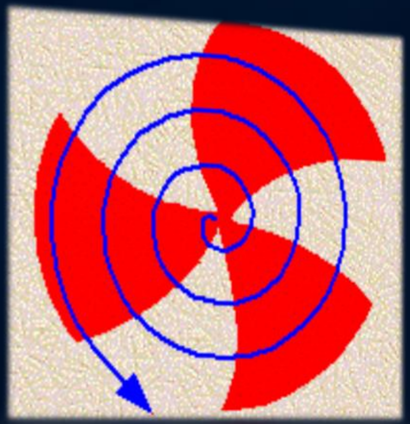
Welcome

A STUDY ON UNIFORMITY OF A MAGNET



COMSOL CONFERENCE 2014 BANGALORE

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore

What is the presentation all about??

The presentation deals with the project conducted at Variable Energy Cyclotron Centre Kolkata

Aim of the Project:

To Design and simulate a 0.4 Tesla Magnet at room temperature and to show its uniformity along the central line of the magnet.

Application of the magnet:

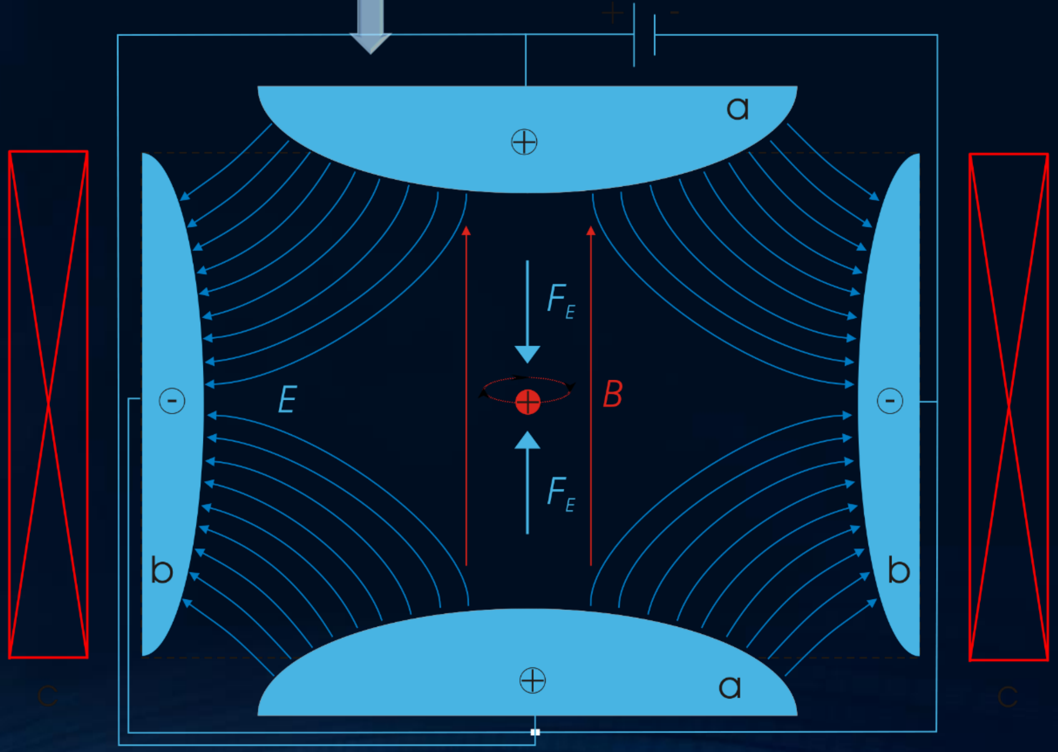
It can be used in a Penning Ion trap.

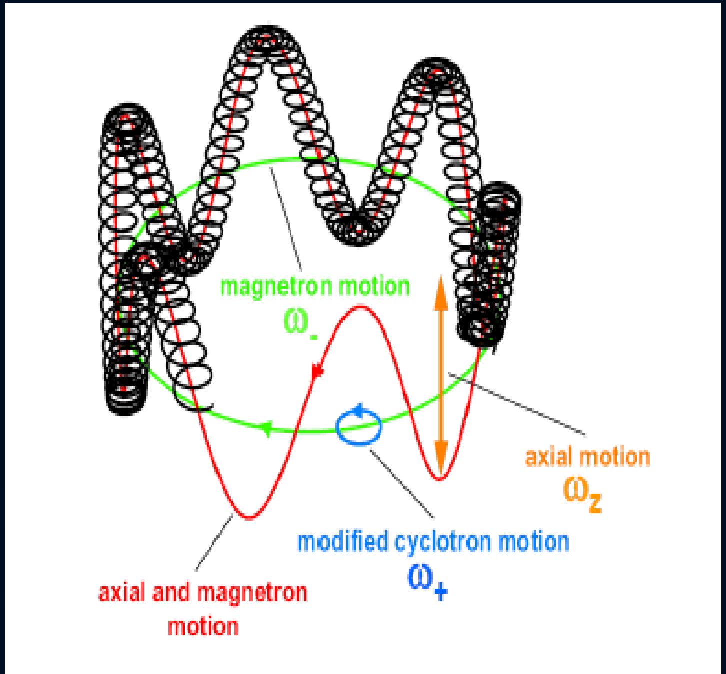
Penning Ion Trap

Penning ion trap is a device used for three-dimensional confinement of ions for high precision nuclear and atomic physics studies.

In a Penning ion trap, superposition of a strong homogeneous magnetic field and a weak quadrupole electric field confines the ions in a very small region.

The uniformity and stability of magnetic field determines the confinement duration.





