




AMIRKABIR
University of Technology

Heat transfer studies of the IRANCYC-10 magnet and its effects on the isochronous field

S.Sabounchi, H. Afarideh, R.Solhju, F.Zakerhosseini, Energy Engineering and Physics Department,
Amirkabir University of Technology, Tehran, Iran

M. Ghergherehchi, School of Information and Communication Engineering, Sungkyunkwan
University, Suwon, Korea



Outline

The project of DMCA

IRANCYC-10

Cooling Characteristics

CFD(Computational Fluid Dynamics) Simulation

Results

Project of the DMCA

The national project of the Designing and Manufacturing of Cyclotron Accelerators for medical purposes

Amirkabir University of Technology

Cyclotron	Phase
10 MeV(IRANCYC-10)	Manufacturing
18 MeV	Detail Engineering
100 MeV	Conceptual Design

Web site : <http://camp.aut.ac.ir>

E-mail : Infocamp@aut.ac.ir

IRANCYC-10

Compact AVF cyclotron

10 MeV H-

FDG production, PET Imaging

Hospital uses

Thermal effect and heat transfer is the phenomenon which can change favourite features of the machine.

RF Cavity (TU2PB03) Cyclotrons 2013

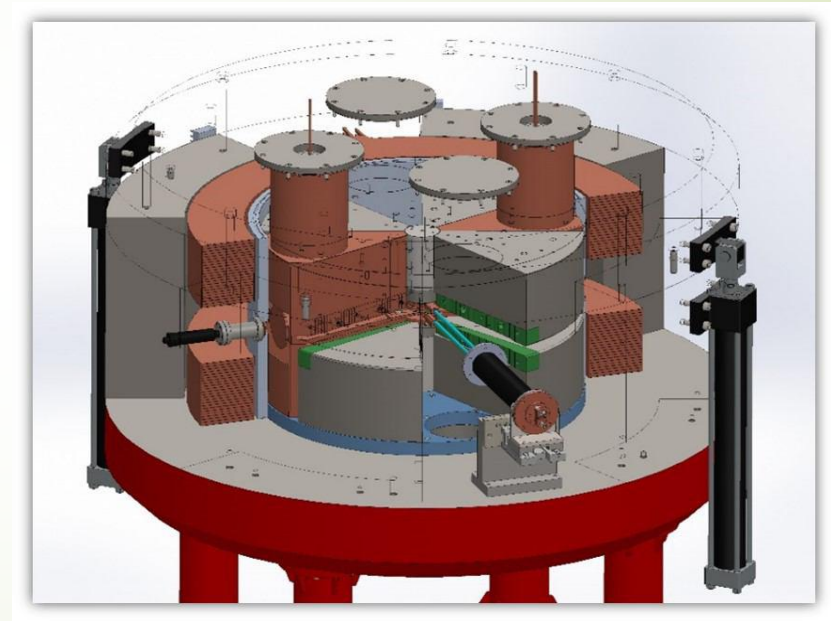
RF Transmission line(TUPMR015) IPAC 2016

PIG Ion Source (TUPMR013) IPAC 2016

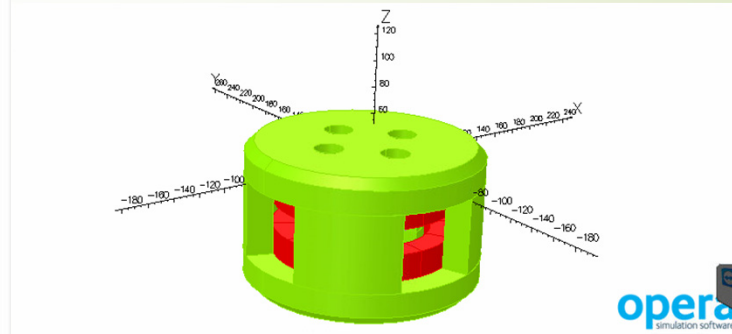
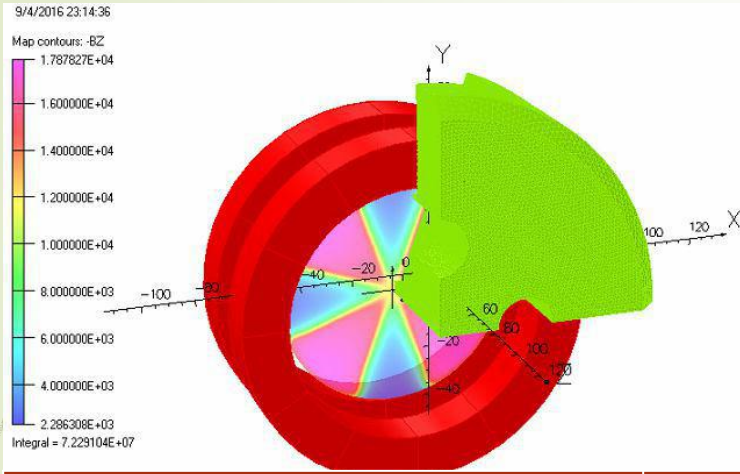
Magnet

