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Magneto Static Analysis of Magneto Rheological Fluid Clutch

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Abstract: *Smart fluid is defined as a fluid that acts as a Newtonian fluid until a specific external magneticfiel d is applied .When the field of the properstreng this applied, micrometer- sized particles suspended in a dielectric carrier fluid will align such that the resistance to flow of thesmart fluid, the viscosity, significantly increases and thus the fluid becomes quasi solid. In thispaper the design of a Magneto rheological (MR) Fluid Clutch consisting of multi plates, electromagnet, housing and the magnetostatic Analysis of the same is presented. A MR Fluid Clutch, is a device to transmit torque by shear stress of MR fluids, has the property that its power transmissibility changes quickly in response to control signal. A 2D Axisymmetric model based on finite element method(FEM) concept has been developed on the ANSYS Platform to analyse and examine the MR Fluid Clutch characteristics. A prototype of the MR Fluid Clutc his fabricated based on the FEM model.Magneto staticAnalysis of the MR Fluid Clutch consisdered was performed for yielding the magneticfield density of the magnetic coil used in the armature.*

Keywords: *Magnetorheological fluid clutch, Newtonian fluid, quasi solid, dielectric carrier fluid, magnetic field density.*

I. Introduction

Magnetorheological Fluids:

An MR fluid is a free-flowing liquid in the absence of magnetic field, but under a strong magnetic field its viscosity can be increased by more than two orders of magnitude in a very short time (milliseconds) and it exhibits solid-like characteristics. Using these characteristics of MR fluids, MR fluid devices have the ability to provide simple, quiet, rapid-response interfaces between electronic controls and mechanical systems. MR devices are playing a vital role now a day's**[1]**. Magneto rheological (MR) fluid clutches are used in several automotive systems such as auxiliary engine devices, active differentials, and automatic transmissions.

MR Fluids are magnetically polarizable particles suspended in viscous fluids. They have the ability to change their rheological properties as shear modulus and viscosity reversibly in milliseconds when subjected to varying magnetic fields. While the magnetic particles are randomly distributed in the liquid when no magnetic field is applied, they form chains in the presence of a magnetic field, and as a result rheological properties of the fluid increase. Typically, the magnetizable particles are metal or metal oxide particles with size of on the order of few microns. Magnetorheological fluids are the suspensions of micron sized, magnetizable particles (iron, iron oxide, iron nitride, iron carbide, carbonyl iron, chromium dioxide, low-carbon steel, silicon steel, nickel, cobalt, and combinations thereof) in an appropriate carrier liquid (non-magnetizable) such as mineral oil, synthetic oil, water or ethylene glycol **[3]**. The carrier liquid serves as a dispersed medium and ensures the homogeneity of particles in the fluid. A typical MR fluid consists of 20-40 percent by volume of relatively pure, 3-10 micron diameter iron particles, suspended in a carrier liquid.

MR fluids are field responsive in nature. The magnetorheological response of these fluids lies in the fact that the polarization is induced in the suspended particles by the application of an external magnetic field. This allows the fluid to transform from freely flowing liquid state to solid-like state within milliseconds, because the magnetically dispersed particles attract each other to form fibril/chain-like structures along the direction of magnetic field. The chain-like structures resist the motion of the fluid and increase its viscous characteristics.**[5]** Such a behavior of MR fluid is analogous to Bingham plastics - non-Newtonian fluids capable of developing a yield stress.A favorable arrangement consists of particle chains aligned in the direction of the applied field and this, in turn, gives rise to a strong resistance to applied strains (Fig.1).

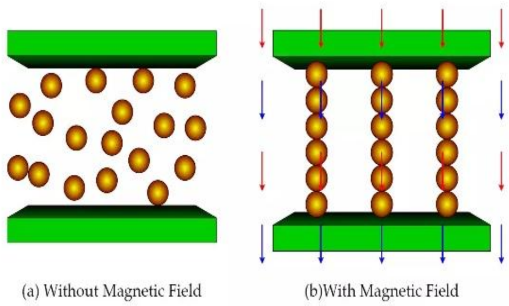

Figure1.MR fluid ferrous particles arrangement in unenergized and energized modes

The viscous fluid can be a non-magnetic liquid, usually oils. Additionally surfactants are used to allow for high particle volume fractions of the MR fluids that can yield higher variations in the rheological properties, and increase the fluid's stability against sedimentation. Figure1illustrates a schematic diagram of MR fluids with and without a magnetic field applied. Depending on the type of the magnetic particles, viscous fluids and their volume rate, the rheological properties of MR fluids vary. The viscosity of MR fluids can vary between 0.2 to 0.3 pa-s at 25° C.MR fluids are being considered in variety of energy dissipation and transfer devices such as shock absorbers, clutches, brakes, and engine mounts.