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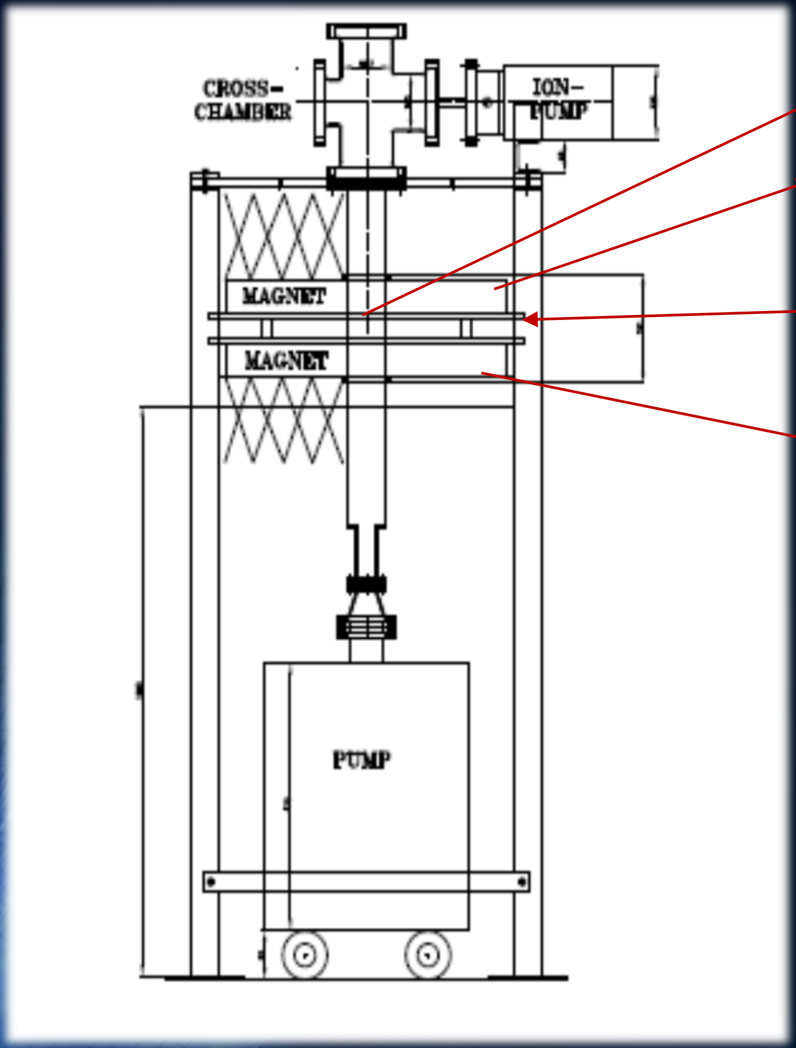
The magnet at VECC



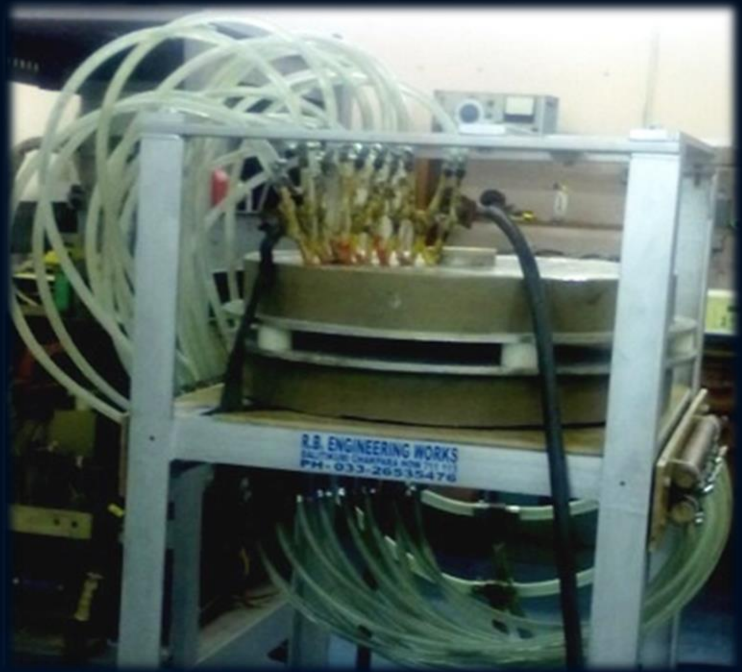
Center of the magnet where the field is to be calculated

Pancake 1

Gap height 3cm

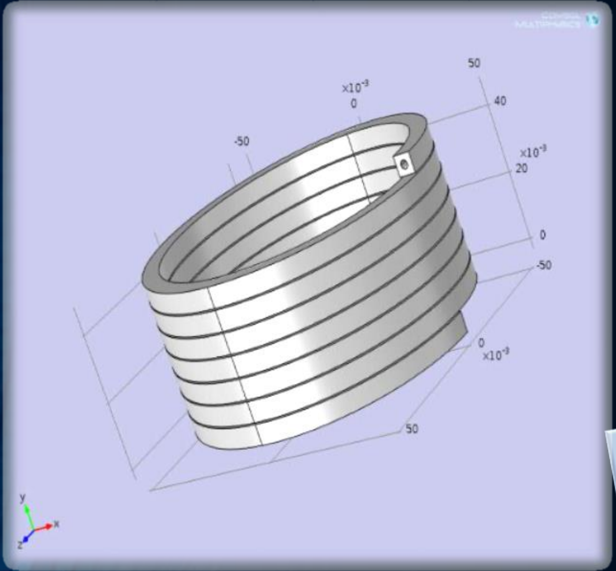
Pancake 2

The magnet consists of two pancakes arranged vertically with a separation of 3cm with a central bore



Each pancake consists of 32 helical layers and with a central bore. Each helix has 7 vertical turns. The coil carrying current is a hollow copper conductor having square cross-section. Low Conductivity Water (LCW) is circulated through the central bore of copper conductor for cooling. The spiral coil is casted in an epoxy for rigidity.

