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Electromagnetic analysis of magnetorheological brakes

J. Thanikachalam *, M. Ramkumar, P. Nagaraj

Deptartment of Mechanical Engineering, Mepco Schlenk Engineering College,
Sivakasi - 626 005, Virudhunagar District, Tamilnadu, India
* Corresponding e-mail address: jthanik@rediffmail.com

ABSTRACT

Purpose: In this proposed work, make a electromagnetic analysis of magnetorheological brake for creating the automobile structure under the drive by wire concept.

Design/methodology/approach: The proposed brake system consists of rotating disks with shaft and immersed in a MR fluid and enclosed in an electromagnet. When the current is passing through the coil wire then electromagnet is formed and magnetic field is applied. Due to the external magnetic filed, the MR fluid is converted to semi solid state and disc produced shear friction generating the braking torque. The relationship between the electric current and braking torque can be determined using electromagnetic analysis created on AutoCAD-2D model and analysed in ANSYS electromagnetics Software. In this work various types of MR fluids has been tested.

Findings: In this study paper are presented at electromagnetic magnetic analysis are solved using ANSYS 15 and determined magnetic field applied on MR Brake and generating braking torque.

Research limitations/implications: In an electromagnetic analysis was also carried out to magnetic distribution of the MR fluid with in brake. For various speed of rpm, when a current of 2A is applied of MRB and No. of coil 300, with the help of analytical model and magneto-static analysis the braking torque obtained.

Keywords: Magneto-rheological fluid; Magneto-rheological brake; Electro-magnetic analysis; Finite Element Method

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ANALYSIS AND MODELLING

1. Introduction

Magnetorheological fluids are the suspensions of micron sized, magnetisable particles (mainly iron) suspended in an appropriate carrier liquid such as mineral oil, synthetic oil, water or ethylene glycol. In the occurrence of an magnetic field applied, the suspended particles appear to align or cluster and the fluid drastically thickens [3]. The flow resistance (apparent viscosity) of the fluid is intensified by the chain particle (Figure 1). While the magnetic field is removed, the particles are returned to their original condition, which lowers the viscosity of the

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fluid. (Newtonian behaviour). The magnetisable particles diameter should be within 3 to 5 microns. Functional MR fluids may be made with larger particles, however, stable suspension of particles becomes increasingly more difficult as the size increases. Commercial quantities of relatively inexpensive carbonyl iron are generally limited to sizes greater than 1 or 2 microns. The MR effect is immediately reversible if the magnetic field is reduced or removed [1].

a) b)

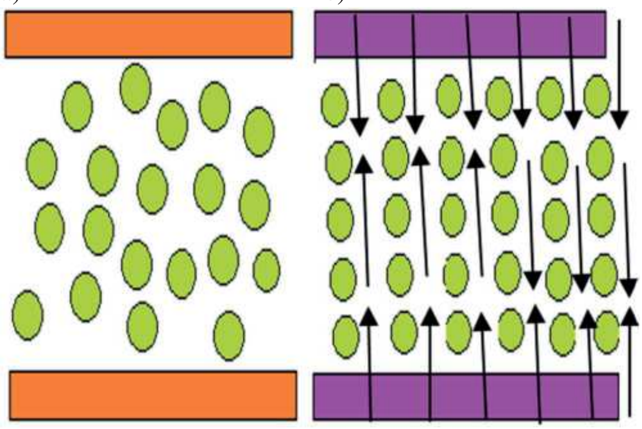

Fig. 1. a) without magnetic applied b) with applied

Magnetorheological materials can achieve yield strengths up to 50-100 kPa at magnetic field strength of about 150-250 kA/m. MR materials is an eventually reach a saturation point where increases of magnetic field strength do not increase the yield strength of the MR material. This phenomenon typically occurs around 300 kA/m. The effect of magnetic saturation on the strength of MR materials can be studied by using finite element analysis [3,8].

Table 1.
Properties of MR fluid

Property	Typical value
Initial viscosity	0.2-0.3 Pa·s (at 25°C)
Density	3-4 g/cm^3
Magnetic field strength	150-250 kA/m
Yield point ,τ_o	50- 100 kPa
Reaction time	few milliseconds
Typical supply voltage and current intensity	25 V, 1-2 A
Work temperature	-50 to 150 °C

Response times of 6.5 ms have been recorded. MR Materials that have been already developed are Stable in temperature ranges from -50 to 150°C. There are slight changes in the volume fraction and hence slight reductions in the yield strength at these temperatures, but they are small [10]. Table 1 shows the properties of MR fluids.

