EXPERIMENTAL INVESTIGATION AND MODELLING OF MAGNETORHEOLOGICAL FLUID BRAKE

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ABSTRACT

This research focuses on Experimental Investigation 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 use of permanent magnets are not suitable.

Keywords: *Elastic properties, MRF Brakes, Magnetic field, Solenoid Coil ,Viscous properties.*

I. INTRODUCTION

Magneto rheological fluid (MRF) [1][2][3] 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

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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.

II. REVIEW OF RESEARCH PAPER

(1) Roger I. Tanner 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.

(2) N.M. Wereley et al. has analyzed 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 nano-particles up to 20 percent by weight, after that again it decreases.

(3) J. Huang et al. 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.

(4) F. Bucchi et al. 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. 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) V. K.Sukahwani and H. Hirani 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.

(7) Mukund A. Patil 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.

(8) Kosuke Nagaya et al. 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.

(9) Bhau K. Kumbhar and Satyajit R. Patil 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.

III. 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.

IV. DESIGN

4.1. Material selection. [10]

(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).

4.2. Sealing.

(1) Flange Sealant.

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

4.3. 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.

4.4. MR fluid selection.[3][10]

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(1) Magnetic Particles: Carbonyl Iron Powder.

(2) Liquid Carrier: Silicone Oil.

(3) Additives: Arabic gum.

4.5. Magnetic circuit design.

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

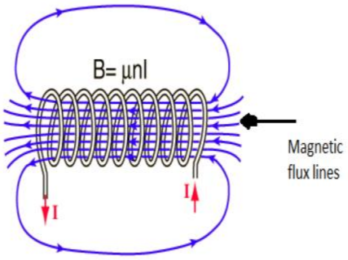

Fig. 1. Direction magnetic flux lines

(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.

Magnetic flux density at the center of coil is given by following formula:

$$B = \frac{\mu_0\, \mu_r NI}{\sqrt{4r^2 + l^2}} \quad (01)$$

4.6. Electric Motor selection:

AC Motor was selected as per the requirement of the speed. So AC motor having specification of 0.5 HP i.e. 350watt power with 1440rpm is selected. The Torque of Motor is calculated by the following formula.

$$\text{Power} = \frac{2\pi n t}{60} \quad (02)$$

$$350 = \frac{2*\pi*1440*t}{60}$$

T = 2.354 Nm. (03)

So, the torque of motor is 2.354 Nm.

4.7. Flywheel selection:

A random mild steel disk has been selected and checked for its feasibility in our system by calculating its moment of inertia and then checking for its energy storage i.e value of torque which is calculated as follows.

Calculation of Moment of Inertia of selected Flywheel (*I*):

Density of MS steel = 7850 kg/m^3

Mass = 7.6 kg

Diameter of wheel = 290mm =0.29m

Thickness = 15mm

Moment of inertia (I) = $\frac{mR^2}{2}$ (04)

$= \frac{7.6 * 0.145 2}{2}$

= 0.079895kg-m^2

Fluctuation of Angular velocity (ω):

There will be very minimum fluctuations in speeds, so assuming maximum fluctuations as of 50*rpm*.

$n_1 = 200$ rpm $n_2 = 250$ rpm

$\omega_1 = \frac{2\pi n_1}{60}$ $\omega_2 = \frac{2\pi n_2}{60}$

$\omega_1 = 20.9439\ rad/s$ $\omega_2 = 26.1799\ rad/s$

Now, Energy stored in flywheel.

$$\Delta E = \frac{1}{2} * I * \omega_2^2 - \frac{1}{2} * I * \omega_1^2 \quad (05)$$

= 27.3795 – 17.5228

= 9.8567 N-m

Energy stored by flywheel in terms of Nm is much more than the value of torque calculated for motor i.e. 2.354Nm it means that flywheel will store the of torque of motor So, This selected mild steel disk can be consider as flywheel in our system.

4.8. Pedestal Bearings:

A standard Pedestal bearing has been selected for 20mm diameter of shaft. As pedestal bearing are self-alignment bearing it is feasible to use it in our system.

