

STRESS ANALYSIS OF FAIR SUPER-FRS QUADRUPOLE MAGNET SYSTEM

U Bhunia, S Roy, A Dutta, S Bhattacharya, J Akhtar, C Nandi, T K Bhattacharya, P R Sarma, G Pal, C Mallik, and R K Bhandari
Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata-700 064

Abstract

The large aperture superferic quadrupole magnets in energy buncher section of Super-FRS will generate high magnetic field gradient in the usable aperture. The magnet system will be assembled at room temperature and will undergo dissimilar thermal contraction during operation at normal liquid helium temperature. It is, therefore, very crucial from engineering design point of view to understand and analyze both thermal and electromagnetic stress in coil, support structures and iron for its safe operation. The paper describes stress analysis of the magnet system as a whole with commercial FEM package ANSYS.

INTRODUCTION

The quadrupole magnets in the Energy Buncher section of the Super-FRS [1] have to generate high magnetic field in a usable aperture. It is indeed a privilege and technological challenge for India to design a very large aperture (± 300 mm horizontally and ± 250 mm vertically) superconducting quadrupole magnet for use at FAIR. Superferic magnets are iron dominated superconducting magnets. The magnets have a maximum field gradient of 5.2 T/m. The aim of the present study is to calculate the stress distribution in uniform current density superconducting coils due to cool-down at liquid helium temperature and electromagnetic force.

Any superconducting magnet while in operation should be structurally sound so that it does not fail during operation. It is therefore, very crucial to understand the stress distribution among various components of the magnet. Based on the preliminary magnet design [2, 3], the layout of the quadrupole magnet and coil was worked out (Fig. 1). The superconductor would be wound on a SS 316 bobbin and potted with resin to fill the voids in order to provide strength to coil and prevent conductor movement. Resisting conductor movement in the coil is very important in a superconducting coil.

The magnet iron and coil are immersed in liquid helium inside the liquid helium chamber made of fully austenite grade of stainless steel, SS 316. The magnet is assembled at room temperature. But, it has to be operated at a temperature of about 4.5 K.

STRESS ANALYSIS

Stress analysis has been performed to determine how the magnet structure would response to both cool-down thermal stresses and Lorentz force loading. The structural design is based upon the room temperature values of mechanical properties of the materials used to have a

conservative design at cryogenic temperatures. ANSYS 2D coupled element PLANE13 with degree of freedom (DOF) of UX, UY, AZ and TEMP is used for two dimensional magneto-structural and thermal analysis using plane stress condition. Here, UX and UY are defined as translation in X and Y direction respectively; AZ is vector potential along Z and TEMP is temperature.

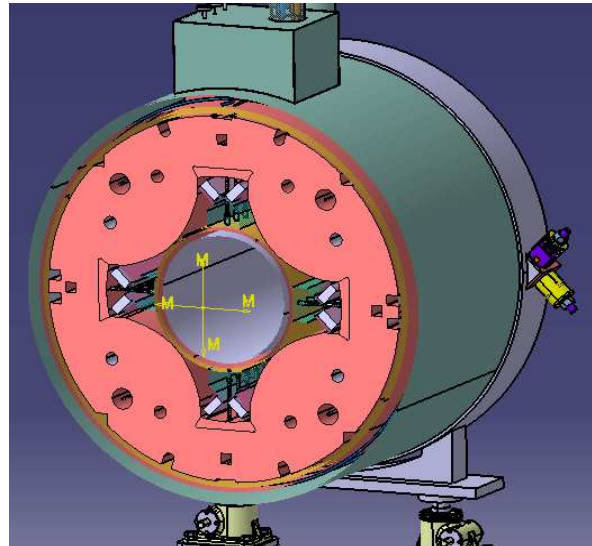


Figure 1: Basic design of Quadrupole magnet

For 3D thermal and magneto structural analysis couple element SOLID98 is used to solve the problem sequentially. Result of thermal stress and magnetic force are used as load in final stress analysis.

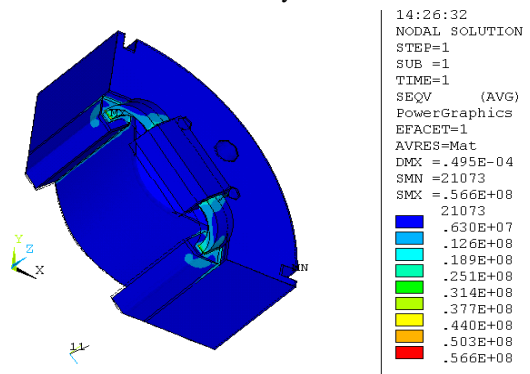


Figure 2: Combined Von Mises Stress contour for thermal contraction and Lorentz force

Thermal stress is developed due to differential thermal contraction of iron yoke, SS 304 shell around the yoke,

coil, and coil support system. Maximum deformation of iron is around 1.8 mm while cooling down from room temperature to 4.5 K. Since the other parts of the assembly also shrinks, therefore, differential thermal stress is not very high. Equivalent tensile stress or Von Misses stress contour developed due to thermal contraction and at maximum excitation of the coil is as shown in Fig. 2.

