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Design and Fabrication of Magnetorheological Brake

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Abstract:- Magneto-rheological fluid (MRF) technology is associate previous ''newcomers'' returning to the market at high speed. A Magneto-Rheological (MR) fluid hydraulic brakes could be a device that transmits a force by the shear force of Mr fluid. The fluid is inserted between the rotating and glued discs and a flux is obligatory on the fluid. during this paper, an entire check rig for associate Mr fluid hydraulic brakes is introduced. Experiments square measure conducted to live the braking force and speed of shaft throughout braking method and therefore the results square measure conferred at totally different voltage input to the brake. Also, theoretical analysis for each Mr brake and therefore the system is developed and is resolved numerically victimization formula for locating braking force. result of current input to the Mr brake, body of fluid and style parameters is taken into thought. style supported theoretical calculations is formed. This work presents associate optimized style for a generator physical science fluid brake. The mechanism consists of a disk that is immersed within the magnetorheological fluid enclosed by associate magnet. The braking force is controlled by variable the DC current applied to the magnet. within the presence of a flux, the magnetorheological fluid particle aligns in a very chain like structure, therefore increasing the body. The shear stress generated causes friction within the surfaces of the rotating disk. The pure mathematics is optimized and performance of the system in terms of braking force is administrated. planned style reveals higher performance in terms of braking force from the present literature.

***Key words*: MRF, DC , MR Brake, Braking Torque.**

1.1 Introduction

Ever since some industrial problems were solved , each the technical and also the industrial edges for varied MRF applications became terribly promising. As a result, MRF development is current unceasingly. roughly sixty years agone, within the Forties, Jacob Rabinov discovered the MRF impact at the U.S.A. National Bureau of Standards. At a similar time W. Wislow was performing on a competitive technology referred to as electro-rheological fluid (ERF). Since the time once each technologies were discovered within the Forties, additional analysis work has been administrated on ERF than on MRF. There ar some similarities between the 2 completely different technologies relating to the desired power, however within the case of ERF, thousands of volts and a few milliamperes ar needed, and within the case of MRF, commonly between two and twenty four V and a few amperes ar needed. The electro - natural philosophy (ER) impact depends on associate electric field and also the magneto-rheological (MR) impact depends on a magnetic flux. MRF product have between twenty and fifty times higher management impact than the equivalent ERF product. Also, with MRF technology nowadays there's higher stability with relation to contaminants. of these MRF technology benefits have created a really high level of interest to introduce product supported MRF technology throughout the foremost recent number of years. Over roughly the foremost recent 5 years additional MRF publications than ERF publications are bestowed within the property right. At the start of the event work on MRF, non-predictable behaviour, like in-use thickening, alluviation and abrasion were delineate. This created some challenges for the industrialisation of the primary application supported MRF, particularly for associate automotive application. throughout the foremost recent few years the soundness, alluviation and abrasive behavior are studies in many universities and firms.The man fluid is characterised by chiefly 3 parts, carrier fluid, iron particles and additives. Carrier fluids ar chosen seeable of their consistency, their temperature steadiness a their similarity with completely different materials within the device. chiefly used carrier fluids ar silicone polymer oil, artificial oil, water, kerosene. the foremost generally utilised material for man fluid particle is carbonyl iron, on account of its high magnetic saturation and is noninheritable by the method of thermal decomposition of iron pentacarbonyl. ($Fe(CO)5$). The additives ar used for particle subsidence, agglomeration, preventing the particle from oxidisation and wear.

2 Organization of the report

Chapter 1: Gives the introduction to the project. It also gives the background data about the working principle of the selected material (MR fluid). It gives general idea about the elements used in the project undertaken. It shows the main motivation and purpose of the project and its various and futuristic applications. The scope of the project is also shown in this chapter.

Chapter 2: The main content of this chapter is the details of the literature survey of various papers and reports. All previous studies and analysis of the related topic are seen in this chapter. They help to understand the topic more deeply and clearly.

Chapter 3: This chapter has the main design of the MR Brake. Dimensions of the brake are selected by proper FEA analysis. The brake torque required for an automobile is very high. This required proper designing of the brake.

Chapter 4: A test-rig is made to calculate the braking torque of the designed and manufactured MR Brake. This braking torque actually decides the application of the brake. It helps to verify the theoretical calculations with the experimental results.

