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Simulation of Magneto-Rheological Brake for Automotive Application

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Abstract: In this paper Magneto-Rheological Brake model has been proposed that can provide the braking torque required for stopping a two-wheeler vehicle under consideration. Firstly the braking torque required to stop the vehicle is calculated analytically. Then appropriate design parameters have been selected and a model has been developed in MATLAB/SIMULINK software to achieve the same braking torque. The braking torque has been calculated at vehicle speed of 70 km/hr. and for stopping time of 2(sec), 3(sec), 4(sec) and 5(sec) respectively. The maximum braking torque at stopping time of 5 seconds is 28.3485 Nm, at the rear wheel. The proposed MR model generates the required braking torque. The MR fluid used is Lord Corporation's MRF-132DG. The use of Magneto-rheological fluids in the braking application has been restricted, as the torque produced is not as much as required for braking, due to limited shear stress the MR fluid can sustain. This paper implicates that MR brake torque capacity can be increased by proper design considerations. Here we have increased the number of discs for the same purpose.

Keywords: MR Fluids, Braking Torque, MATLAB/Simulink, Number of discs.

I. Introduction

Magneto-Rheological fliud is one of the smart materials recently used by the automotive Sector. The rheological properties of fluid change when a magnetic field is applied across it. When in normal conditions the MR fluid behaves like a Newtonian fluid, but when magnetic field is applied across it the viscosity of the fluid changes and it shows semi-solid like characteristics [1].

An appropriate carrier fluid carries iron particles (magnetisable particles) in it. Homogeneity of the particles is maintained by the carrier fluid which serves as a dispersed medium. To promote non- settlement of the particles and appropriate suspension of particles, also to enhance the lubricity and initial viscosity of the fluid various surfactants and stabilizers are are added to it [2]. Dipole moment is acquired by the iron particles when an external magnetic field is applied and the viscosity of the fluid increases. The same is depicted in Figure 1, below.

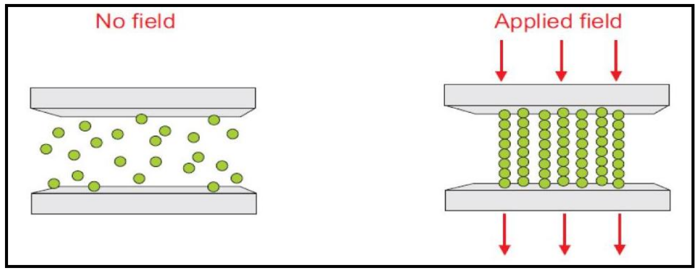

Figure1. Chain-Like Structure Formation in Controllable Fluids [3]

A generalised braking configuration has been shown in the figure 2. MR fluid fills the gap between the Stationary casing and the rotating disc that is attached to the wheel shaft. When the magnetic field is applied across the MR fluid it resists the motion of the rotating disk due to shearing action, and the required braking effect is obtained [4].

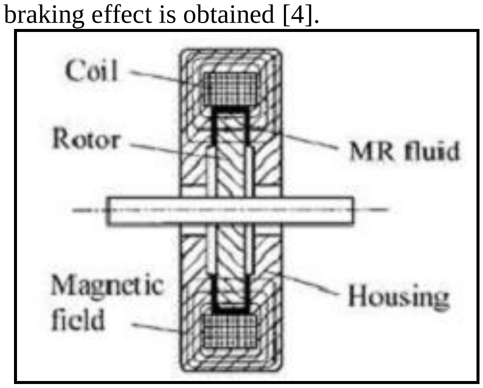

Figure 2. Operational Principle of MR Brake [4]

In a thesis work done by Karakoc [5], MR brake for a electric bike, Sports bike and a four wheeler passenger car was studied. The work mainly focussed on the selection of material and magnetic circuit design. Here the optimum design configuration was obtained using FEA analysis and the results were compared with experimental data.

Braking torque required for E-bike is less, an MR brake was designed for the same experimentally [6]. Here the braking torque required was calculated first theoretically and on the basis of same appropriate MR fluid was selected, and a physical set up was done.

