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Finite Element Analysis of Multidisc Magnetorheological Brake with B-H curve Using ANSYS

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ABSTRACT

In an automobile disc brake, due to mechanical contact between pads and disc, the lining materials of the brake pads are subjected to a large amount of frictional heating and associated wear during forced deceleration and leads to excessive thermal deformation of the surfaces and alters the contact configuration. The online control of torque by Magnetorheological (MR) brake is an attractive option to replace the disc brake.A magnetorheological brake consists of rotating disc(s) immersed in a MR fluid and enclosed in an electromagnet casing. The torque characteristics of the Magnetorheological (MR) brake are controlled by regulating the yield stress of the MR fluid. To understand and predict the behaviour of the multidisc it is necessary to predict the performance of the brake through simulation. In the present study an attempt has been made to investigate the effect of multidisc MR brake on magnetic flux density on Ansys software. B-H curve is incorporated into the analysis to introducing the condition of magnetic saturation. The obtained results are presented and compared with single disc MR brake finite element modelling.

***Keywords:* B-H curve, Finite element modelling, Multi disc Magnetorheological brake, Magnetorheological fluid.**

I. INTRODUCTION

The generation of the information technology has stimulated material sciences and led to a new family of engineered smart materials and structures.Smart materials are materials that have multiple properties (chemical, electrical, magnetic, mechanical and thermal) [1]. Magnetorheological fluid (MR fluid) is a type of smart material when subjected to the magnetic field greatly increases its apparent viscosity up to the point for becoming viscoelastic solid. The principle of Magnetorheological fluid is shown in Fig. 1 [2].

In automobiles, disc brakes are used to retard the rotation of the wheels. On application of brake the mechanical contact between the disc and pad exerts frictional torque to hinder the motion of wheels [3]. The drawbacks of conventional disc brake such asperiod replacement due to wear, more response time, bulky size and polluting environment can be overcome by replacing conventional disc brake with Magnetorheological brake [4-6]. The Magnetorheological fluid (MRF) is presently being employed in various engineering systems with the Magnetorheological Brake (MRB) being the most popular application [7-8]. The advantages of Multidisc MR brake is higher braking torque as compare to single disc MR brake. Multidisc MR brake also have some disadvantages as their bulkiness, more space requirement, complexity in manufacturing, more cost. One major limitations of multidisc MR brake is that it is very difficult to attach the separator plate with housing and pouring of MR fluid. Another major limitations of multidisc MR brake is leakage of MR fluid as temperature in multidisc

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MR brake increases drastically, therefore seal material can not withstand with this much of temperature. In spite of having these disadvantages, it can be used for the applications where braking torque requirement is very high. Therefore in the present study an attempt has been made to do finite element analysis of multidisc MR brake.

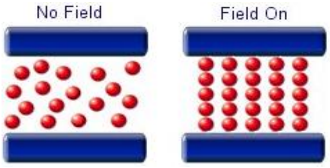

Fig 1. Principle of MR fluid [2]

II. FINITE ELEMENT MODELLING OF MULTI DISC MAGNETORHEOLOGICAL BRAKE

In multidisc MR brake, In place of single disc, more than one disc was used. Other components of MR brake were remain same as single disc MR brake. The purpose of multidisc MR brake is to increase the braking torque which overcome the limitation of single disc MR brake. Two dimensional axi-symmetric model of multidisc (18 disc) MR brake is shown in Fig. 2. PLANE 13 was chosen for meshing the geometry. PLANE 13 element has four nodes and each node have four degree of freedom. EMUNIT command was used to set SI units throughout the analysis. The B-H curve used for imposing the condition of magnetic saturation in the present analysis is shown Fig. 3. NBUST command was used to incorporate the B-H curve into finite element analysis. It was assumed that there was no leakage from housing to the environment. Therefore flux parallel to the housing was made zero (AZ=0). Non-magnetic seal was used to prevent the leakage of MR fluid. All Discs were attached to the shaft as interference fit. MR fluid consists of 80, 18.5, 0.25 and 0.25 weight percentage of iron particle, silicon oil, oleic acid and tetramethyl ammonium hydroxide respectively was used in the analysis. AWG Copper coil having 1000 number of turns was used. Maximum saturation current (2.78 amp) was supplied to the magnetic coil. For a given current density, magnetic flux density can be calculated. Coil having 0.017 m^2 cross-section area was incorporated into the analysis. The dimension of all 18 disc was kept constant. The free space permeability value was kept as $\mu_0 = 4\Pi\times10^{-7}$ H/m.MR fluid gap of 1mm was maintained throughout the analysis. The relative permeability for Housing, Seals, Bearings, Shaft, Rotor and MR fluid was taken as 100, 1, 100, 5000, 5000 and 8 respectively. MAGSOLV and plot command was used to get the vector plot and nodal plot.

