HEAT TRANSFER STUDIES OF THE IRANCYC-10 MAGNET AND ITS EFFECTS ON THE ISOCHRONOUS MAGNETIC 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

Abstract

In magnets for cyclotron, one of the prominent problems is difference between simulation and feasible operations. By considering more factors in simulation these difference can be reduced. Thermal effect and heat transfer is one phenomenon which can change favourite features of the magnets. IRANCYC-10 is a compact AVF cyclotron which is in manufacturing phase at AmirKabir University of Technology. In IRANCYC-10 heat transfer studies have been done for RF cavity, RF transmission line and PIG ion source. In this paper, accurate simulation of heat transfer and magnetic field have been done. Also thermal effects on isochronous magnetic field for IRANCYC-10 is investigated. For heat transfer and CFD simulations, Ansys CFX and for magnetic simulation Opera 3D Tosca have been used. The initiate magnet ampere-turn in simulation is 45201 and water mass flow rate for magnet system is considered 53 lit/min.

INTRODUCTION

IRANCYC- 10 is a 10 MeV cyclotron for accelerating of H^- in FDG production which is under manufacturing phase at AmirKabir University of technology [1] IRANCYC-10 exclusively has been designed for FDG production in hospital. Heat transfer and thermal analysis has been done for RF cavity, RF transmission line and PIG ion source [2], [3] and [4] in IRANCYC-10. In this project heat transfer and temperature raise for coil of the IRANCYC-10 has been simulated. As one of the main parts of this machine, AVF magnet have been designed by opera 3D Tosca. AISI 1010 is used for this magnet [5]. In Table 1 and Figure 1 relevant parameters of the magnet and magnetic field mapping can be seen.

Table 1: Relevant Parameters

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

This magnet had been designed by Opera 3D Tosca and it was optimized as much as possible. On the other hand there is always difference between simulation and feasible problems and this difference create time-consuming tuning of the machine. One of the major reasons for the discrepancy between the simulation and operation in magnet of the cyclotrons, is temperature raise of the coils. In operation when the coil start to heat and raise temperature in fact it can effect OFHC copper conductivity. So other parameters of the magnet can change and isochronous field will be effected. Heat transfer study and optimized cooling system is essential in order to reduce inconsistency between magnetic field and isochronous field. In these coils it is almost impossible to eliminate the heat effects on the magnets even with the cooling system so it should be diminished and compensated if it is significant. This study is useful in cyclotron tuning phase.

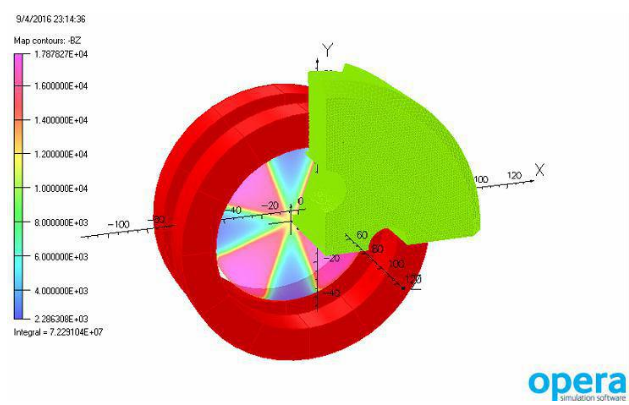

Figure 1: Magnetic field mapping.

COOLING CHARACTERISTICS

The coil of IRANCYC- 10 made of 18 pancakes in Figure 2 one pancake is shown. The main reason is less pressure drop of the cooling water. In this coil like other conventional coils in AVF cyclotrons, hollow conductors has been used. The dimension of this hollow conductor is rectangle (10*10 mm) and its hollow is circle (5.7 mm diameter). In order to avoid erosion and other mechanical problems in OFHC copper, the maximum velocity of the water should be less than 2.43 m/s [6]. So the maximum mass flow rate of each hollow conductor can be calculated by Eq. (1):

$$\dot{m} = \rho \times V \times A \ . \qquad (1)$$

ISBN 978-3-95450-167-0

In Eq. (1) $\dot{m}$ 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 is 5.7 mm so the maximum mass flow rate should be less than 62 gr/s.

