Modelling and Simulation of a Magnetorheological Brake with and without B – H curve Using ANSYS

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ABSTRACT

Magnetorheological brake (MRB) is becoming popular in automotive, aerospace, optics and human prosthesis due to fast sensing and control. MRB consists of rotary disc immersed in Magnetorheological fluid (MRF). After application of current, MR fluid shows viscoelastic behaviour which stops the motion of MRB disc. The aim of present research work is to develop a finite element model to investigate the effect of disc material and magnetic saturation (by inserting B-H curve) on magnetic flux density. For this iron disc having higher relative permeability as 5000 is used. An APDL code has been developed. Finally, Variation of torque by increasing the current with and without magnetic saturation is presented.

Keywords: B-, FEM, Magnetorheological Fluid H Curve, Electromagnetic Simulation, Relative Permeability.

I. INTRODUCTION

Magnetorheological brakes having lesser response time, less wear, smaller size and pollution free environment (no formation of wear debris) are advantageous in automotive vehicles as compared to conventional disc brake [1-3]. The MR particles are randomly distributed in the absence of magnetic field and after application of magnetic field, MR fluid greatly increases its apparent viscosity from 100 to 1000 times up to the point to becoming the viscoelastic solid [4-5]. The strength of chain formation of MR particle and braking effect is dependent on the applied magnetic field and relative permeability of disc material of MR brake. The principle of MR fluid is shown in Fig 1 [6]. A magnetorheological brake consists of rotating disc(s) immersed in a MR fluid and enclosed in an electromagnet casing as shown in Fig. 2 and 3 [7].

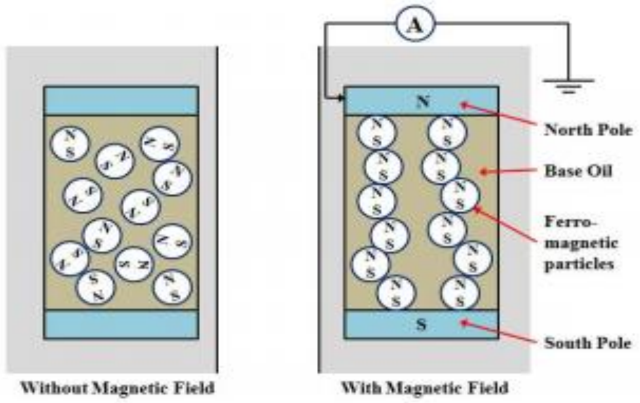

Fig 1. MR Fluid Principle [6].

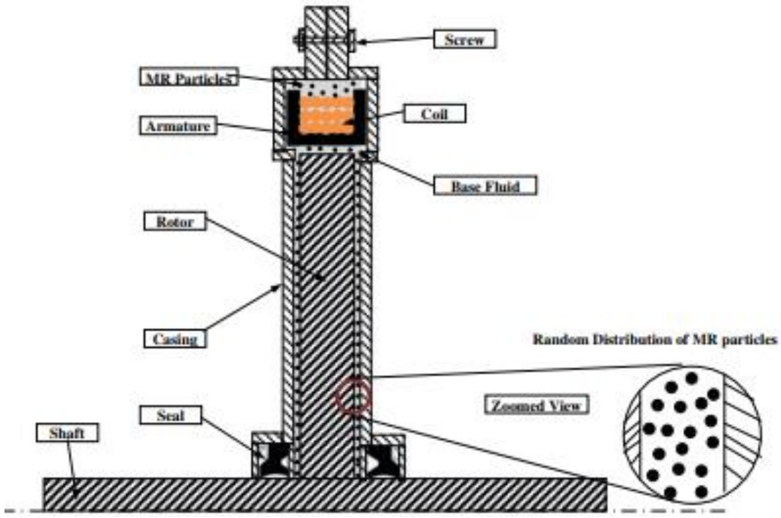

Fig 2. Rndom Adistribution Of MR Particle In The Absence Of Magnetic Field [6].