Design of the magnet for simulation studies



Each pancake consists of an overall of 7 coils.

Each coil consists of a separate inlet and an outlet.

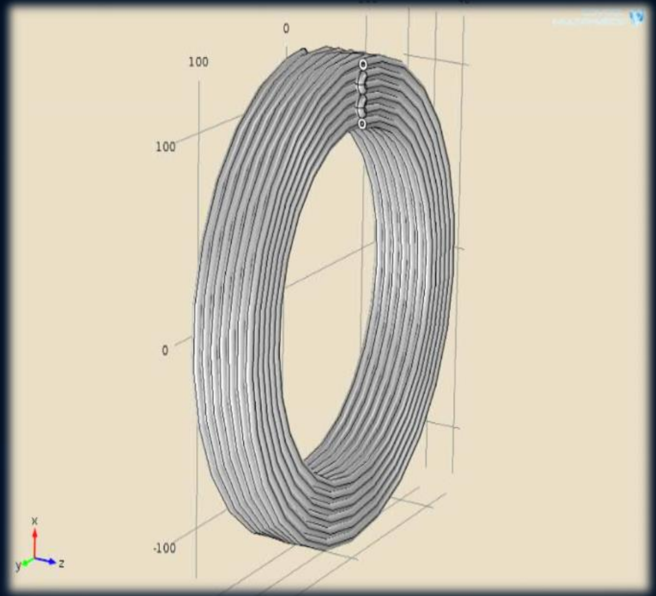
The first coil first forms a helix of 7 vertical turns then continues and wraps over the first helix and forms a second helix. In this way it continues up to 6 layers, with each helix considered as a single layer. After the sixth layer the second coil starts and again forms 6 layers. In this way the 7 coils forms a total number of 32 layers.

The number of helixes contained in each coil is as follows

Coils 1 and 2 : 6 turns each

Coils 3 to 7 : 4 turns each

The coils are connected in series and current is given to any one of the coils. Usually Copper is used as the conductor in the coils.



Structural details of the magnet

Area of cross-section of the current carrying conductor

No. of Coil sets: 02

Gap Height between the coils: 40 mm

Winding: spiral winding

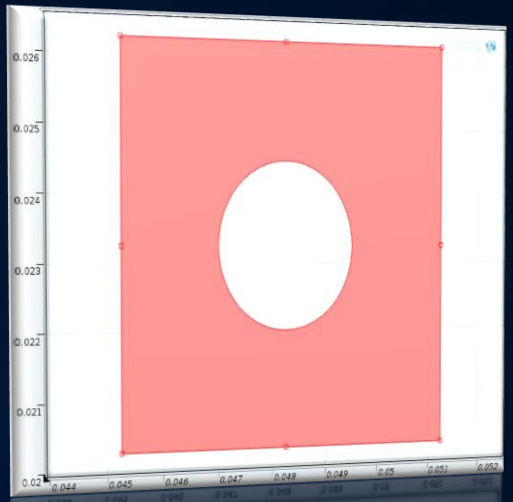
Inner Diameter: 90 mm

Outer diameter: 506 mm

Number of turns (nr × nz)/coil: 32 × 7

Conductor size (without insulation): 6 mm × 6 mm

Total area of conductor: $6 \times 6\ mm^2$
Inner diameter of hole: $2.5\ mm$
Area of the hole for water flow: $\pi \times 1.25^2\ mm^2$
Area of cross section of the current:
$(6 \times 6\ mm^2) - (\pi \times 1.25^2\ mm^2) = 31.09126148\ mm^2$



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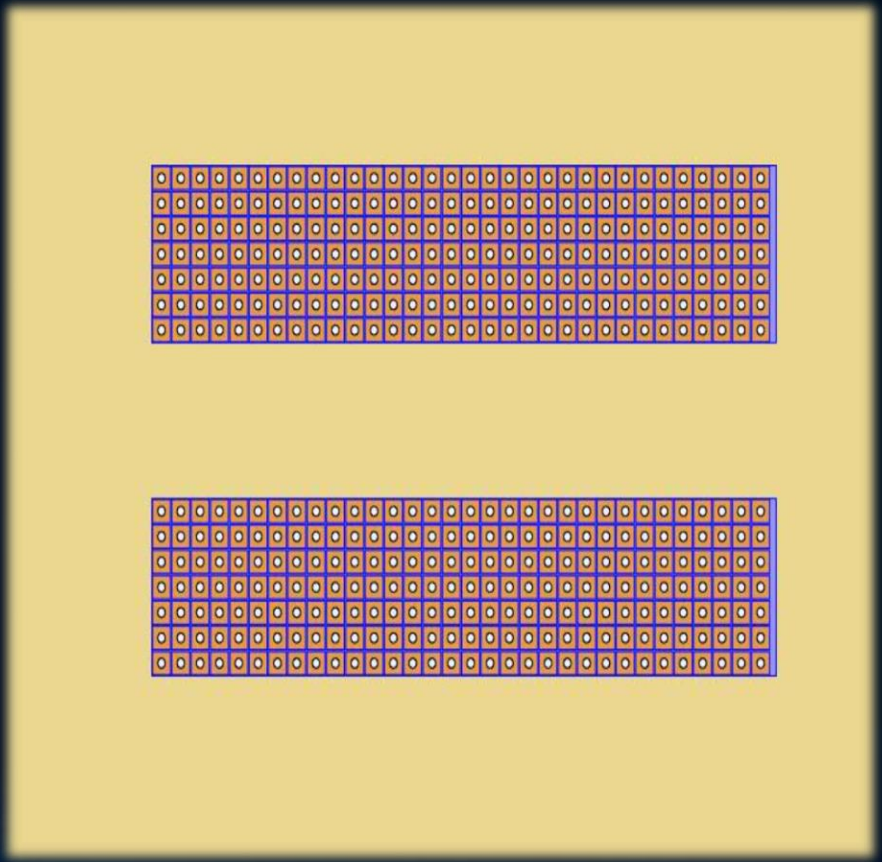
2D representation of the magnet

The work has been done on a 2D axi-symmetric plane with **r** co-ordinate on one axis and **z** co-ordinate on the other.