Chapter 5: This chapter represents analysis, applications and limitations of MR Brake system. The MR Fluid based systems may have many applications in the field of clutch, dampeners, medical as well as commercial automobile vehicles' braking system.

Discussions, Tables and Figures

Fig. 1: CAD Model of the manufactured Test-rig

Fig 2: Photos of the project:

Table 1. The properties of the MRF 132 DG:

Property	Value/Limits
Base fluid	Hydrocarbon
Operating temperature	−40 to 130 °C
Density	3090 kg/m^3
Colour	Dark grey
Yield stress	45 kPa
Weight percent solid	81.64%
Specific heat at 25 °C	800 J/kg K
Thermal conductivity at 25 °C	0.25–1.06 W/m K
Flash point	>150 °C
Viscosity at 40 °C	0.09 (±0.02) Pa s
K (MRF-dependent constant parameter)	0.269 Pa m/A
β (MRF-dependent constant parameter)	1

Formula for calculation of Braking Torque:

The latency of the brake is 15–20 ms. The shear stress and thus the braking force may be varied by this input to the magnet. The braking force additionally depends on the angular speed, the man fluid-dependent constant parameters, the man fluid gap, the disc size and therefore the variety of discs of the brake, as evident from Eqs. (1) and (2) given below.

$$T_H = \frac{2\pi}{3} NKH^{\beta}_{MRF}(r_z^3 - r_j^3)$$

………………………………………………………… (1)

where TH is the torque due to the magnetic field, N is the number of discs, H is the magnetic field intensity, rz and rj are respectively the outer and inner radii of the disc, and K and b are the MR fluid dependent constant parameters. Common values for K and b are 0.269 Pa m/A and 1.

$$T_\mu = \frac{\pi}{2h} N\mu_p({r_z}^4 - {r_j}^4)w$$

……………………… (2)

where TH is that the force because of the field, N is that the variety of discs, H is that the field intensity, rz and rj ar severally the outer and inner radii of the disc, and K and b ar the mister fluid dependent constant parameters. Common values for K and b ar zero.269 Pa m/A and one.

$$T_b = T_H + T_\mu \quad \text{...(3)}$$

3.8 Design of MR Brake test-rig:

This part of the design represents the designed test-rig for the calculation of braking torque of the designed MR Brake.

Components of test-rig:

1. Motor
2. Coupling
3. MR Disk Brake
4. Battery
5. Speed Sensor
6. Arduino
7. Computer

Taguchi Method :

Table 2: Cost of the project approximately is shown in the Table below.

Sr No.	Materials	Quantity	Cost (approx.)
1.	Motor	1	10,500
2.	Battery	1	8,500
3.	MR Brake	1	7,000
4.	Speed Sensor	1	500
5.	Arduino	1	750
6.	Extra (Manufacturing and other)	-	1000
			Total cost = 28,250

Table 3: Taguchi L9 Tests

Factor	Type	Levels	Values
MR Fluid	Fixed	3	A, B, C
Speed	Fixed	3	100, 200, 350
Voltage	Fixed	3	12, 24, 36

Exp. No.	MR Fluid	Speed (rpm)	Voltage (V)	Torque (Nm)
1	A	1	1	0.78
2	A	2	2	1.06
3	A	3	3	1.65
4	B	1	2	0.92
5	B	2	3	1.24
6	B	3	1	1.07
7	C	1	3	1.08
8	C	2	1	0.83
9	C	3	2	1.13

Fluid B:

SR NO	PART NAME	MAT	QTY
1	CI PARTICLE 80 PERCENT	CI	2 KG
2	OLEC ACID 12 PERCENT	-	0.5 L
3	WHITE GREESE 6 PERCENT	-	0.5 KG
4	PARAFFIN OIL 2 PERCENT	-	0.5 L
5	MIXING CONTAINER	GLASS	1 NOS

Fluid A:

SR NO	PART NAME	MAT	QTY
1	CI PARTICLE 85 PERCENT	CI	2.5 KG
2	OLEC ACID 12 PERCENT	-	0.5 L
3	WHITE GREESE 2 PERCENT	-	0.5 KG
4	PARAFFIN OIL 1 PERCENT	-	0.5 L
5	MIXING CONTAINER	GLASS	1 NOS

Fluid C:

SR NO	PART NAME	MAT	QTY
1	CI PARTICLE 70 PERCENT	CI	1.5 KG
2	OLEC ACID 12 PERCENT	-	0.5 L
3	WHITE GREESE 12 PERCENT	-	0.5 KG
4	PARAFFIN OIL 6 PERCENT	-	0.5 L
5	MIXING CONTAINER	GLASS	1 NOS

