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Simulating Magnetorheological Fluid under Shear Mode for Breaking System

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ABSTRACT:
Thisminiprojectworkintendstosimulatethebrakingeffectandtocalculate the Braking Torque obtained by the MRFBS for varying magnetic field intensity (namely 0 T / 0.5 T / 1 T / 2 T) on 3 mm thickness rim and 400 mm inner diameter (ID). The software of choice for simulation shall be ANSYS v15.0.

The rim is simulated in different magnetic field intensity for the different magnetic field intensities to find the suitable field intensity for the given rim model.

Keywords: Brake,disc,magneto-rheological fluid, braking force, Simulations Simulating magnet or heological behavior under shearmode for automobile braking application

I. INTRODUCTION:

WiththeadventofICengines,thepaceatwhich mankindtravelsacrosstheglobe was redefined. Hence new and more efficient braking systems had to be evolved along with stringent standards to monitor various aspects such as braking distance, the brake temperature, braking force, etc. Currently, the disc brake has proven to be the choice of mechanism employed in almost every road transport vehicle. However, as a paradigm shift is being observed, the IC engine powered vehicle is anticipated to soon be substituted by electricity powered vehicle. This emerging trend would also demand a new braking system and the magneto- rheological braking system has revealed some promisingresults.

A magneto-rheological fluid (MRF) is a smart fluid. The MRF Braking System (MRFBS) works by keeping an MRF between two parallel plates attached to the wheel. Then, on application of a magnetic field, the viscosity of the MRF can be increased,andduetothefrictiongeneratedbyShearForcebetweentheMRFand thebrakedisc,thevehiclecanbebroughttoahalt.TheadvantagethattheMRFBS possesses is that very precise control of the magnetic field is possible and hence the shear force that is applied can be very precisely controlled. Hence, the MRFBS provides a very precise control over the braking force that needs to deployed in a certain condition. Also, MRFBS boasts a reaction time of 15ms. That is, the braking action is initiated within 15ms after the driver activates the magnetic field via the brakepedal.

II. LITERATURE REVIEW:

Magnetorheological Fluid:

Amagneto-rheologicalfluid(MRF)consistsofawaterorsynthetic oilorsilicone oil-based media with micro or nano sized particles suspended in it. The particle sizeissmallenoughtoremainsuspendedinthe mediaviaBrownianmotionhence avoiding a solid-liquid phase separation due to stagnation. On application of magneticfield,theviscosityofthisMRFcanbevariedasthesuspendedparticles line up along the magnetic field. The viscosity can vary to an extend where the MRF starts to behave as a viscos-elasticfluid.

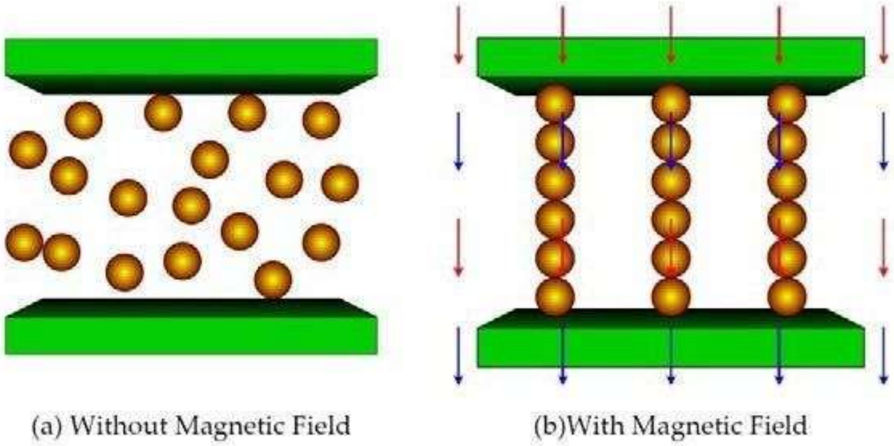

(a) Without Magnetic Field (b)With Magnetic Field

Figure 1: MRF Behaviour under magnetic field.

The MRF can be used in 3 Modes:

a) Valvemode:

Here, the MRF flows between two fixed parallel plates and at some patch in the flowthemagneticfieldisapplied.Thiscausestheviscosityofthefluidtoincrease in the patch where the magnetic field is applied. This causes a drop in flow velocity and an increase in fluid density in the patch where magnetic field is applied. Hence, magnetic field acts as a virtual valve that can be used to throttle theflowofMRF.Thisiswidelyusedindampeningsystemsandshockabsorbers with MRFtechnology.

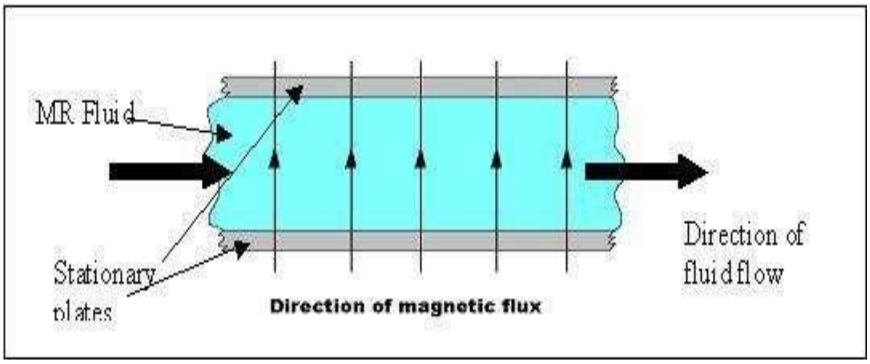


Figure 2: Valve Mode.

b) ShearMode:

Inthismethod,thequantumofMRFisfixedbetweenafixedplateandamoving plate.Asthemagneticfieldisapplied,ashearforceisexperiencedonthemoving plate. This **mode of operation is applicable forMRFBS**.

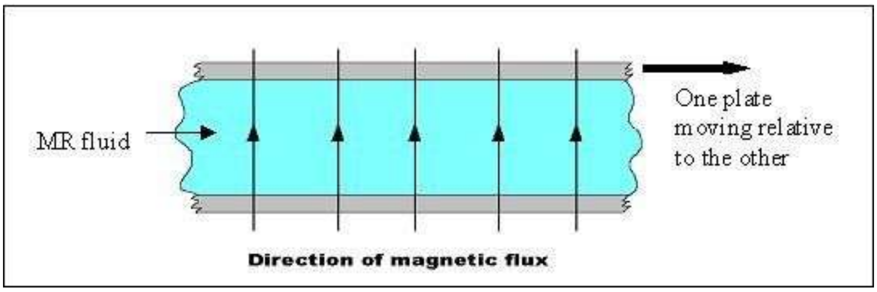


Figure 3: Shear Mode.

c) SqueezeMode:
Here,oneplatemovesperpendicularrelativetotheotherandtheMRFinbetween is squeezed and under a magnetic field poses a resistance to this squeezing motion.

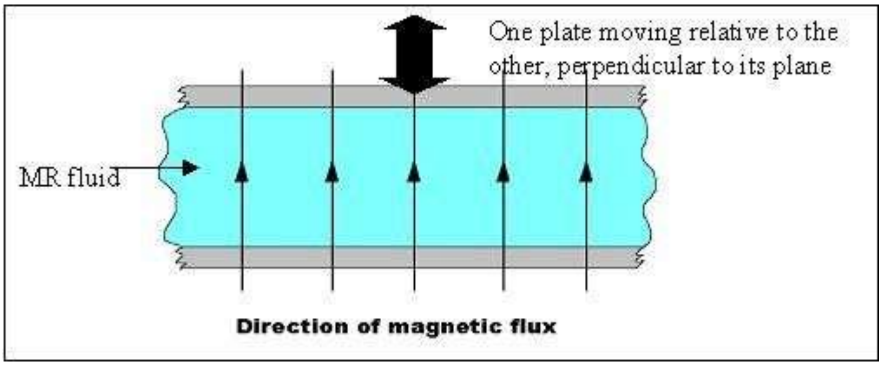


Figure 4: Squeeze Mode.

The Bingham model of an MR fluid includes a variable rigidperfectly plastic element connected in parallel to a Newtonian viscosity element, so that the stress–strain constitutive relationship can be expressed as-

$\tau = \tau_y(H)\mathrm{sgn}(\dot{\gamma}) + \eta\dot{\gamma}$

where, τ is the shear stress, τ_y is the yielding shear stress controlled by the magneticfield,ηistheNewtonianviscosityindependentoftheappliedmagnetic field,$\dot{\gamma}$istheshearstrainrateandsgn(·)isthesignumfunction.