The aim of this work was to design and fabricate a high-efficiency MR Clutch with transmittable high torque, good long-term stability, and simple in construction. To accomplish this goal, an efficient magnetic field was analyzed and designed using ANSYS for static magnetic analysis.The transmitted torque equation for the disc-shaped clutch was derived based on the Bingham, plastic model. The mechanical performance of the MR clutch will be evaluated experimentally with a specially designed test rig, and the experimental results concerning transmitted torque will be compared with Ansys results.MR fluids can withstand high torque and require lower voltage (and moderately large currents) to be activated. A disadvantage of using MR fluids is that electromagnets are required. This increases the weight of the device. However, this can be minimized through appropriate design solutions for the magnetic circuit. Also, if the clutch is stationary, the performance is the critical design parameter not the weight.

This paper describes the design, modeling, and control of a MR fluid based clutch, which functions as a torque transfer device.The main objectives described in the paper includes Magnetostatic analysis of MR Fluid Clutch.

II. Design Of Magneto Rheological (MR) Fluid Clutch

This paper presents a research activity about the design and the development of a Clutch using a magneto rheological fluid that allows to control the torque and consequently improve the vehicle handling. To evaluate the effectiveness of the proposed device, a physical prototype was developed.Experimental tests helps in validating the design process.

A conceptual drawing of a Magneto Rheological Fluid clutch (MRFC) and its Assembly is shown in Fig.2. An electric coil rolled round an output shaft which generates magnetic fluxes shown by dashed lines in the drawing will be used. Multi-layered disks will be fixed on the input / output shaft. The MRF is filled between these disks. MRFs have basically low relative magnetic permeability (3.5~10) **[2]**, and that is significantly lower than ferromagnetic materials that will be used for a magnetic circuit. In many previous reports [**6**] ~ [**8**], millimeter-size (0.5~1.0mm) gaps of MRF layers have been applied. Micro-size-gaps (1mm)approximately are used, to reduce the magnetic resistance of the MRF layers. The need to transmit the torque to the driving wheels and, at the same time making the wheels free to rotate at a different speed, make the clutch very functional for the purpose. The commonly employed clutch receives the torque from the gearbox and splits it into two equal parts that act on the driving wheels. Consequently, neglecting the internal friction loss, the driving wheels subjected to the same driving torque can rotate at a different speed in accordance with the vehicle kinematics. The Clutch can transmit the torque to a wheel even if the other wheel is on a slippery surface**[9]**. The Clutch depends on mating the two side gears with the effect of generating different driving torques.