Arduino Programming for Speed sensor

```
#include<LiquidCrystal.h>

LiquidCrystal lcd(3,4,5,6,7,8); //LiquidCrystal lcd(12,11,6,5,4,3);

float value=0;

float rev=0;

int rpm; // pin 2 ir sensor

int oldtime=0;

int time;

void isr() //interrupt service routine

{

rev++;

}

void setup()

{

Serial.begin(9600);

lcd.begin(16,2); //initialize LCD

lcd.clear();

 lcd.print("M.R. BRAKING");

 lcd.setCursor(0,1);

 lcd.print("");

 delay(3000);

  lcd.clear();

 lcd.print( "K.J. Somaiya ");

 lcd.setCursor(0,1);

 lcd.print(" ");

 delay(3000);

  lcd.clear();

 lcd.print("Guided By:Prof.");

 lcd.setCursor(0,1);

 lcd.print("Manoj J.Pawar");

 delay(3000);

  lcd.clear();

attachInterrupt(0,isr,RISING); //attaching the interrupt

}

void loop()

{

delay(1000);

detachInterrupt(0); //detaches the interrupt

time=millis()-oldtime; //finds the time

rpm=(rev/time)*60000/4.5; //calculates rpm//4.50OFFSET

oldtime=millis(); //saves the current time

rev=0;

lcd.clear();

lcd.setCursor(0,0);

lcd.print("_SPEED SENSOR__");

lcd.setCursor(0,1);

lcd.print(   rpm);

lcd.print(" RPM");

lcd.print("   ");

Serial.println(rpm);

attachInterrupt(0,isr,RISING);

}
```

Design Considerations:

We are taking standard motor of Power 246 watt and 1350 rpm

P = 2 x 3.14 x N x T / 60

246 = 2 x 3.14 x 1350 x T/ 60

T=246 x 60/2x 3.142 x 1350 = 1.7400 N-m = 1740 N-mm

Motor pulley and shaft pulley dia. 100 mm

Now, Angular velocity (ω)for flywheel.

$\omega = 2\ \pi N/60$

= 3.142 x 2 x 1350/60

= 483.80/60

ω = 130.8 rad/s.

Design of V- belt:

Number of V-Belts:

We know that the power transmitted per belt

P = (T1-T2) x V

As we know maximum torque on shaft = T_{max} = T = 1740 N-mm

Where ,

T1 = Tension in tight side

T2 = Tension in slack side

O1,O2 = center distance between two shaft

From fig.

$\sin \propto = \frac{R1 - R2}{O1O2}$

$\sin \propto = \frac{50 - 50}{305}$

$\sin \propto = 0$

$\propto = 0$

To Find θ:

$\theta = (180 - 2\propto) \times 3.14/180$

$\theta = (180 - 2*0) \times 3.14/180$

θ =3.142 rad

we know that,

$T1/T2 = e^{\mu\theta \text{ Cosec } \beta}$

$T1/T2 = e^{0.25 \times 3.142 \text{ cosec } 20}$

T1 = 2.36T2

Design of V- belt:

Fig 4: V-Belt

Number of V-Belt:

We know that the power transmitted per belt

P = (T1-T2) x V

As we know maximum torque on shaft = T_{max} = T = 2480 N-mm

Where ,

T1 = Tension in tight side

T2 = Tension in slack side

O1,O2 = center distance between two shaft

From fig.

$\sin \propto = \frac{R1 - R2}{O1O2}$

$\sin \propto = \frac{50 - 50}{305}$

$\sin \propto = 0$

$\propto = 0$

1)

To Find θ:

$\theta = (180 - 2\propto) \times 3.14/180$

$\theta = (180 - 2*0) \times 3.14/180$

θ =3.142 rad

we know that,

$T1/T2 = e^{\mu\theta \text{ Cosec } \beta}$

$T1/T2 = e^{0.25 \times 3.142 \text{ cosec } 20}$

T1 = 8.36T2

We have,

T = (T1 – T2) X R

2480 = (2.36T2 – T2) X 50

T2 = 2480/68= 36.47N

T1 = 2.36 X 36.47

T1 =72.94 N

So tension in tight side = T1= 72.94 N

$V = \pi DN/60$

$= 3.142 \times 0.1 \times 1440/60$

7.06 m/sec. 7060 mm/sec

P = (72.94 –36.47) x 7.06

P = 257.48 W (N-m/s)

