prepare “Bimodal MRF” by chemical composition. Michael Kargutewicz and Victor Marrero [7] develop MRF model from the microscopic point of view using the discrete element method to understand MRF behavior in tribological application. Kerem Karaoke and Edward J.Park [8] proposed the MRB to obtain optimal design parameters that can be generate maximum torque in brake by multidisciplinary design optimization system. Edward J.Park and Afzal Suleiman [9] proposed multidisciplinary design optimization of an automotive magneto-rheological brake design which provides finite element analysis using magneto-statics fluid flow and heat transfer analysis. Dilian Stoikov and

Luis Falcao Luz [10] introduce the performance evaluation of automotive MRB with a sliding mode controller for an optimal wheel slip control and control simulation results show fast anti-lock braking.

## III. MAGNETO –RHEOLOGICAL BRAKE TECHNOLOGY (MRB)

The MRB is the Electro-mechanical brake having both mechanical components as well as electrical components resulting in more reliable and faster braking actuation. This brake consists of single/multiple rotary disks which immersed in a MRF and an enclosed electromagnet by wounding the coils over the drives that is "Drive by wire" method. This works on the principle of "Direct shear mode", by shearing the MRF filling the gap between the two surfaces moving with respect to one another. Here the rotor is fixed to the shaft, which is placed in bearing and can rotate in relation to housing. Resistance torque in the MRB depends on viscosity of the MRF that can be changed by magnetic field. At the time of brake application, the electromagnet which is built within casing is energized. Then the magnetic field is passes over the MRF, so it produces "MR-Effect".

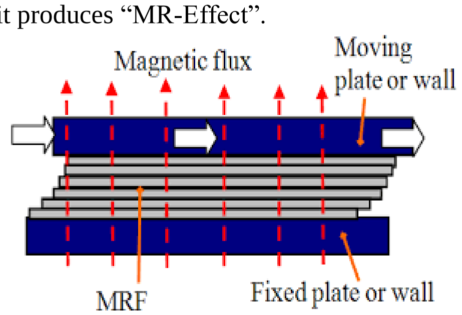


Fig: 1 Direct shear mode operation

MR-Effect is the principle which describes that the fluid becomes semi-solid as viscosity increases with few milliseconds and shearing friction occurs along the disc surface which results in **Braking** and thus de-accelerated. This effect is reversible, viscosity of MRF reduces it returns to liquid state. The model of MRB is shown below

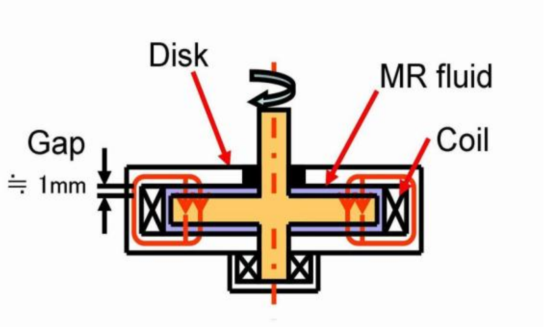


Fig: 2 Model of magneto-rheological brake

## IV. MATERIAL SELECTION PROCESS

Materials used for the brake have crucial influence on the magnetic circuit as well as the structural and thermal characteristics. The permeability of ferromagnetic materials is highly nonlinear and it varies with temperature and applied magnetic field (saturation & hysteresis). Then considering the cost, permeability, availability **AISI 1018** was selected as the magnetic material in the magnetic circuit. The shaft should be non-ferromagnetic in order to keep the flux far away from the seals that enclose the MRF (to avoid from being solidified). So the material **304 Stainless steel** is chosen for high yielding stress and availability. Due to the temperature dependent permeability values of the ferromagnetic materials and the MRF viscosity, heat generated in the brake should be removed as quickly as possible. In order to increase the heat flow from the brake, a material with high conductivity and high convection coefficient has to be selected as materials for the non-magnetic brake components. So **Aluminum** is the good candidate material for the thermal considerations.