2. Proposed magnetorheological brake

In modern automobile industries are electromechanical brake replaced by conventional hydraulic brake.it is used as wire by wire technology are improve the existing mechanical system that are able to response time, faster, accuracy etc. In this MR Brake main parts are shaft, upper casing, lower casing, rotor, MR fluid, coil. It consists of a rotating disk through shaft and is enclosed by a static casing, and the1mm gap 1mm between the disk and casing is filled with the MR fluid and the coil is placed with the casing. The principle of this brake, in this coil wire is connected through to DC current supply the current electromagnet is formed. When the brake is applied the magnetic field is attracted at the fluid yield stress is produced, then the MR fluid is converted to semi solid state is formed. The shear friction between the rotating disk and the solidified MR fluid provides the required braking torque. when release the brake no magnetic field is appeared then will remains fluid behaviour. MRB is fully electronically controlled actuator and as result stopping distance time are reduced as CHB. A CHB system involves the brake pedal, hydraulic fluid, transfer lines and brake actuators (e.g. disk or drum brakes). When the brake is pressed on the brake pedal, the master cylinder provides the pressure in the brake actuators that squeeze the brake pads onto the rotors, generating the useful friction forces (thus the braking torque) to stop a vehicle. However, the CHB has a number limitations, including: (i) delayed response time (200-300 ms) due to pressure build up in the hydraulic lines, (ii) bulky size and heavyweight due to its auxiliary hydraulic components such as the master cylinder, (iii) brake pad wear due to its frictional braking mechanism and (iv) low braking performance in high speed and high temperature situation [6,9].

3. Electro-magnetic analysis

Electro-magnetic Analysis of an MR brake system is a magneto-statics analysis that determines the magnetic field distribution. In the electromagnetic analysis the resulting magnetic field intensity distribution within the MRB design configuration is analysed. The relationship between applied electric power and the braking torque can be determined using electromagnetic analysis. This is a non-linear problem and requires an iterative approach. Braking torque generated depends on the magnetic field distribution along the disk radius. In order to determine the magnetic field distribution, a 2D axisymmetric Finite Element Model of the brake is created using a commercial package AutoCAD-2D model.

$\nabla * H = J$

$\nabla * B = 0$

H is the magnetic field intensity,
B is the magnetic flux density,
J is the electric current density.

By solving these equations over a defined domain with proper boundary conditions, the magnetic field intensity distribution (H) can be obtained. In order to construct the FEM of the brake, the axisymmetric geometry of the proposed design is first created in ANSYS Multiphysics®.

4. Geometry

In this MR Brake design consist of shaft, casing, rotor, coil, MR Fluid gap. These brakes were created key points using ANSYS as shown in Figure 2. Tables 2 and 3 shows the dimensions and types of materials.

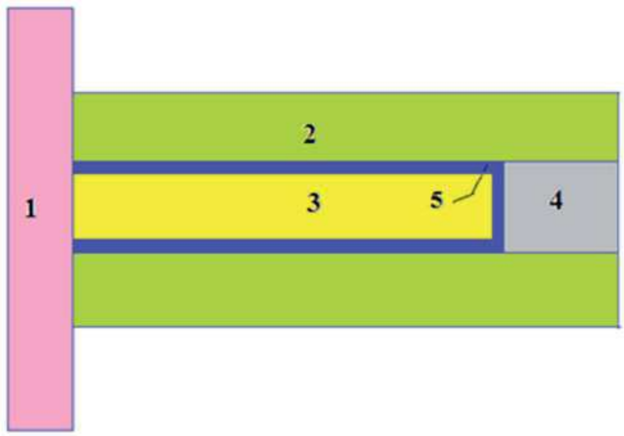

Fig. 2. Magnetorheological design brake: 1 – shaft, 2 – casing, 3 – rotor, 4 – coil, 5 – MR fluid gap

Table 2.
Dimension of MR brake

Radius of the disc	85 mm
Length of the disc	70 mm
MR Fluid gap	1 mm
Length of the shaft	15 mm
Height of the shaft	200 mm

Table 3.
Material used in MR brake

Casing, coil and rotor	Low carbon steel
Shaft	Stainless steel

5. Material properties of AISI 1018 steel

In the Table 4 it indicates the properties of casing and disc. Table 5 shows the parameters for the electrical connections. The Table 6 show the value and property of shaft.