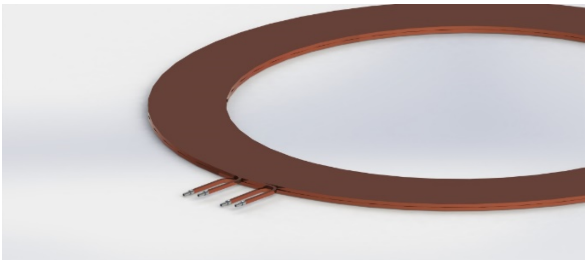

Figure 2: Pancake of coil.

For heat generation in a hollow conductor, Resistance of one hollow conductor extracted from basic equation (Eq. (2)). Total Heat generation for one hollow conductor by considering the safety factor of 1.33 is resulted 500 w. This safety factor can compensate other parameters which were not considered.

$$R = \rho \frac{L}{A} \tag{2}$$

In Eq. (2), ρ is resistivity, L length of the conductor and A is cross section area of the conductor. Also the cooling water is deionized and resistivity of the water will be checking during the operation. The resistivity of the cooling water will stay more than 3 $M\,\Omega.cm$ for all parts which need cooling water in IRANCYC-10 [7].

CFD GEOMETRY

As one of the most accurate codes for CFD simulations, Ansys CFX has been used for heat transfer simulation. For CFD simulations in coil of the IRANCYC- 10 all parts modelled by SolidWorks and all joints considered as perfect connection which does not make a difference in simulation. Also the exact geometry of the coil in too complex for CFD simulation and it is almost impossible to converge the residual during the calculations in order to extract accurate values. The geometry of the coil is Symmetric in term of heat transfer. So for Ansys CFX, an equivalent geometry in term of heat transfer has been designed for CFD simulation. In Figure 3 this geometry can be seen. This geometry contained one hollow conductor in a pancake and by reducing the volume of the calculations, the accuracy of the CFD simulation became significant. Also the number of contacts reduced to just two contacts, upper surface of circle hallow and bottom side. In these contacts, OFHC copper appointed as contact body and deionized water as a target body.

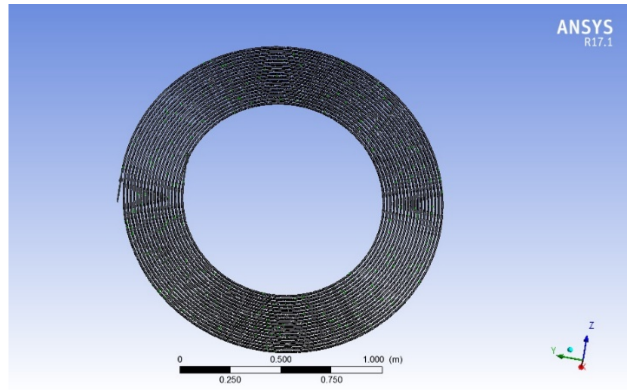

Figure 3: Geometry for CFD simulation.

CFD MESHING

In this simulation although efforts have been made to make the geometry simpler by designing the equivalent shape, it was still challenge to make meshing with high quality. Twisted shape and sharp edges are the main reason for difficulty in meshing. Tetrahedral patch conforming which is usually used for complex geometries did not resulted to high quality meshing. The method of sweep has been used for meshing in this simulation. Sweep is more effective in term of aspect ratio and skewness but some geometries are not sweep able. Meshing with significant quality has been created by optimized parameters. In Table 2 meshing statistics for fluid domain has been shown.

Table 2: 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

In Ansys CFX solver the aspect ratio for the fluid domain should be less than 50 in order to good convergence and accuracy of the simulation. Also parameter of skewness is crucial in mesh quality. In Figure 4, relation between skewness and mesh quality has been shown. As it can be seen from table 2, maximum aspect ratio and skewness in fluid domain is 8.24 and 0.6 which is incredibly suitable for this geometry [8].

Figure 4: Skewness and mesh quality.

ISBN 978-3-95450-167-0

CFD SIMULATION

After high quality meshing, Ansys CFX has been tuned for precise simulation. In this simulation two domain has been defined OFHC copper and cooling water. Copper domain, a subdomain has been considered for heat generation. In this problem, heat generation is completely uniform in OFHC copper so it was applied as total source energy. In fluid domain water considered as continuous fluid and for turbulence model Shear Stress Transport has been applied. This model is combination of k-omega and k-epsilon in different regions. In eddy diffusivity for turbulent flux closure for heat transfer, value of 0.85 has been appointed as prandtl number. 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.