32 × 7 squares were constructed at their respective positions. Then 32 × 7 holes have been subtracted from each of the squares. Then another rectangle is created which borders the 32 × 7 blocks for filling in the insulation.

A copy of this rectangular block is made and placed at a position symmetric with respect to the **z=0** axis. Now a boundary is given to the two blocks.



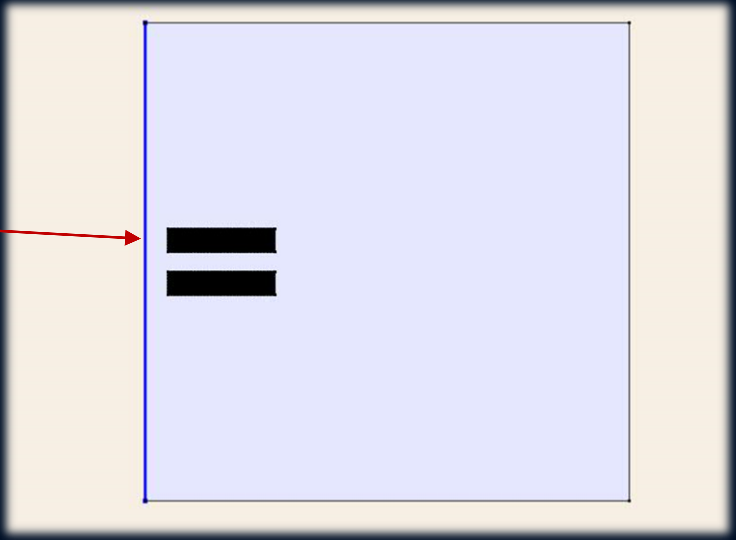
Materials used

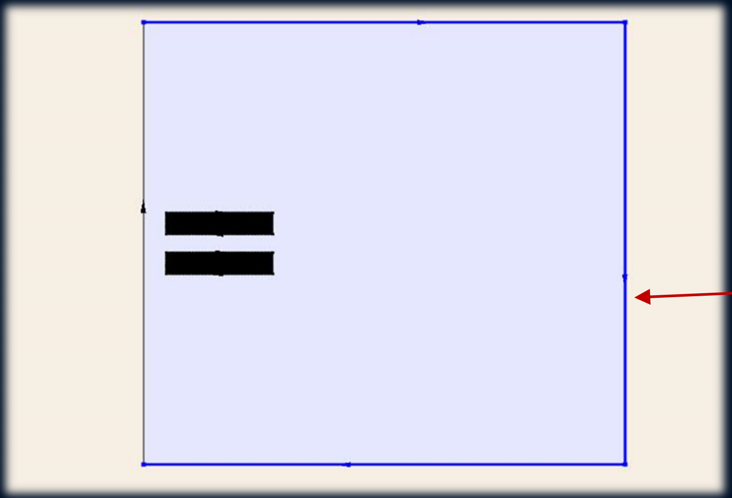
The deep orange portion represents the region where current has been given and so these regions have been filled with Copper. The blue portions include the region where insulation has been given. Here Glass has been used as insulation. The remaining mud yellow portion including the circular dots have been filled with Air.

Boundary Conditions

Ampere's Law:
The entire geometry will follow the Ampere's Law.
It has been selected for all domains.

Axial Symmetry:
The blue line shows the line of Axial Symmetry





Magnetic Insulation:
The 3 sides of the outer boundary has been magnetically insulated so that the flux lines can follow the path of the external boundary.

External Current Density:

Current density has to be provided to the metallic copper portion from outside which will produce the magnetic field. However **Jo** current density is provided in the phi (ϕ) direction which is in a direction perpendicular to the **r** and **z** axes. **Jo** is measured in $Ampere/metre^2$. However the value of Jo depends on the current applied to the coils and the area of cross section of the coils.

Expression for Jo:

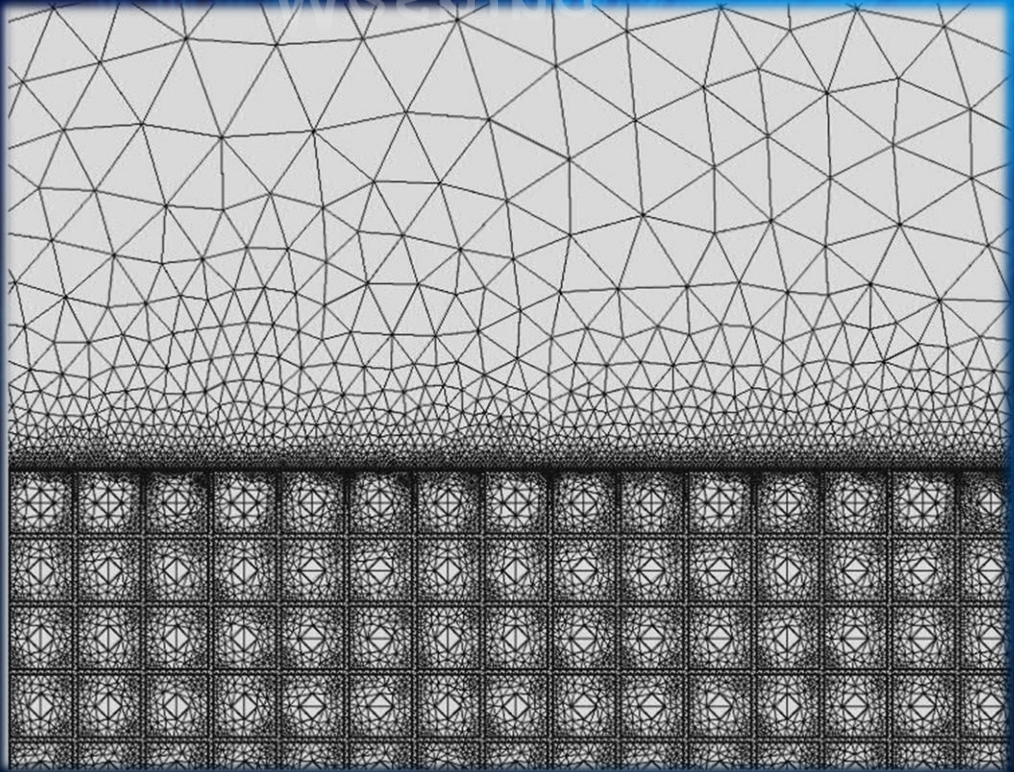
$$Jo = \frac{Current\ Applied\ \ (A)}{Area\ of\ the\ cross\ section\ (m^2)}$$