4.9.Jaw couplings:

In system shaft of brake prototype should couple with flywheel and also flywheel must couple with motor shaft that also with proper alignment. For coupling we have different types of couple available in market. We have selected Jaw coupling because it has following advantages over other type of coupling:

a. Jaw couplings are versatile & robust.

b. They operate in a wide band of temperatures, can handle angular misalignment, can handle reactionary loads due to misalignment.

c. Jaw couplings are fail-safe.

d. They have dampening capability.

4.10. Power Supply:

Power Supply is used for Current source to solenoid coil. As Braking torque of the MR brake depends on viscosity of MR fluid. Viscosity of MR fluid is the function of applied magnetics flux density on the MR fluid. Since solenoid coil is used as source of magnetic field, current passing through the coil was the monitoring parameter. For setting constant magnetic flux density by the coil, current is monitored by constant current source using Power supply. With the help of that Instrument it was feasible to vary the solenoid coil current up to 1.5 amps only.

4.11. AC Dimmer stat:

To control the speed of single phase AC motor we used AC to AC dimmer stat. Which was able to vary the voltage across the terminal and resulting speed was varied.

V. BRAKE MODEL.

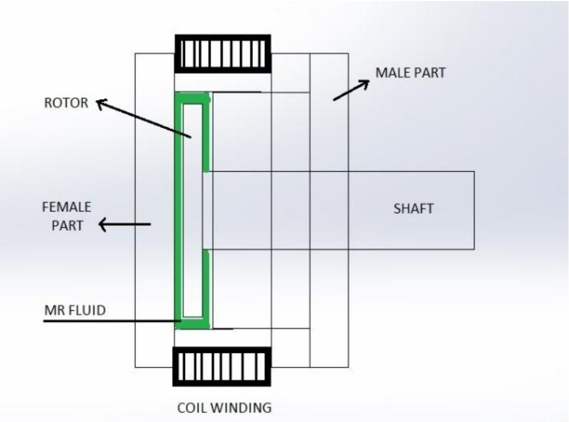

Fig. 2. Assembly drawing (brake)

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

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

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VI. TESTING RESULTS & DISCUSSION.

6.1 Testing Procedure:

Braking effect of designed prototype is to be justified by using this experimental setup. First complete the circuit by connecting the Power Supply and AC dimmer stat to solenoid coil and electric motor respectively. Make the connection in such a way that the power supply should not allow current to flow through the solenoid coil until the needed speed of motor had been achieved.

The supply current is adjusted using power supply first before starting the motor, as current get adjusted, the supply through coil is cut off. Than the motor is adjusted to its required speed using AC dimmers as the speed is required speed is achieved the motor is turned off, as flywheel is coupled to motor it stores the energy and keep rotating at the same speed that was achieved by the motor, now at same time adjusted current is supplied through the solenoid coil. This supplied current generates corresponding magnetic flux density which will correspondingly increase the viscosity of MR fluid present in between the rotor and surface of female part. This will generate the frictional force in between them which allows the flywheel to stop.