III. METHODOLOGY AND SIMULATION:

Geometry:
The cross section of an MRFBS under shear mode is described in Figure 5.

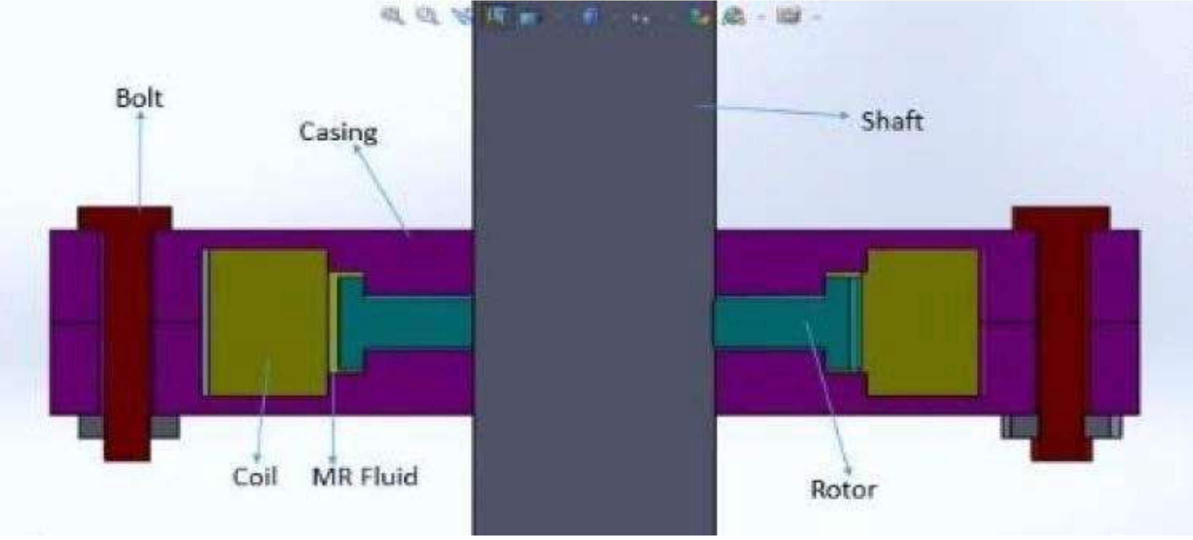
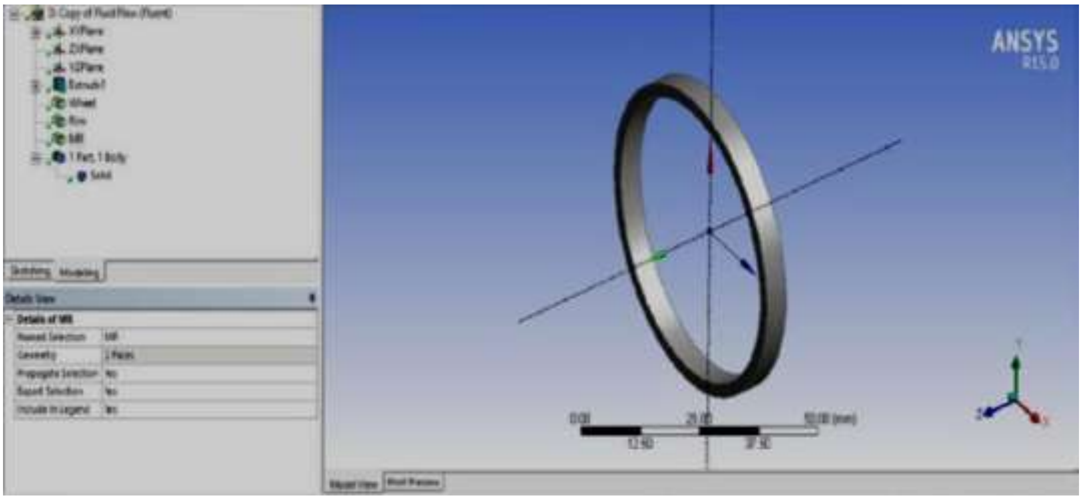


Figure 5: Typical MRFBS Arrangement (Cross Section).

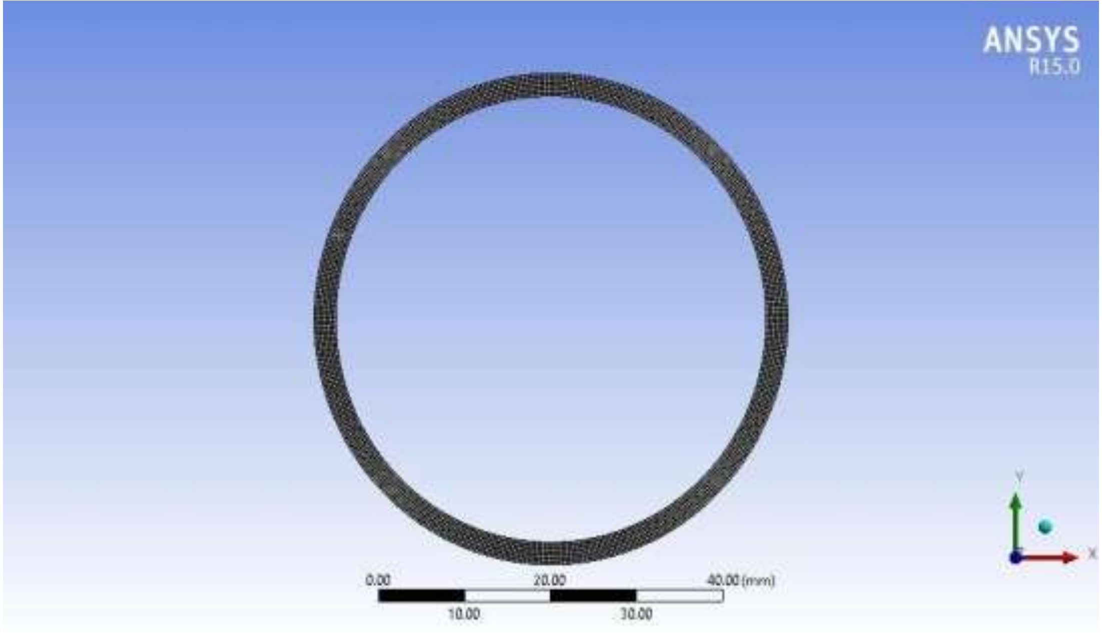
Hence the MR fluid element will be in the gap that varies as per design between 1mm to 5mm. TheFluidelementgeometryconstructedasshowninfigure6asitisbeingimport from the Solidworks. The diameter of wheel (ID of the ring in the geometry) is taken as 400mm and thickness of3mm.



Details of MR	
Named Selection	MR
Geometry	2 Faces
Propagate Selection	No
Export Selection	No
Include in Legend	Yes

Figure 6: Geometry of Fluid element in the clearance gap.

Meshing:
The ring periphery was divided into 500 parts and mapped face meshing was applied to the body.
Also Named Selections of Rim, Wheel, MR_Wall was assigned to the inner surface, outer surface, and the two side walls of the ring geometry respectively.