Table 4.
Properties of casing and disc

Property	Value
Ultimate tensile strength	350 MPa
Yield strength	276 MPa
Poisson’s ratio	0.33

Table 5.
Properties of coil

Value	Property
Coil wire	AWG 21
Number of turns	100-300
Current	1-2A

Table 6.
Properties of shaft

Property	Value
Ultimate tensile strength	505 MPa
Yield strength	215 MPa
Poisson’s ratio	0.29
Magnetic permeability	1.008

6. Finite element model and boundary condition

Finite element model is shown in Fig. 3. The electromagnetic analysis using ANSYS Multiphysics® to find the magnetic field intensity and magnetic flux were analysed. In an element type Magnetic vector and Quad 4 node 13 and five different material model were used and create the key points using the schematic diagram. The model is meshed with material properties. In that boundary condition force apply on rotor and current density give its value. This means magnetic field is distribution on MR Fluid and braking torque are generated. The Figures 4-6 shows the electromagnetic analysis for the brake design with the various constraints.

$$\text{Current density} = \frac{\text{No. of coil} * \text{Current(A)}}{\text{Area of coil}}$$

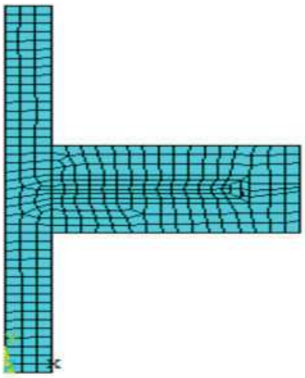

Fig. 3. Finite element model

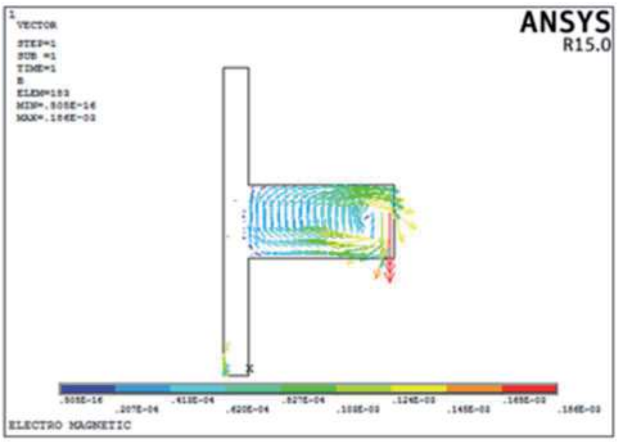

Fig. 4. Magnetic flux and gradient

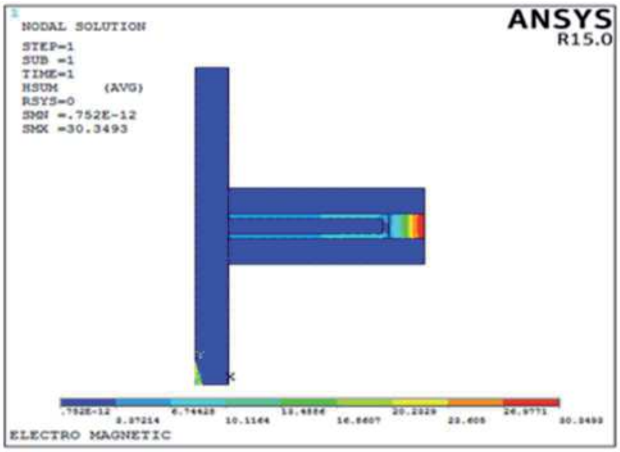

Fig. 5. Magnetic field intensity

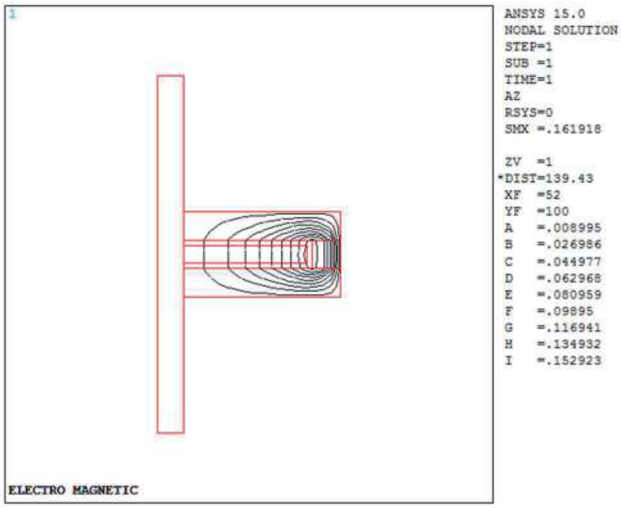

Fig. 6. 2D Magnetic flux lines

7. Results and discussion