Heat transfer (Ansys CFX)

Magnetic field (Opera 3D Tosca)



Magnet Parameters



Parameter	Value
Pole radius	45 cm
Maximum Magnetic field in main plan	1.78 T
Initiate Ampere turns	45201
Number of coil pancakes	18
Material of the coil	OFHC copper (C 10100)
Material of the magnet	AISI 1010

Cooling Characteristics

Why Using Pancakes?

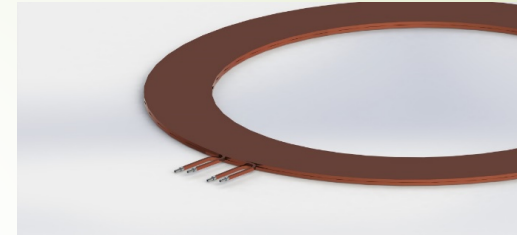
- Pressure drop
- Temperature of cooling water

According to The Copper Development Association Inc. (<https://www.copper.org>)

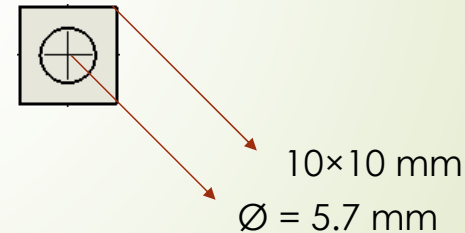
Maximum velocity of the water should be less than 2.43 m/s.

$$\dot{m} = \rho \times V \times A$$

In this equation \dot{m} is mass flow rate (Kg/s), ρ is density (Kg/m^3), V is velocity of the water (m/s) and A is the cross section area of the cooling line (m^2). In this cooling line the diameter of the hollow conductor is 5.7 mm so the maximum mass flow rate should be less than 62 gr/s.



Hollow Conductor Cross Section:



Provided By: LUVATA Co.

Heat Generation

Resistance of one hollow conductor

$$R = \rho \frac{L}{A} \quad \longrightarrow \quad 0.01186 \Omega$$

Resistivity of water for cooling: $3 \text{ M } \Omega \cdot \text{cm}$

Total Heat generation for one hollow conductor by considering the safety factor of 1.33 will be 500 w

CFD(Computational Fluid Dynamics)

Computational fluid dynamics (CFD) is the use of applied mathematics, physics and computational software to visualize how a gas or liquid flows -- as well as how the gas or liquid affects objects as it flows past. Computational fluid dynamics is based on the Navier-Stokes equations. These equations describe how the velocity, pressure, temperature, and density of a moving fluid are related

CFD Simulation

Computational fluid dynamics (CFD) is the science of predicting fluid flow, heat and mass transfer, chemical reactions, and related phenomena by solving numerically the set of governing mathematical equations.

ANSYS CFD solvers are based on the finite volume method

- The fluid region is decomposed into a finite set of control volumes
- General conservation (transport) equations for mass, momentum, energy, species, etc. are solved on this set of control volumes

Ansys CFX

Geometry

Meshing

Parameters

Convergence and
Solution

CFD GEOMETRY

CFD simulations in coil of the IRANCYC- 10 all parts modelled by SolidWorks and all joints considered as perfect connection