MR brake simulation for E-bike was done in another work and results were compared with the experimental study. It was found that the experimental values deviated from those obtained by simulation due to the non-consideration of the thermal effect on MR fluid due to friction. The study also reveals that torque due to viscosity is independent of the speed [7].

A prototype was built to check the MR fluid application in E-car. Here the main design parameters like saturation of magnetic field, braking torque, high shear speed were obtained by finite element method which was integrated with optimization tools. Obtained parameters were then run using simulated model and results were plotted. The braking torque obtained as a simulation was much smaller than actually required [8].

As per the literature study done E-bike, E- car have been the topic of study for application of MR brakes. The normal bikes and car are not studied due to their higher torque requirements. In this paper MR brake system is been proposed for two-wheeler motorcycle. First, the required parameters for calculation of braking torque are obtained and the braking torque is calculated theoretically. Then the appropriate design parameters and configuration are obtained from the literature study.Then a model is built for the MR brake using MATLAB/SIMULINK software and braking torque is obtained.
It is found that with increase in number of discs the barking torque requirement for the two wheeler under consideration can be obtained.

II. Model Description and methodology

1. Calculation of Braking Torque:

The parameters required for the braking torque are tabulated below.

Table 1.Measuring of Axle Loads [9]

Weight (kg) (W)	Reaction at front wheel in satic condition W_{fs} (kg)	Reaction at rear wheel in static condition W_{rs} (kg)	Reaction on front wheel in lifted condition W_{lf} (kg)
191 Rider (unladed)	71	120	84
261 Rider + 70kg	74.5	186.5	94.5

Table 2.Calculation of CG [9]

Weight (kg)	Distance of CG from front wheel Lf (mm)	Distance of CG from front wheel Lr (mm)	Height of CG from ground level h (mm)
191 Rider (unladed)	835.60	494.39	622.18
261 Rider + 70kg	950.36	379.63	662.10

The maximum braking force required is given as [6],

$F_{mxf} = W_f * \mu_p$ ……………………(1)

Where,
W_f = Dynamic load on front axle
F_{mxf} = Maximum braking force
μ_p = peak coefficient of friction = 0.7

The dynamic load on the front axle is given by,

$W_f = W_{fs} + (h/L) * (W/g) * D_x$ ………………(2)
Where,

W_{fs} = Reaction at front wheel (kg),
h = Height of CG from ground level (mm),
L = Length of wheel base (mm) = 1330 [9],
W = Total mass of the vehicle (kg),
g = gravitational acceleration (m/sec^2),
D_x = deceleration = (v/t) (m/sec^2),
v = maximum velocity of the vehicle (m/sec),
t = stopping time (seconds).

The vehicle is assumed to be running at speed of 70 (km/hr).
Now the dynamic load on the rear axle is given by,

$W_r = W_{rs} - (h/L) * (W/g) * D_x$ …………..(3)

Where,
W_{rs} = Reaction at rear wheel in static condition (kg).
The maximum braking force at rear wheel then will be given as,

$F_{mxr} = W_r * \mu_p$ ………………………….. (4)

The maximum braking torque at front and rear wheel are then given by [6]

$T_{bf} = F_{mxf} * R$ …………….. (5)

T_{bf} = Maximum braking torque at front wheel (Nm),
R = Effective radius of wheel = 0.3 (m) [9]

$T_{br} = F_{mxr} * R$ …………….. (6)

T_{br} = Maximum braking torque at rear wheel (Nm)

The values obtained from above formulas at different deceleration rates are tabulated below.