In an electromagnetic analysis was also carried out to magnetic distribution of the MR fluid with in brake. For various speed of rpm, when a current of 2 A is applied of MRB and No. of coil 300, with the help of analytical model and magneto-static analysis the braking torque obtained (Figs. 2-8).

These analysis three different radius, coil, current used and all value of electromagnetic analysis result were carried out in the Table 7.

This results are three types of radius of rotor, current, number of turns used to varied with the magnetic field intensity of analysis (Figures 7, 8).

Table 7.
Results of magnetic field intensity

Radius of disc, mm	Number of coil, n	Current, A	Magnetic field intensity
85	100	1	4.48534
85	200	1.5	15.6251
85	300	2	30.348
80	100	1	4.165
80	200	1.5	14.541
80	300	2	29.3184
75	100	1	3.0375
75	200	1.5	14.4335
75	300	2	28.2828

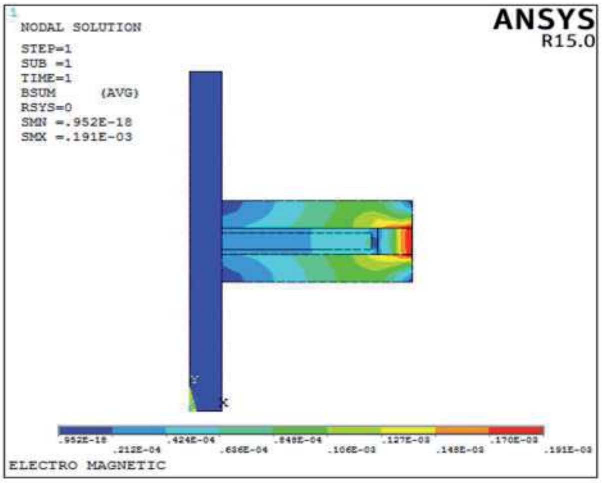

Fig. 7. Magnetic flux

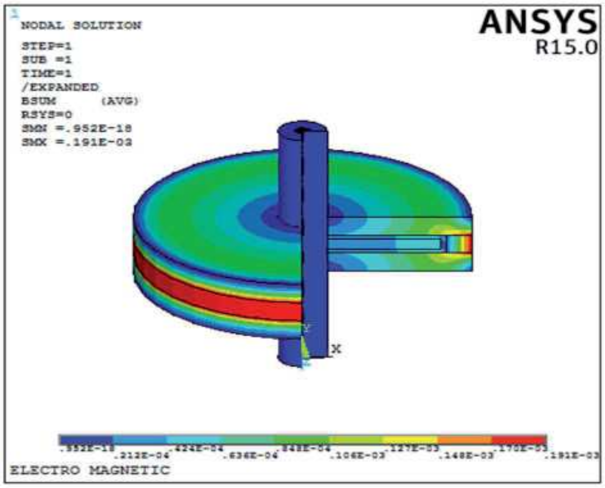

Fig. 8. Axisymmetric view

8. Conclusion

In this study paper are presented at electromagnetic magnetic analysis are solved using ANSYS 15 and determined magnetic field applied on MR Brake and generating braking torque. By doing the higher braking torque for the electromagnetic analysis of MR brake of these values.

Radius of disk – 85 mm,
Number of coil – 300 turns,
Input current – 2 A.

This will obtained the maximum magnetic field appeared in the analysis of the MR brake and Braking torque.

Acknowledgements

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