Smart Brakes for Automotive Application

S. M. Muzakkir

Department of Mechanical Engineering
Jamia Millia Islamia, New Delhi, India
smmuzakkir@jmi.ac.in

ABSTRACT: The smart materials are finding wide applications in active controlled engineering systems. The Magnetorheological Fluid is a smart material wherein its actuation and sensing can be easily and effectively controlled using an automatic feedback control system. Since, these characteristics are very much desirable in modern engineering systems, therefore the Magnetorheological Fluids are gaining wide popularity in several applications like automotive braking systems, automatic vibration dampers, engine mounting systems, clutches etc. In the present research work, a Single Disc Magnetorheological Brake comprising of a central peripheral electromagnet is proposed for automotive applications. Its performance analysis has been carried out to determine its effectiveness.

Keywords: Smart materials, Magnetorheological Fluids; Magnetorheological Brake

INTRODUCTION

The majority of the automotive vehicles utilizes the conventional brakes which are both disc type and drum type. The retardation of the vehicles due to the use of these conventional brakes are dependent upon the friction forces developed due to the contact between the disc and pads (or drum and brake shoe). This frictional force causes wear of the brake pads/shoes that deteriorates the braking performance over a period of time in addition to causing environmental pollution. The conventional brakes are passive in nature and require a set of mechanical/hydraulic control mechanism for its operation. A Magnetorheological Brake (MRB), proposed for automotive applications, utilizes a smart material: Magnetorheological Fluid (MRF).

The Magnetorheological Fluid (MRF) is a smart material wherein its rheological property is dependent upon the strength of the externally applied magnetic fields. The MRF consists of micron sized carbonyl iron particles which are dispersed in a non-magnetic and low viscosity carrier fluid like silicone oil. A suitable surfactant is generally required to prevent the agglomeration of the carbonyl iron particles.

The micron sized carbonyl iron particles remain suspended in the carrier fluid in a random fashion until the application of magnetic field, as depicted in Figure 1.

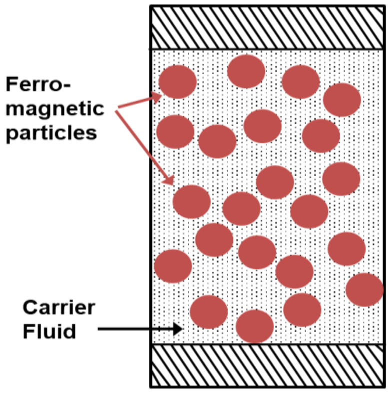

Fig. 1 Distribution of carbonyl iron particles in carrier fluid without the magnetic field

On the application of magnetic field, the formation of chains of carbonyl iron particle takes place which eventually leads to the development of a reversible yield stress in the Magnetorheological Fluid which is dependent upon the magnetic field as depicted in Figure 2.

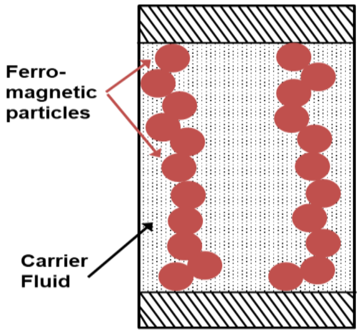

Fig. 2 Chain formation of carbonyl iron particles in carrier fluid under the magnetic field

In the present research work, a Single Disc Magnetorheological Brake (MRB) with central peripheral electromagnet is proposed for automotive application and its performance analysis has been carried out to determine its effectiveness.

A Magnetorheological Brake (MRB) is depicted in figure 3.

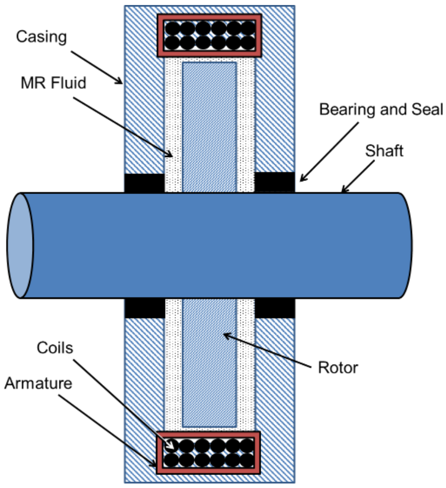

Fig. 3 A Single Disc Magnetorheological Brake

A Magnetorheological Brake (MRB) is an active system and its performance do not significantly deteriorate with passage of time [1-8]. A MRB which consists of a single disc (acting as a rotor) is enclosed in a leak proof casing (acting as a stator) with a space for electrical winding. The seal provides leakage prevention whereas the bearing permits the relative motion between the disc and casing.

The space between the disc and casing is filled with magnetorheological fluid. The working clearance between the disc and casing is very small (about 1mm).