## V. MAGNETO-RHEOLOGICAL FLUID PREPARATION (MRF)

MRF formulation consists of three main components are such as magnetic particles (with a volume fraction typically between 20 to 40 percent), a base fluid which act as a carrier fluid and an association of various additives. The proper selection and combination of these components is of prime importance since it will define all the macroscopic characteristics of the fluid such as it's off state viscosity, maximum yield stress, shear rates.

Due to high permeability, 'B' iron particle is added with equal amount to 'A' iron particle to achieve MR-effect perfectly. Here silicone oil is preferred as carrier liquid for having viscosity stability, low temperature resistance and thermal conductivity. Here three types of additives are used to control the settling of the metal particles, viscosity of the fluid, maintain friction between the metal particles and to reduce the rate of thickening of the fluid. Due to long term use of the fluid, thus additives also increase the life of the fluid.

To obtained simple and efficient MRF, the dispersion of iron particles in silicone oil and using some surfactants to avoid irreversible aggregation. The stabilized fluid can be made by using additives before adding magnetic particles to the base fluid which leads to efficient fluid preparation.

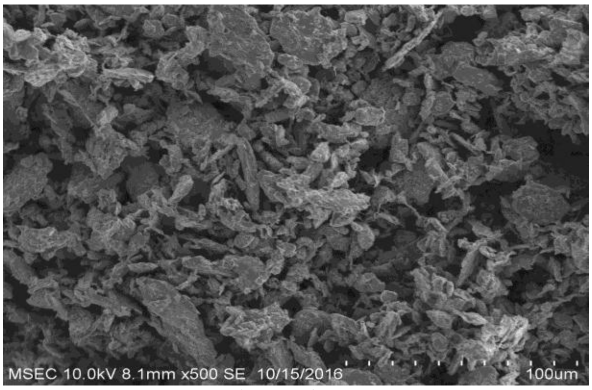


Fig: 3 SEM image of 'A' Iron powder

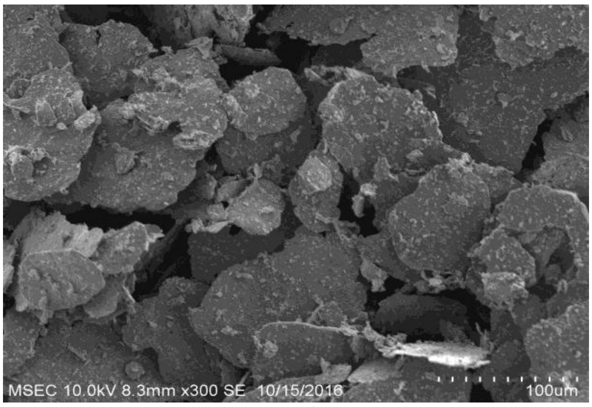


Fig: 4 SEM image of 'B' Iron powder

## VI. WEIGHT/WEIGHT RATIO METHOD

Weight ratio percentage is the way of expressing the concentration of a solution. Any units of mass (weight) can be used for the calculation but the mass of solute and the mass of solvent must be in the same units. If the mass of solute is in grams, the mass of solvent must also be in grams. If the mass of solvent is in kilograms, the mass of solute must also be in kilograms. The total ratios of the materials used in the MRF are calculated by w/w ratio percentage formula. The materials used for preparing MRF are such as two different types of iron particles, carrier liquid and for stabilization of the fluid three types of additives are added for effective function. Here the MRF samples are prepared in three different percentage are such as 20%, 30%, 40% of magnetic particles. Among the following three samples we suggested that the sample containing 30% of iron particles is efficient for MRB application, data's are given below;