Parameter used:

Name	Expression	Value	Description
Jo	8040844.53 667921163 295012755	8040845	Current Density in each coil

Meshing

The Mesh features enable the discretization of the geometry model into small units of simple shapes, referred to as mesh elements.

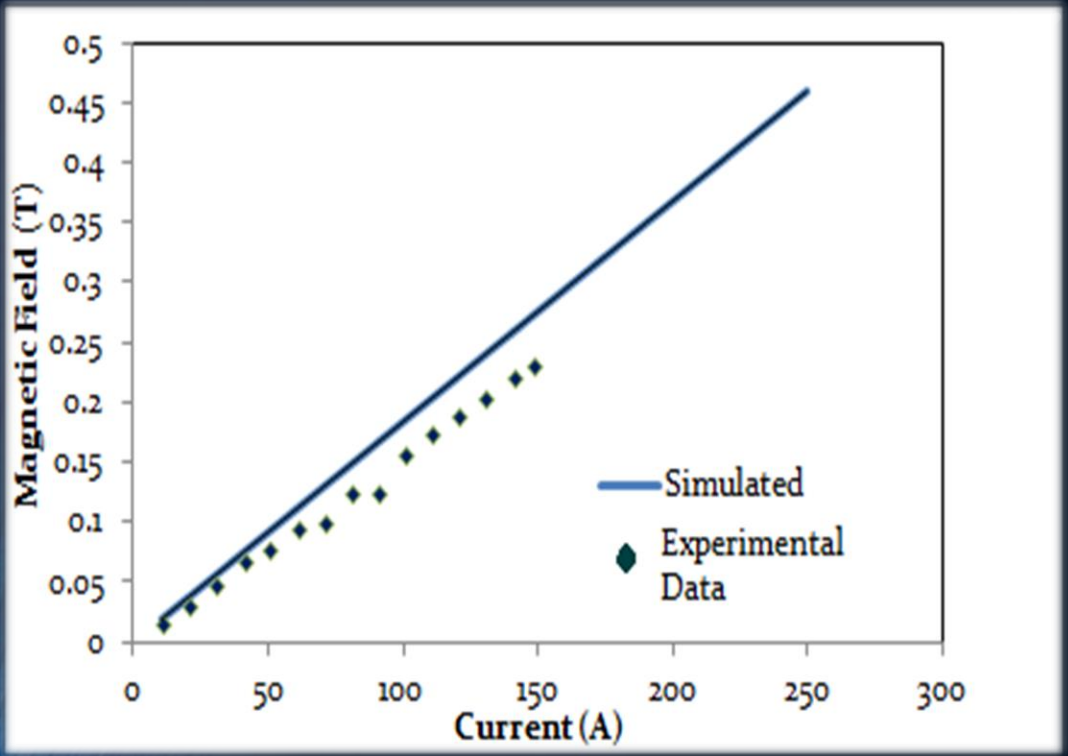


The picture shows that The mesh generator discretizes the domains into triangular mesh elements

Since the simulation has been performed in 2D, only triangular and quadrilateral meshes were possible. However Free triangular meshing has been done.