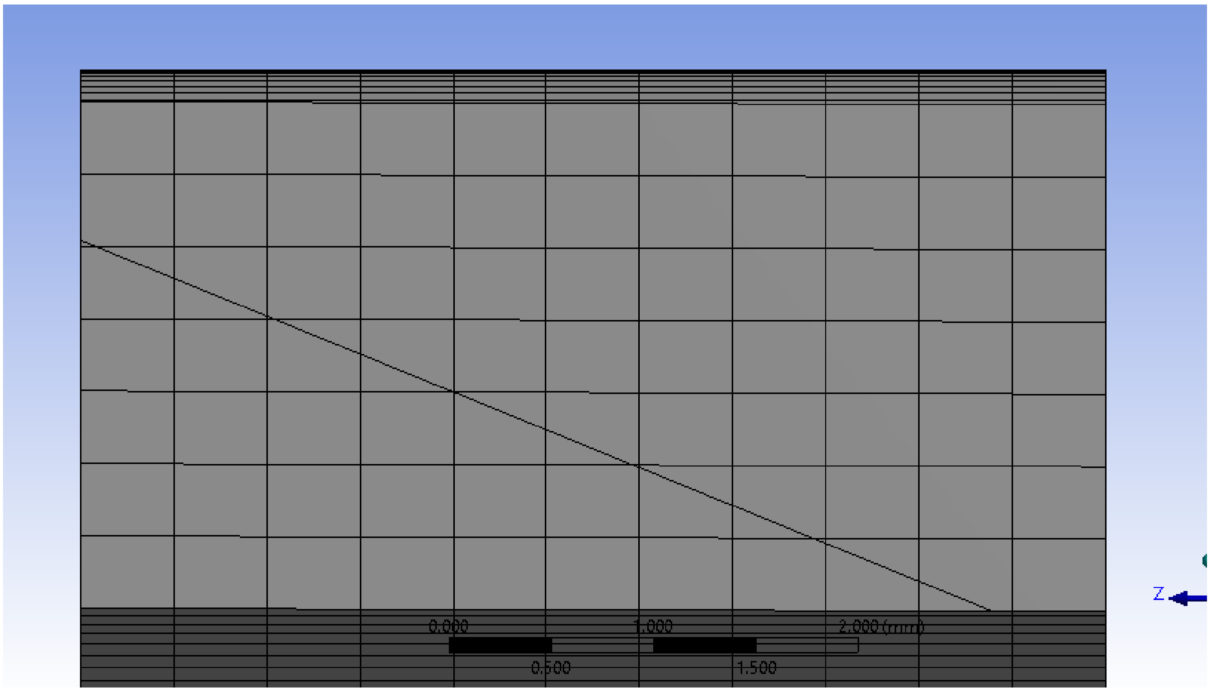
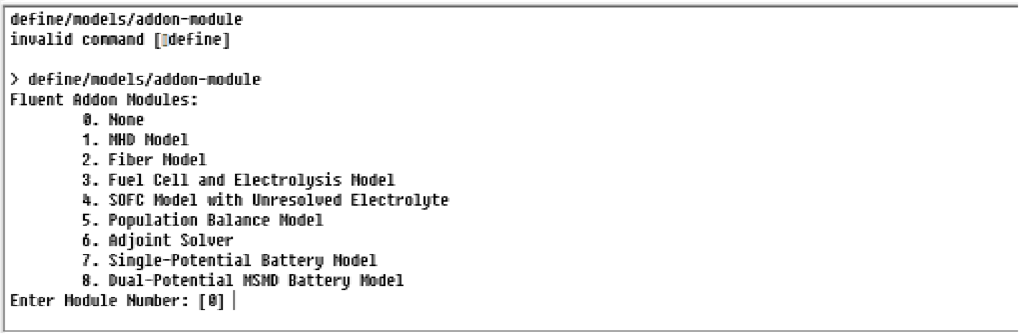


Figure 7: Meshing of Geometry.

Figure 8: Cross Section of the ring geometry with meshing.

Fluent Set-Up:

- For simulating MRF, and the interaction of MRF with external magnetic field,theMHD(Magneto-HydroDynamics)moduleinANSYSFluentwas activated.
- For accessing MHD, first the Fluent solver was initialized with Parallel Solver and 2 cores. Also, Double Precision wasenabled.
- In CLI, to access add-on modules, the command- “define/models/addon- module” was typed. Then “1” is typed to accessMDH.



```
define/models/addon-module
invalid command [▯define]

> define/models/addon-module
Fluent Addon Modules:
        0. None
        1. MHD Model
        2. Fiber Model
        3. Fuel Cell and Electrolysis Model
        4. SOFC Model with Unresolved Electrolyte
        5. Population Balance Model
        6. Adjoint Solver
        7. Single-Potential Battery Model
        8. Dual-Potential MSMD Battery Model
Enter Module Number: [0] |
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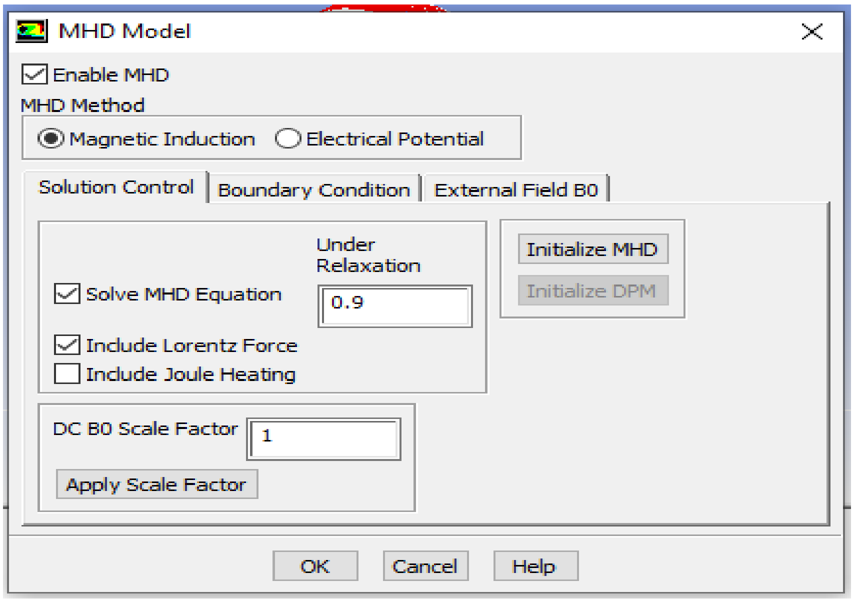


MHD Model

☑ Enable MHD

MHD Method

● Magnetic Induction ○ Electrical Potential

Solution Control | Boundary Condition | External Field B0

☑ Solve MHD Equation

Under Relaxation: 0.9

☑ Include Lorentz Force

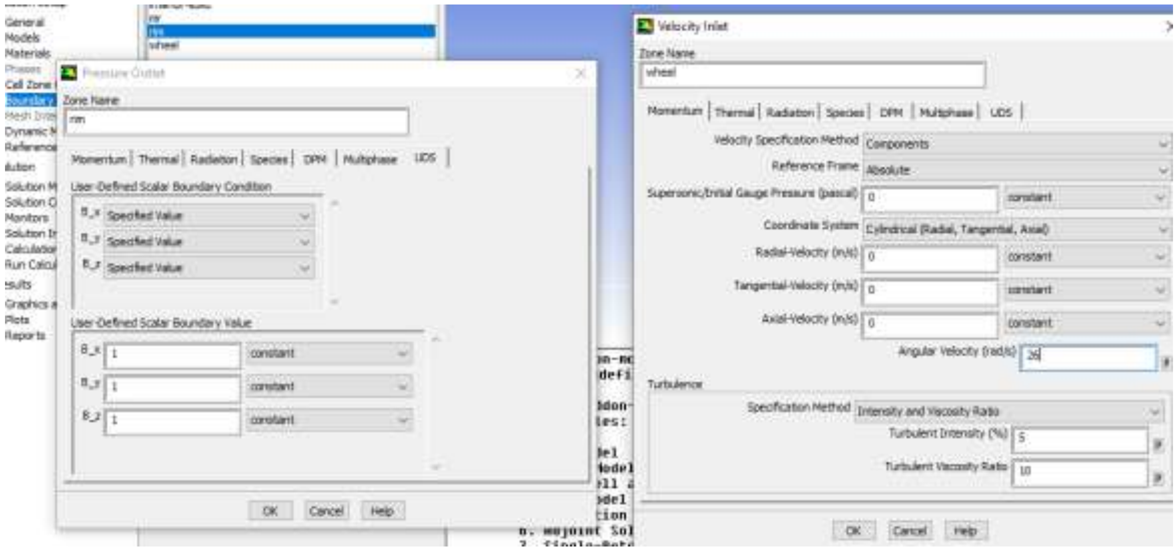
☐ Include Joule Heating

DC B0 Scale Factor: 1

Figure 9: MHD Access Command
Figure 10: Setting Up MHD Module

In Models, MHD appears, and the MHD module is set up as follows:

- Under External Field "B0", the values of X, Y, Z external field was given progressively0T/0.5T/1T/2T.
- After entering each of the above external field values, the external field was initialized by the "Initialize MHD"command.
- Inthe**Model**,viscousmodelwaschangedtostandardk-εturbulentmodel.
- Under **Materials**, the default fluid "Air" properties was edited to MRF as it was found to have same density/viscosity/Magnetic Permeability values asthatofMRFortheexistingvalueswereslightlychanged.TheFluidwas then renamed toMRF.