Original Geometry



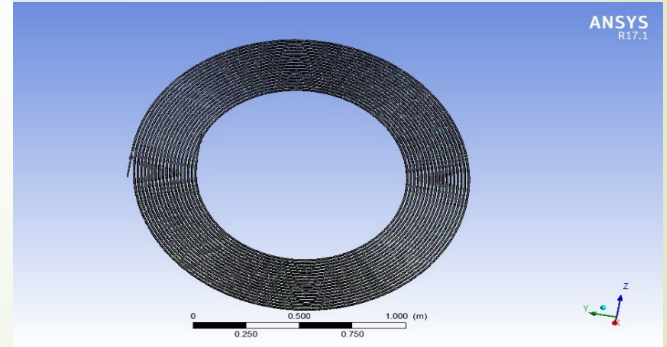
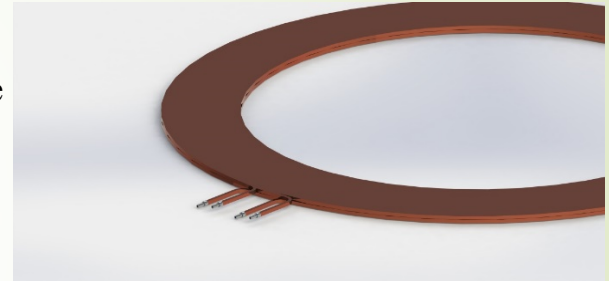
Symmetry



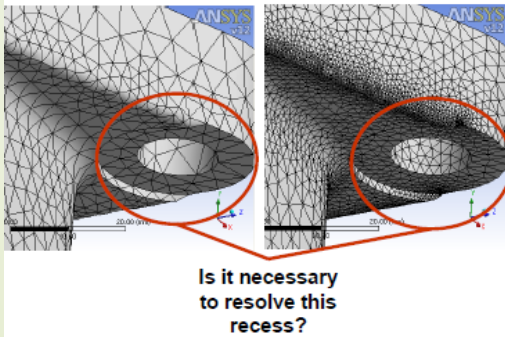
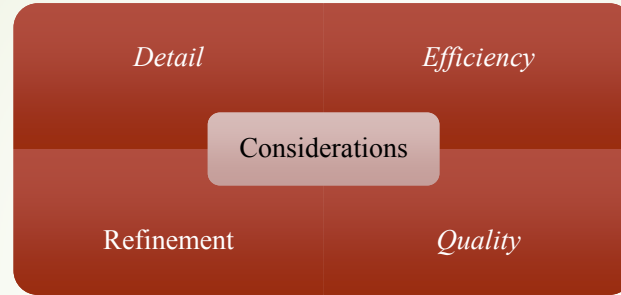
Equivalent

Convergence and Accurate Simulation
Almost Impossible

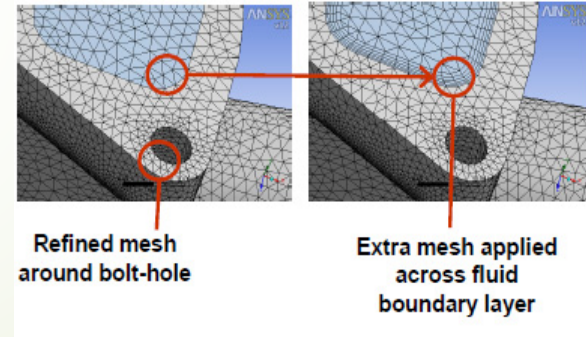
Still complex but solvable



CFD Meshing



Detail



Refinement

CFD Meshing

Efficiency

Greater numbers of elements require more compute resource (memory / processing time). Balance the fidelity of the simulation with available resources

Quality

In areas of high geometric complexity mesh elements can become distorted. Poor quality elements can lead to poor quality results or, in some cases, no results at all!

There are a number of methods for measuring mesh element quality. For example, one important metric is the element 'Skewness'. Skewness is a measure of the relative distortion of an element compared to its ideal shape and is scaled from 0 (Excellent) to 1 (Unacceptable).

CFD Meshing

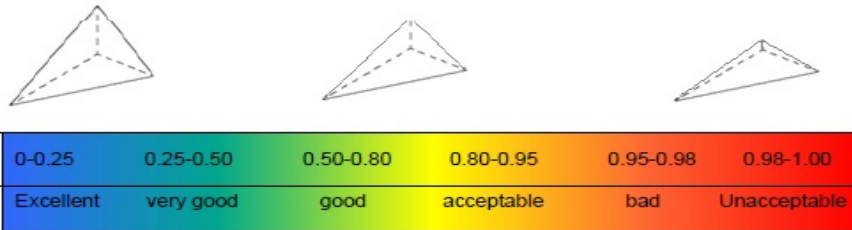
Sweep meshing is a meshing method available in ANSYS Meshing that can be used to maintain high solver accuracy at the same time as reducing mesh cell counts (leading to a serious speedup in solve times).

