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Finite Element Analysis of Magnet or heological Brake having Three Electromagnet using ANSYS

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ABSTRACT

The use of smart materials becoming popular as their behaviour is changed by applying the external field and comes back to their original state after removing the external field. Magnetorheological (MR) fluid is a type of smart material which is used in many applications such as automotive industry, dampers, aircraft cockpit, defence and optics.MR brake is the most popular application of MR fluid. In the present research work, the finite element analysis of MR brake having three electromagnet is presented. Obtained results are presented and compared with single electromagnet MR brake. Increasing the electromagnet leads to more uniform generation of magnetic flux density which in turns results in smoother operation of MR brake.

Keywords:* *Braking torque, Finite element analysis, Magnetorheological brake, Magnetorheological fluid, Relative permeability.

I. INTRODUCTION

Periodic replacement of brake pad due to mechanical contact, noise, pollution, localized heating and high energy consumption limits the usage of conventional hydraulic disc brake [1-2]. The magnetorheological fluid (MR) brake, having time invariant friction performance, low power requirement, no metal to metal contact, fast response, easy to control, may be considered as a good replacement for hydraulic disk brakes. Also the yield stress of MR fluid when in its active ("on") state can be controlled very accurately by varying the magnetic field intensity. MR fluid consists of micron sized magnetically permeable particles dispersed throughout the non-magnetic fluid carrier. On application of magnetic field, MR fluid greatly increases its apparent viscosity by a factor of 100 to 1000 times [3]. The schematic representation of various parts of MR brake and chain like structure of MR fluid is shown in Fig 1 (a) & (b) respectively [4]. Iron powder, having high saturation magnetization, is the most popular material to be used as magnetic particles. Under the presence of the magnetic field, magnetic dipole moment within particles induces, causing dipole interactions to form chains in the direction of flux paths [5]. The formed particle-chains restrict fluid movement and increase yield strength of MR fluid. Rotational movement of disk in shear mode affect the particle chains, and therefore the braking torque of MR brake.

Sarkar et al. reported the finite element analysis of MR brake to understand the performance evaluation of MR brake on Ansys software [6]. In our previous study, finite element analysis of single disc MR brake having one magnetic coil was reported on Ansys software [5]. In the present study an APDL code has been made by increasing the number of electromagnet from one to three to investigate the effect of increased electromagnet on magnetic flux density. The magnetic flux density and torque is determined for a given current density at the disk.

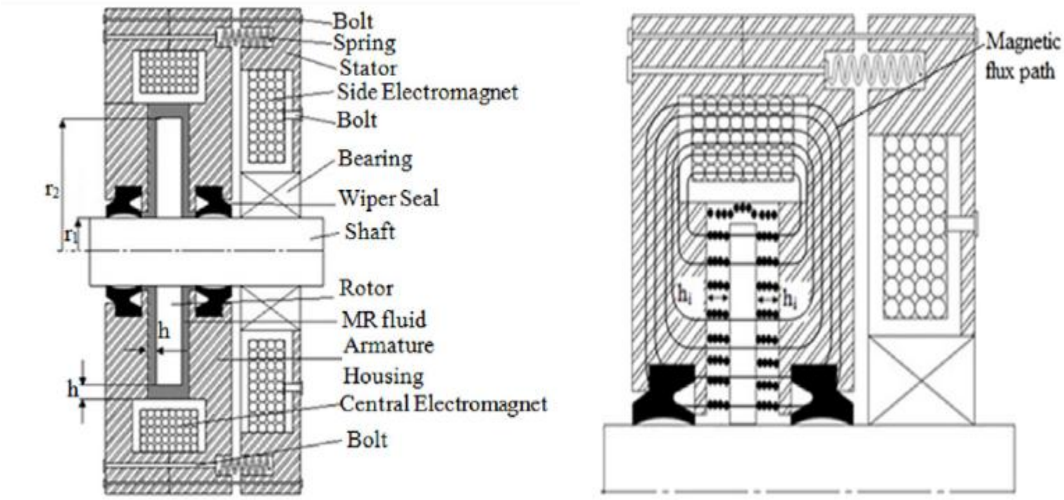

Fig 1.(a) MR brakerepresentation (b) Chain formation of iron particle on application of magentic field [4].