Concentrated % W/W = (g of solute) / (g of solution)*100%

g of solute = (concentrated % w/w)*(g of solution)/100%

Test Data:

| Data Point | Step Point | Speed RPM | Torque (%) | Temperature °C | Time (Sec) | Viscosity cP | Shear Stress dyn/cm | Shear Rate 1/s |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1.00 | 35.7 | 30.3 | 00:00:05.0 | 214.15 | 2.62 | 1.223 |
| 2 | 1 | 1.00 | 77.0 | 30.3 | 00:00:10.0 | 461.90 | 5.65 | 1.223 |
| 3 | 1 | 1.00 | 113.1 | 30.3 | 00:00:15.0 | 678.46 | 8.30 | 1.223 |
| 4 | 1 | 1.00 | 120.6 | 30.3 | 00:00:20.0 | 723.45 | 8.85 | 1.223 |
| 5 | 1 | 1.00 | 120.6 | 30.3 | 00:00:25.0 | 723.45 | 8.85 | 1.223 |
| 6 | 1 | 1.00 | 120.6 | 30.3 | 00:00:30.0 | 723.45 | 8.85 | 1.223 |
| 7 | 1 | 1.00 | 120.6 | 30.3 | 00:00:35.0 | 723.45 | 8.85 | 1.223 |
| 8 | 1 | 1.00 | 120.6 | 30.3 | 00:00:40.0 | 723.45 | 8.85 | 1.223 |
| 9 | 1 | 1.00 | 120.6 | 30.3 | 00:00:45.0 | 723.45 | 8.85 | 1.223 |
| 10 | 1 | 1.00 | 120.6 | 30.3 | 00:00:50.0 | 723.45 | 8.85 | 1.223 |

Fig: 5 Viscosity test data for 30% sample of silicone oil

Test Data:

| Data Point | Step Point | Speed RPM | Torque (%) | Temperature °C | Time (Sec) | Viscosity cP | Shear Stress dyn/cm | Shear Rate 1/s |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1.00 | 21.6 | 25.4 | 00:00:05.0 | 129.57 | 1.58 | 1.223 |
| 2 | 1 | 1.00 | 28.5 | 25.4 | 00:00:10.0 | 170.96 | 2.09 | 1.223 |
| 3 | 1 | 1.00 | 29.5 | 25.4 | 00:00:15.0 | 176.96 | 2.16 | 1.223 |
| 4 | 1 | 1.00 | 29.5 | 25.4 | 00:00:20.0 | 176.96 | 2.16 | 1.223 |
| 5 | 1 | 1.00 | 29.4 | 25.4 | 00:00:25.0 | 176.36 | 2.16 | 1.223 |
| 6 | 1 | 1.00 | 29.2 | 25.4 | 00:00:30.0 | 175.16 | 2.14 | 1.223 |
| 7 | 1 | 1.00 | 29.0 | 25.4 | 00:00:35.0 | 173.96 | 2.13 | 1.223 |
| 8 | 1 | 1.00 | 28.9 | 25.4 | 00:00:40.0 | 173.36 | 2.12 | 1.223 |
| 9 | 1 | 1.00 | 28.8 | 25.4 | 00:00:45.0 | 172.76 | 2.11 | 1.223 |
| 10 | 1 | 1.00 | 28.6 | 25.4 | 00:00:50.0 | 171.56 | 2.10 | 1.223 |

Fig: 6 Viscosity test data for 30% sample of vegetable oil

From the above table values silicone oil having the viscosity range of 0.5 to 0.7 Pa.s, which is lies in between the standard value of Lord Corporation MRF. Also vegetable oil having a viscosity range of 0.1 to 0.2Pa.s, which is not suitable for braking. The fig: 6 shows the Bingham model graph for 30% sample of silicone oil which shows relationship between viscosities vs. time. Then fig: 7 show the Bingham model graph for 30% sample of vegetable oil. Among the following graphs there will be some deviation in viscosity of vegetable oil with respect to time.