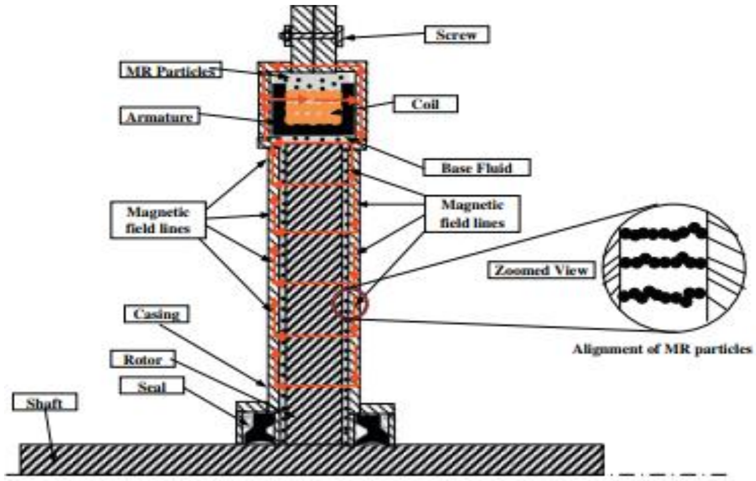

Fig 3. Alignment of MR particle in the presence of magnetic field [6]

In our previous study the analysis of Magnetorheological brake with a single low carbon steel disc on Ansys software without considering the effect of magnetic saturation was reported (B-H curve) [7]. In the present study an Ansys APDL code was developed to investigate the effect of B-H curve on magnetic field strength in magnetorheological brake. Higher the relative permeability of the disc material leads to higher magnetic field generation which is subsequently leads to higher braking torque. Therefore iron disc was used as disc material having relative permeability about 5000.

II. FEM MODDELING AND TORQUE CALCULATION OF MAGNETORHEOLOGICAL BRAKE

An APDL code was developed to predict the performance of MR brake. Fig. 4 shows the 2D axi symmetric modelling of MR brake. It is symmetric about the rotational axis. Two dimensional axi symmetric modelling drastically reduces the computational cost. Also there is no tribological contact between the surfaces therefore wear was eliminated up to a great extent.The disc was attached to the shaft therefore disc and shaft was considered as single element for analysis. In order to predict the effect of magnetic saturation on magnetic field strength, Finite element analysis with and without B-H curve was carried out. Current was supplied in order to get the magnetic effect at the disc, housing and MR fluid. PLANE 13 element having four nodes with each nodes having four degree of freedom was used to mesh the geometry. PLANE 13 element have provision to insert B-H curve (using NBUST command) for prediction of magnetic saturation effect on magnetic field strength. The B-H curve used in finite element analysis is shown in Fig.5 [3]. All other input parameter as current (2.5 amp), number of coils (1000), cross sectional area of coil (0.017 m^2) was kept same for both the case (without and with B-H curve). The MR fluid gap was acts as a torque arm and kept as 1 mm. EMUNIT command was used to maintain the SI units throughout the analysis. It was assumed that there is no leakage from housing to environment. Therefore flux parallel to the boundaries of the housing was made constrained. The convergence criteria was decided as 0.016. Convergence checking was based on magnetic potential, magnetic field, or magnetic flux density. The free space permeability value was kept as $\mu_0 = 4\Pi\times10^{-7}$ H/m. 2D magnetic analysis was carried out by using MAGSOLV command. The relative permeability of various parts of MR brake as Housing, Seals, Bearings, Shaft, Rotor and MR fluid was taken as 100, 1, 100, 5000, 5000 and 8 respectively [8].

The MR fluid follows the Bingham plastic model and the magnitude of the torque developed by MR brake is dependent upon the electric current supplied to the MR fluid as given below [9].

$$T = 2\Pi n h \tau_{yd}(r_2^2 - r_1^2) + \frac{4}{3}\eta \Pi n \omega (r_2^3 - r_1^3) \quad (1)$$

Where, T-Torque, n- No. of disc =1, h- MR fluid gap, τ_{yd} - Yield stress, r_2 and r_1 outer and inner radius of disc respectively, Ƞ - kinematic viscosity, ω – speed, N- no. of turns, I- current. Yield stress τ_{yd} is a function of magnetic field intensity (H =NI/2h) and can be expressed as

$$\tau_{yd} = \alpha_1 H^{1.5} \quad (2)$$

Fig 4. Two dimensional axi-symmetric model of MR brake.