PERFORMANCE ANALYSIS OF MRB

The braking torque generated by the MRB is a function of the magnetic field density. The performance analysis of a MRB is carried out using finite element modeling. In order to save computational time/cost, a two-dimensional axi-symmetrical model has been developed. A 2-D solid element with four nodes is used.

The figure 4 depicts the ANSYS model of MRB. A 2-D magneto-static analysis was conducted with an assumption that there is no leakage of magnetic flux to the environment. This constrained the magnetic flux to remain in parallel direction on the casing boundaries. The following permeability was considered:

Relative permeability of casing: 0.000004

Relative permeability of disc: 0.000004

Relative permeability of shaft: 1

Relative permeability of Seal: 1

Relative permeability of MR Fluid: 1

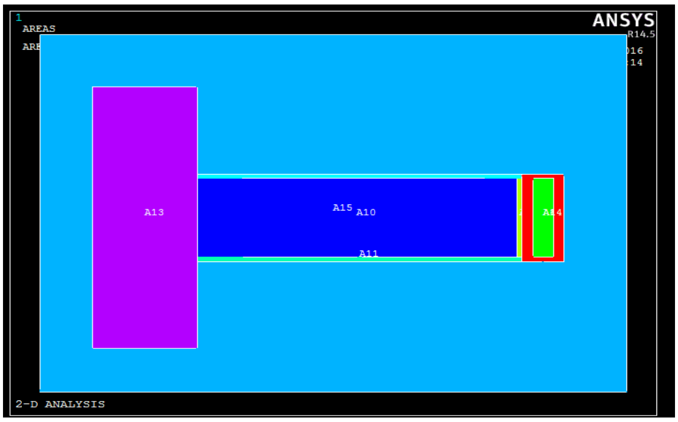

Fig. 4 Two-Dimensional model of Single Disc Magnetorheological Brake

RESULTS AND DISCUSSION

The Figure 4 depicts the flux lines of the finite element model.

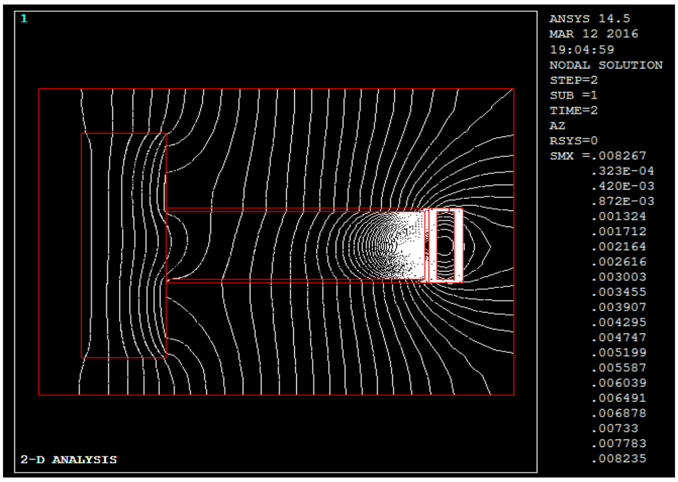

Fig. 5 Nodal Solution showing Flux lines of the MR Brake

One important observation from Figure 5 is that the flux lines does not gets obstructed due to the disc since it is metallic. However, flux lines get obstructed due to the seals since it is non-metallic. The nodal solution is obtained and magnetic flux density is shown in Figure 6 and 7.