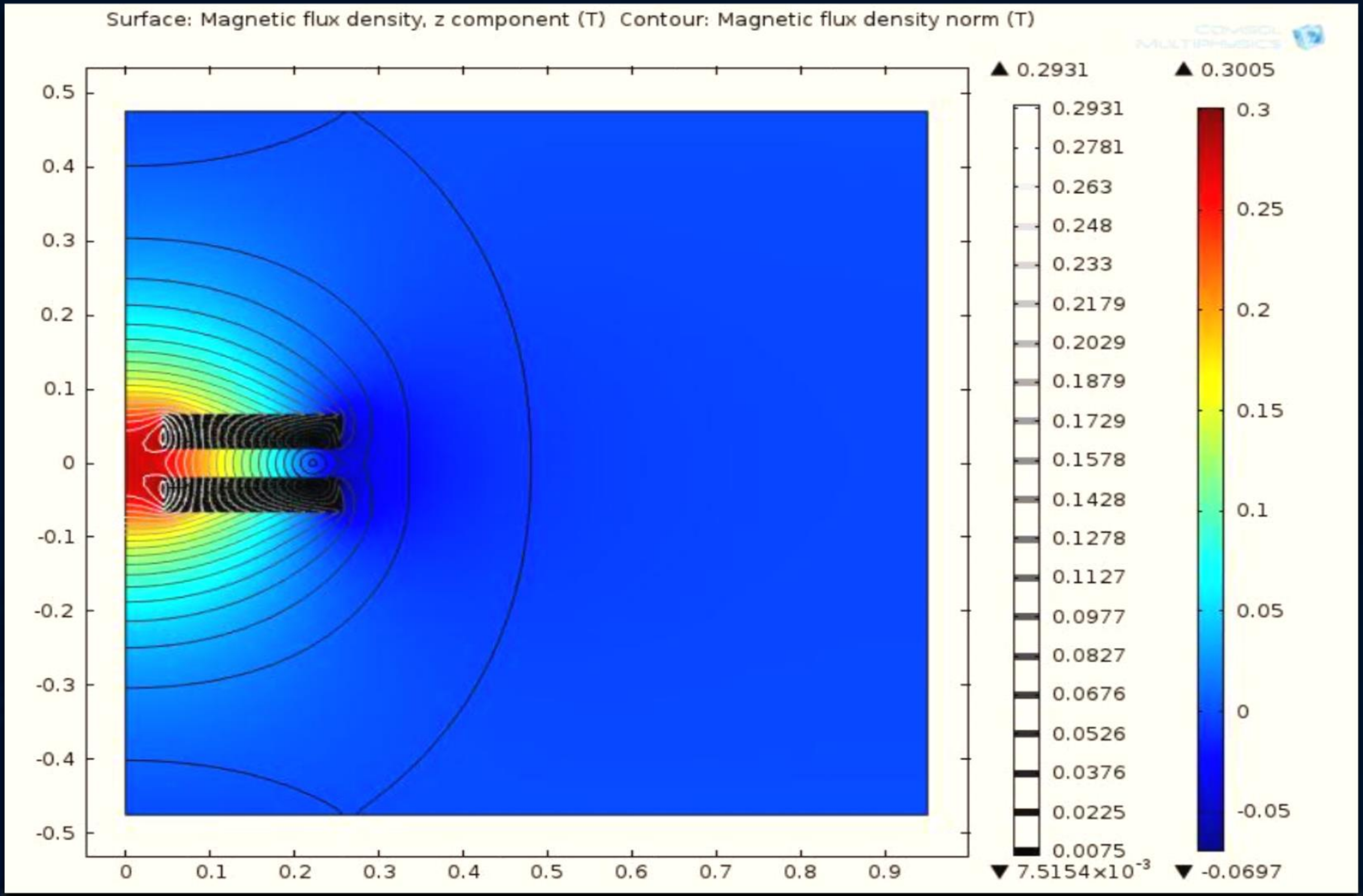
Besides The boundaries defined in the geometry are discretized (approximately) into mesh edges, referred to as boundary elements (or edge elements), which conforms with the mesh elements of the adjacent domains.

Results

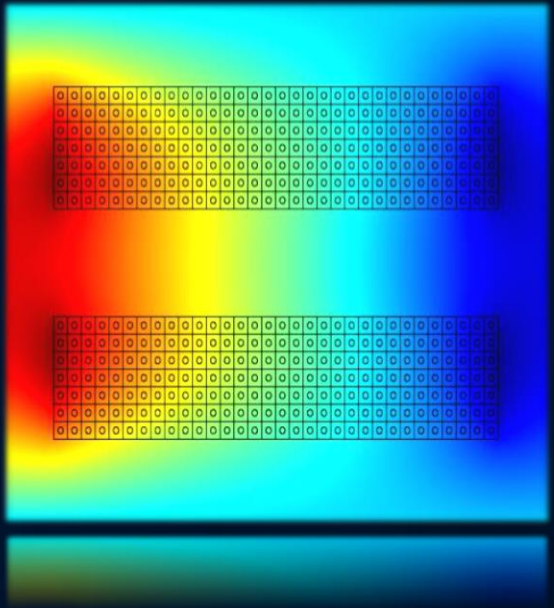


Current(A)	Current density(A/m^2)	Experimental Magnetic Field(T)	Magnetic field (T)
10	321633.7815	0.01581	0.01840
20	643267.5629	0.03174	0.03680
30.1	968117.6822	0.047745	0.05539
40.2	1292967.801	0.0681	0.07398
49.9	1604952.570	0.078405	0.09183
60.2	1936235.364	0.094616	0.11078
70.2	2257869.146	0.10126	0.12918
80.1	2576286.590	0.1257	0.14740
90	2894704.033	0.1245	0.16562
100	3216337.815	0.15832	0.18402
110	3537971.596	0.1740	0.20243
120.1	3862821.715	0.1900	0.22101
129.9	4178022.821	0.2055	0.23905
140	4502872.941	0.22154	0.25763
147.2	4734449.263	0.2315	0.27088
250	8040844.536	…	0.46008

The magnetic field increases linearly with the increase in the applied current. At 150 A current a magnetic field of 0.23T is generated whereas the simulated value of magnetic field is 0.27T for the same current.



The various colors show the intensity of the magnetic field. .



Contour lines showing the variation of the magnetic flux density.