Meshing Statistics

Parameter	Value
Maximum Skewness	0.6
Maximum aspect ratio	8.24
Total number of elements	3966782
Total number of nodes	5010720
Element size	7e-4 m

Desirable < 0.95

Desirable < 50






Skewness Range

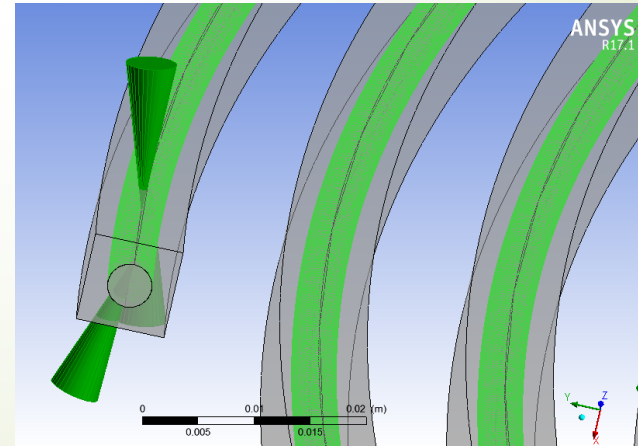
Parameters

In fluid domain water considered as continuous fluid and for turbulence model Shear Stress Transport has been applied

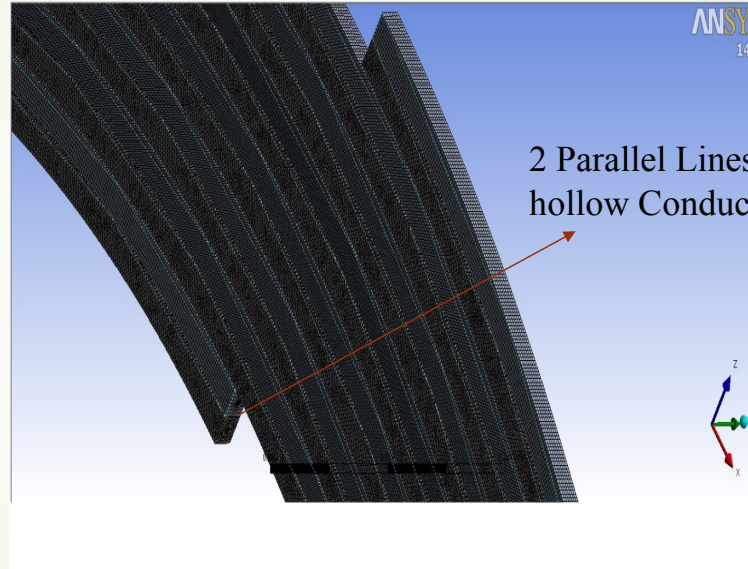
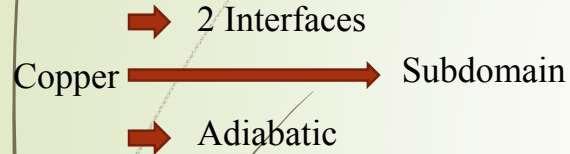
At inlet mass flow rate considered 24.5 gr/s and in outlet, average static pressure appointed with zero. Initial temperature of water and copper has been set as 293 kelvin.