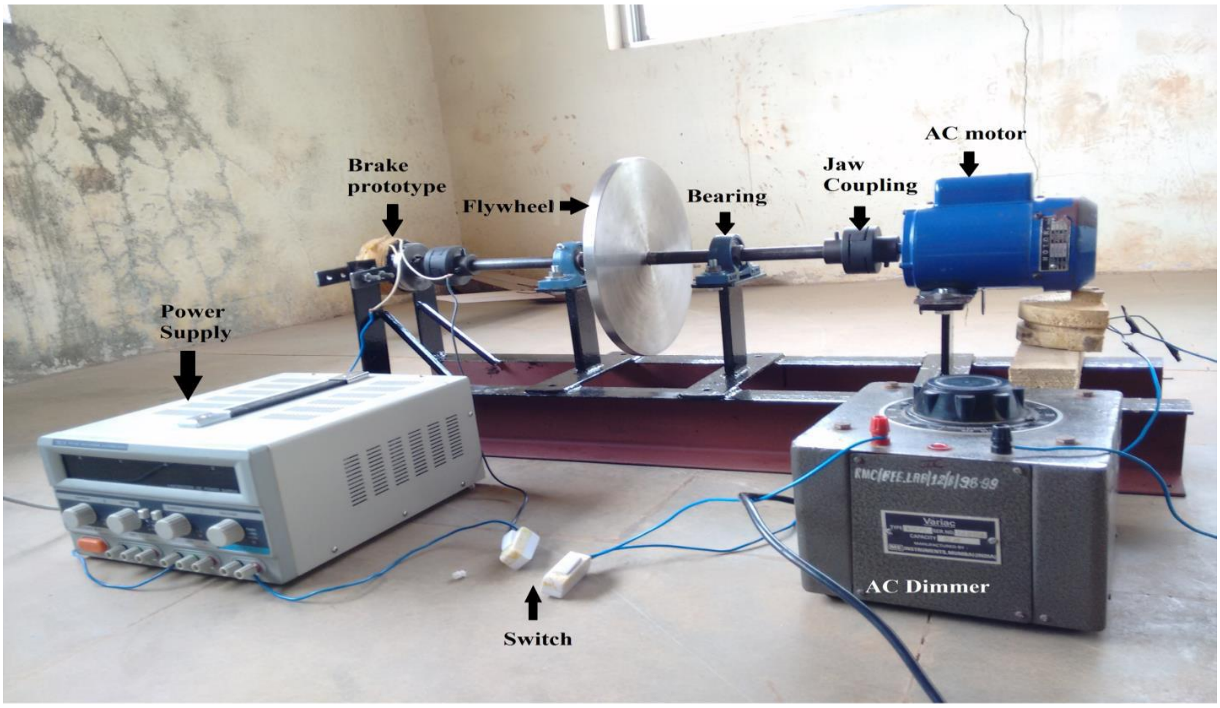

Fig. 3 Final experimental set up.

6.2 Practical result analysis of braking torque: [7]

As procedure discussed in 6.1, the time for assembly to come to rest with and without applying brake i.e. with or without current supply through solenoid coil was measured using stopwatch**.** From the obtained time period retardation was calculated and using the value of retardation the braking torque was estimated. During

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experimentation, observations were tabulated and analyzed for the variations in current through the coil and also variation in rotation (rpm).

6.3 Results and Calculations:

The formula for calculation of braking torque is given as follows.

$$T = I * \alpha \quad (6)$$

Where, α- Angular acceleration in rad/s^2

Now, angular acceleration can be calculated as

$$\omega = \omega_0 + \alpha t \quad (7)$$

Where,

ω - Final angular velocity.

ω_0 - Initial angular velocity.

As final velocity is always going to be zero, $\omega = 0$ Rewriting equation 2,

we get. $\alpha = -\frac{\omega_0}{t}$ (8)

Where, negative sign indicate deceleration value.

As per the above formulae we get the following Table 2 of results:

Sr. No.	Current (A)	Rotation(N)	Angular velocity (ω)	Time without braking (sec)	Time(t) with braking (sec)	Deceleration without braking.	Deceleration with braking (α)	Braking effect	Braking Torque (T) (N-m)
1	0.5	200	20.944	8.8	7.9	-2.38	-2.6511	0.2711	0.2118
	1				6.9		-3.0354	0.6554	0.2425
	1.5				5.5		-3.8080	1.4280	0.3042
2	0.5	400	41.888	14.5	11.3	-2.8888	-3.7069	0.8181	0.2962
	1				9.6		-4.3633	1.4745	0.3486
	1.5				7.7		-5.4400	2.5512	0.4346
3	0.5	600	62.832	21.5	15.4	-2.9224	-4.0800	1.1576	0.3260
	1				13.5		-4.6542	1.7318	0.3718
	1.5				12.9		-4.8707	1.9483	0.3891
4	0.5	800	83.776	27.2	18.8	-3.08	-4.4562	1.3762	0.3560
	1				17.4		-4.8147	1.7347	0.3847
	1.5				15		-5.5851	2.5051	0.4462
5	0.5	1000	104.72	33.5	21.4	-3.1260	-4.8935	1.7675	0.3910
	1				20.2		-5.1842	2.0582	0.4142

	1.5				17.1		-6.1240	2.9980	0.4893

From the of above table 2 it is clear that stopping time decreases as the current value goes on increasing. At higher speeds stopping time reduces drastically. It is clear from table 2 that as value of current goes on increasing the Braking effect will also goes on increasing the highest braking effect recorded is 2.9980 rad/sec^2 at 1.5apms for 1000rpm. Similarly it is clear from graph 9.3 that for higher values of current braking torque increases in large scale. Maximum value of braking torque achieved was about 0.4893 N-m retardation at 1000 RPM when current was 1.5 Amp.