- In boundary conditions, the Wheel was given velocity inlet and was given a rotation of 250RPM or 26rads/sec (Average RPM of an automobile wheel travelling at40kmph).
- The Rim was given Pressure outlet and under USD tab the magnetic field was set up to same value asB0.
- TheSecondOrderUpwindSchemewasselectedforgreaterprecision.And the values were initialized using "Hybrid Initialization".
- For all calculations and computations here onwards, the value of Yield Point is taken to be 75kPa, initial viscosity is taken to be 0.25 Pa s and density is considered to be 3.5g/cc.
- The number of iterations was set to 600 and the solver was run till convergence was achieved.



Pressure Outlet

Zone Name: rim

User-Defined Scalar Boundary Condition
B_x: Specified Value
B_y: Specified Value
B_z: Specified Value

User-Defined Scalar Boundary Value
B_x: 1 constant
B_y: 1 constant
B_z: 1 constant

Velocity Inlet

Zone Name: wheel

Velocity Specification Method: Components
Reference Frame: Absolute
Supersonic/Initial Gauge Pressure (pascal): 0 constant
Coordinate System: Cylindrical (Radial, Tangential, Axial)
Radial-Velocity (m/s): 0 constant
Tangential-Velocity (m/s): 0 constant
Axial-Velocity (m/s): 0 constant
Angular Velocity (rad/s): 26

Turbulence
Specification Method: Intensity and Viscosity Ratio
Turbulent Intensity (%): 5
Turbulent Viscosity Ratio: 10

Figure 11: Boundary Conditions

Contours:
For 0T (i.e., no magnetic field) (Residues converged after 107 iterations.):

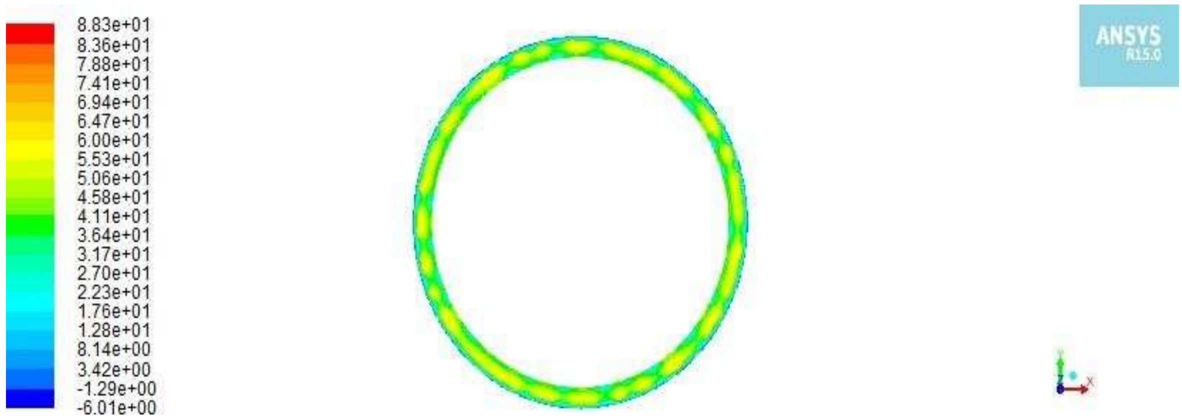


Figure 12. (i): Static Pressure (Pa) Contour

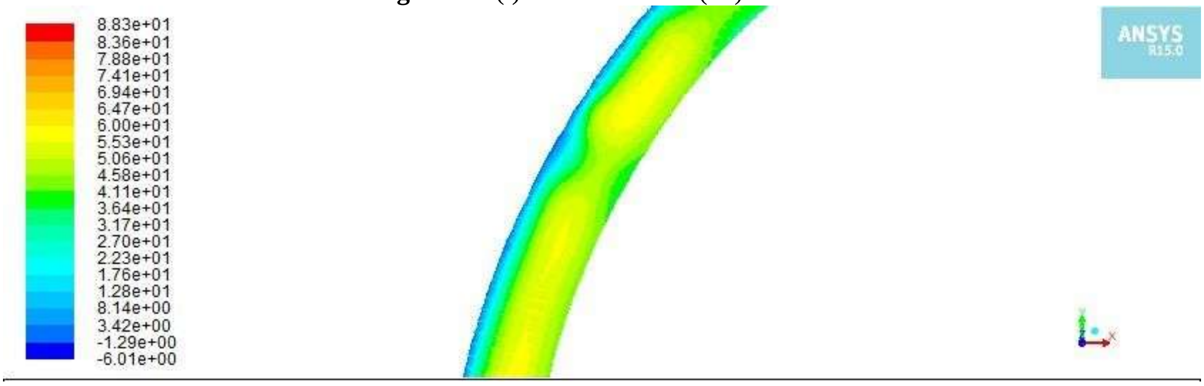
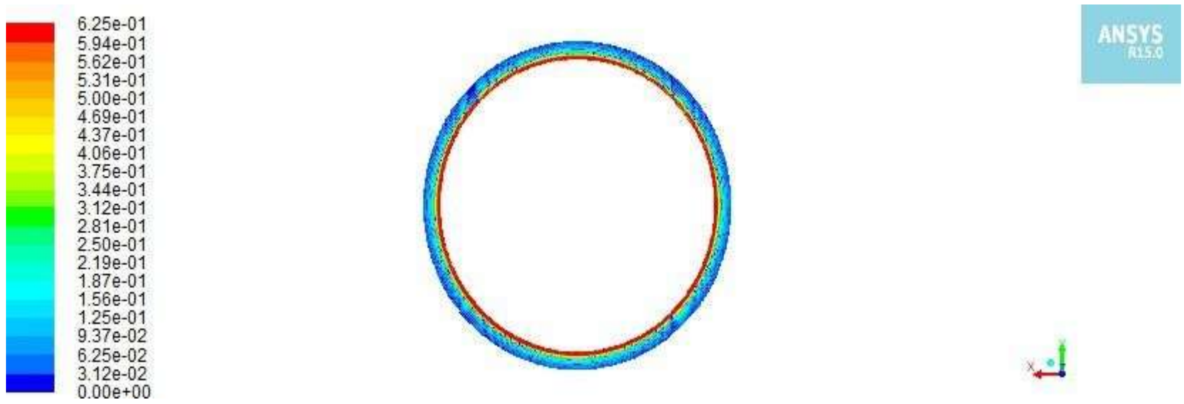


Figure 12. (ii): Static Pressure (Pa) Contour



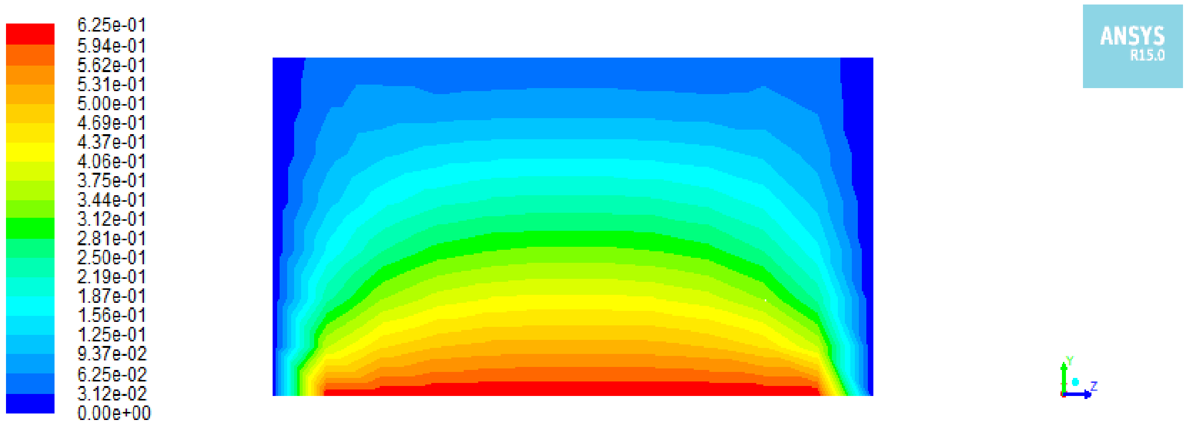


Figure 12. (iii): Velocity Magnitude (m/s) Contour
Figure 12. (iv): Velocity Magnitude (m/s) Contour

Figure 12. (v): Skin Friction Coefficient Contour

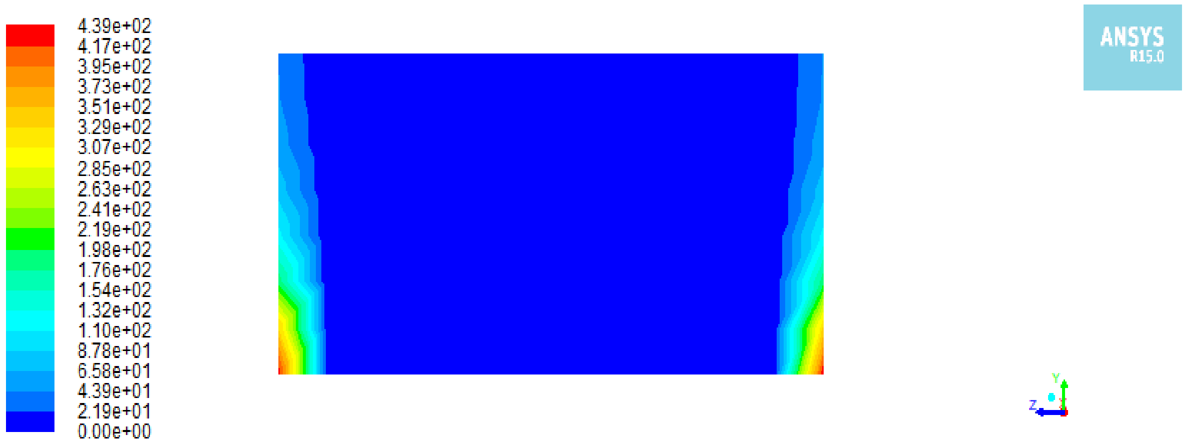