Number of V-Belts:-

$$N = \frac{\text{Total Power transmitted}}{\text{Power transmitted per belt}}$$

$$= \frac{257.48}{373} \text{ (0.5 hp power = 373watts)}$$

$$= 0.69$$

Say 1 belt

So 1 belt is sufficient for transmission of power

Calculation of Length of Belt:

We know that radius of pulley on shaft

r1 = d1/2 = 100 /2 = 50mm

Radius of pulley on motor shaft

r2 = d2/2 = 100/2 = 50 mm

Center distance between two pulley = 290 mm

We know length of belt

$L = \Pi (r2+r1) + 2 \times X + (r2-r1)^2/x$

$= \Pi (50 + 50) + (2 \times 290) + (50 - 50)^2/305$

L = 889 mm = 35 inch

Designing of Shaft:

Torque transmitted by shaft,

$T = \pi/16 \times \tau \times d^3$

Select permissible shear stress (τ) from design data book.

$\tau = 70 \text{ N/mm}^2$

Therefore, $1650 = \pi /16 \times d^3 \times 70$

d^3 = 1650 x 16/3.142 x 70

d = 26400/219.911 = 120.04

d = 4.93 mm

Take Factor of safety 2

d = 4.93 x 2

d = 9.86 mm

But we are using 20mm shaft , therefore our shaft design is safe.

By using 20mm shaft , our shaft design is safe.

Shafts Subjected to Combined Twisting Moment and Bending Moment

Let τ = Shear stress induced due to twisting moment, and

σb = Bending stress (tensile or compressive) induced due to bending moment.

According to maximum shear stress theory, the maximum shear stress in the shaft,

The total weight on shaft coming is

W=2 kg= 20 N

M= FxL

M= 20x100=2000 N-mm

$T_e = \sqrt{M^2+T^2} = \sqrt{2000^2+2378.3^2}$

$= \sqrt{9.65\times10^6}$

T_e=3107.4 N-mm

$T_e = \pi/16 \times 65 \times d^3$

$d^3 = 3107\times16/\pi\times65 = 243.44$

$d = 3\sqrt{90.77} = 4.49 = 4.5$mm

d=6.24 mm

but we are using 20mm shaft so design is safe.

Let the total weight (P) of our machine be 60 kg, now this 60 kg weight is kept on four angle,

P = 60/4 = 15 kg.

P = 15 x 9.8 = 147 N.

L = 300 mm.

M = WL/4 = 147 × 300/4

= 11025 N-mm

$Z = B^3/6 - b^4/6 \times B$

$Z = 30^3/6 - 26^4/6 \times 30$

$Z = 1961 mm^3$

$= M/Z = 11025/1961 = 5.622 N/mm^2$

As induced bending stress is less then allowable bending stress i.e. 270 N/mm^2 design is safe.

1. **Design of TRANSVERSE FILLET Welded Joint on shaft:**

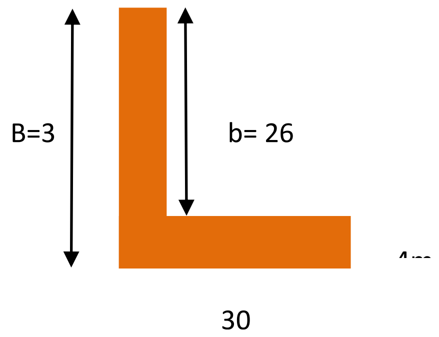


Fig 5: Welded Joint

Perimeter = π x dia = 3.142 x 20 = 62.83 mm

Hence, selecting weld size = 3.4 mm

Area of Weld = 0.707 x Weld Size x L

= 0.707 x 3.4 x 62.3

$= 139 mm^2$

Force Exertred = 30 x 9.81

= 300 N

Stress induced = Force Exerted / Area of Weld

= 300 / 142.15

$= 2.11 N/mm^2$

For filler weld :

Maximum Allowable Stress for Welded Joints = 210 Kgf/ cm^2

= 21 N/mm^2

Hence safe.