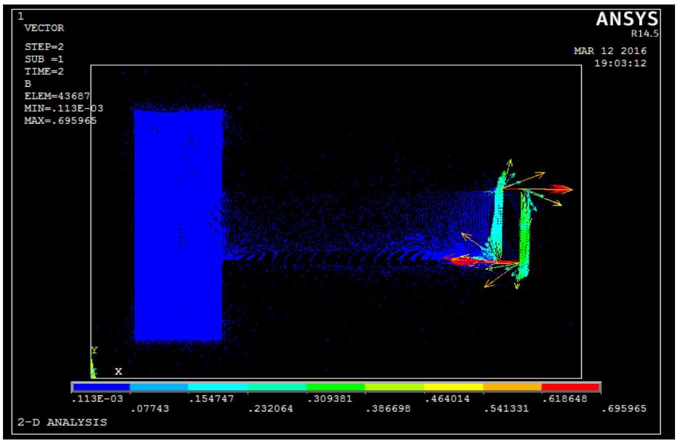

Fig. 6 Vector plot of Magnetic Flux Density

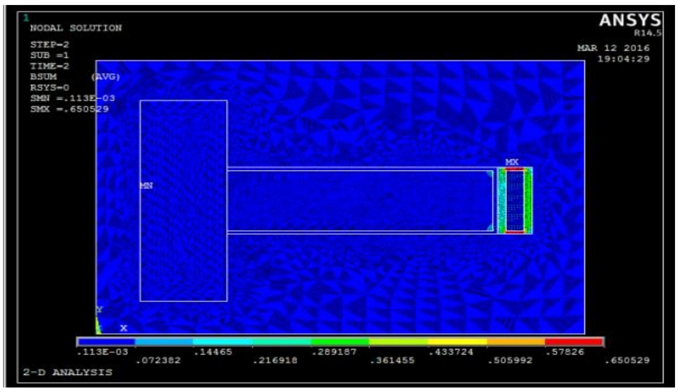

Fig. 7 Magnetic Flux Density

The Figure 8 depicts the retarding torque generated in the MR Brake with supply of current in the coils. It is observed that there is almost linear increase in the retarding torque with increase in the current. It is observed that the maximum retarding torque is achieved at 2 Ampere current. This retarding torque remains constant with further increase in the current.

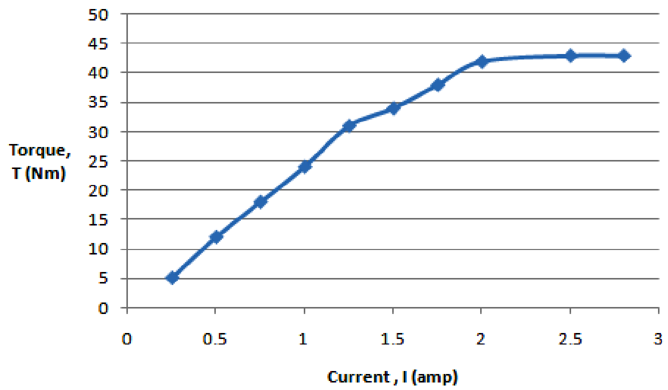

Fig. 8 Generation of retarding torque with change in supplied current

CONCLUSIONS

A smart brake for automotive application is the most promising solution to incorporate the active control of the braking system employing smart material. In the present research work, a Single Disc Magnetorheological Brake (MRB) with central peripheral electromagnet is proposed for automotive application and its performance analysis has been carried out to determine its effectiveness. The MRB uses the Magnetorheological Fluid, a smart material. The performance analysis is carried out using the finite element modelling and the flux lines and magnetic flux density was obtained. It is observed that the magnetic flux density is dependent upon the magnitude of current supplied to the electromagnet which in turn governs the rheological behavior of the MR Fluid. The retarding torque is a function of current intensity. It is concluded that the saturation of retarding torque occurs at the higher limit of current and remains almost constant from 2 amp current onwards.

References

[1] S.M Muzakkir and Deepak Kumar, "Analysis of a magnetorheological brake with a single low carbon steel disc using ANSYS", IEEE International Conference on Innovative Mechanisms for Industry Applications, ICIMIA 2017 - Proceedings, art. no. 7975558, pp. 717-719. (2017)

[2] K. P. Lijesh, S. M. Muzakkir, and H. Hirani, "Rheological measurement of re-dispersibility and settling to analyze the effect of surfactants on MR particles," Tribol. - Mater. Surfaces Interfaces, vol. 10, no. 1, pp. 53–62, 2016.

[3] K. P. Lijesh and S. M. Muzakkir, "Problems related to Synthesis and Application of MR Fluids," Int. J. Appl. Eng. Res., vol. 10, no. 24, pp. 45489–45495, 2015.

[4] K. P. Lijesh and S. M. Muzakkir, "Service Life Estimation of Rubber Seals," Int. J. Appl. Eng. Res., vol. 10, no. 24, pp. 0–5, 2015.

[5] K. P. Lijesh and S. M. Muzakkir, "Experimental Evaluation of MR Brake with Elliptical Profile," Int. J. Appl. Eng. Res., vol. 10, no. 24, pp. 45541–45545, 2015.

[6] K. P. Lijesh and S. M. Muzakkir, "Models for Boundary Lubrication," Int. J. Appl. Eng. Res., vol. 10, no. 24, pp. 45533–45540, 2015.