II FINITE ELEMENT MODELLING OF MAGNETORHEOLOGICAL BRAKE HAVING THREE ELECTROMAGNET

Finite element analysis of MR brake was carried out by considering a 2-Dimensional axi-symmetrical model. PLANE 13 element having four nodes was chosen a structural element for the analysis. Ansys provides the flexibility to set the unit by using EMUNIT command. Two dimensional axi-symmetric model of MR brake having three electromagnet is shown in Fig. 2. B-H curve to incorporate the magnetic saturation into analysis is shown in Fig 3. PLANE 13 element have provision to insert the B-H curve. Controlled meshing was done for the analysis to increase the accuracy of the results. The MR fluid having 18.5 % silicon oil, 80% Sigma Aldrich iron powder, 0.25% tetra-methyl ammonium hydroxide and 0.25% oleic acid was used in the present study [7].Disc material affects the magnetic flux density and which in turns affects the overall performance of the MR brake [5]. Pure iron with 99.99% purity was taken as disc material as the relative permeability of iron is very high about 5000. Minimum flux lines should pass through shaft and housing to minimize the power loss. Therefore, non-magnetic material as stainless steel was chosen for housing and shaft having relative permeability value about 100. Non-magnetic nitrile rubber seals were used to prevent the leakage of MR fluid. It was assumed that there was no leakage from housing to the environment, therefore flux parallel to the housing was made zero. It was observed that MR fluid was gets saturated after 2.8 ampwhich results insaturation of retarding torque value. Therefore maximum input current of 2.8 amp was supplied to each electromagnet. Increasing the coil area, also increased the size of the MR brake. Therefore in order to make MR brake compact, small electromagnet having 0.017 m^2 cross section area and 1000 number of turns of copper AG25 wire was taken for the analysis.The free space permeability value was taken as $\mu_0 = 4\Pi\times10^{-7}$ H/m. The input to the MR brake electromagnet was provided in terms of current density which includes the number of turns, supply current and cross sectional area of the coil. MAGSOLV command was used to get the final solution. Convergence criteria was set as 0.014 to get the final solution. Torque developed by MR brake is dependent upon several factors such as current, inner and outer radius of the disc, relative permeability of various parts of disc brake, kinematic viscosity of MR fluid, gap of MR fluid, rotational speed of the disc and brake actuating force. It was expected that by increasing the number of electromagnet, torque value should also increase.