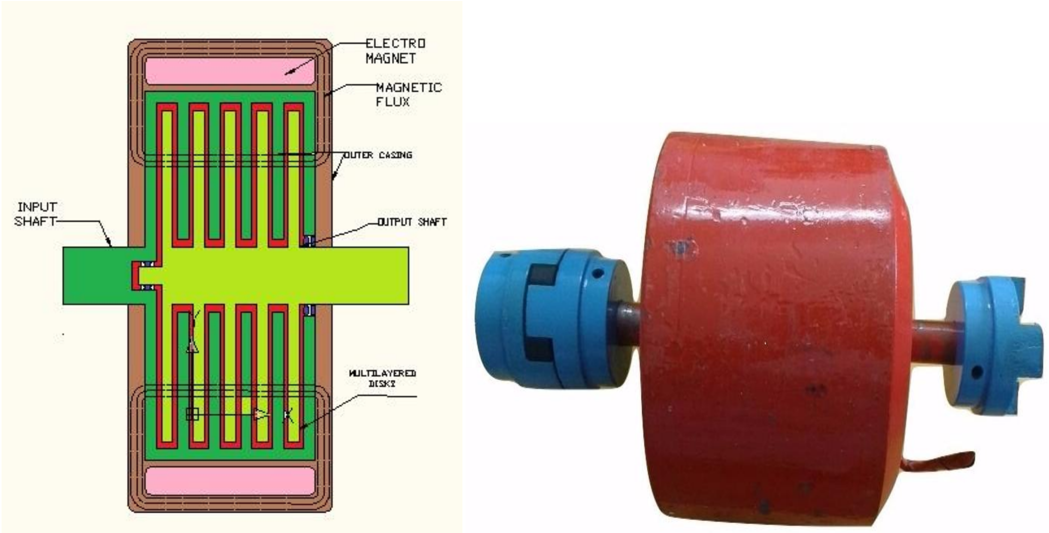

Figure2.Cross Section of Magneto Rheological Fluid Clutch and its Assembly with Couplings

This differential's locking effect make the vehicle capable of moving itself alos in presence of a wheel characterized by low traction. The locking torque depends typically on the relative wheel speed or on the torque acting on the clutch and generates its effects independently from the vehicle handling, e.g., under steering / oversteering. As a result, in some dynamic conditions, the locking torque can also produce an undesired vehicle behaviour.

III. Magneto Static Analysis Of MR Fluid Clutch

Ansys workbench 15.0, Magneto Static modulewas used to optimize the magnetic circuit. An MR clutch is to be analysed as a 2-D axisymmetric model. For a given current, we can determine the magnetic flux density at the MR Fluid, the casing and the plates.

MR fluid MRF-132DG provided by Lord Corporation was used in the device. Ansys iterations were run at various input current values from 200 mA to 2000 mA and magnetic flux densities are obtained from which yield stress and the effective torque values are calculated. Fig.3. shows the Ansys results for magnetic field density and magnetic induction for current input of 2A. An MR clutch is to be analysed as a 2-D axisymmetric model. For a given current, we can determine the magnetic flux density at the MR Fluid, the casing and the plates.MR fluid gap, the casing and the plates complete the magnetic circuit. A wound coil taking 4000 turns, and 8000 turns is assumed and shown in Fig.3, provides the magnetic flux field that is necessary for energizing the MR fluid. The electrical current through the coil can be varied to change Magnetic flux density.In Fig.3.b cross section of the electrical coil is shown.

The flux leakage out of perimeter of the model is assumed to be negligible enough that no saturation of the material occurs. This allows a single iteration linear analysis. This assumption simplifies the analysis and allows the model to remain small. The model would normally be created with a layer of air surrounding the iron equal to or greater than the maximum radius of the iron to model the effects of flux leakage.

The non-magneticgapismodelled so that a quadrilateral mesh is possible. A quadrilateral mesh allows for a uniform thickness of the air elements adjacent to the engine where the virtual work force calculation is performed. The assumption of no leakage at the perimeter of the model means that the flux will be acting parallel to this surface. This assumption is enforced by the "flux parallel" boundary condition placed around the model. This boundary condition is used for models in which the flux is contained in an iron circuit.

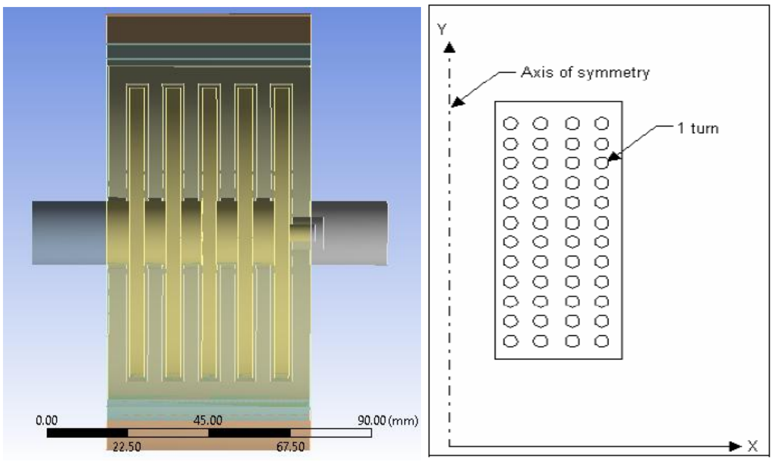

Figure3.a)2-D Axis-symmetric MR Clutch in ANSYS, b)Electrical coil cross section

For a static (DC) current, ANSYS requires the current to be input in the form of current density (current over the area of the coil).