Figure 12. (vi): Wall Shear Stress Contour

For 0.5 T (Residues converged after 91 iterations.):

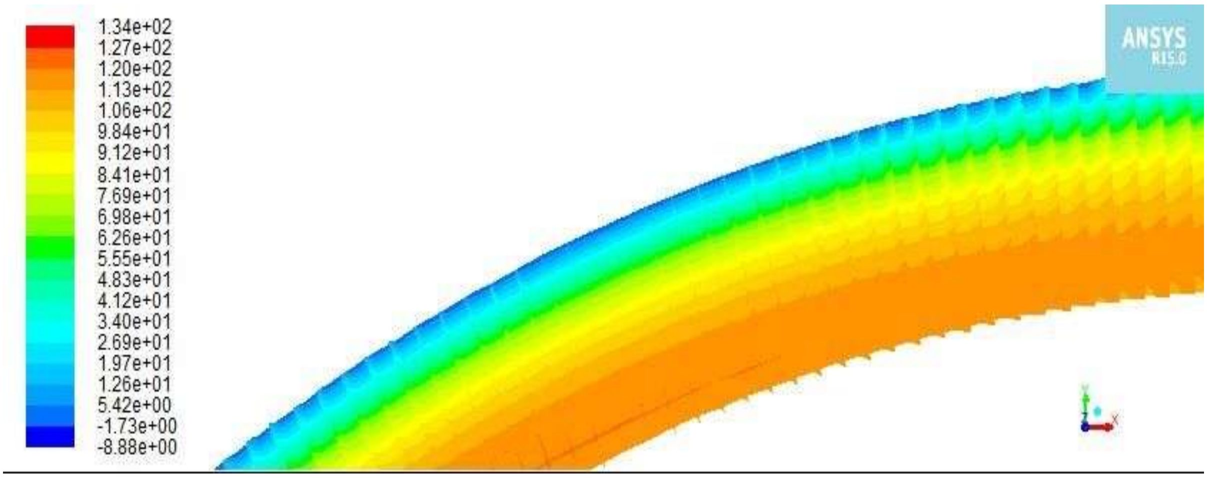


Figure 13. (i): Static Pressure (Pa) Contour

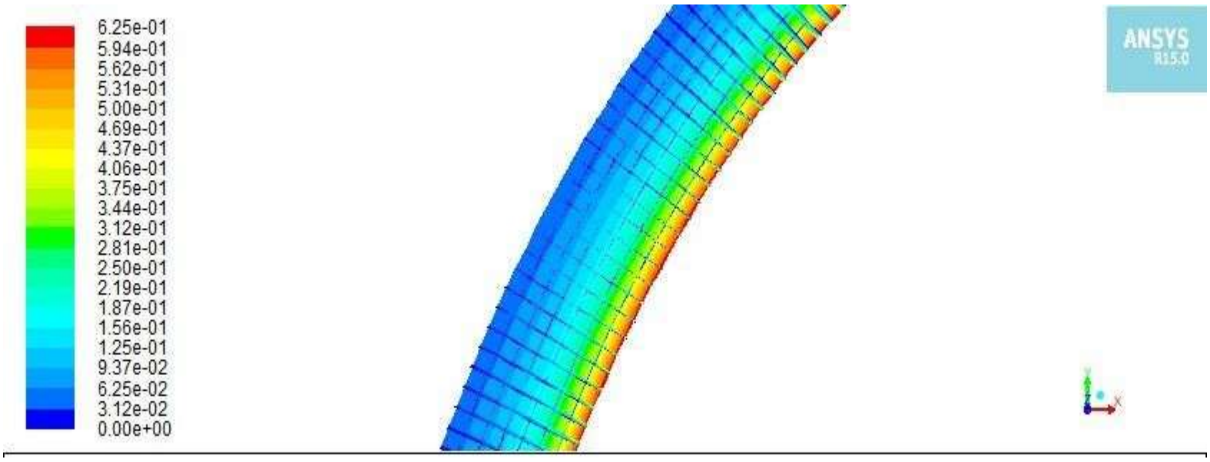


Figure 13. (ii): Velocity Magnitude (m/s) Contour

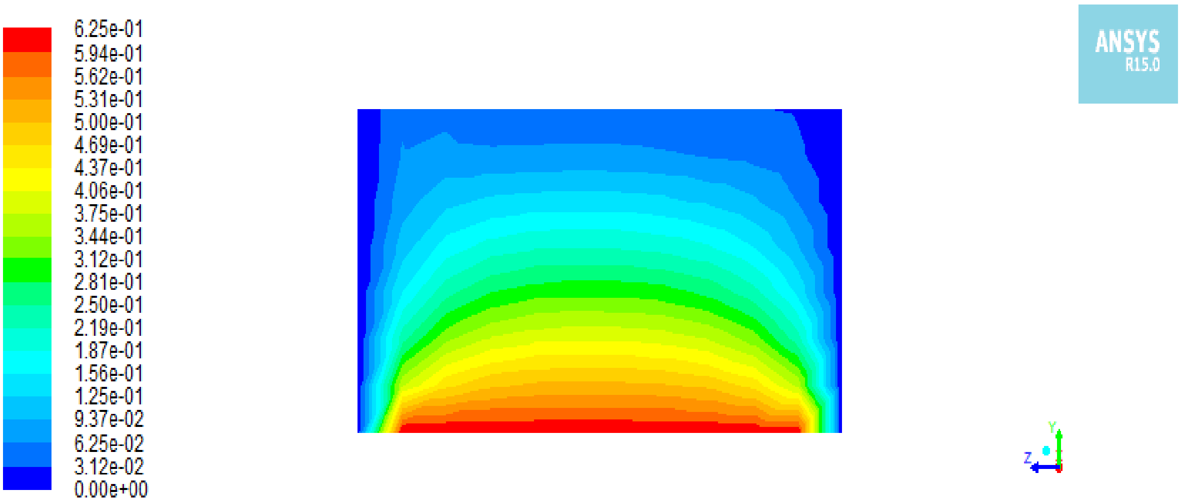


Figure 13. (iii): Velocity Magnitude (m/s) Contour

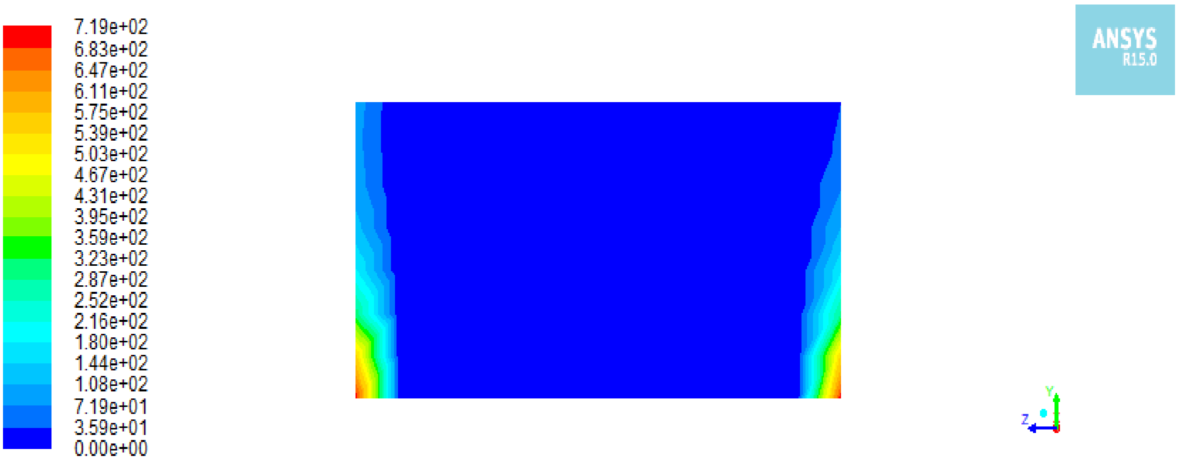


Figure 13. (iv): Skin Friction Coefficient Contour

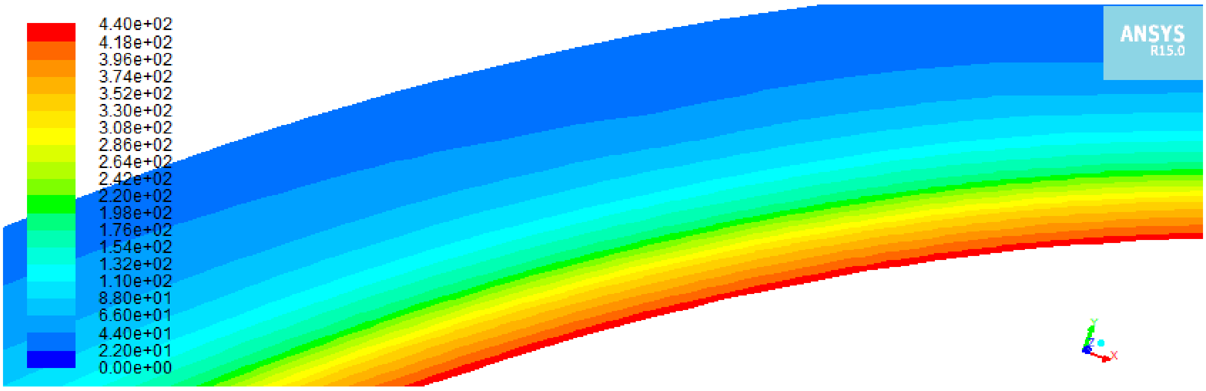


Figure 13. (v): Wall Shear Stress Contour

For 1.0 T (Residues converged after 81 iterations.):

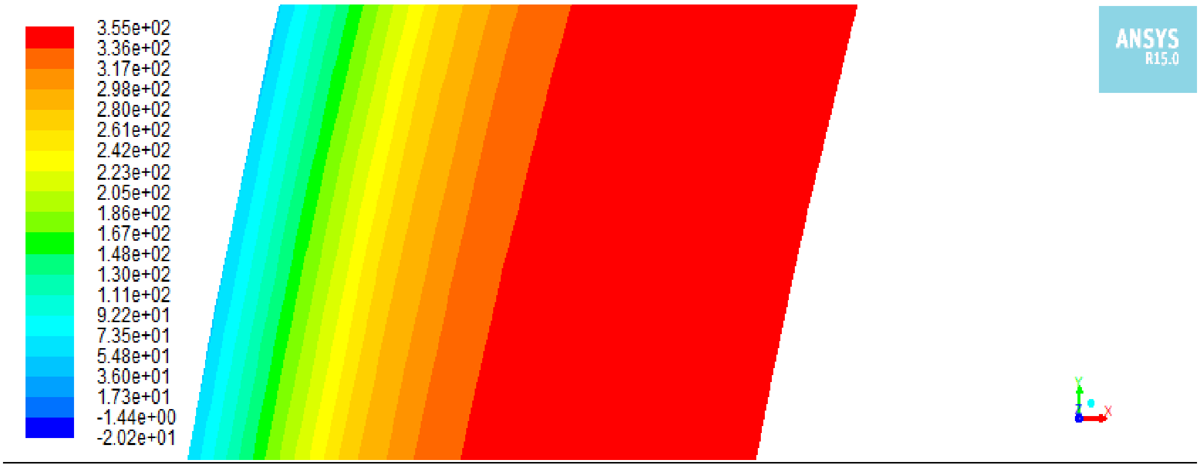


Figure 14. (i): Static Pressure (Pa) Contour

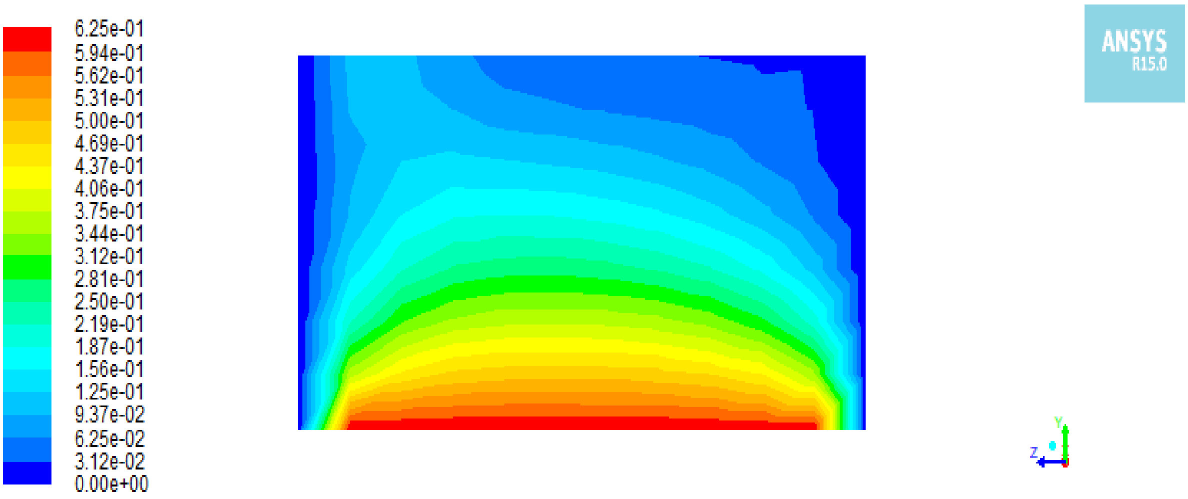


Figure 14. (ii): Velocity Magnitude (m/s)Contour

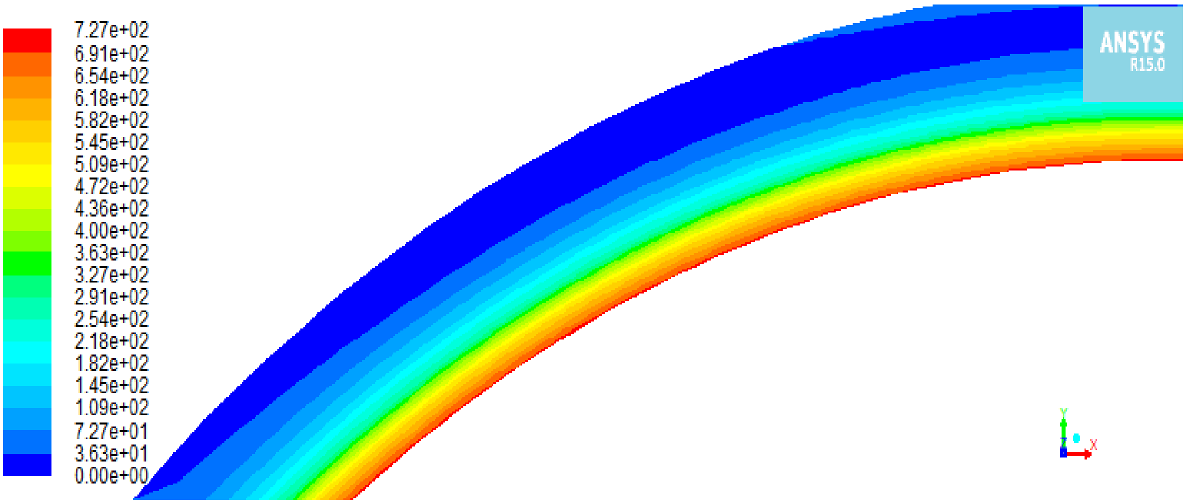


Figure 14. (iii): Skin Friction CoefficientContour

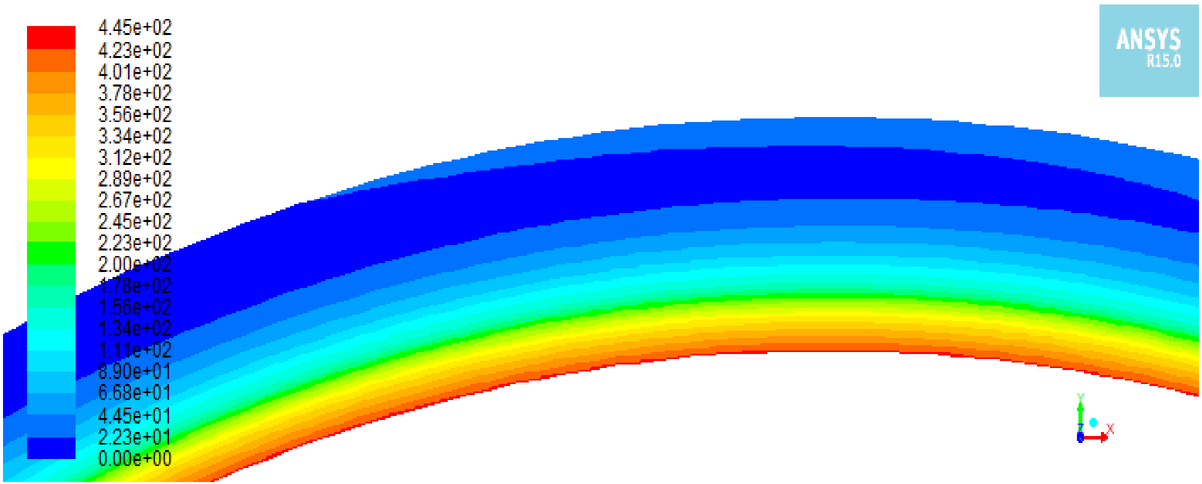


Figure 14. (iv): Wall Shear Stress Contour

For 2.0 T (Residues converged after 66 iterations.):

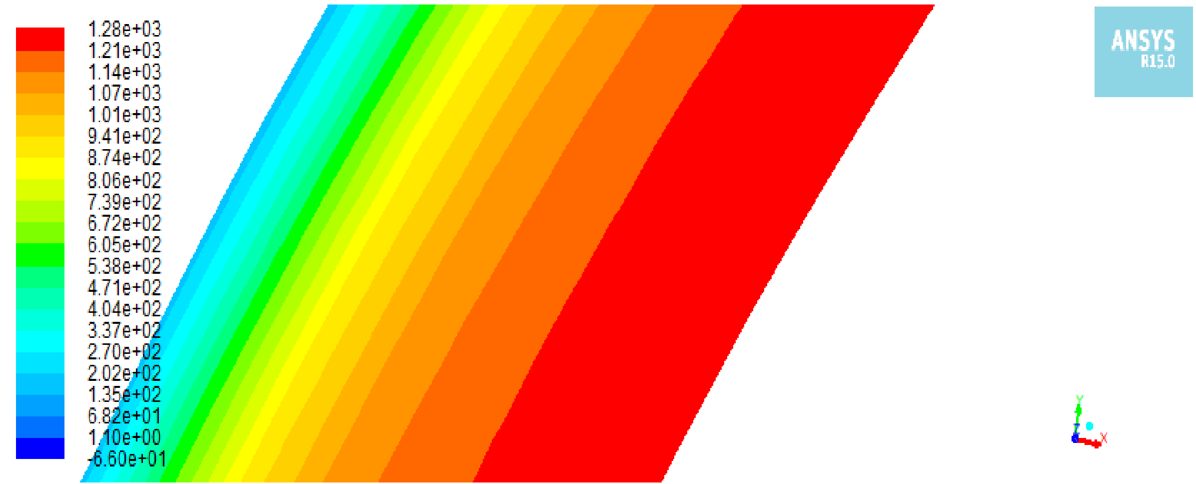


Figure 15. (i): Static Pressure (Pa) Contour

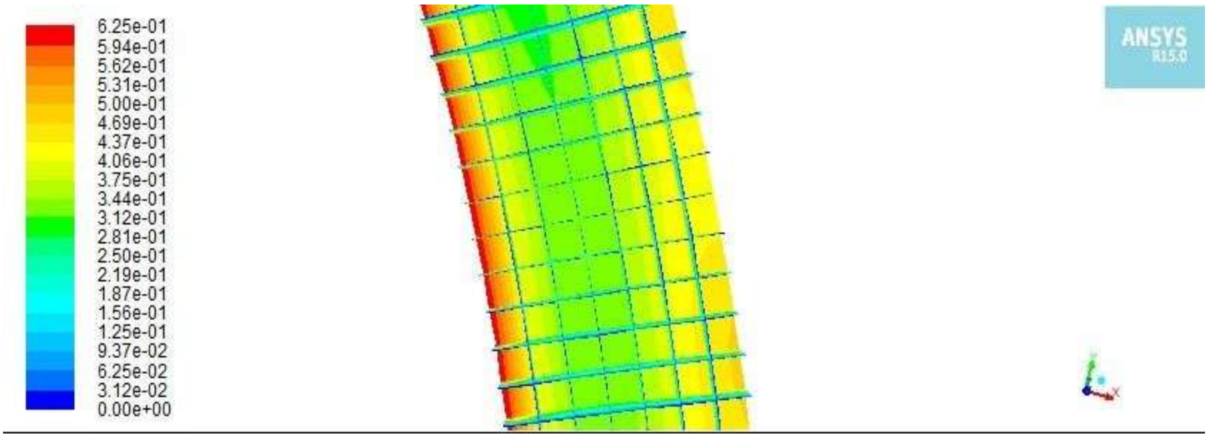


Figure 15. (ii): Velocity Magnitude (m/s) Contour

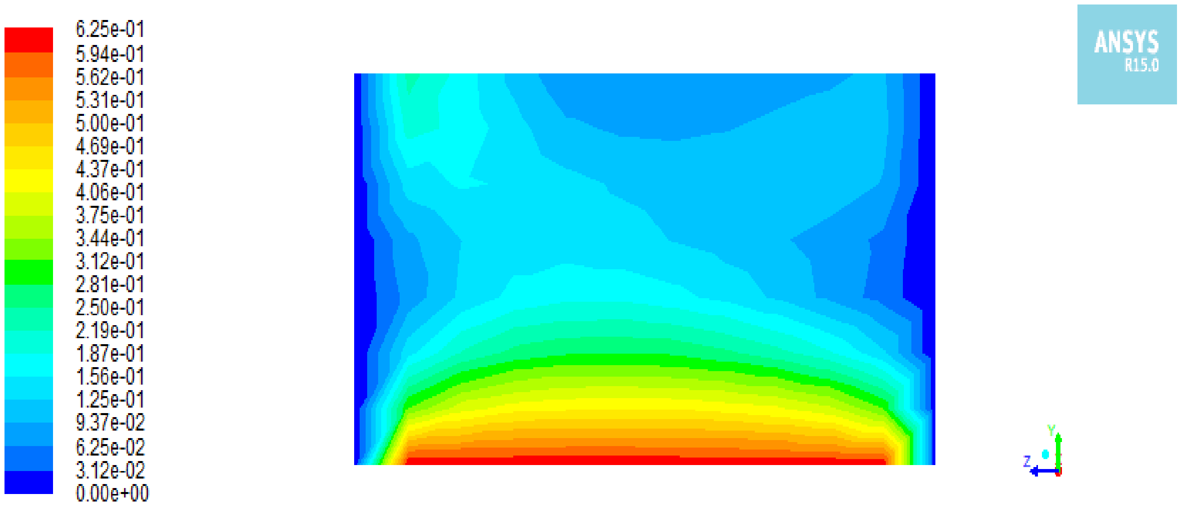


Figure 15. (iii): Velocity Magnitude (m/s) Contour

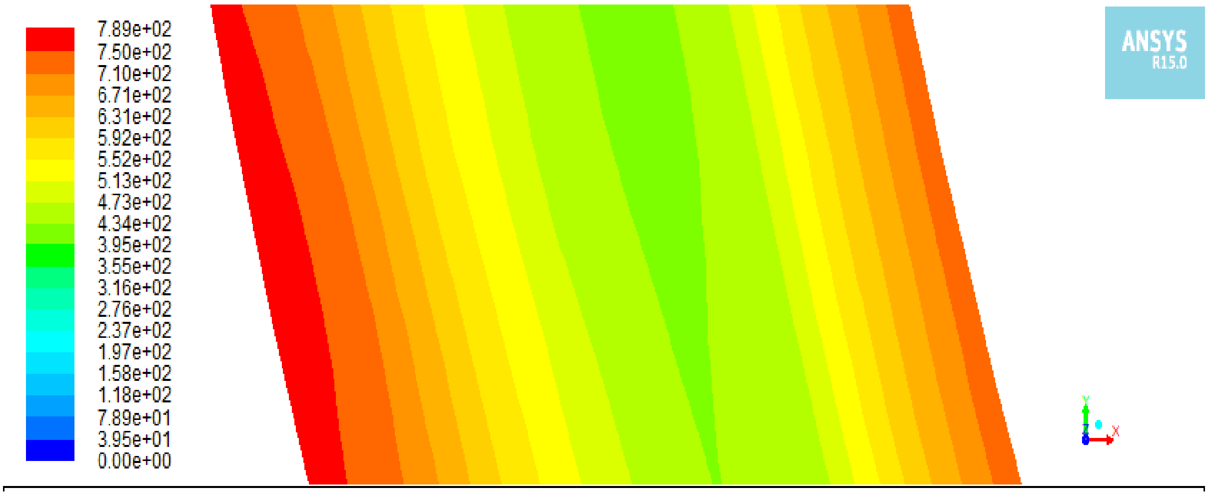


Figure 15. (iv): Skin Friction Coefficient Contour

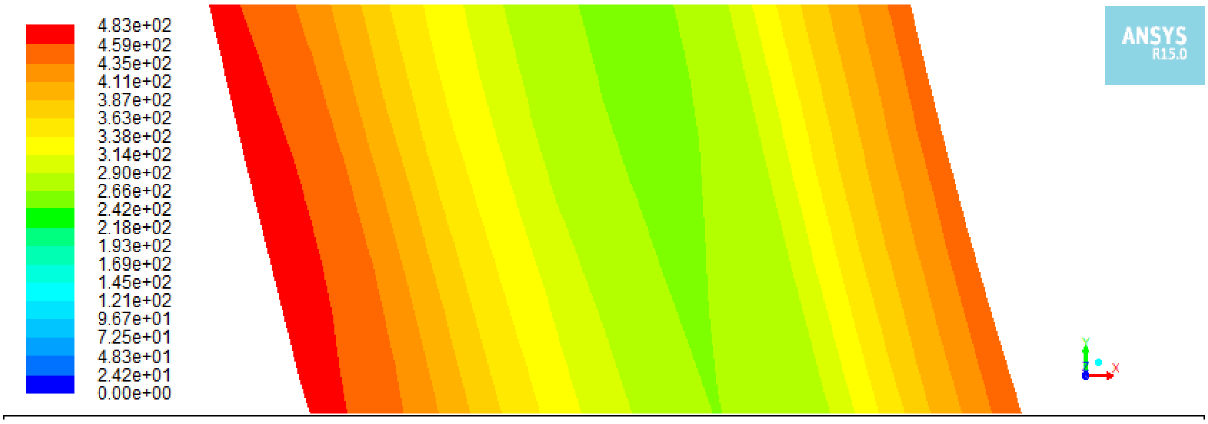


Figure 15. (iv): Wall Shear Stress Contour

Inference:

- Forstaticpressurecontour,itcanbeinferredthatfor Figure12.(i),(ii),13. (i), 14. (i) and 15. (i) as the magnetic field intensity increased, the static pressure in the fluid is observed to beincreased.

As for the 0 T, the average pressure was found to be around 41-60 Pa (average 50.5 T) as for 0.5 T, 1.0 T and 2.0 T it was 62.6-127 Pa (average 95Pa),167-355Pa(average261Pa)and605-1280Pa(average942.5Pa) respectively in which pressure is increased in the lower portion of the rim. The exponential increase was seen for the pressure contour when the magnetic fieldintensified.