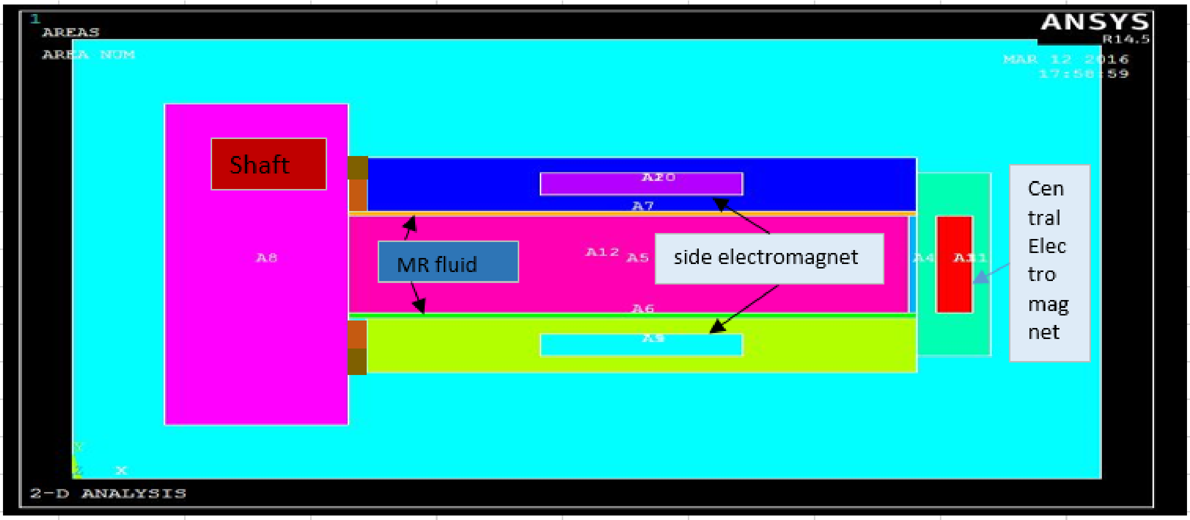

Fig 2.Two dimensional axi-symmetric model of MR brake.

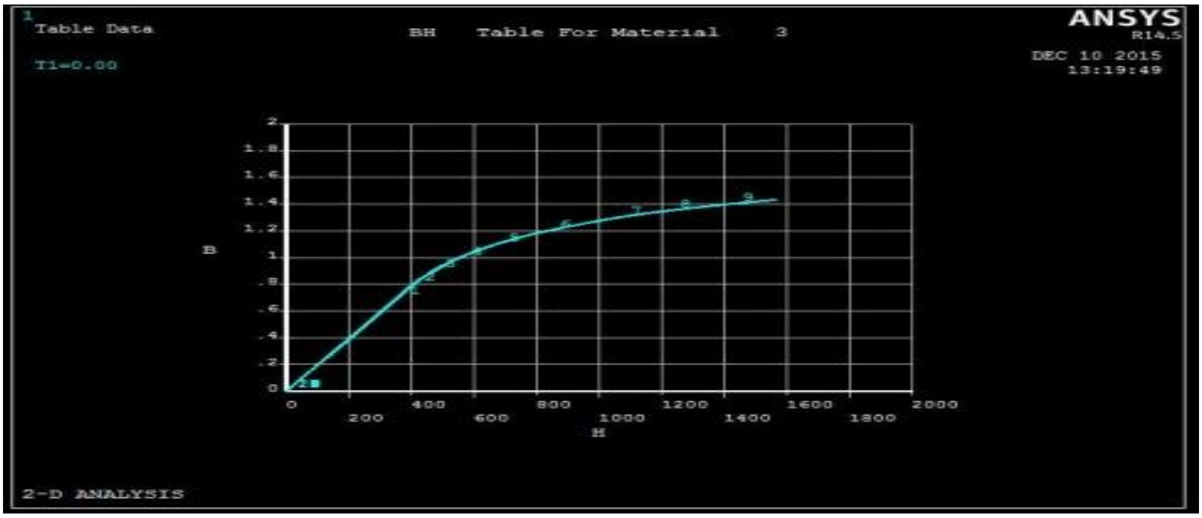

Fig 3. B-H curve for Finite element analysis.

III RESULTS AND DISCUSSIONS

Fig. 4 shows the passage of flux lines through various parts of MR brake. By default, Ansys uses the flux to be normal to all exterior faces.It is observed that by having side electromagnet along with the central electromagnet, flux lines also passes through the shaft which can degrades the performance of MR brake. However more flux lines also passes through the disc of MR brake which can accommodate the decreases performance of the MR brake. Fig. 5&6 shows the magnetic flux density distribution by vector plot and nodal solution respectively. The maximum value of magnetic flux density of 3.44284 and 3.29284 Tesla is observed. The obtained values in the analysis is higher than the previous reported values [5]. An APDL code is developed to get the analysis easier and faster. The torque is dependent upon the supplied current as shown in Fig. 7. From the torque curve, it is observed that after saturation of MR fluid (at 2.8 amp current), there is no further increase in torque value. However the torque produced in the present analysis by having three electromagnet is much higher than the single electromagnet brake. Therefore performance of MR brake is increased by the increasing the electromagnet of the MR brake.