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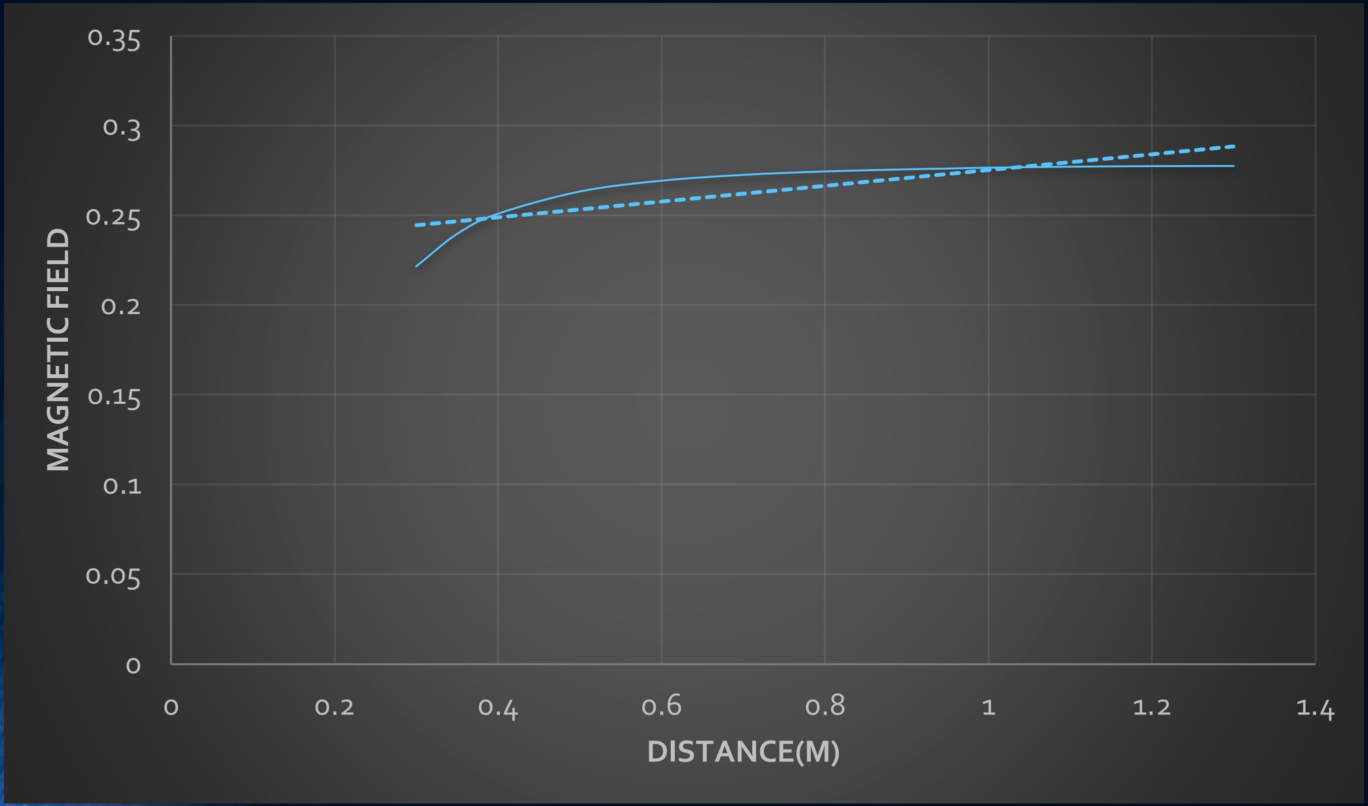
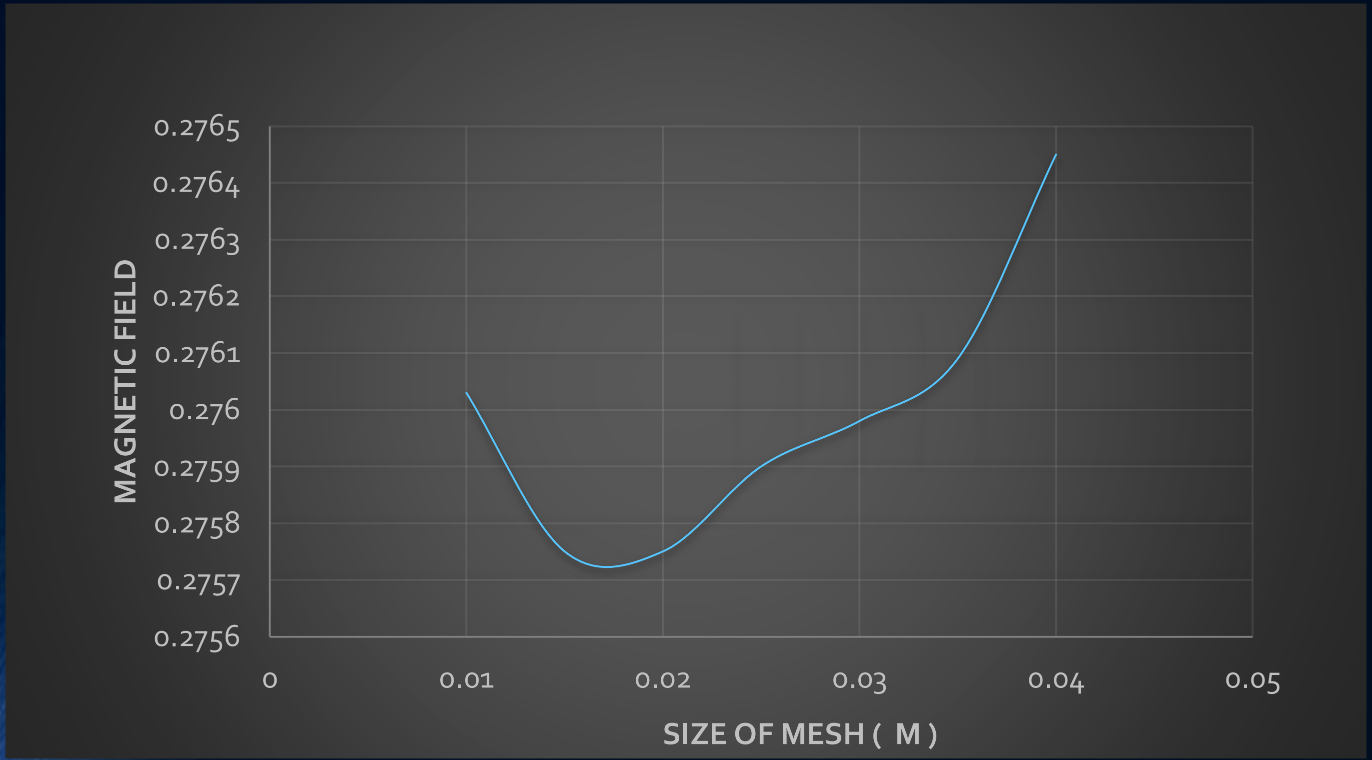
Observation 1 : Change of Magnetic Field with size of boundary



Length of square (m)	Magnetic Field (T)
0.3	0.22145
0.35	0.23959
0.4	0.25086
0.5	0.26323
0.6	0.26926
0.7	0.27252
0.8	0.27443
0.9	0.27561
0.95	0.27603
1.0	0.27653
1.1	0.27707
1.2	0.27738
1.3	0.27747

The blue line shows that the magnetic field at first increases linearly, then it bends exponentially and finally saturates in the form of a straight horizontal line. Thus we take the magnetic field to be an average of 0.27T at a square boundary size of edge length **1.0** meters.