- For velocity magnitude contour, it can be inferred that for Figure 12. (iii), (iv), 13. (ii),(iii), 14. (ii) and 15. (ii), (iii) as the magnetic field intensifies, the velocity magnitude is dissipated among the layer of the MRF and the value of velocity dissipation was found to be same as RPM was fixed for this case but the proper dissipation was found when the magnetic field increased.
- Fortheskinfrictioncoefficient,itcanbeinferredthatforFigure12.(v),

13. (iv),(iii), 14. (iii) and 15. (iv) as the skin friction coefficient increases. Itcanalsobeattributedwiththeincreaseofstaticpressureincrease.Asfor the0T,theaveragepressurewasfoundtobearound 0.00-717(average~0 since 0 magnitude contour is present) as for 0.5 T, 1.0 T and 2.0 T it was 35.9-719(average287),0.00-727(average363.5)and355-789(average 572) respectively.

The same pattern is observed for the wall shear stress as the values are different from the skin friction but the pattern was identical. It can also be inferred that skin friction coefficient is directly proportional with the wall shear stress.

IV. RESULT AND DISCUSSION:

- As evident from the velocity contours and static pressure contours that the velocity contour plot in a given cross section of the fluid element suggests that as the magnetic field intensity in increased, the velocity gradient increases as well as the staticpressure.
- It is worth noting that it the velocity of fluid in contact with the wheel is having maximum velocity and the fluid in contact with the rim in almost stationary in all the cases (excluding the 0 T in which no magnetic field is applied so consecutively no change occurs). However, the gradient with which the fluid velocity approaches zero increases as External Magnetic Field increases. (i.e., the red region in the contour plot reduces insize)