By high resolution advection scheme, high resolution turbulence numeric and RMS of 10e-4 convergence has been achieved. In Figure 5, temperature distribution of the one pancake can be seen.

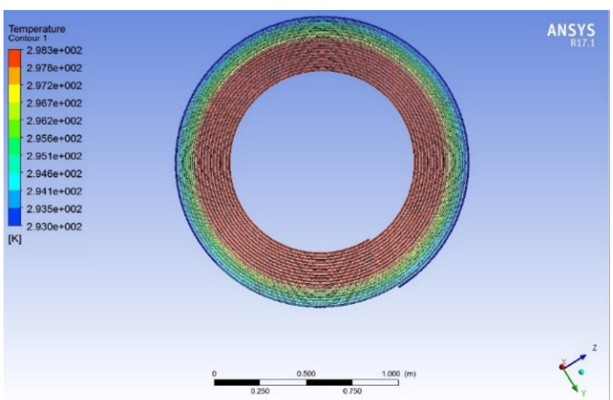

Figure 5: Temperature distribution.

MAGNETIC FIELD CHANGES

As it can be seen the maximum temperature raise in coil is 5.3 kelvin. 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- turn in magnet. In this coil after consider the temperature raise the ampere- turn changed to 44622.

In Figure 6, two magnetic fields before and after the temperature raise can be seen. The red curve is field which is fitted to isochronous field without temperature effect and after considering heat transfer blue curve has been resulted. It can be seen that the maximum difference is 50 G.

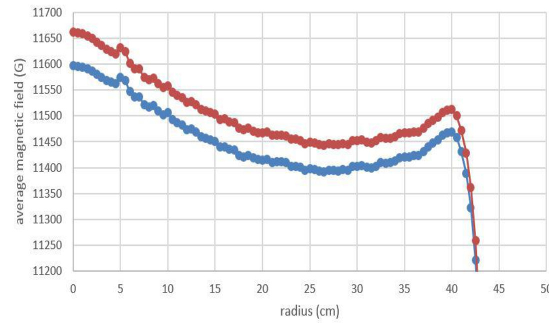

Figure 6: Temperature effect on magnetic field.

CONCLUSION

This study can be useful at tuning phase of IRANCYC-10. In fact it can provide the better simulation and diminish the inconsistency between feasible and simulation. In Table 3 final results is shown. For 22 pancakes total mass flow rate is 53 lit/ min has been considered

Table 3: Final Results

Parameter	Value
Maximum Temperature Change	5.3 °C
Ampere-turns Change	580 Ampere-turns
Difference from Isochronous Magnetic Field	50 G

REFERENCES

[1] DMCA, http://camp.aut.ac.ir/

[2] S. Saboonchi, H. Afarideh, M.R. Asadi, M. Ghergherehchi , and J.S. Chai, “Heat transfer study and cooling of 10 MeV cyclotron”, in *Proc. Cyclotrons`13*, Vancouver, BC, Canada, Sep. 2013, paper TU2PB03, pp. 150-152.

[3] S.Sabounchi, M.Mohamadian, M.Salehi, H.Afarideh, M.Ghergherehchi, and J.S.Chai, “Cooling and Heat Transfer of the IRANCYC-10 Transmission Line”, in *Proc. IPAC`16*, Busan, Korea, May 2016, paper TUPMR015, pp. 1259-1261.

[4] F. Zakerhosseini, S. Sabounchi, H. Afarideh, J. Chai, and M. Ghergherehchi, **“**Heat transfer study of PIG ion source for 10 MeV cyclotron”, in *Proc. IPAC’16*, Busan, Korea, May 2016, paper TUPMR013, pp. 1256-1258.

[5] R.Solhju, *et al.,* “Design of a 10 MeV Cyclotron Accelerator”, *Iranian Journal of Physics Research*, vol 15, no 2, May 2016. pp. 225-234

[6] The copper development association Inc. https://www.copper.org/applications/plumbing/techcorner/designing_piping_systems.html

[7] E. Swetin, M. Kirshenbaum, and C. Putnam, “Cooling Water Systems for Accelerator Components at the Advanced Photon Source”, *2nd International Workshop on Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation (MEDSI02)*, September 2002 – Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois, USA, pp. 445-453.

[8] Ansys Meshing Application Introduction, Appendix A, Mesh quality, April 2009, pp. 5-10.

ISBN 978-3-95450-167-0