DESIGN OF BOLTED JOINT:

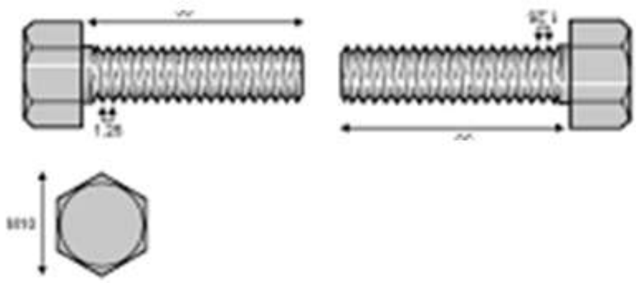


Fig 7: Bolt

For Bolted Joint we used M10 Bolts

do = 10mm

dc = do x 0.84

dc = 8.4mm

Shear Area $A = \prod / 4 \times (8.4)^2$

$A = 55 mm^2$

Fig 7: Bolt

$\tau = \frac{F}{A}$

$\tau = \frac{500}{55}$

$\tau = 9.09 N/mm^2$

τ on bolt < τ i.e. $9.09 N/mm^2 < 80 N/mm^2$

Design is Safe.

Design of Joint Nuts and Bolts:

Here the bolt will be double sheared as shown below in the figure ---

Arm guide way arm

Fig 6: Weld Geometry

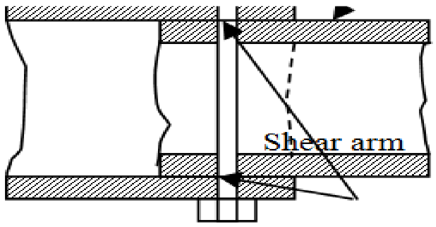


Fig 8: Joint Nuts and Bolts

Resisting area = (π / 4 x d²) x 2

$$. \; fs = \frac{P}{2 \times \pi / 4 \times d^2}$$

$$. \; fs = \frac{600}{2 \times \pi / 4 \times d^2}$$

d = 2.52 mm

for safe design adopt diameter = 6 mm

Design of The Bearing:

Here. We have to determine the value of dynamic load rating for 5000hrs of operation with not more than 10% of failure

W1 = 20 kg

W2 = 80 kg

N = 1000 rpm

Therefore no.of revolution during 90% of time,

L1 = 0.9 x 1000 x 60 x 5000

L1 = 270 x 10^6 min

Number of revolution during 10% of time

L2 = 0.1 x 1000 x 60 x 5000

L2 = 30 x 10^6 min.

Basic dynamic load rating = C

$$C = \left(\frac{L1W1^3 + L2W2^3}{10^6} \right)^{1/3}$$

$$C = \left(\frac{(270 \times 10^6 \times 20^3) + (30 \times 10^6 \times 80^3)}{10^6} \right)^{1/3}$$

$$C = [\, 2160000 + 15360000]^{1/3}$$

$$C = [17520000]^{1/3}$$

C = 259.28 kg.

Now using reference table, for static load of 259.28 kg bearing no 204 is used.

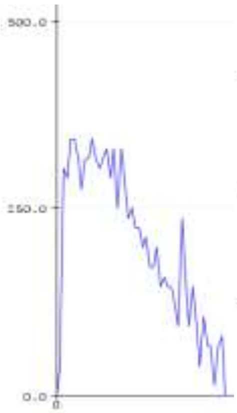
SKF 6204

Sealing

Sealing of the MRB is another vital style criterion. Since the brake employs Associate in Nursing mister fluid, it's to be sealed properly against a doable discharge, which is able to cause the loss of braking. as a result of mister fluids square measure extremely contaminated thanks to iron particles that makes protection a essential issue. additionally, within the case of the dynamic protection needed between the static casing and also the shaft, there's a larger risk of protection failure once the mister fluid is repetitively coagulated (due to the repetitive braking) round the neighborhood of the seals. so as to decrease the chance of protection failure, the dynamic seals got to be unbroken aloof from the magnetic circuit within the brake. this may decrease the magnetic flux intensity that's generated within the neighborhood of the seals throughout braking, therefore avoiding the on/off cycle of the mister fluid. Also, since the fluid is contaminated, surface finishes and also the protection methodology itself square measure of a good importance. during this work, the dynamic seals were unbroken aloof from the magnetic circuit by introducing a non-ferromagnetic shaft and shear disk support outside the circuit that holds the magnetic shear disks (see Figure three.1). additionally the surface finishes were improved and also the tolerances were unbroken tight for higher interface between the seals and also the counterpart surfaces. In Figure three.8, the protection varieties employed in the MRB and their locations square measure shown. within the MRB projected, Viton O-rings were used for each static and dynamic applications. additionally, as a sealing material, Loctite 5900® rim sealing material, was additionally used.