Table 3. Braking Force and Braking Torque For Unladen condition

Sr. No	Stopping Time (sec)	D_x (m/sec^2)	Braking Force Front Wheel (N)	Braking Force Rear Wheel (N)	Braking Torque Front Wheel (Nm)	Braking Torque Rear Wheel (Nm)
1.	2	9.7	111.71	22.01	33.51	6.60
2.	3	6.4	90.62	42.67	27.18	12.80
3.	4	4.8	80.69	53.00	24.20	15.90
4.	5	3.8	74.49	59.20	22.34	17.76

Table 4. Braking Force and Braking Torque For Laden condition

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1 June 2016

Sr. No	Stopping Time (sec)	D_x (m/ sec^2)	Braking Force Front Wheel (N)	Braking Force Rear Wheel (N)	Braking Torque Front Wheel (Nm)	Braking Torque Rear Wheel (Nm)
1.	2	9.7	142.28	40.41	42.68	12.12
2.	3	6.4	112.24	70.46	33.67	21.13
3.	4	4.8	97.21	85.48	29.16	25.64
4.	5	3.8	88.20	94.49	26.46	28.34

As seen from the table above the braking torque for Laden condition when the stooping time is 5 sec is 28.34 Nm at the rear wheel. This is the torque that simulated model has to generate.

2. Selection Of Design Parameters :

Various design criteria were considered in study done by Karakoc [5] and an optimum MRB configuration was obtained. The same configuration has been used here.

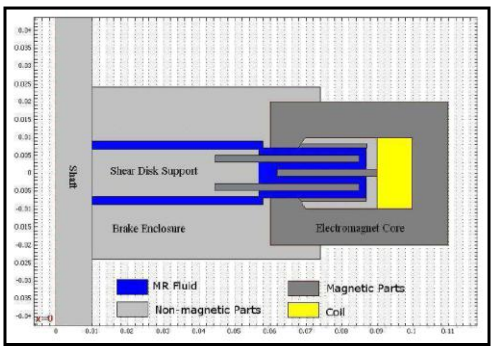

Figure 3. Selected Design Configuration for MRB [5]

The braking action in MR fluid is through shear friction, which produces heat and the temperature of the assembly increases. Thus the MR fluid should have a wide operating range of temperature. Falco da Luz [10] in his work found that Lord Corporation's MRF- 132DG that has plastic viscosity of 0.09Pa-s. is suitable for braking application due to its wide operating range. The same fluid has been selected here.

Simulation of MR brake generally has three parts. First is the mathematical modelling of the electric motor, second is the mathematical modelling of MR brake and the third is the modelling in MATLAB/Simulink software. The mathematical modelling and electric motor and modelling of MR brake has been already done in [7], the same is used for plotting the input parameters for the Simulink model.

The study of Karakoc [5] also revealed that the braking torque increases with increase in number of discs. The figure below

indicates the same. In study [7] the number of discs used is 2, whereas in this study the number of discs is increased to 4.

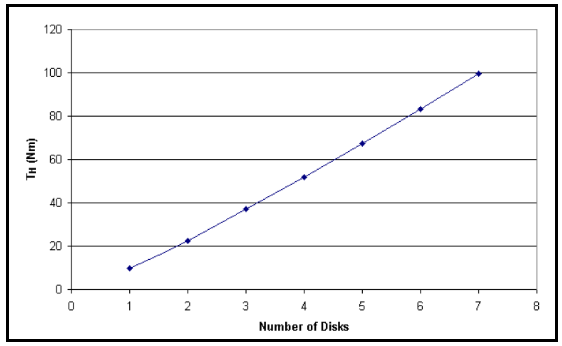

Figure 4. Graph showing increase in braking torque with increase in number of discs [5]

3. Modelling in MATLAB/Simulink:

The simulation model is run considering that motor is running at 200 rpm (21 rad/sec) and the voltage supplied to the motor is 230 volts.

According to modelling modelling of the motor referred from [7] the various input parameters for simulation of motor in developed model have been given below [11].

La = Self- inductance = 0.003H
Ra = Armature resistance = 3.94Ω
B_1 = Viscous torque coupling = 2 N.m/(rad/sec)
J = Polar Moment of Inertia = 0.0167 Kg-m^2/sec^2
K_b = Induced emf constant = 0.8 volt/rad/sec
V_t = Supply Voltage = 230 V

Different values for MR brake from design are as follows,

n = Number of turns = 135 turns
h = MR gap = 0.001m
N = Number of discs = 4
r_z = Outer radius of disc = 0.080m
r_j = Inner radius of disc = 0.020m
K = MR fluid dependant constant = 0.269 Pa.m/A
μ_p = Viscosity of MR fluid = 0.09 Pa.sec
I = Current supplied to MR Brake = 1.5 A
The Simulink model is shown in the figure 5.

