Design of large aperture superconducting magnets for FAIR

An array of high end workstations suitable for maximum performance on large data sets and complex multi-threaded applications along with high end design, modelling and FEM analysis softwares, viz., multiphysics software ANSYS, magnet analysis software OPERA with quench analysis module QUENCH, modeling software CATIA with capability for part, assembly, fitting simulation, clash analysis modules are available (Fig. 1).

Fig. 1: Design and analysis software

Large aperture dipole, quadrupole and sextupole superconducting magnets have been designed in order to meet the requirement for a spectrometer magnet. The end profiles for the magnets have been optimised in order to minimise harmonics for different excitations. Mechanical design of the magnets has been carried out for structural, thermal and magnetic interaction (Fig. 2). Design of the cryostat containing the magnet has been carried out for self weight, thermal load, magnetic force, thermal contraction, external pressure (Fig. 3), acceleration due to transportation, etc. Safety analysis of superconducting coils of the magnets has also been carried out to assess the temperature rise, voltage rise and pressure rise due to a quench.

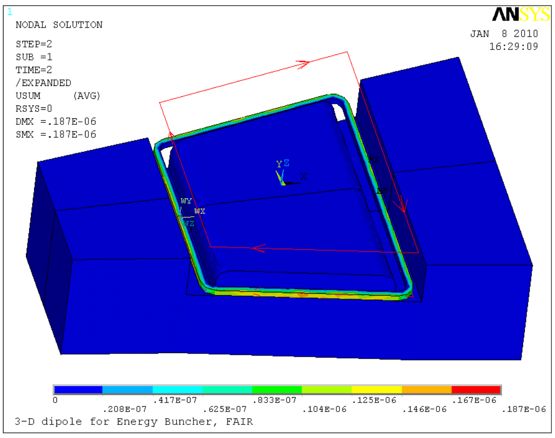


Fig. 2: Coil stress of dipole magnet under magnetic field

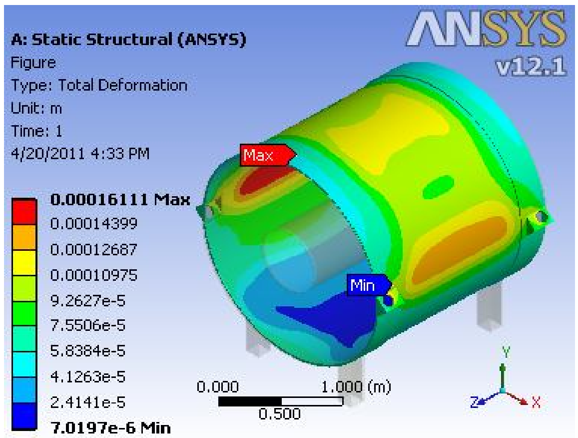


Fig. 3: Deformation of outer vessel for quadrupole magnet cryostat

Large aperture dipole magnet

The large aperture dipole magnet will have radius of curvature of 4.375 m, magnetic field up to 1.6 T over elliptical bore of size ± 380 mm × ± 100 mm and effective length 2.43 m to bend ion beams by an angle of 30°. The main criticality of this

magnet is to achieve field uniformity better than ± 3 × 10–4 throughout this large elliptical beam path. 3D magnetic field simulation was carried out by OPERA software. After a large number of iterations with OPERA software, the desired shape of magnet (Fig. 1) was achieved to attain the required field quality. The overall size of the magnet is 3.51 m (w) x 3.20 m (b) x 3.08 m (h) and weight is 115 ton.
The helium vessel will be supported from the room temperature vessel by eight vertical and four horizontal support links. The links will be made of glass-epoxy to reduce the conduction heat load to the liquid helium. Detail thermo-mechanical analysis has been carried out to optimize the support links for the high mechanical strength and low heat conduction to the liquid Helium chamber.
Finite element analysis of the SS 316L helium chamber has been carried out considering the thermal load due to cool-down and the structural load for the maximum pressure of 5 bar (Fig. 2). The vacuum chamber is also analyzed for its peak stress (Fig. 3). It was observed that the maximum stress on vertical and horizontal support links were 400 MPa and 900 MPa respectively. Adjustment (loosening) of horizontal support links during cool-down is required to protect the support links from damage.

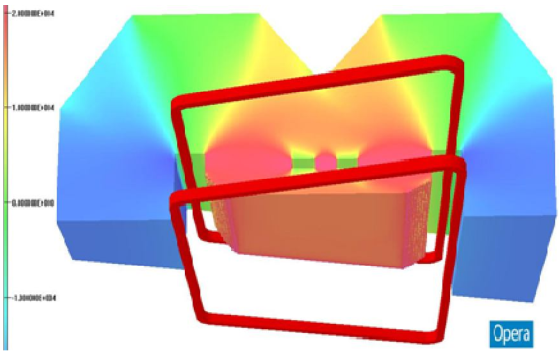


Fig. 1: Magnetic field distribution in dipole magnet.