- From the skin friction coefficient contours the friction coefficient (As observed in the contours) is directional proportional to the braking torque being applied.

The braking torque T can be calculated as:

□= (2□×□×□×□)/2

As average pressure (P) can be obtained from Post processing of fluent (and can also be seen in pressure contour graphs above)

A is braking surface area. Hence in case of MRFBS, it can be taken as

π×d×t.

Wheretisthethicknessofthering(0.003m)shapedgeometryanddisthe diameter (0.4m)

Hence,

□= □×□×□×□×□×□

Substituting values, the braking torque for 0.5T, 1T and 2T are found to be:

41.115 Nm, 143.066 Nm and 812.959 Nm whereas for 0 T it is 0 Nm as skin friction coefficient is taken as 0. Hence, it can be observed that as the magnetic intensity increases, the braking torque increases exponentially. To increase the magnetic field strength, the voltage must be increased. Hence, to deploy more braking power and to attain grater deceleration, higher voltage must be applied keeping a threshold to ensure the safety of the rim and thus the vehicle wheel stability.

V. CONCLUSIONS:

Braking time decreases as the voltage increases with increase in applied current and voltage, there is an increase in braking torque. For a Wheel rotation at 250 rpm, and a magnetic field of 2T, the maximum braking torque of 812.959 Nm was observed. This braking torque is enough to bring a vehicle of 1-1.5 tonne from 40 kmph to a complete stop. Hence the braking distance would be less than

m which is at par with conventional brakingsystem. Problemsencounteredincludeagglomerationandin-usethickening(IUT)aswellas rusting and crusting. Again, the limited magnetic field intensity should be sothatthestructureoftherimshouldnotbedeterioratedaswellasoptimalbreakingtorque is observed.

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