ELECTROMAGNET

An magnet could be a sort of magnet within which the flux is created by an electrical current. The flux disappears once the present is turned off. Electromagnets sometimes contains an utsized range of closely spaced turns of wire that make the flux. The wire turns ar usually wound around core made up of a magnetism or ferrimagnetic material like iron; the core concentrates the magnetic flux and makes a a lot of powerful magnet. the most advantage of ANmagnet over a static magnet is that the flux will be quickly modified by dominant the number of electrical current within the winding. However, in contrast to a static magnet that desires no power, AN magnet needs a continual offer of current to take care of the flux. Electromagnets ar wide used as parts of different electrical devices, as motors, generators, relays, loudspeakers, hard disks, MRI machines, scientific instruments and magnetic separation instrumentality. Electromagnets also are utilized in business for choosing up and moving significant iron objects likeiron, steel



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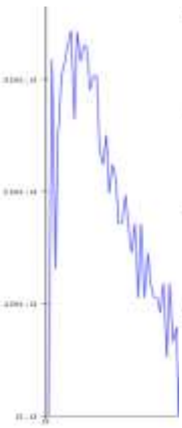

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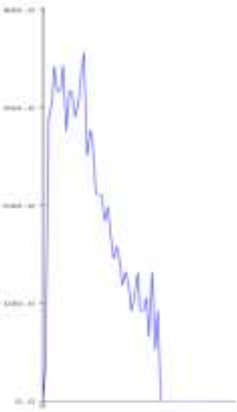

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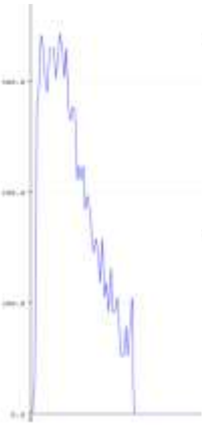

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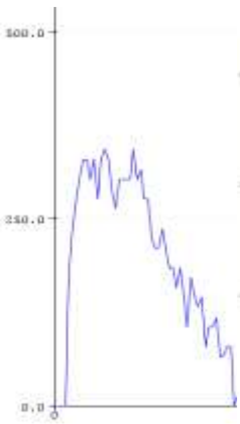

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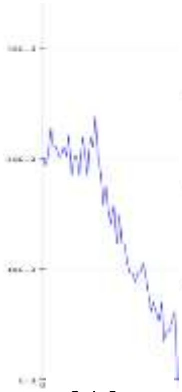
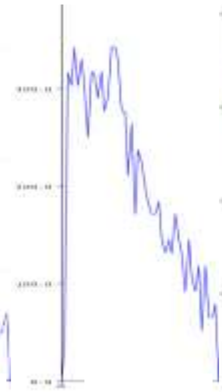
B-3-1



C-1-3



C-2-1

C-3-2

Conclusion and Future Scope

In this work, a magneto rheological brake (MRB) is introduced as a attainable substitute for the standard brake system (CHB). Since MRB is associate degree mechanical device, it's many benefits over CHB, like the reduced feat delay, easy package management implementation and lower system weight. during this work, the planning method is started with associate degree analytical model of the planned MRB. Then, the MRB was designed intimately with a spotlight on magnetic circuit improvement and material choice. A three-D CAD model of the optimum Mr Brakes is meant.

Supported literature analysis, the authors have determined for the foremost promising Mr Brake kind, factory-made it and take a look ated it on a specially designed test rig. The studies have shown that the tested Mr brake has potential for sensible applications because of easiness and accuracy of management. However, the worth of the general braking torsion remains tiny. to extend it, higher utilization of the prevailing flux is required. The authors prompt completely different approach compared to the standard Mr brake style that might increase the general braking torsion by increasing the flux potency and Mr brake's fluid contact space.In order to maximise planned Mr brake's potential, any investigations on flux propagation square measure required also as style improvement.