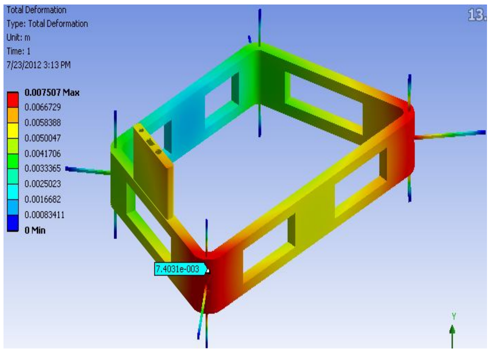


Fig. 2: Total deformation of He chamber due to cool down

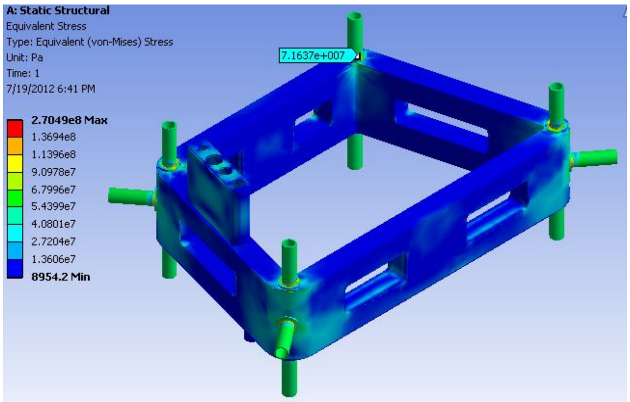
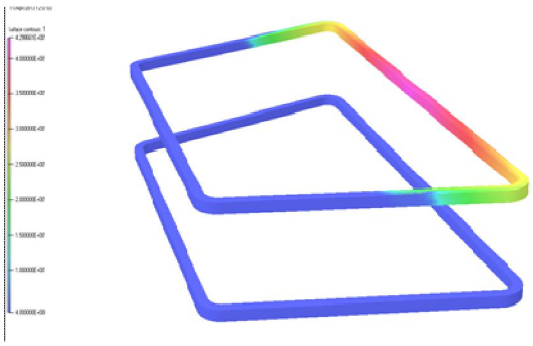


Fig. 3: Equivalent Stress on vacuum chamber

Structural analysis has also been carried out for the vacuum load and thermal load reaction arises due to supports. The analysis shows maximum stress 80 MPa will be at support link ports considering horizontal support link adjustment.

The maximum temperature and voltage rise within the coil was estimated using 3D transient coupled field (electrical, magnetic and thermal) finite element software, OPERA. Fig. 4 shows quench propagation in the coil. Figure 5 shows quenching voltage raise and current decay in the coil without dump resister. The maximum voltage and maximum temperature may rise up to 1.5 kV and 110 K respectively.



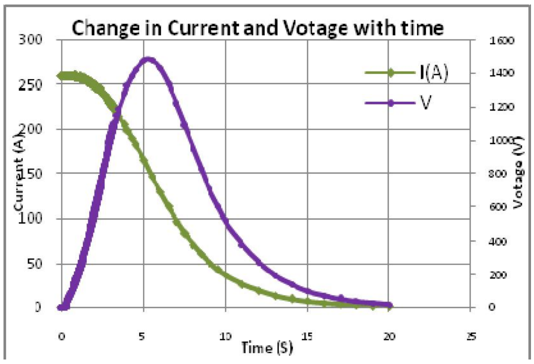


Fig. 4: Quench propagation in a coil

Fig. 5 Quench current and voltage without dump resistor

Large aperture superferric multipole magnets

VECC is designing large aperture superconducting magnets for low energy buncher line of superconducting fragment separator (Super-FRS) at Facility for Antiproton and Ion Research (FAIR), GSI, Germany. This Division has carried out the design of large bore superconducting superferric quadrupoles and sextupoles. The magnets have stringent design criteria. The quadrupole magnets have large usable aperture of ±300 mm horizontally and ±250 mm vertically with field gradient quality (ΔG/G) of 8 $\times 10^{-4}$. The design of these magnets is quite complex as they have short length, large aperture and have to achieve the high magnetic field quality. The stringent specifications require the use of iron-dominated magnets where the magnetic field is formed by shaped iron poles using superconducting coils. Each of the magnets will be weighing about 25 Ton (Fig. 1). A number of iterations have been carried out in design to optimize the coupled physics and mechanical problems. This type of magnet having unique characteristics has been designed for the first time in the world.