Boundary Conditions

-  Inlet
- water  Outlet
-  2 Interfaces



Parameters

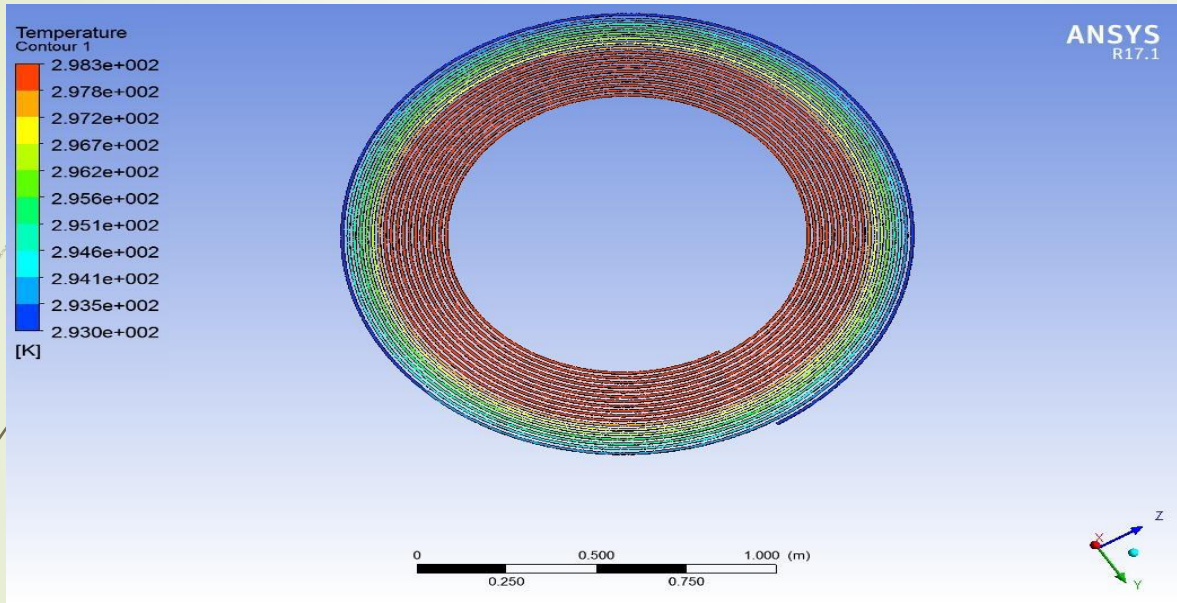


→ Symmetry Conditions

$$\frac{dT}{dx} = 0 \rightarrow q = k \frac{dT}{dx} = 0$$

↓
 Adiabatic Boundary Conditions on Copper to Copper Wall Conditions

Results



Temperature Distribution in coil

As it can be seen the maximum temperature raise in coil is 5.3 kelvin. With **constant voltage**, even this range of temperature raise can effect on the isochronous magnetic field. The main reason of this phenomenon is changing of the conductivity and ampere- turns in magnet. In this coil after consider the temperature raise the **ampere- turn changed from 45201 to 44621**

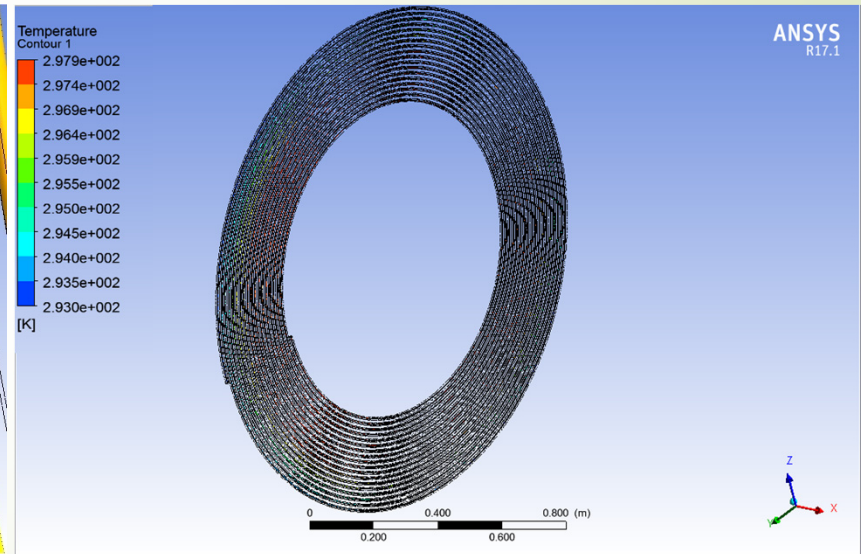
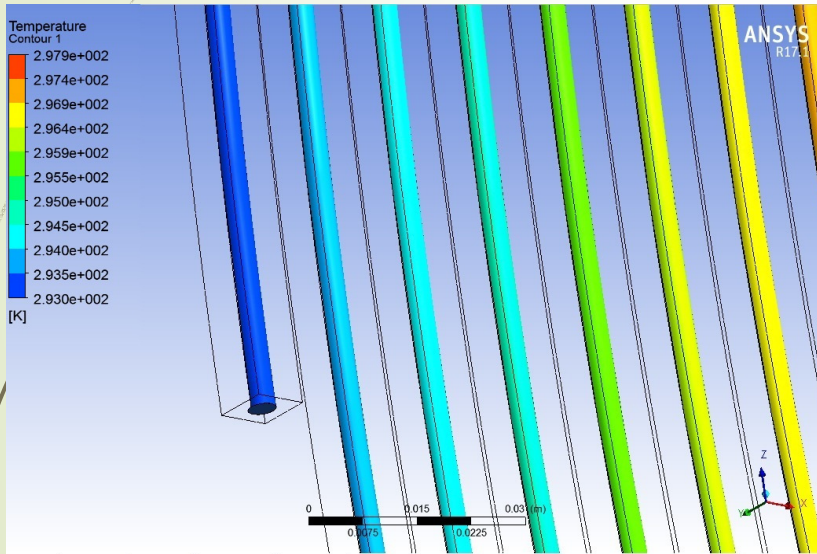
Results