[7] S. M. Muzakkir and S. Kumar, "Design of Mechanical Oil Seal and Gasket," Int. J. Appl. Eng. Res., vol. 10, no. 12, pp. 30911–30926, 2015.
[8] K. P. Lijesh, S. M. Muzakkir, and H. Hirani, "Experimental tribological performance evaluation of nano lubricant using multi-walled carbon nano-tubes (MWCNT)," Int. J. Appl. Eng. Res., vol. 10, no. 6, pp. 14543–14550, 2015.
[9] Lijesh, K. P., and Harish Hirani. "Magnetic bearing using rotation magnetized direction configuration." Journal of Tribology 137, no. 4 (2015): 042201.
[11] H. Hirani, "Multiobjective optimization of journal bearing using mass conserving and genetic algorithms," *Proc. Inst. Mech. Eng. Part J J. Eng. Tribol.*, vol. 219, no. 3, pp. 235–248, 2005, doi: 10.1243/135065005X9844.
[12] H. Hirani, K. Athre, and S. Biswas, "Comprehensive design methodology for an engine journal bearing," *Proc. Inst. Mech. Eng. Part J J. Eng. Tribol.*, vol. 214, no. 4, pp. 401–412, 2000, doi: 10.1243/1350650001543287.
[13] C. Sarkar and H. Hirani, "Effect of Particle Size on Shear Stress of Magnetorheological Fluids," *Smart Sci.*, vol. 3, no. 2, pp. 65–73, 2015, doi: 10.1080/23080477.2015.11665638.
[14] S. S. Goilkar and H. Hirani, "Parametric study on balance ratio of mechanical face seal in steam environment," *Tribol. Int.*, vol. 43, no. 5–6, pp. 1180–1185, 2010, doi: 10.1016/j.triboint.2009.12.019.
[15] H. Hirani, K. Athre, and S. Biswas, "Lubricant shear thinning analysis of engine journal bearings," *Tribol. Trans.*, vol. 44, no. 1, pp. 125–131, 2001, doi: 10.1080/10402000108982435.
[16] K. P. Lijesh and H. Hirani, "Magnetic bearing using rotation magnetized direction configuration," *J. Tribol.*, vol. 137, no. 4, 2015, doi: 10.1115/1.4030344.
[17] H. Hirani, K. Athre, and S. Biswas, "Dynamic analysis of engine bearings," *Int. J. Rotating Mach.*, vol. 5, no. 4, pp. 283–293, 1999, doi: 10.1155/S1023621X99000251.
[18] K. P. Lijesh and H. Hirani, "Design and development of Halbach electromagnet for active magnetic bearing," *Prog. Electromagn. Res. C*, vol. 56, pp. 173–181, 2015.
[19] K. P. Lijesh, S. M. Muzakkir, and H. Hirani, "Failure mode and effect analysis of passive magnetic bearing," *Eng. Fail. Anal.*, vol. 62, pp. 1–20, Apr. 2016, doi: 10.1016/j.engfailanal.2015.11.033.
[20] H. Hirani, "Root cause failure analysis of outer ring fracture of four-row cylindrical roller bearing," *Tribol. Trans.*, vol. 52, no. 2, pp. 180–190, 2009, doi: 10.1080/10402000802180151.
[21] H. Hirani, K. Athre, and S. Biswas, "A Simplified Mass Conserving Algorithm for Journal Bearing under Large Dynamic Loads," *Int. J. Rotating Mach.*, vol. 7, no. 1, pp. 41–51, 2001, doi: 10.1155/S1023621X01000045.
[22] S. S. Goilkar and H. Hirani, "Design and development of a test setup for online wear monitoring of mechanical face seals using a torque sensor," *Tribol. Trans.*, vol. 52, no. 1, pp. 47–58, 2009, doi: 10.1080/10402000802163017.
[23] H. Hirani, K. Athre, and S. Biswas, "A Hybrid Solution Scheme for Performance Evaluation of Crankshaft Bearings," *J. Tribol.*, vol. 122, no. October, pp. 733–740, 2000.
[24] K. P. Lijesh and H. Hirani, "Modeling and development of RMD configuration magnetic bearing," *Tribol. Ind.*, vol. 37, no. 2, pp. 225–235, 2015.

[25] K. P. Lijesh, D. Kumar, and H. Hirani, “Effect of disc hardness on MR brake performance,” *Eng. Fail. Anal.*, vol. 74, pp. 228–238, 2017, doi: 10.1016/j.engfailanal.2017.01.009.

[26] K. P. Lijesh and H. Hirani, “Design of Eight Pole Radial Active Magnetic Bearing using Monotonicity,” in *IcIIS Conference*, 2015, no. April.

[27] V. K. Sukhwani and H. Hirani, “Synthesis and characterization of low cost magnetorheological (MR) fluids,” *Behav. Mech. Multifunct. Compos. Mater. 2007*, vol. 6526, p. 65262R, 2007, doi: 10.1117/12.720870.

[28] P. Kumar, H. Hirani, and A. Kumar Agrawal, “Effect of gear misalignment on contact area: Theoretical and experimental studies,” *Measurement*, vol. 132, pp. 359–368, Jan. 2019, doi: 10.1016/J.MEASUREMENT.2018.09.070.

[29] P. Kumar, H. Hirani, and A. Agrawal, “Fatigue failure prediction in spur gear pair using AGMA approach,” *Mater. Today Proc.*, vol. 4, no. 2, pp. 2470–2477, 2017, doi: 10.1016/j.matpr.2017.02.099.