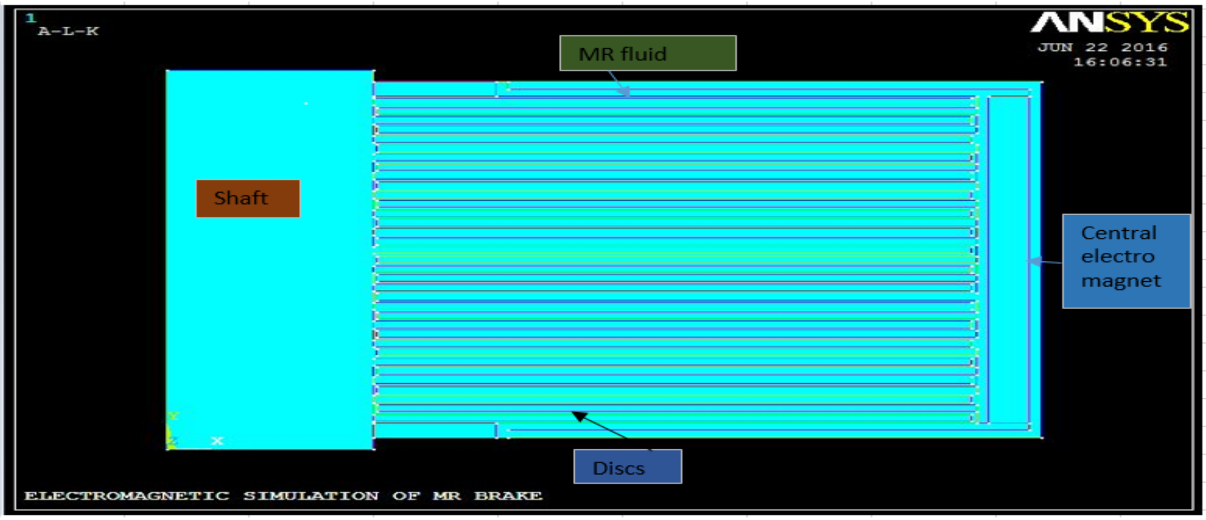

Fig 2.Two dimensional axi-symmetric model of Multidisc MR Brake.

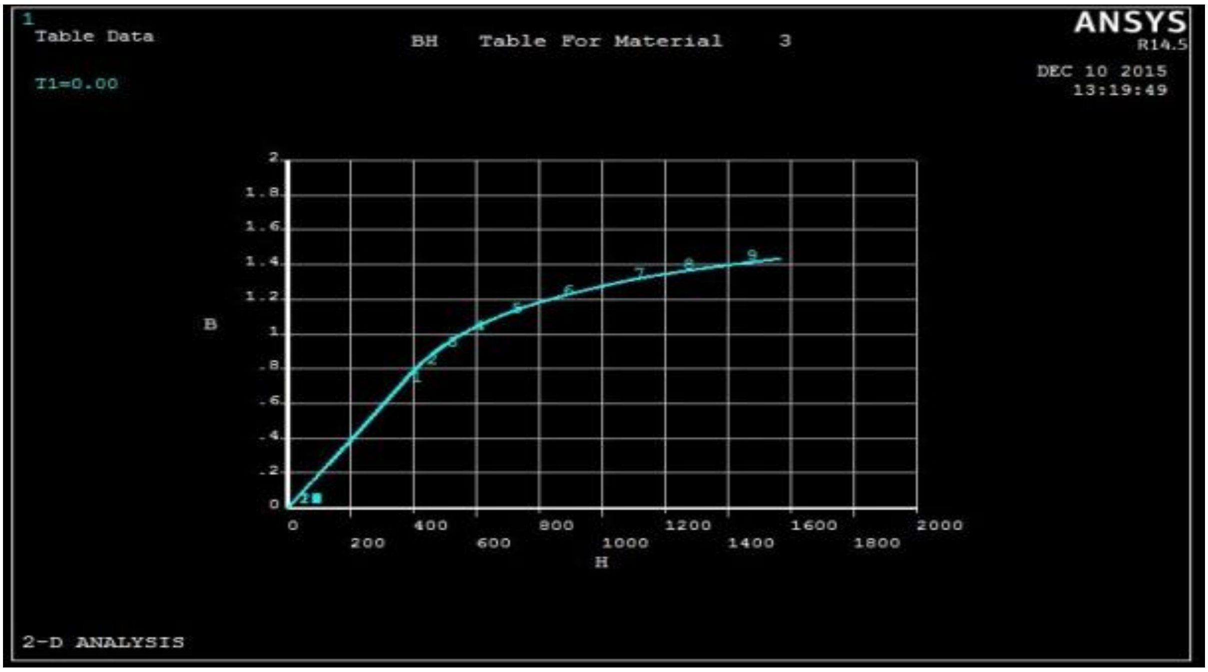

Fig 3.B-H curve for Finite element analysis.