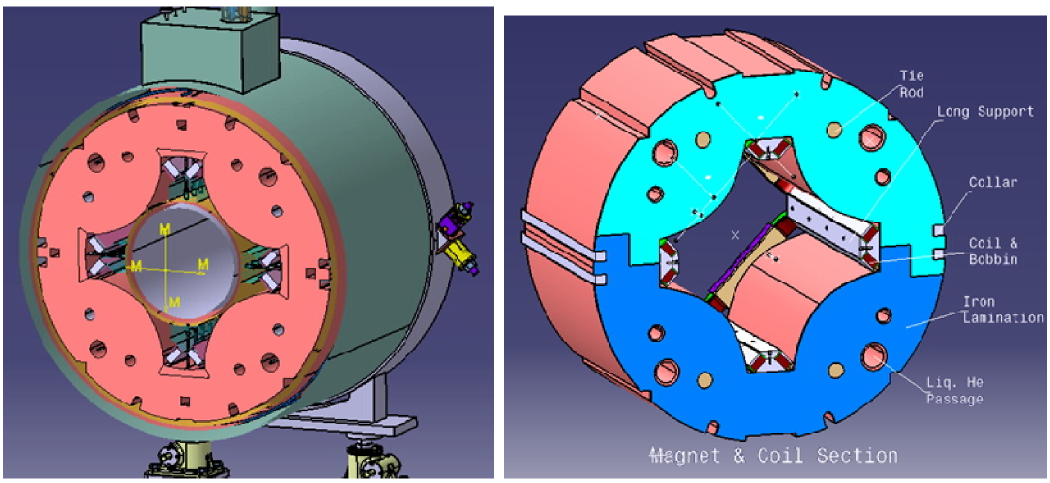


Fig. 1: Model of superferric magnets

Outer vacuum chamber for long superconducting quadrupoles for fair super FRS energy buncher

The outer vacuum chamber of the cryostat has 15 mm wall thickness with a flat head thickness of 40 mm. The vessel is kept on saddle support whose span is 120^0 .Wear plate has a thickness of 15 mm is also provided. The Outer Vacuum Chamber design conforms to ASME Boiler and pr4essure Vessel Code Section VIII Division II. The magnet is supported by two compression supports of G10 Fiber Epoxy.

The Helium Vessel is also of 15 mm wall thickness with a flat head thickness of 40 mm. Tri-Unions are provided on the flat head for lifting. A total of four tri-unions are provided (two on each side). A total of eight locks are provided for the purpose of transportation. Four transportation locks are provided on the flat heads and 4 on the curved surface on the vacuum chamber.

Finite element Analysis was performed with the applied loads and the optimal geometry of the cryostat was determined. Fig. 1 and 2 show the stress distribution and the total deformation of the outer vacuum chamber with loads namely, external pressure and the magnet weight.

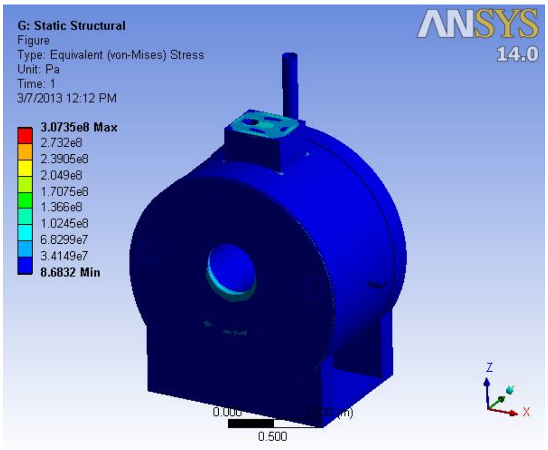


Fig. 1: Von Mises Stress

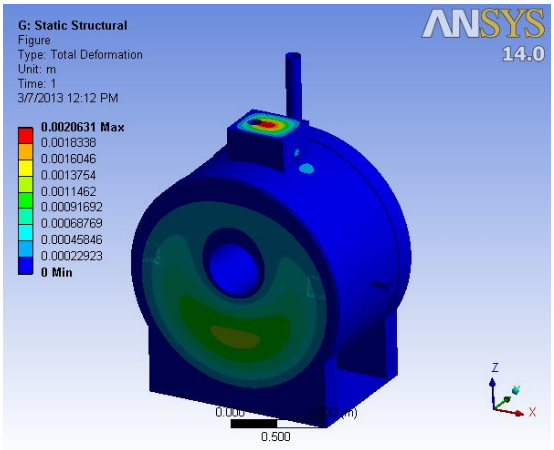


Fig. 2: Total Deformation