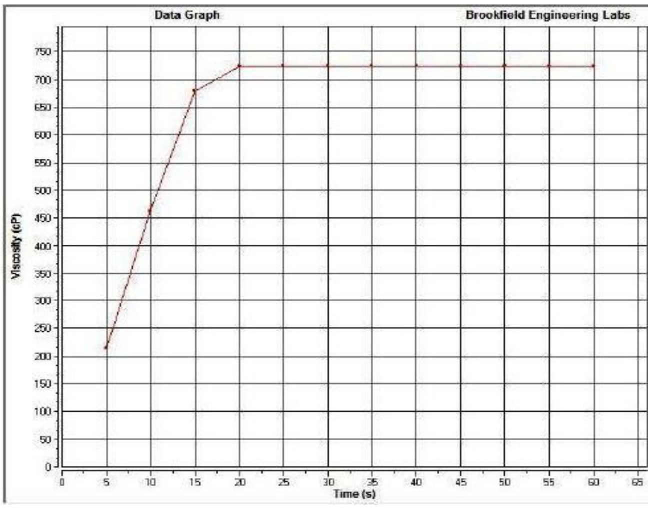


Fig: 7 Bingham model for 30% sample of silicone oil

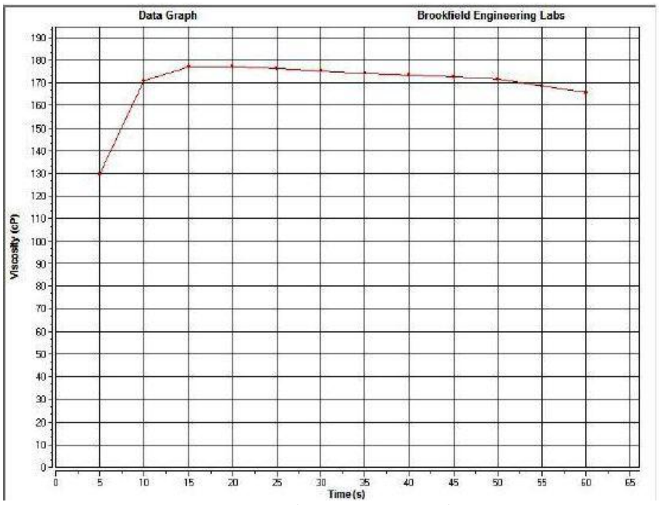


Fig: 8 Bingham model for 30% sample of vegetable oil

## VII. DESIGN OF MAGNETO-RHEOLOGICAL BRAKE

Engineering studies fall into one of two categories: analysis problems, where the goal is to understand the operation and performance of existing systems and design problems, where the goal is to conceive a system capable of achieving a predefined performance. In order to increase the braking torque, the amount of fluid consumption is also one of the parameter to increase the braking efficiency. In the previous design there will be some sliding occurs during the braking operation which is not suitable for shearing friction between the rotor and casing. For that purpose the new rotor (Rotating disc) design is proposed in this work. This design gives some additional support for braking operation by increasing the shearing friction and high yield strength in the presence of magnetic field between the cylindrical surfaces of the fluid channel. Thus there will be improvement in the field torque for the braking operation. The new rotor design having some design modification for completely submersible in the fluid with each and every part contact to each other while passing external DC voltage supply to the coils wound around rotor. The rotor specified with some holes with equal division and also teeth profile with having specified gap between each other which is present around the surface of the rotor.

## VIII. BOUNDARY CONDITIONS FOR MAGNETO-RHEOLOGICAL BRAKE

The transient analysis is used to determine the response of a structure to arbitrarily time-varying loads. Here this work attempts to estimate the temperature rise of MRB disc is within the operating range of the fluid and check whether the brake satisfies the condition of the fluid range.

### *A. Study properties*

The transient analysis is preferred for analyzing the rotor disc and the solver type is FFE plus is used. The total time for this analysis is awarded 900 seconds with time increment of 30 seconds. Here solid mesh type of rotor disc is preferred.

### *B. Model information*

In this analysis the modal information gives the details about volumetric properties of the components such as rotor disc and disc connected to the driving shaft. Here the properties like mass, volume, density and weight of the brake components are required for the work.

### *C. Material properties*

The material properties for the rotor and shaft are given with linear elastic isotropic is preferred. The material for rotor should be magnetic and shaft should be non-magnetic material. The materials should have specified thermal conductivity, specific heat and mass density is required for the analysis work.