Torque developed by MR brake is a function of magnetic field strength and MR fluid gap. The torque equation used for calculating of torque is shown in equation 1 [5]. It is expected that increasing the number of disc of MR brake, the developed retarding torque should also be increased.

$$T = 2\Pi n\left[\left\{2.727\times10^{-4}N^{1.5}I^{1.5}\left(\frac{1}{\sqrt{h_f}}-\frac{1}{h_i}\right)(r_2^2-r_1^2)\right\}+\left\{0.101\times10^{-4}N^{1.5}I^{1.5}\left(\frac{1}{h_f^{1.5}}-\frac{1}{h_i^{1.5}}\right)K(H)(r_2^3-r_1^3)\right\}\right.$$

$$\left.+\left\{\frac{\eta\omega(\log h_i-\log h_f)}{3}(r_2^3-r_1^3)\right\}\right]+\frac{2\Pi n\eta\omega}{3}(\log h_s-\log h_i)(r_2^3-r_1^3) \quad (1)$$

Where, $h_s = 2h_i - h_f$, n- number of disc, N- number of turns, I- current, h_f- final MR fluid gap width, h_i- Initial MR fluid gap width, r_2- outer radius of disc, r_1- inner radius of disc, K (H)- function of magnetic field strength, η - kinematic viscosity, ω – speed.

III. RESULTS AND DISCUSSION

Magnetic static analysis was used to carry out two dimensional flux lines analysis .The torque is calculated along the disc, therefore maximum flux lines should pass through the disc to get the maximum braking torque and the flux lines around the shaft, seal and housing should be minimum to have the minimum power loss during off state condition as shown in Fig. 4.For this non-magnetic material as low carbon steel was selected for shaft, seal and housing. The magnetic flux density generated by vector plot and nodal plot for multidisc MR brake is 8.96284 and 9.02765 Tesla as shown in Fig. 5 and 6 respectively. Along the disc periphery, the magnetic flux value is maximum which indicates that more braking torque was generated by MR fluid at that particular region.Magnetic flux density is different along each nodes. A developed APDL code was used to get the magnetic flux density at each node. In case of single disc MR brake maximum magnetic field was generated as 0.922 and 1.04 Tesla by vector plot and nodal plot respectively [7]. The magnitude of retarding torque developed by MR brake is dependent on supplied current. Torque developed by multidisc MR brake is increasing with current as shown in Fig. 7. After 2.5 amp current, MR fluid saturates and therefore torque value also saturated and variation of torque becomes negligible after saturation of MR fluid. Therefore it is concluded that by increasing the number of disc in MR brake is also increasing the maximum magnetic flux density and subsequently leads to higher braking torque. Present analysis clearly indicates that higher braking torque is possible by using Multidisc MR brakein place of single disc MR brake.

