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Modeling and Analysis of Magnetorheological Fluid Brake

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Abstract- This paper contains the theory behind Magnetorheological Fluid (MRF) Brakes. Conventional brakes have some disadvantages like wearing of plates, heating of parts, high applied stresses during non-working time also. The objectives of the present study is to provide innovations in brakes which having minimum number of wearing parts and reducing overall size of system and having reduction in stress level. Increasing demands for smart brakes. MR fluid makes dramatic changes in their viscous and elastic properties in milliseconds when subjected to magnetic field. These properties of MR fluid can be implemented in variable velocity reducing brakes. Reduction of speed occurs due to viscosity of MR fluid which is induced due to its own composition and change in viscosity after application of magnetic field. The primary objective is to provide magnetic field by high power permanent magnets. Variation in magnetic field could be achieved by varying axial distance. Solenoid coil was another option in case uses of permanent magnets are not suitable.

Index Terms- MRF Brakes, Solenoid coil, Viscosity, Yield Strength**.** .

1. INTRODUCTION

Magneto rheological fluid (MRF) [1] fluid has the smart property that its viscosity changes with respect to magnetic field applied. As magnetic field applied, the particles get chain aligned in the direction of field. Which results in increase in fluid viscosity. This phenomenon takes only milliseconds to occur. The yield strength of MRF varies from 50 kPa to 100 kPa at magnetic field of 150 to 280 kA/m. So, it can be consider for its application in brakes. Magneto rheological fluid basically contains the following components:

(1) Base fluid (Liquid carrier).
(2) Metal Particles (Magnetic Particles).
(3) Additives
(4) Surfactants

Existing Brakes have wide applications in every field of motion and power transmission. Along with this they have Mechanical problems from commercial brakes like leakage in Brake lines, Wear and Tear of mechanical linkages, Frictional Pad changing problem, Noise, Heavy weight for Drum Brakes etc. In order to make collapsible fluid link to stop the motion of driving shaft, MR fluid can be used as a medium. In this process magnetic field act as actuator and Magneto rheological fluid operated brake. By this way we can use one of the smart fluid as a research application.

Finally it can be concluded that continuously applied spring force (frictional force) can be replaced by Collapsible Fluid link of MR fluid. Shear properties of that link can be adjusted by applied magnetic field which can control braking torque and effective braking system can be controlled digitally.

2. LITERATURE REVIEW

2.1. Review of research paper:

(1) Stuart W. Charles [2] has given a lot of ideas regarding preparation of nanosized particles and ferrous-fluids. Nano-sized ferrite particles can be formed by Wet grinding process which involves ball-mill. This process usually takes a very long time (1000 hours) and it is mainly for this reason that the process has been superseded by a rapid and simple method involving the co-precipitation of metal salts in aqueous solution using a base.

(2) Roger I. Tanner [3] has discussed concept of Rheology. His research gives brief history about the development of rheological concept and experimental analysis. There is a lot of experimental work done on viscosity, but contrary to that very less on the normal stresses.

(3) N.M. Wereley et al. [4] has analyzed Bidisperse MR Fluid which is the combination of micron size particles and nano particles. Increase in the weight percentage of nano particles in the MR fluid increases the time to mud line formation, showing that the bidisperse fluids are capable of maintaining the suspension for longer periods of time. Yield stress of bidisperse fluid increases like a function of percentage

of nanoparticles up to 20 percent by weight, after that again it decreases.

(4) F. Bucchi et al. [5] have been done research on reduction of power absorption of auxiliary devices in vehicles. Innovative vacuum pump reduces the device consumption of about 35%, whereas the use of MR clutch coupled with the innovative vacuum pump reduces it up to about 44% in urban driving and 50% in highway driving.

(5) KeremKarakoc et al. [6] have proposed MR brake consists of multiple rotating disks immersed in a MR fluid enclosed in electromagnet. The Current passing through electromagnet produces controllable yield stress which imparts shear friction on the rotating disks for the generation of the braking torque. In their work the practical design criteria's such as material selection, sealing, working surface area, viscous torque generation, applied current density, and MR fluid selection were considered to select a basic automotive MR brake configuration.

(6) J. Huang et al. [7] have derived the equation for the torque transmitted by the MR fluid for the MR brake which provides the theoretical foundation in the cylindrical design. Based on derived equation mathematical manipulation has been done. The calculations of the volume of MR fluid, thickness and width of the annular MR fluid in the cylindrical MR fluids brake were yielded in the study.