$$JS = \frac{NI}{A} \qquad (1)$$

Where, JS= current density, N= no. of turns, I= current, A= coil area

3.1ASSUMPTIONSAND RESTRICTIONS

In any 2-D axisymmetric model, there are some assumptions and restrictions which will allow us to create the model and be able to revolve it around the axis of symmetry. The assumptions made for this study are:

- The area of the element must be positive.
- The element must lie in a global X-Y plane.
- Y-axis must be the axis of symmetry for axisymmetric analysis.
- An axisymmetric structure is modelled in the +X quadrants.

3.2STEPS IN A STATIC MAGNETIC ANALYSIS

This section describes the procedure for a static magnetic analysis, consisting of the following main steps:

- Import assembly
- Create enclosure
- New simulation
- Import new materials
- Mesh the assembly
- Add boundary condition- magnetic flux
- Add boundary condition- conductor
- Add solution objects
- Add Inductance and Flux Linkage-coil
- Solution Results

3.2.1 Import Assembly

Before importing the assembly into ANSYS Workbench, save the Solid works file with IGES extension (.IGES). To import the file in workbench:

Main menu> Import external geometry file> Select file> Open

And then click on the *Generate Feature*. The assembly is imported to Workbench as shown in fig.4

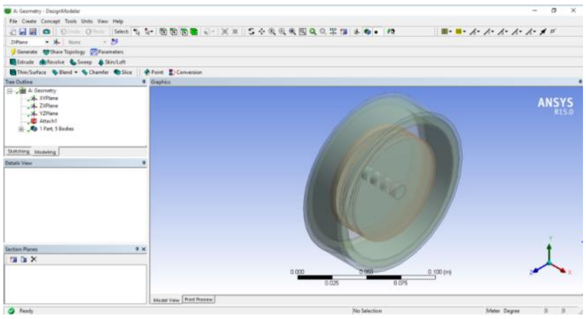

Figure 0. Importing the model into Workbench

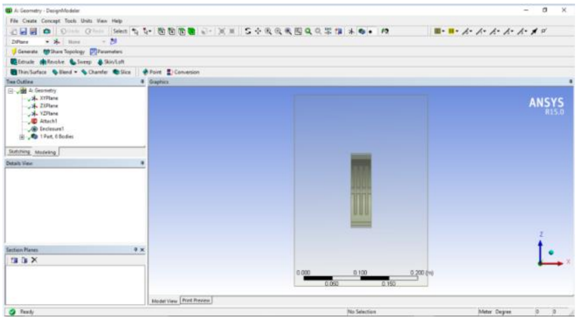

Figure 5. Air enclosure around the model is created.

3.2.2 Create Enclosure

To analyse the behaviour of the MR fluid between the plates, an enclosure is created around the entire assembly as shown in fig.5.To do so, the following steps need to be taken:
Tools> Enclosure
Enter the details of the enclosure.

- Shape = box
- No. of planes = 1
- Symmetry plane = ZX
- Model type = full model
- Cushion = 225mm
- Target bodies = all bodies
- Merge parts? = yes

Click on the generate button. The enclosure is created.
One assembly made up of 6 parts is created. To differentiate the parts for subsequent analysis rename the parts as input plates, output plates, fluid, magnet, casing and enclosure.