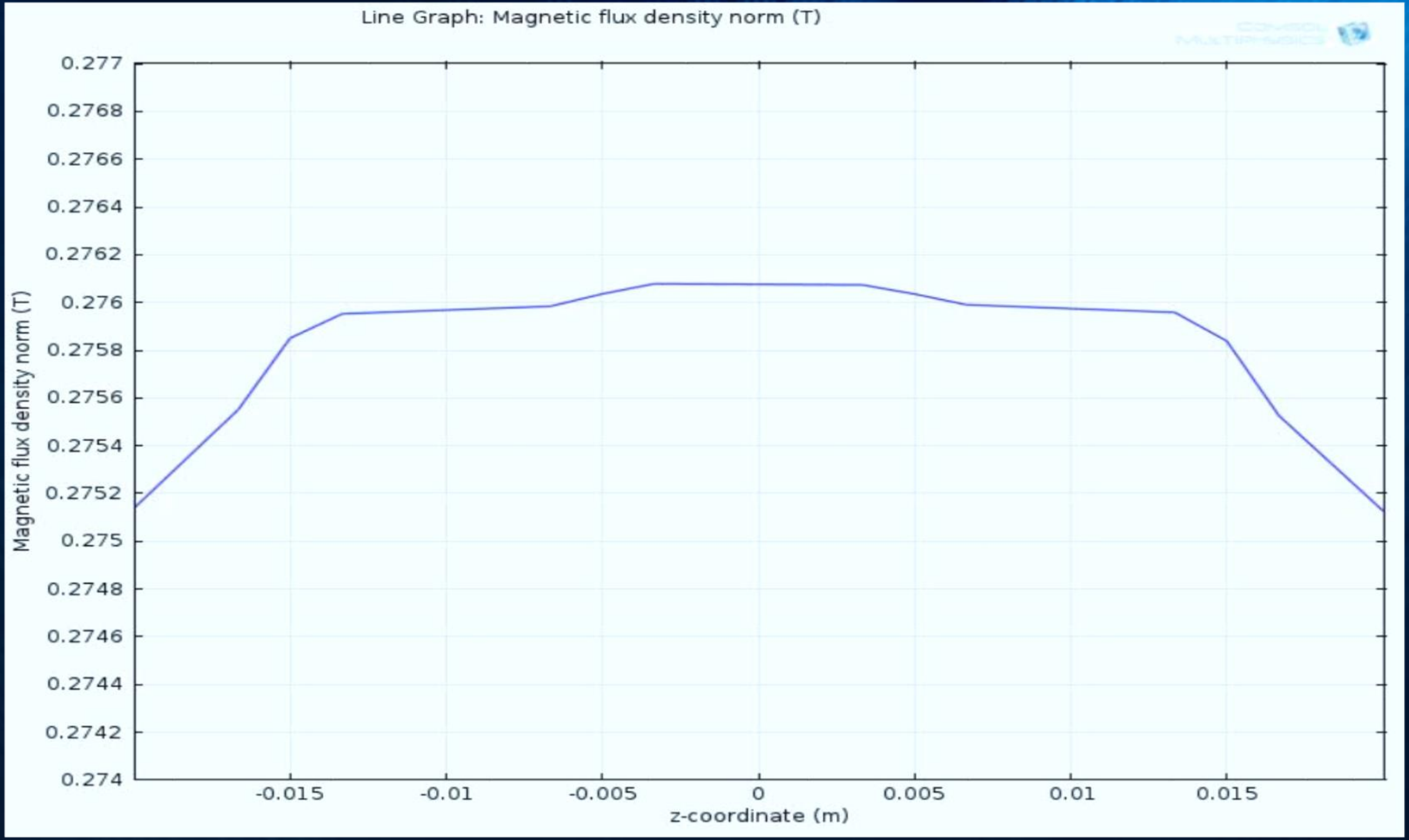
Observation 2: Change of Magnetic field with size of mesh



Mesh Size (mm)	Magnetic Field
0.01	0.27603
0.015	0.27575
0.02	0.27575
0.025	0.27590
0.03	0.27598
0.035	0.27609
0.04	0.27645

The change in the magnetic field with the change in the size of the mesh, is of a very small order(of the order of 1/thousandth of a Tesla).

Plot 1



This shows a 1 dimensional plot which shows the variation of the magnetic field along the z axis passing through the center of the magnet.

Conclusion

Conclusion

The simulation result and experimentally measured values of magnetic field of the magnet studied agrees with a few micro-Teslas.

The experimental and the simulated magnetic field strength increases with increasing current and simulation results match with design value.

Up to 150 amp current, measured value is in agreement with experimentally measured magnetic field value at the central point of the magnet.

Along the central line along z-axis we find that there is an uniformity in the magnetic field for a range of 3 cm in order of 1 in 10^{-3} Tesla in both the experimental and the simulated studies.

As the current flows through the coils, the coils get heated up mainly due to Joule heating. This affects in the result. So water is passed through the coils to cool and correct the discrepancies in the result.

Here there is a difference between the simulated result and the experimentally determined result as the water cooling effects has not been used in the simulation.

However Dr. P Das , Dr. A Nandi and myself are working on the cooling effect of the coils and hopefully by the end of the next month we will be able to generate the exact required values…

Thank You…