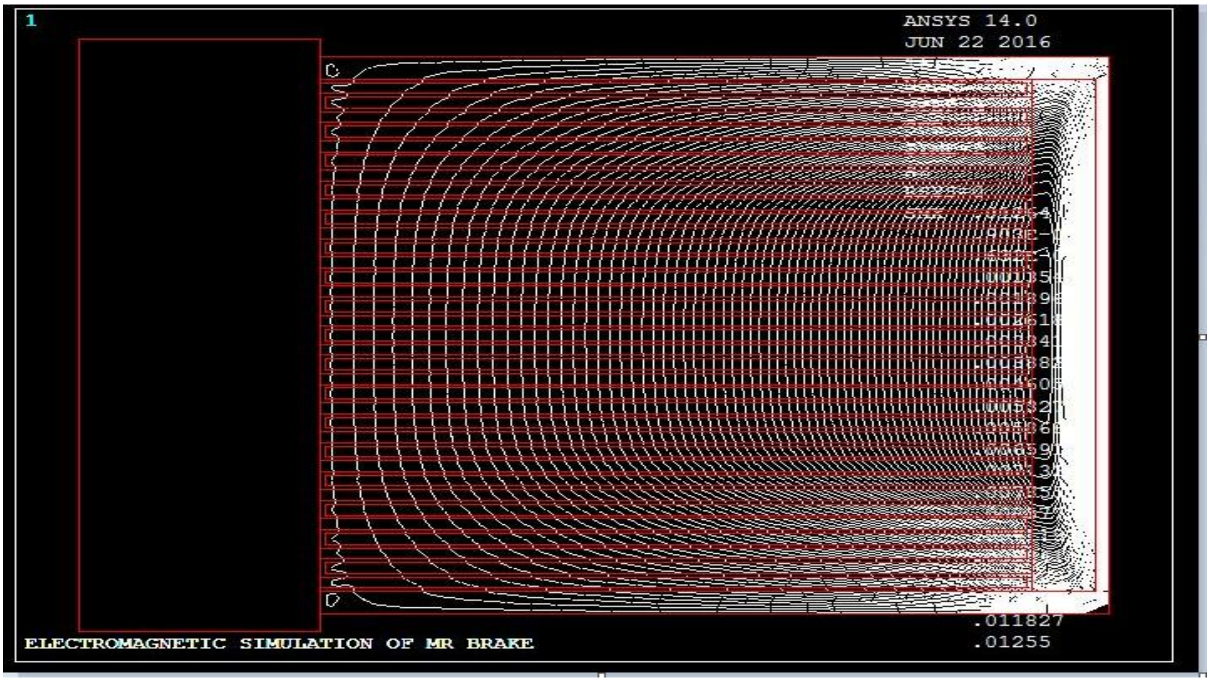

Fig 4. Two dimensional flux lines.

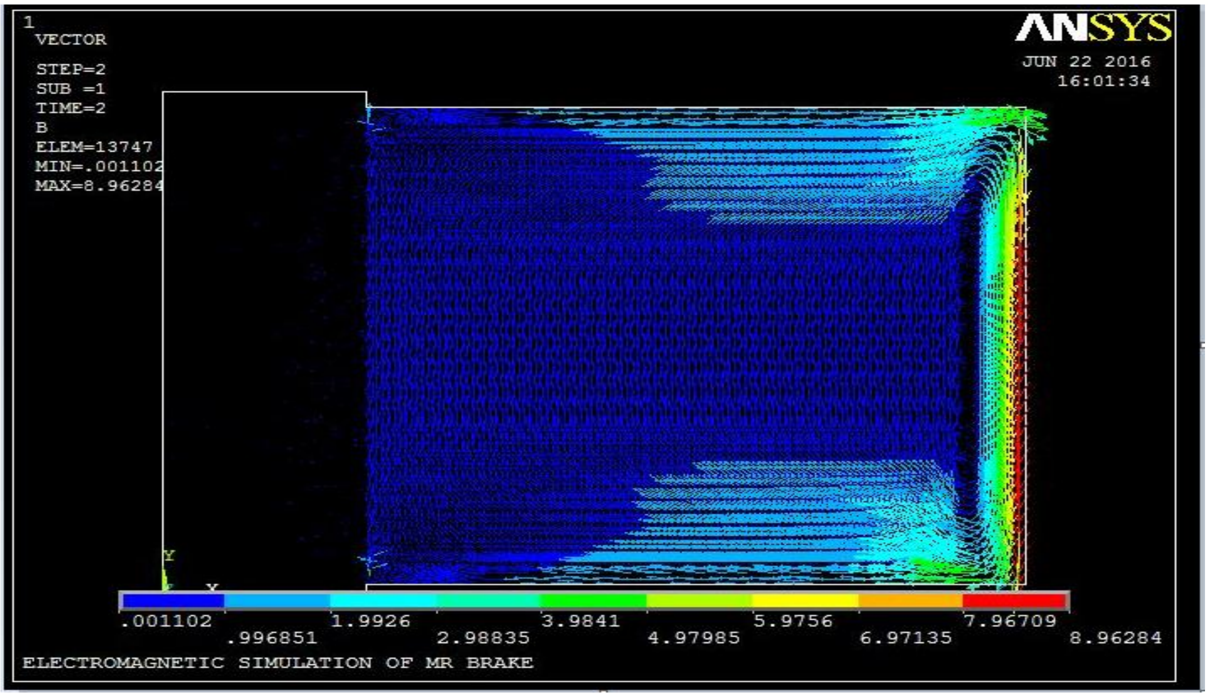

Fig 5. Magnetic flux density by vector plot.