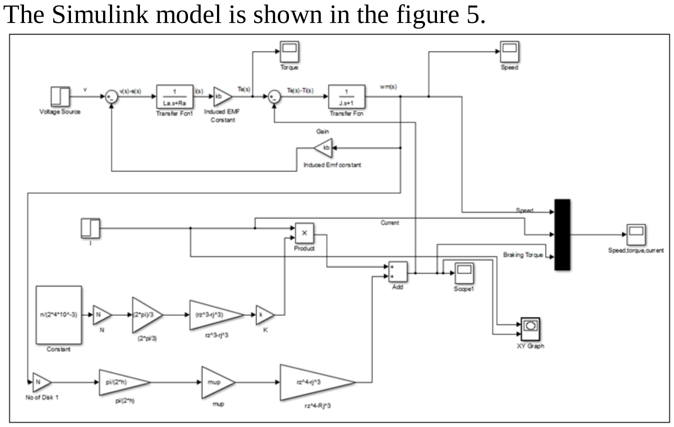

Figure 5. Simulink Model

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III. Results and Tables

The figure below shows the variation of the braking torque with respect to time. As per evaluated earlier the maximum braking torque requirement for stopping distance of 5 seconds is 28.34 Nm. The peak value of torque is nearly same as per required, thus the model MR brake can be considered for practical application.

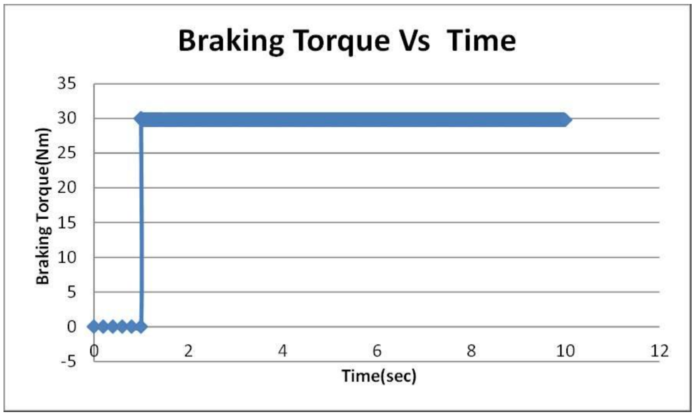

Figure 6. Braking Torque vs Time

The change in braking torque by change in the applied current is shown in the figure 7. It can be seen that at the start when current is not applied only viscous torque acts on the fluid, but when the current is applied the braking torque increases approximately linearly.

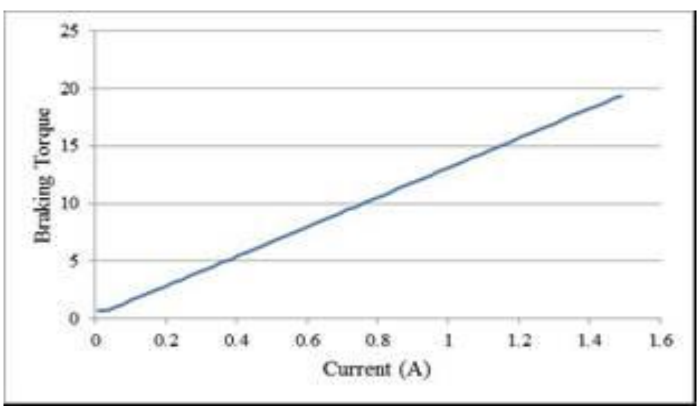

Figure 7. Braking Torque vs Current

The speed of the motor has least effect on the braking torque that is shown by the figure 8. Here the motor speed is varied from 0 to 400 rpm and the graphs are plotted for the same.