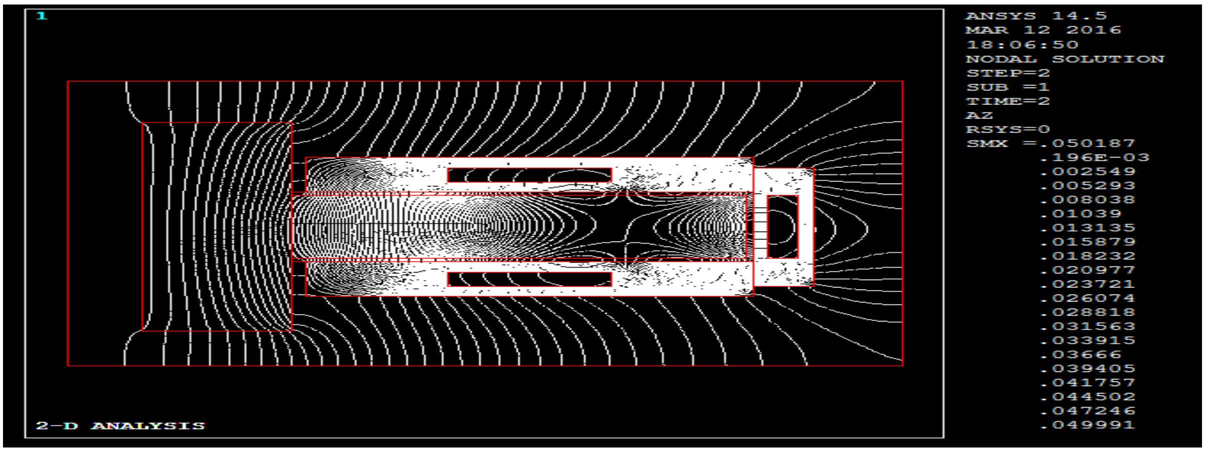

Fig 4. Two-Dimensional Flux lines

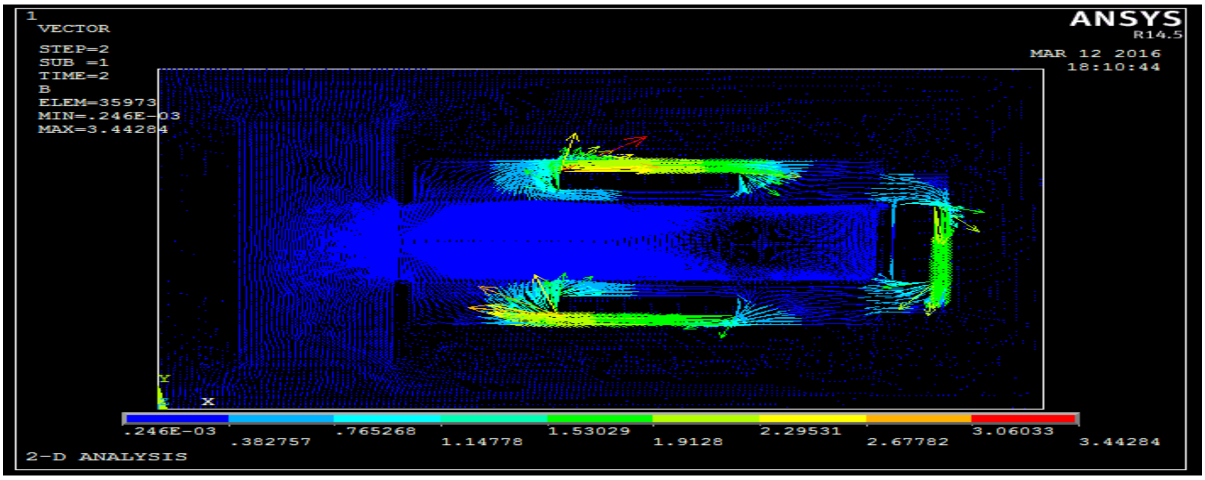

Fig 5. Magnetic flux density by vector solution.