Thermal stability: ΔT for cooling water = 4.9 kelvin

$$P = \dot{m} \times c \times \Delta T \quad \longrightarrow \quad 0.0245 \times 4184 \times 4.9 = 502 \text{ w}$$

0.4 % Error

500w

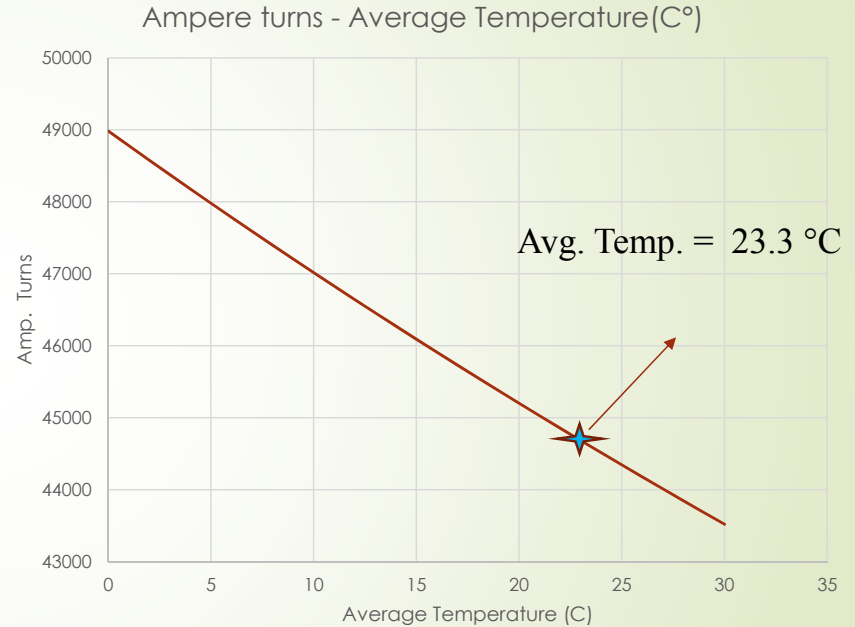
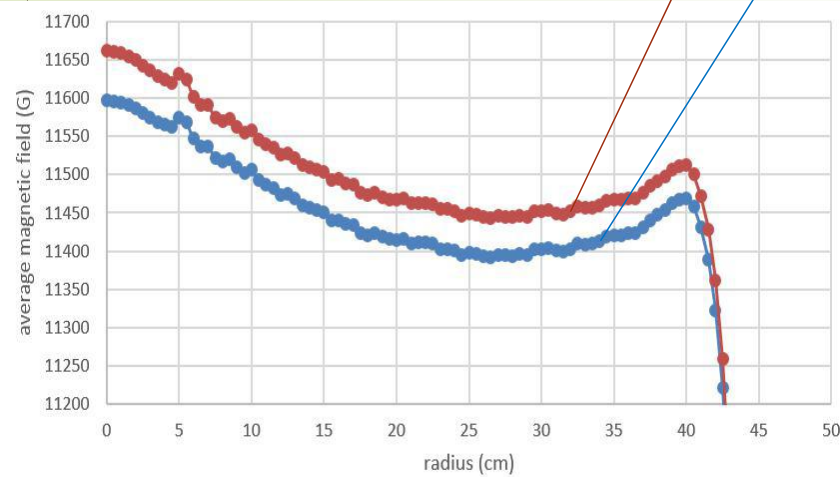


Temperature Distribution in cooling water

Results

Without temperature effects

With temperature effects



Parameter	Value
Maximum temperature change	5.3 kelvin
Ampere turns change	580 ampere turns
Maximum Difference from isochronous magnetic field	50 G

Conclusion

Parameter	Value
Total mass flow rate	53 lit/min
Maximum temperature change	5.3 kelvin
Ampere turns change	580 ampere turn
Initiate Ampere turns	45201
Ampere turns after temperature effect	44621

In case of having constant voltage on coil, resistivity of the coil will increase due to temperature raise. The raise of resistivity results in current reduction of 580 ampere turns and the magnetic field will be declined maximum 50 G. This will occur in case of constant voltage on coil. So current reduction should be compensated by magnet power supply.



Thanks for your attention

Comments ?

Questions ?