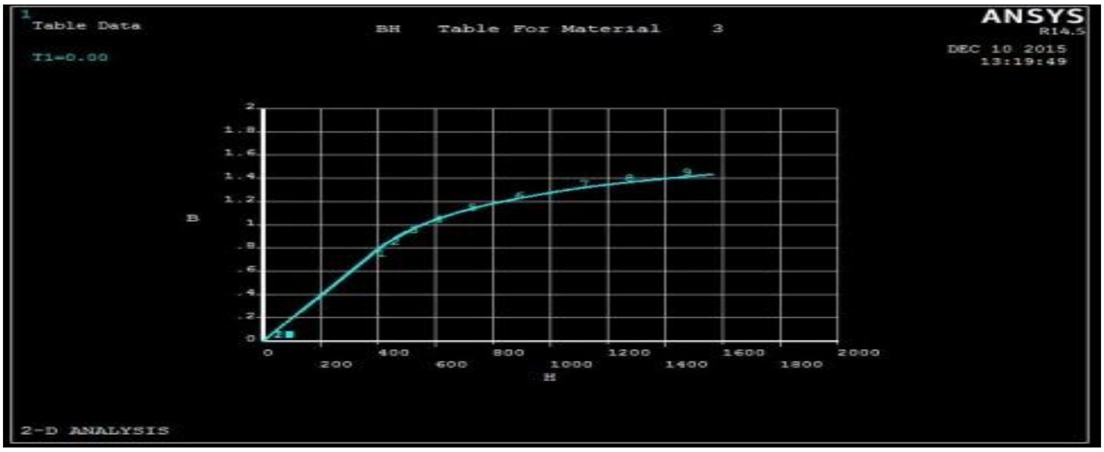

Fig 5. B-H curve for Finite element analysis.

III. RESULTS AND DISCUSSION

Fig. 6 and 7 shows the vector plot and nodal plot solution of magnetic flux density without considering the effect of B-H curve. The maximum magnetic flux density (SMX) 1.2056 and 1.4486 Tesla was observed in the vector and nodal plot solution respectively. The vector and nodal plot solution with considering the effect of B-H curve is shown in Fig. 8 and 9. In this case higher value of magnetic flux density was obtained as 1.45032 and 1.73384 Tesla. Therefore it is necessary to provide magnetic saturation condition for analysis of MR brake. The strength of magnetic flux is maximum near the shaft and near periphery of MR brake disc.

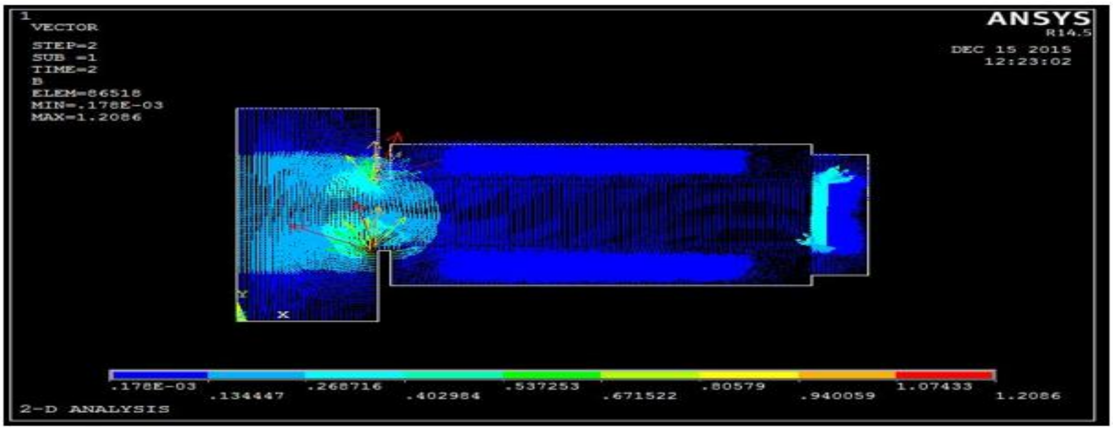

Fig 6. Magnetic flux density by vector solution (without B-H curve).