This represents applications and limitations of MR Brake system. The MR Fluid based systems may have many applications in the field of clutch, dampeners, medical as well as commercial automobile vehicles' braking system. These fluids can reversibly and instantaneously change from a free-flowing liquid to a semi-solid with controllable yield strength when exposed to a magnetic field. In the absence of an applied field, MR fluids are reasonably well approximated as Newtonian liquids. For most engineering applications, a simple Bingham plastic model is effective in describing the essential, field-dependent fluid characteristics. MR technology has moved out of the laboratory and into viable commercial applications for a diverse spectrum of products. Applications include automotive primary suspensions, truck seat systems, control-by-wire/tactile-feedback devices, pneumatic control, seismic mitigation and human prosthetics. In contrast to conventional electro-mechanical solutions, MR technology offers:

- Real-time, incessantly variable management of
- Damping
- Motion and position management
- Locking x perception feedback
- High dissipative force freelance of rate
- Greater energy density
- Simple style (few or no moving parts)
- Quick latency (10 milliseconds)
- Consistent effectivity across warmth variations (range of 140C to a hundred thirty C)
- Minimal power usage (typically 12V, one Amp GHB current; fail-safe to battery backup, which might fail-safe to passive damping mode)
- Inherent system stability (no active forces generated) x

MR fluids will be operated directly from low-tension power provides. Mr technology will offer versatile, reliable management capabilities in styles.

Future Scope:

The terribly very first thing that needs to be done is to enhance the correlation between the simulation and therefore the experimental results. The simulation results will be improved to match the experimental knowledge by employing a a lot of elaborate model of the fabric properties and by as well as the temperature effects within the simulation. As was mentioned antecedently in Chapter one, the most objective was to style Associate in Nursing EMB which might be used as a substitute for CHB. However, the braking torsion generation capability of the MRB planned during this work isn't high enough for a typical rider vehicle. Therefore, the braking capability of the MRB should be improved by restful the constraints outlined for the MRB optimisation drawback, i.e. by increasing the quantity of disks hooked up and by ever-changing the magnetic circuit configuration. This improved MRB then needs to be prototyped and tested.

One among the main issues with the particular implementation of Associate in Nursing adult maleB into a automobile is that the warm temperature result on the MR fluid. In observe, the planned MRB would possible need a physical (e.g. active or passive) cooling system to alleviate the heating drawback within the adult male fluid and so up the braking performance. Since, the brake mechanism transforms mechanical energy into heat; all mechanical energy of the automobile are going to be regenerate into heat within the MRB. As mentioned antecedently within the material choice section, the magnetic properties square measure extremely addicted to the temperature of the adult male fluid (the consistency varies with temperature). Hence, heat transfer analysis needs to be enclosed in future studies. once the changed MRB is tested, a closed-loop controller needs to be designed so as to get rid of the residual flux generated thanks to the physical phenomenon characteristics of the magnetic materials utilized within the MRB. This controller are going to be then combined with alternative controllers like Associate in Nursing antilock braking controller that avoids slippery of the tires throughout braking. Then, the MRB and therefore the controllers are going to be tested on a ergometer to simulate real road conditions. because the final step, the MRB are going to be mounted on for a vehicle and tested for on-road performances.

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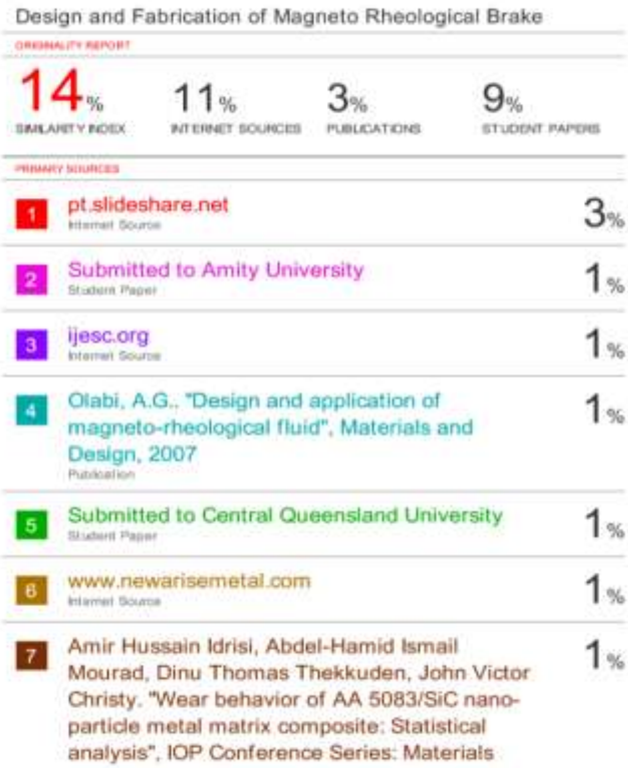
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