3.2.3 New Simulation

For a new simulation use the following: *Design Modeller Tasks> New simulation*

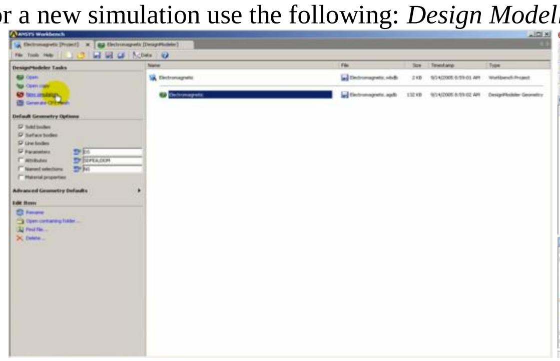

Figure 6. Starting a new simulation

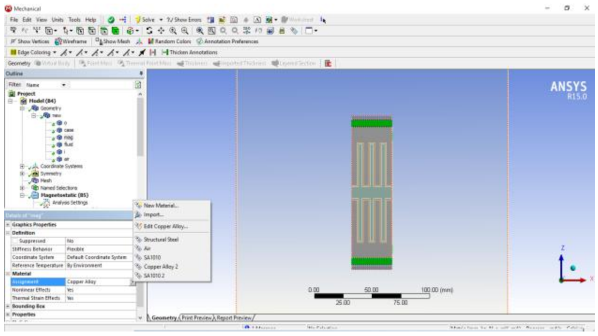

Figure7. Selecting material for each part

Now, the assembly is available for analysis.

3.2.4 Import New Materials

Select a part and then, in Graphics Properties click on material and then select import option in the box as shown in fig.7 and fig.8.
Then to import select every material required for the assembly from the material library.

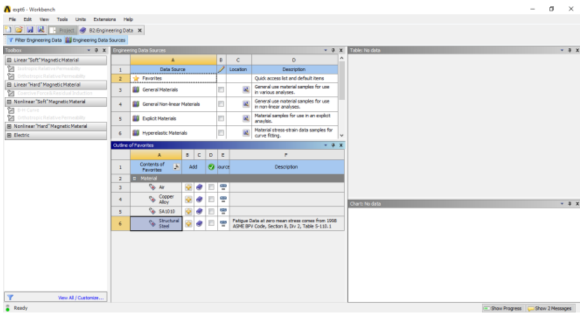

Figure 8. Selecting the materials from material library

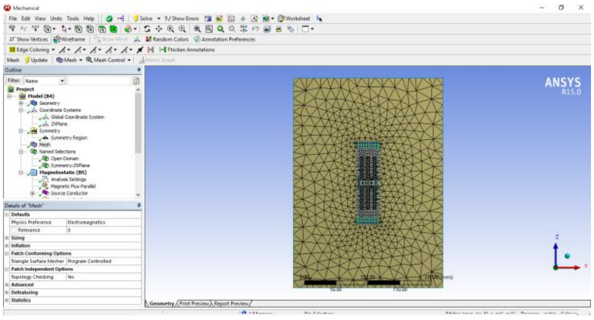

Figure 9. Meshing the model

Now, select the material for each part.

3.2.5 Mesh The Assembly

The assembly is now prepared to be meshed. Use mesh options to set mesh parameters and preview the mesh. Follow: *Mesh> Relevance>*Enter 40 as relevance value Now right click on the mesh and select preview option in the box displayed. Mesh is displayed. If more accurate result is required, decrease relevance value of the mesh. Display all parts to see the mesh as shown in fig.9.

3.2.6 Add Boundary Condition-Magnetic Flux

A magnetic flux parallel boundary condition is specified for the symmetry plane shown in fig.10. To do so click on environment button and follow:
Electromagnetic> Magnetic flux parallel
Now enter the details of magnetic flux parallel in the box as

- The symmetry plane is selected for boundary condition. It is already defined as named selection.
- Scoping method = Named selection
- Named selection = Symmetry ZX plane
- Type = Magnetic flux parallel
- Supressed = No

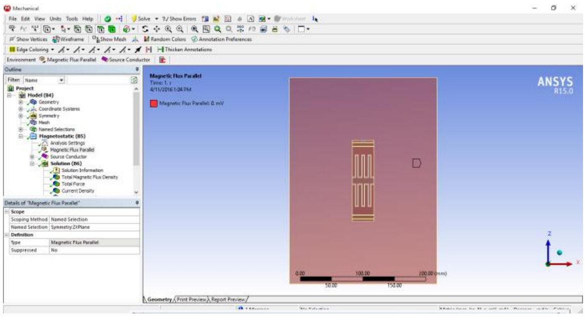

Figure 10. Appling magnetic flux as a boundary condition

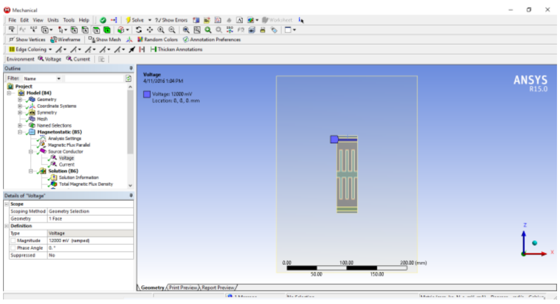

Figure11. Adding voltage as a boundary condition

3.2.7 Add Boundary Condition-Conductor

Add a conductor boundary condition that applies voltage and amperage loads to the faces of the coil shown in fig.11 and fig.12. To do so click on the environment button and follow:
Electromagnetic> Conductor
Now enter the details as