A comparison of stress developed in iron due to thermal and thermal with excitation is as shown in Fig. 3.

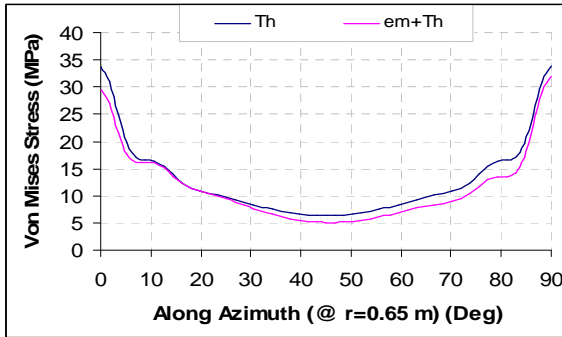


Figure3. Stress comparison in iron @ 0.65m

During excitation, coil experiences Lorentz force. Total body force developed on coil is calculated using Maxwell stress tensor as $F_x = +3.17E+05$ N/m and $F_y = -5.2E+04$ N/m. Von Mises stress contour developed in the coil due to both thermal contraction and Lorentz force is as shown in Fig. 4. Maximum equivalent stress developed on the coil is around 65 MPa.

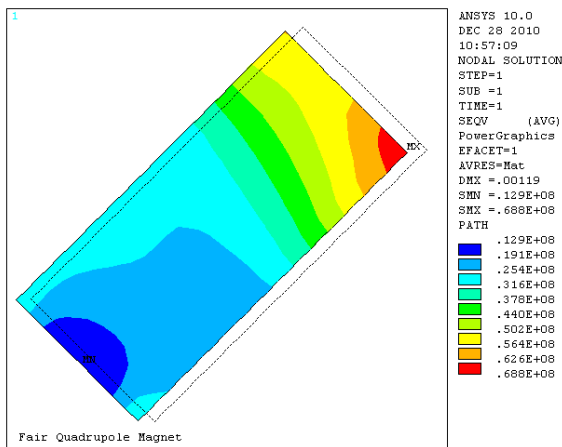


Figure 4: Von Mises Stress contour on coil due to thermal contraction and Lorentz force

While cooling down the Stainless Steel (SS-316) shell shrinks more w.r.t. iron yoke and therefore, differential thermal stress developed. Combined stress contour developed due to thermal contraction and coil in excited condition on SS shell around the iron yoke is as shown in Fig. 5 and the distribution in the middle of the thickness of shell is as shown in Fig. 6.

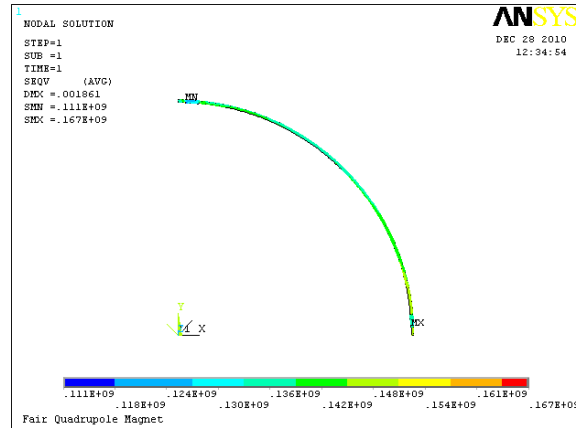


Figure 5: Von Mises Stress contour on SS shell

Maximum stress developed on the shell material is around 147 MPa which is much less than the yield stress of SS316 (~ 600 MPa) at 4 K. Distribution of Von Mises stress at the middle of the shell is as shown in Fig. 6.

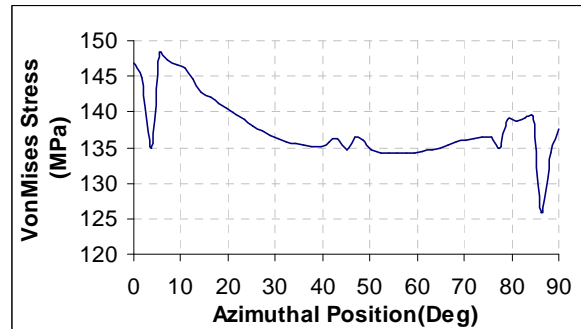


Figure 6: Von Mises Stress distribution on SS shell

CONCLUSION

Thermal and electromagnetic stress developed on various parts of the assembly has been analyzed in details using both 2D and 3D models. As per 2D simulation, stress developed in all parts of magnet is quiet low and manageable. Using present scheme of coil support, 3D analysis, which is more actual shows that structure is safe as per as magneto-structural and thermal stress is concerned. Our group has also studied other issues like quench scenario, related protection, details of cryostat assembly, etc. Further, we are planning to develop a reduced scale of prototype FAIR quadrupole magnet to experimentally verify the stress developed using strain gauges mounted on it and other complications that might occur before going to develop actual FAIR magnets.

REFERENCES

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