(7) V. K.Sukahwani and H. Hirani [8] have designed MR fluid operated brake. Their study includes the design of two brake prototypes having fluid gap of one mm and two mm respectively and measures the braking torque by varying the current in the electromagnet coil from 0 to 1.2 amp.

(8) Mukund A. Patil [9] has proposed Magneto-Rheological (MR) fluid brake is a device to transmit torque by the shear force of an MR fluid. An MR rotary brake has the property that its braking torque changes quickly in response to an external magnetic field strength. In this paper, the design method of the cylindrical MR fluid brake is investigated theoretically. The mechanical part is modeled using Bingham's equation, an approach to modeling the magnetic circuit is proposed in this work.

(9) Kosuke Nagaya et al. [10] have proposed a torque controllable viscous coupling. The coupling consists of two types of discs with slits. MR fluid is filled in the housing. Magnetic fields freeze the fluid for generation of shear torque between the driving discs and follower discs. The torque was controlled by electromagnets.

(10) Mark R. Jolly et al. [11] have presented and discussed rheological and magnetic properties of various commercial MR fluids. In the paper composition of different MR fluid were studied. Fluid viscosity is significant function of the composition and chemistry of the carrier oils. The MR fluids exhibit approximately having linear magnetic properties.

(11) J. Wang and G. Meng. [12] have discussed about basic properties of MR fluid and its applications. Their study describe that MR fluids have a yield strength of up to 50– 100 kPa, which is higher than ER fluids.

(12) Seval Genç. [13] in this paper were to advance the science of MR fluids. More specifically, the goals were: (a) influence of interparticle forces on stability and redispersibility of MR fluids and (b) factors affecting the "on" and "off" state rheological properties of MR fluids.

(13) Bhau K. Kumbhar and Satyajit R. Patil [14] have given the various MRF component and its proper selection different properties are explained about MR fluid and their developments during recent years. Discussed possible candidates of carrier fluid, Magnetic Particles, additives and surfactants.

3. SCOPE OF RESEARCH

As seen that the MR Fluid contains four different types of components. So by varying the ratio of these components we can vary its properties too. So, experiment can be conducted for calculation of braking torque by varying ratios of the components. Also by varying the current supplied to the coils, the reaction time of MR fluid as well as the braking torque can be varied. In experimental setup the speeder rpm of the motor can be varied by using voltage regulators or rheostat which can be conducted as third experiment i.e. calculation of braking torque by varying the speed of the motor. The gap between the stator and rotor can be varied by providing threads on the male and female part. By screwing action of it we can get desired gap in between stator and rotor, by Which the fourth experiment to find the braking torque by varying the gap between stator and rotor can be conducted. The must be varied from 0.5 to 2 mm for the effective results of torque.
From the above experiments this brake prototype will be conducted for second and third experiment only.

4. DESIGN CONSIDERATIONS. [06]

4.1. Magnetic circuit design

(1) $\varphi = \frac{ni}{R} = \frac{mmf}{R}$ ………..ref Fig. 1

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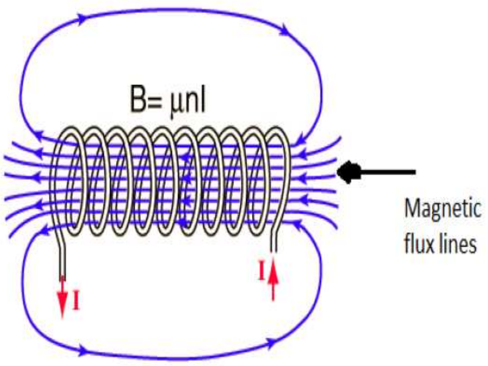


Fig. 1. Direction magnetic flux lines

(2) $R = \frac{l}{\mu A}$

(3) $\varphi = \int_A^1 B.n\, dA = \int_A^1 \mu H.n\, dA$

Table 1. Description of symbols.

Symbol	Description
φ	Magnetic flux.
n	Number of turns in coil.
i	Current in ampere.
R	Reluctance
mmf	Magneto motive force.
µ	Permeability of member
A	Cross sectional area.
B	Magnetic flux Density.
l	Length.
H	Field intensity.

4.2. Material selection.

(1) The property that defines a material's magnetic characteristic is the permeability. However, permeability of ferromagnetic materials is highly non-linear. It varies with saturation and hysteresis.
(2) Considering more cost effective material with required permeability have been selected.
(3) For low carbon steel relative permeability (µr) > 1.1
(4) Shaft should be non-ferromagnetic to keep the flux away from sealing.
(5) Shaft is not under any external loading so any material can be chosen.(for e.g. we can consider Aluminum as a material).