- Scoping method = Geometry selection
- Geometry = Select by clicking on the electromagnet in the assembly
- No. of turns = 750
- Supressed = No

Now ,*Electromagnetic> Voltage*
Then click on the face button and select one of the faces of the electromagnet by clicking on it. And the click on *Geometry>Apply.T*he voltage to ground is set to, V = 0volts.
Now select *Electromagnetic> Current*

Then select the face button and select the other face of the electromagnet by clicking on it and click on *Geometry> Apply.*
The value of current is set between 0-2Amps. Different solutions are noted for different currents.

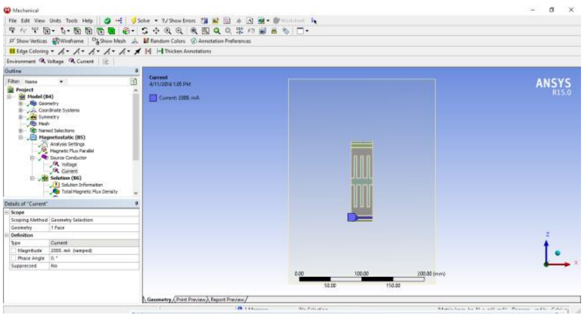

Figure 12. Adding current as a boundary condition

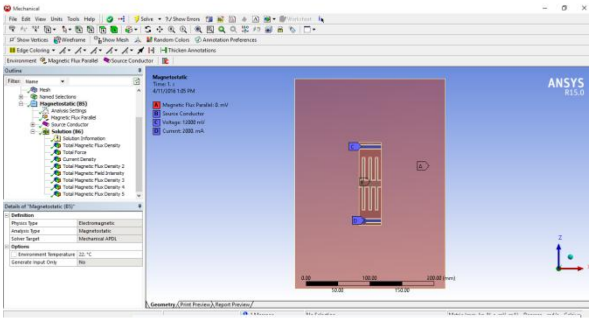

Figure 13. All environment conditions

Now, all environment variables are set.

3.2.8 Add Solution Object- Air

Specify Total Flux density as a result object for the enclosure in order to view the effects in the fluid as shown in fig.14. and fig.15. To do so click on the solution and then select air enclosure by clicking on it and follow:
Electromagnetic> Total flux density
Now Total magnetic flux density is a result object.

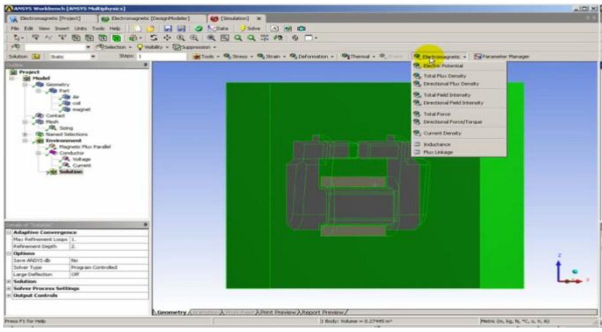

Figure 14. Adding total flux density as a result object

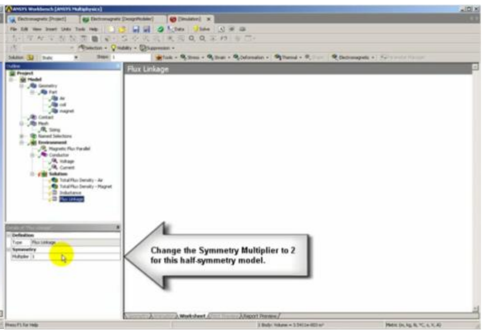

Figure 15. Adding flux linkage and inductance as a solution objects

3.2.9 Add Inductance And Flux Linkage- Coil

Click on the solution and select the coil by clicking on it and follow:*Electromagnetic> Inductance*
And change the symmetry multiplier to 2 for this half-symmetry model.*Electromagnetic> Flux linkage*
And change the symmetry multiplier to 2.