The selection of fluid gap as 1mm has been justified by the figure 9. Here the gap thickness is varied from 0.5mm to 2mm and the braking torque for various applied current has been plotted.

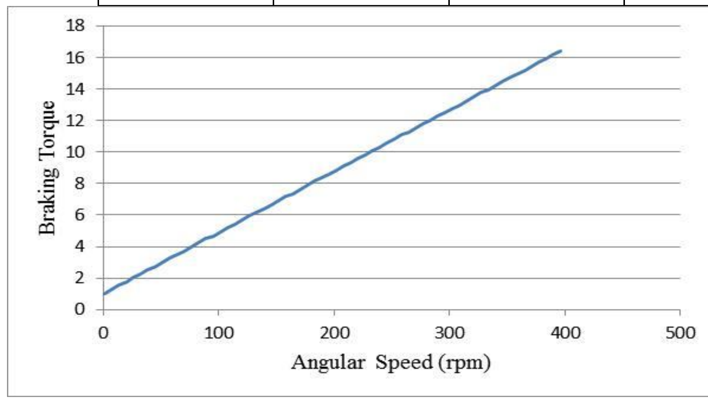

Figure 8. Braking torque vs Angular speed

It can be seen that with the minimum fluid gap the braking torque generated is more. But due to manufacturing constraints at smaller values the minimum gap of 1mm is optimum.

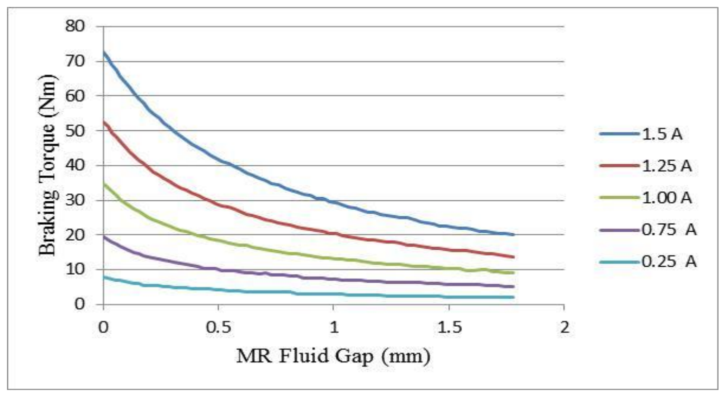

Figure 9. Braking Torque vs MR Fluid gap(mm)

The model is validated by plotting the graph for input parameters used for experimental analysis in [5,12]. The result of the simulation model shows the same trend as per obtained by Karakoc [5] shown in figure 10, where results obtained from the experiment were compared with finite element analysis. The variation is due lack of details of the MR fluids used and due to the change in viscosity due to rise in temperature, that has not been conserved in simulation.

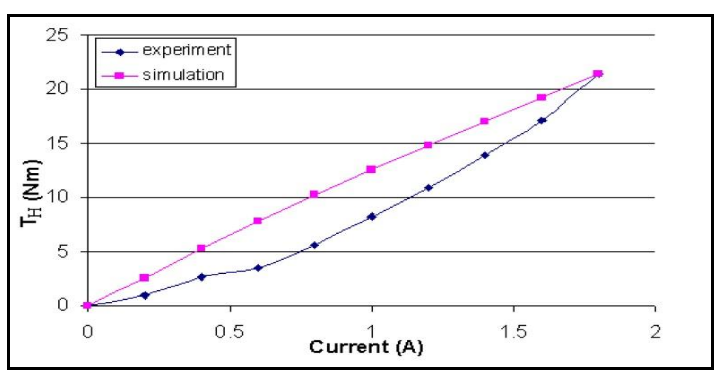

Figure 10. Experimental Vs simulation results [5]

IV. Conclusion

In this work the simulation model has been developed for a two wheeler vehicle. The braking torque generated by the model is nearly equal to the braking torque calculated theoretically. It can be also seen that increasing the applied current increases the braking torque linearly. The study also reveals that to obtain maximum torque the MR fluid gap has to be minimum.

The developed model can be used to evaluate the MR braking system with less resources and computational time.

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