4.3. Sealing.

(1)Flange Sealant.
(2)Viton O-Rings for static as well as dynamic sealing.

4.4. Working surface area.

(1)A working surface is the surface on the shear disks where the MR fluid is activated by applied magnetic field intensity.
(2)Braking torque is directly proportional to working surface area.

4.5. MR fluid selection.

(1)Magnetic Particles: Carbonyl Iron Powder.
(2)Liquid Carrier: Silicone Oil.
(3)Additives: Arabic gum.

□

5. PARTS OF BRAKE PROTOTYPE

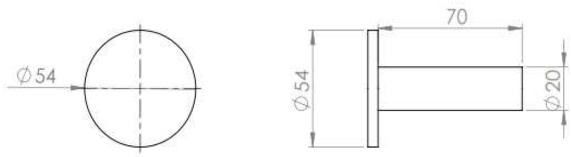


Fig. 2. Rotor(Stationary part)

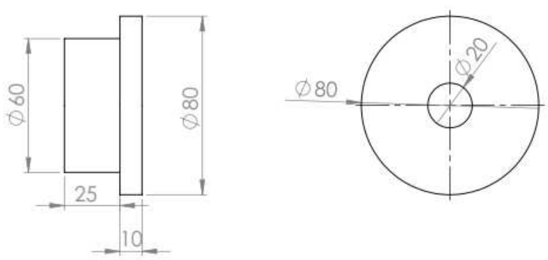


Fig. 3. Male part (stationary part)

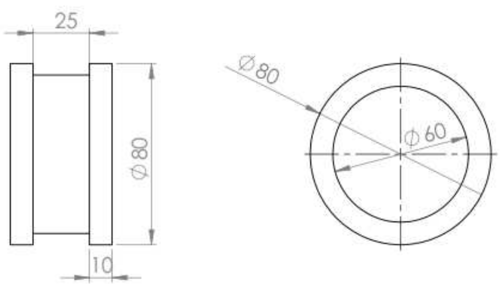


Fig. 4. Female part (stationary part)

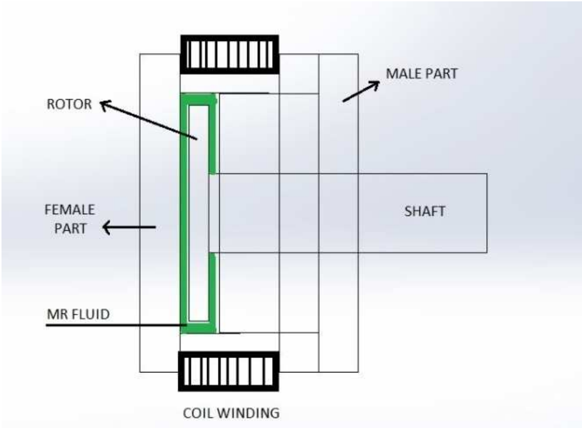


Fig. 5. Assembly drawing (brake)

The dimensions of this brake prototype has been considered suitably and referring the pervious paper [8], [6]. Dimensions considered for this prototype is safe enough to sustain high pressure and forces, shown in analysis part further.

5.1. Analysis of brake components

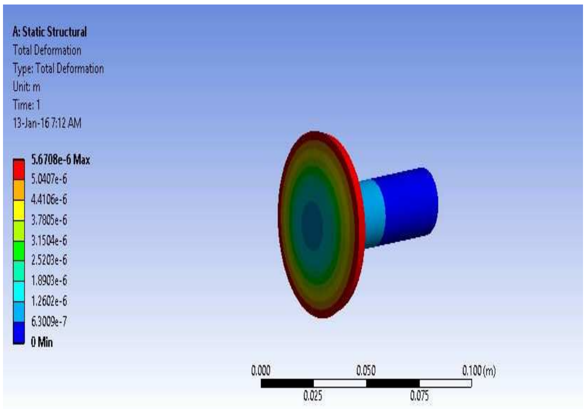


Fig.6. Deformation of rotor part.