VII. CONCLUSION

In this system no any wear of components occurs so, this mechanical device gives long lasting braking effect. The heat generation in the system is very low as compared to normal conventional braking systems and the heat generated in our system is due to the supply of magnetic field whenever required to stop the rotor. In this brake system we need unidirectional magnetic field. So it is necessary to have a DC current source for implementation of these brakes. As the braking effect is seen from this research work we can get more effective braking torque by using standard MR fluid and by standard calculations for implementation in automobile.

VIII. FUTURE SCOPE

The Future scope of this research work is very wide. The current supplied in the coil plays an important role in braking power of the brake. This current can be increased by considering the heat generated by it at the time of braking. The clearance between the rotor and the female part matters a lot at the time of braking and it can be varied. So by changing different parameter such as listed below one can get various readings which will help to determine the relation between parameters like braking torque, magnetic field generated, distance between rotor and back wall of female part, proportioned MR fluid sample.

1. Due to variation in the clearance, how the braking effect is affected that can be found.
2. The proportion of ferromagnetic micron particles and viscous oil can be varied to take readings.
3. As the magnetic field is also dependent on permittivity of core material so, by changing the material of rotor we can see the effect on braking torque.

This design can be modified according to how many parameters to be taken in consideration. This type of braking have many advantages over conventional braking such as it has no wear, very less heat generation compared to conventional braking systems, independent braking to each wheel, no need to handle complexity of braking fluid and pumping it so, may be one day it can replace them when much research is done.

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REFERENCES

Journal Papers:

[1] Roger I. Tanner, *"The changing face of Rheology", Journal of Non-Newtonian Fluid Mechanics, Volume.157, 2009.*

[2] N.M.Wereley, A.Chaudhari, J.H.Yoo, S. John, S.Kotha, A. Suggs, R.Radhakrishnan, B.J.Love, T. S. Sudershan, *"Bidisperse Magneto rheological Fluids using Fe particles at nanometer and micron scale", Journal of intelligent material systems and structures, Volume.17,2006.*

[3] J. Huang, J.Q. Zhang, Y. Yang, Y. Q. Wei, *"Analysis and design of a cylindrical magneto-rheological fluid brake", Journal of Materials Processing Technology, Volume.129, 2002.*

[4] F. Bucchi, P. Forte, F. Frendo, *"A magneto rheological clutch for efficient automotive auxiliary device actuation", The Italian research on smart materials and MEMS, Volume.23, 2013.*

[5] Kerem Karakoc, Edward J. Park , Afza lSuleman, *"Design considerations for an automotive magnetorheological brake,"j.mechatronics, 2008.*

[6] V.K.Sukhwani and H Hirani, *"Design, development, and performance evaluation of high-speed magneto rheological brakes," Proc. IMechE Vol. 222 Part L: J. Materials, 2008.*

[7] Mukund A. Patil, Ashutosh S. Zare, *" Theoretical Studies on Magnetorheological Fluid Brake," IJRMET Vol. 2, Issue 2, May - Oct 2012.*

[8] Kosuke Nagaya, Akihisa Suda, Hidenari Yoshida, Yasuo Ohashi, Haruo Ogiwara, Ryoji Wakamatsu, *"MR fluid viscous coupling and its torque delivery control", Wear, Volume.288, 2012.*

[9] Bhau K. Kumbhar and Satyajit R. Patil,*" A Study on Properties and Selection Criteria for Magneto-Rheological (MR) Fluid Components", International Journal of Chemical Tech Research, Vol.6, No.6, pp 3303-3306, Aug-Sep 2014.*