3.2.10 Solution Results

Now right click on the solution and then select solve option. Check the various solutions by clicking on them under solution, for getting the total magnetic flux densities in fluid ,input and output plates, casing and in electromagnet as shown in the fig.16, fig.17,fig.18.,fig.19.

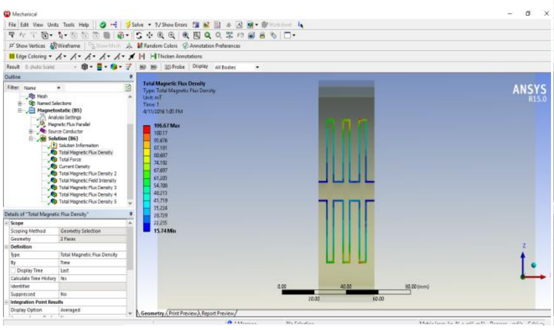

Figure 16. Total magnetic flux density in fluid

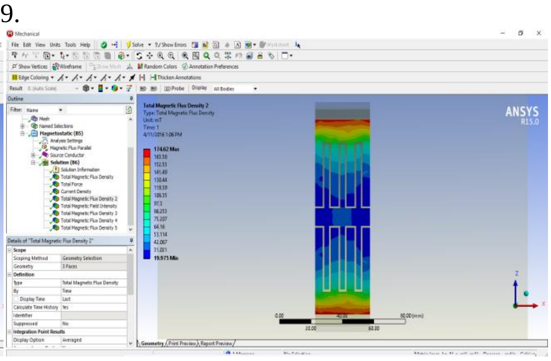

Figure17. Total magnetic flux density in input and output plates

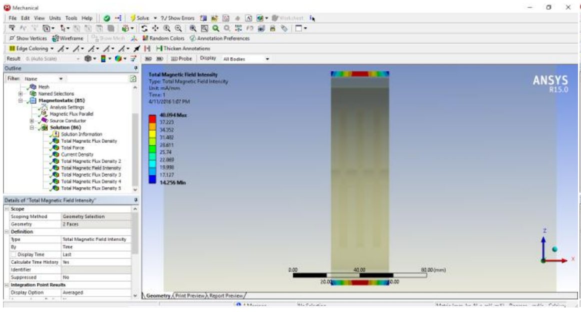

Figure 18. Total flux density in casing

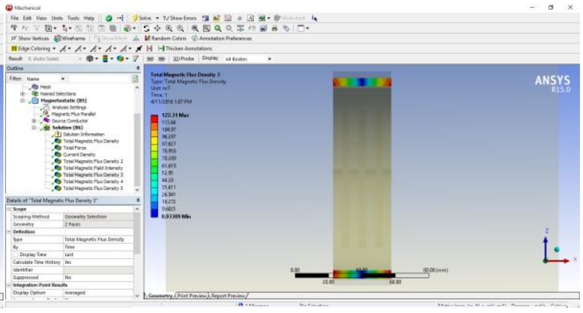

Figure 19. Total flux density in electromagnet

IV. Conclusion

Magneto rheological fluid Based clutch is described with its design details and Analysis in this paper. The design of the clutch using Solid works is done and to estimate the torque transmission efficiency magneto static analysis is done. To eliminate the wear, engagement, shock and variable loading during operation, a successful magneto rheological fluid based clutch is manufactured. The detailed description of the MRF Clutch Analysis is given. Torque transfer devices are an essential part for a variety of electro-mechanical/robotics systems, in active control of vibrations, optical polishing and in seismic protection. The design and performance of the clutch are optimized by electromagnetic finite element analysis. Though the transmitted Torque is high, the power consumption of the MRF clutch needs to be optimized for automotive application. It is concluded that the transmitted Torque is not sensitive to the input velocity since the viscous Torque is negligible compared to the Torque due to MR effect. Upon experimental analysis it can be demonstrated that this MR fluid clutch design can transfer high, controllable Torques with a fast response time[10].

Acknowledgements

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