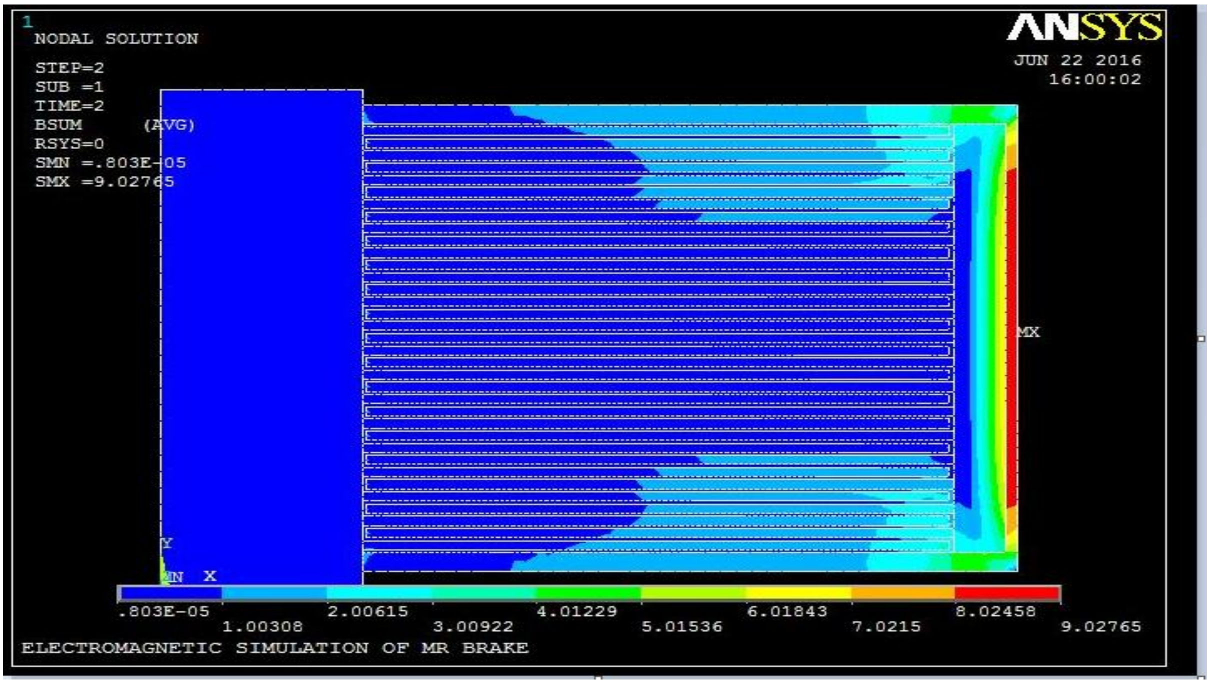

Fig 6. Magnetic flux density by nodal plot.

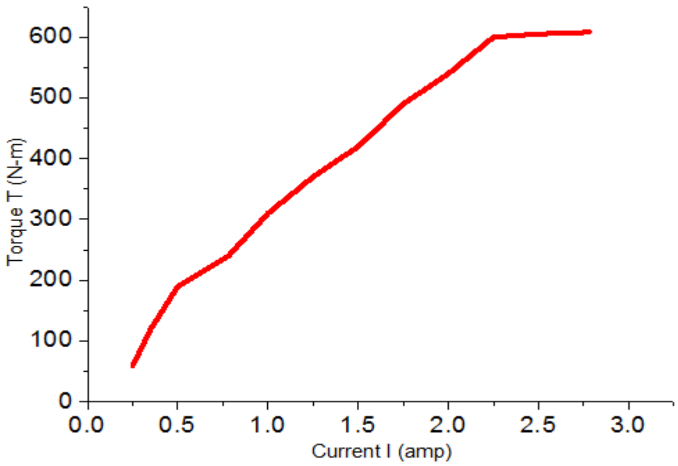

Fig 7. Torque variation with current

IV. CONCLUSION

Magnetic behaviour of multidisc Magnetorheological brake was analysed by using finite element method. Based on the analysis following conclusion was drawn:

- Magnetic flux density is dependent upon disc radius, MR fluid gap and current.
- The maximum magnetic flux density is generated along the disc periphery.
- Non-magnetic material of shaft restricts the passage of flux lines through the shaft, therefore power loss during off state condition is minimised.
- After saturation of MR fluid at higher current, torque value also gets saturate.
- The magnetic flux density is increased by increasing the number of disc of MR brake which subsequently results in higher braking torque.

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