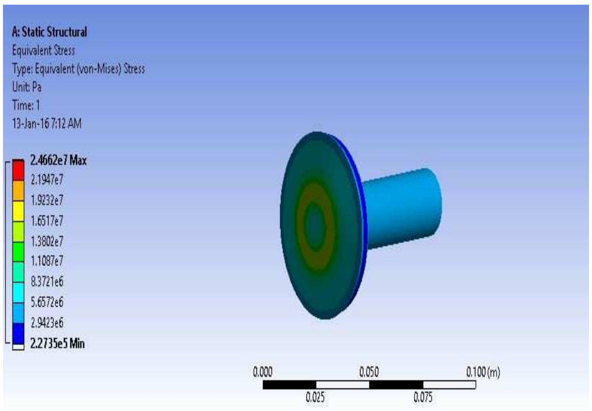


Fig.7. Stress analysis of rotor part.

- Force= 1131 N.
- Maximum Deformation= 5.67e-6 m.
- Maximum stress = 2.4667e7 Pa.

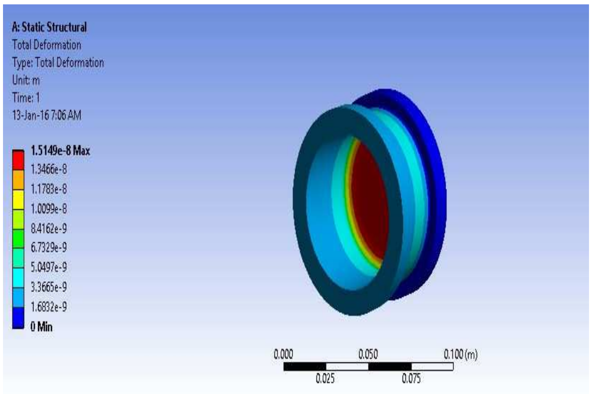


Fig.8. Deformation of female part.

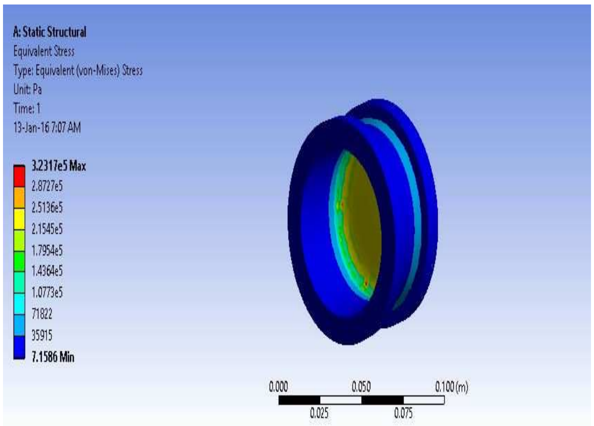
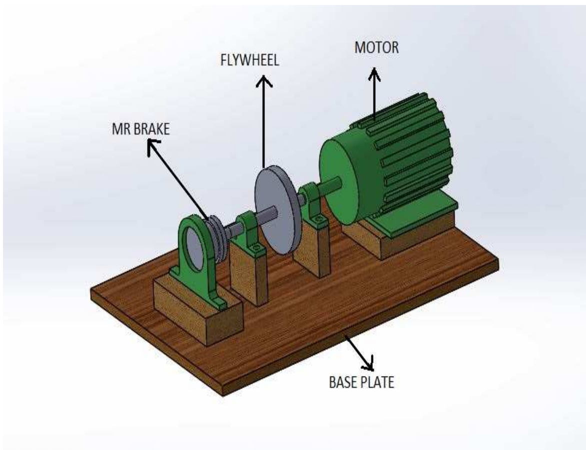


Fig.9. Stress analysis of female part

- Maximum Deformation= 1.5149e-8 m
- Maximum stress = 2.2317e5 Pa

The force is calculated from the yield stress of Magnetorheological Fluid which is 50-100 kPa and we have considered it as 100 kPa. The factor of safety for the roller comes out to be 2.99 and for the female part it is 10.34. From this our design is safe for experimental procedure

6. PROPOSED EXPERIMENTAL SETUP



7. FUTURE SCOPE

Magneto rheological fluid has wide scope in future because of its smart properties. Research work is going on the wide applications part such as clutches, Brakes, Dampers, Muscular rehabilitation devices, etc. Only From which commercial breakthrough for Dampers was made in 2002. As in brakes there are different types of prototype has been invented Drum, Inverted Drum, T-shaped rotor, Disk, Multiple disks.
In this paper we have designed totally new prototype. As in MRF brake there is no chance of wear and tear, So the life span of prototype can definitely increased.

8. CONCLUSION

By this we can say that, the prototype we have design is safe for the working experiment. And we can further calculate the braking torque by varying current and speed of the motor.

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