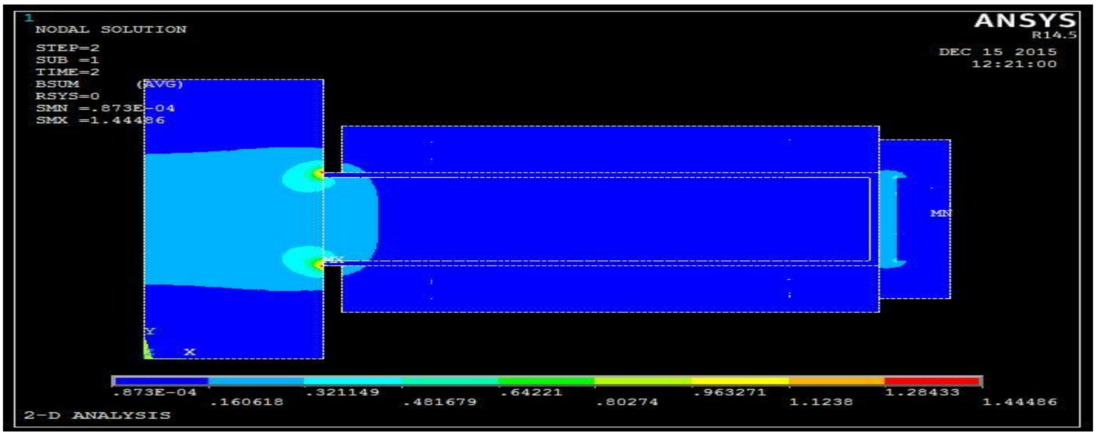

Fig 7. Magnetic flux density by nodal plot (without B-H curve).

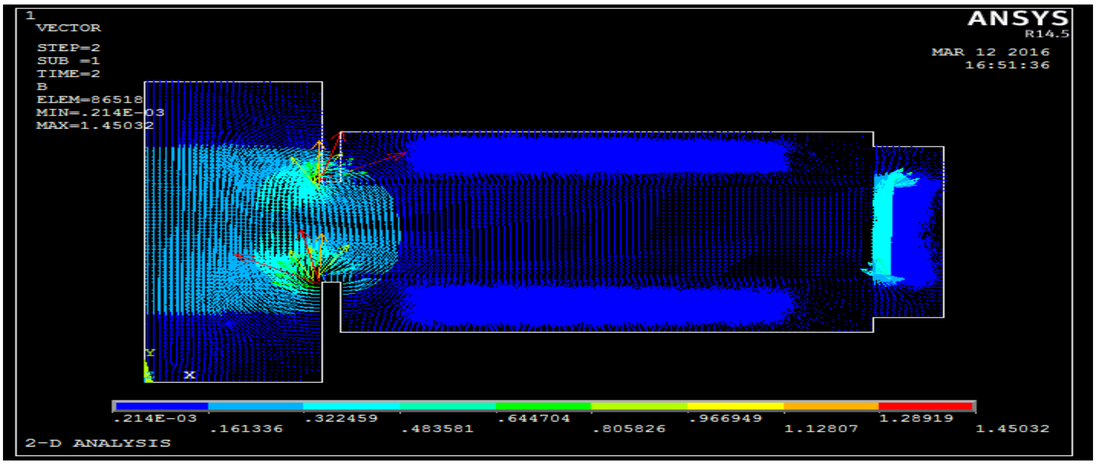

Fig 8. Magnetic flux density by vector solution (with B-H curve)