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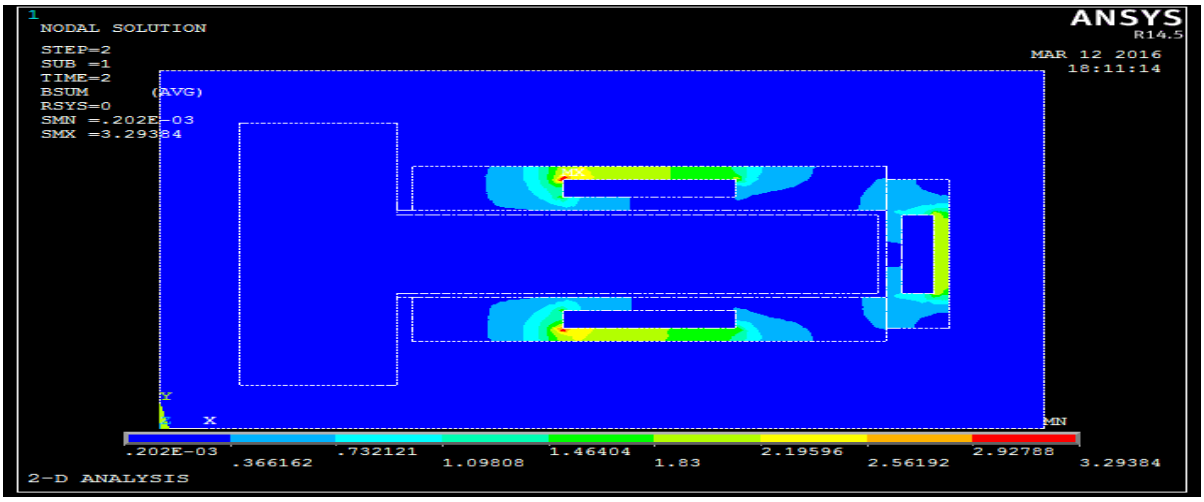

Fig 6. Magnetic flux density by nodal plot.

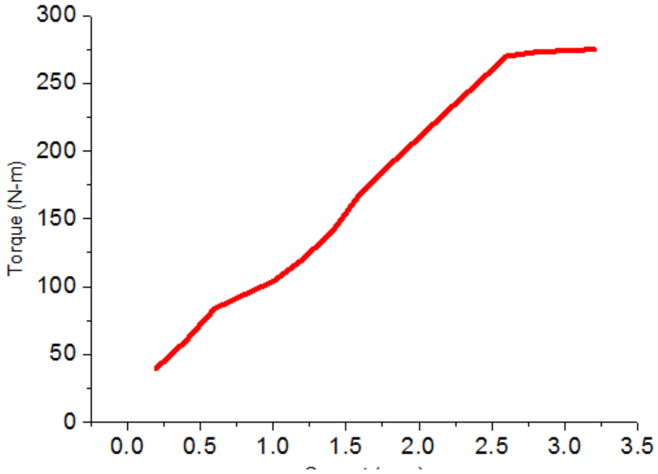

Fig 7.Torque vs increasing current.

IV CONCLUSION

Finite element analysis of MR brake is helpful to understand the performance characteristics of MR brake. Higher magnetic flux density near the periphery of MR brake disc is observed. Incorporating the B-H curve into analysis leads to more uniform generation of magnetic flux density. Non-magnetic nitrile rubber seals prevents the leakage of MR fluid. By increasing the electromagnet from one to three, magnetic flux density is also increasing which can be used in higher braking torque application in automotive sectors. The torque developed by MR brake having three electromagnet is much higher than the conventional disc brake.

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