### *D. Thermal loads*

During braking operation the shearing friction occurs between the rotor and casing and then the heat will be generated in that surface. [5] Also the coil gets heated due to flow of current through it i.e. generation of joule heating is formed while flowing of current through the coils. This flowing of current in the coil is equal to the voltage and current. From this work the total amount of supply voltage and maximum current value gives heat generated in the coil. Therefore the internal heat generated in the coil can be defined by heat generated in the coil by total volume of the coil. The heat flux generated in the coil can be defined by during the braking operation there will be some power lost in the coil. From this power lost and the area of friction surface between the rotor and casing is calculated. For convection heat transfer coefficient and bulk ambient temperature, the atmospheric air temperature may be vary from 32°C to 40°C, let us take the values for max temperature from the heat transfer data book and evaluated.

## IX. RESULT AND DISCUSSION

An MRB design has been introduced as a viable alternative to the current CHB system which overcomes its drawbacks such as reduced actuation delay, ease of software control implementation and lower system weight. Here the new rotor design is proposed as rotating disk to increase the sliding friction between the fluid and casing with consuming more fluid to increase the braking torque efficiently. An effort has been made to synthesize for preparing fluid by adding two different types of iron particles and additives to achieve **MR-Effect** perfectly. The sizes of iron particles are different which also improves in mechanical properties such as shearing friction increases between casing and the rotating disc.

The transient analysis results shows that the maximum temperature attained in the MRB is **48ºC**, which is in between the operating range of the MRF working temperature. So the MRF prepared in this work is suitable to use in the MRB to achieve the braking torque. Hence the brake temperature satisfies the fluid working temperature range.

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## REFERENCES

[1] Yaojung Shiao and Quang-Anh-Nguyen (2014) "*Torque enhancement for a new magneto- rheological brake*" Procedia engineering 76 12-33.

[2] Bhau K. Kumbhar and Suresh M. Sawant (2015) "*Synthesis and characterization of magneto- rheological fluids for MRB application*" an International journal 18 432-438.

[3] J.Wang and G. Meng (2014) "*Magneto-rheological fluid devices: principles, characteristics and applications in mechanical engineering*" State Key Laboratory of Vibration, Shock and Noise, Shanghai Jiao Tong University.

[4] Yaojung Shiao and Quang-Anh-Nguyen (2014) "*Structural analysis and validation of the multi-pole magneto -rheological brake for motorcycles*" Procedia engineering 76 24-34- ICMAT Symposia proceedings.

[5] Satyajit R.Patil and Kanhaiya P.Powar (2016) "*Thermal analysis of magneto-rheological brake for automotive application*" applied thermal engineering 98 238-245.

[6] H.Shokrollahi (2016) "The effect of the fraction and viscosity on the compression and tension behavior of the cobalt-ferrite magneto-rheological fluids" International journals 19 604-609.

[7] Mickacl Kargulewicz and Victor Marrero (2012) *"Modeling of Magneto- rheological Fluids by the Discrete Element Method"* [DOI: 10.1115/1.4006021] Transactions of the ASME JULY 2012, Vol. 134 / 031706-3.

[8] Kerem Karakoc and Edward J.Park (2008) "Design consideration for an automotive magneto-rheological brake" Mechatronics 18 (2008) 434–447 Elsevier Ltd.

[9] Edward J.Park and Afzal Suleiman (2008) "Multidisciplinary design optimization of an automotive magneto-rheological brake design" Computers and Structures 86 (2008) 207–216.

[10] Dilian Stoikov and Luis Falcao da Luz (2006) *"A performance evaluation of an automotive magneto-rheological brake design with a sliding mode controller"* Mechatronics Journal., Volume 16, Issue7, Pages 379-450 (September 2006).

[11] R. Sundarajan and G.T. Prasanth (2014) "Implementation of magneto-rheological dampers in bumpers of automobiles for reducing impacts during accidents" Procedia engineering 97 1220-1226.

[12] Shyam sundar and Gangadharan (2014) "Experimental study of damping characteristics of air, silicon oil, magneto-rheological fluid on twin tube damper" Procedia material science 5 2258-2262.

[13] Doruk Senekal and Hakan Gurocak (2010) "Serpentine flux path for high torque MRF brakes in haptics applications" Mechatronics 20 (2010) 377–383 Elsevier Ltd.

[14] R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

[15] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," IEEE Transl. J. Magn. Japan, vol. 2, pp. 740-741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[16] M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.