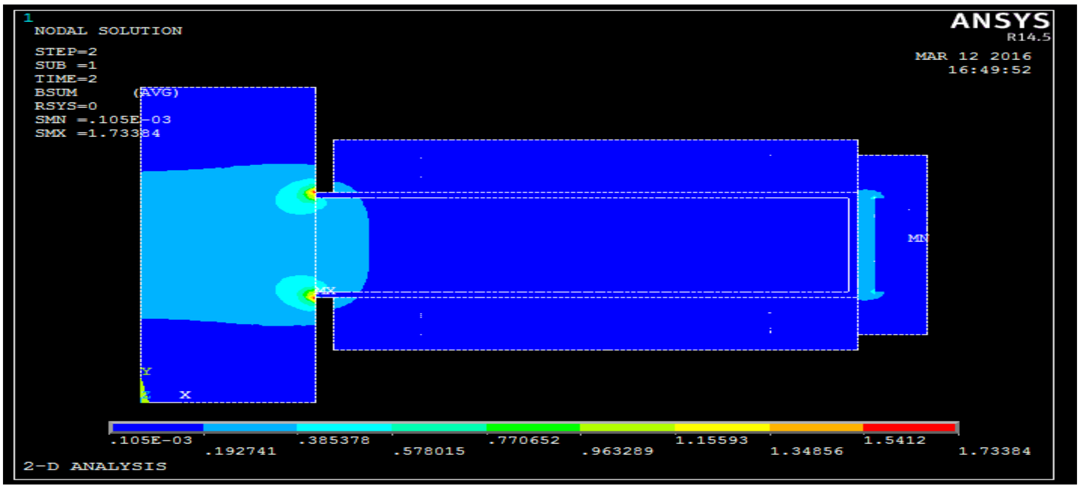

Fig 9. Magnetic flux density by nodal plot (with B-H curve)

(Fig. 10 (a) and (b)) shows the torque variation with increasing current without and with B-H curve respectively. At higher values of current, the torque values saturate as MR fluid saturate after 2.5 amp current. However the torque developed by MR brake is higher by taking B-H curve into account.

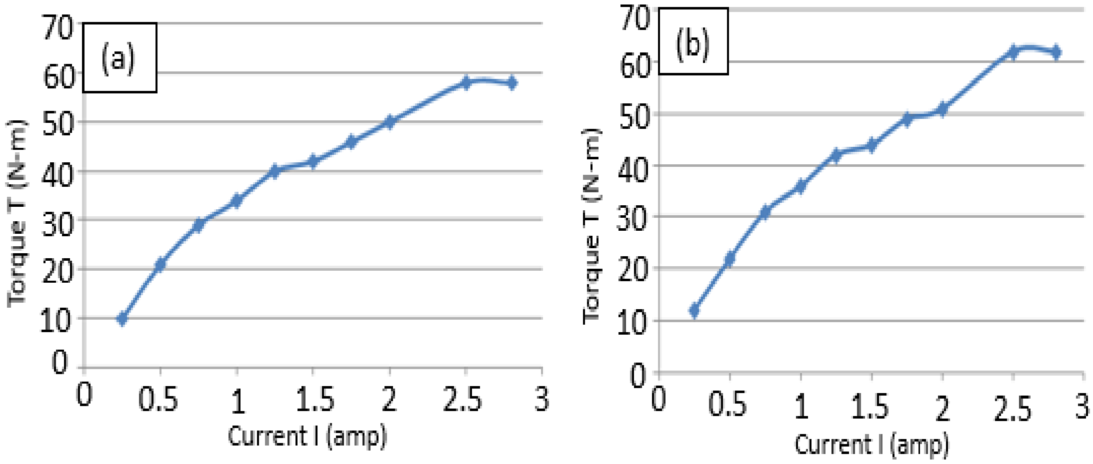

Fig 10. Torque variation with current (a) Without B-H curve (b) With B-H curve

IV. CONCLUSION

Finite element analysis of MR brake was carried out to investigate the effect of disc material and B-H curve on magnetic flux density and torque and following conclusion was drawn.

- Higher value of relative permeability of disc material is able to generate more magnetic flux density and torque.
- By introducing magnetic saturation (B-H curve) significant increase in braking torque is observed as compared to without magnetic saturation.

- The torque of MR brake is increasing with the current and after saturation of MR fluid at higher current, torque becomes constant.

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