QUENCH ANALYSIS FOR THE ENERGY BUNCHER DIPOLE MAGNETS OF FAIR PROJECT

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Abstract

VEC Centre is pursuing the design of the superconducting magnets for the Energy Buncher of the Facility for Antiproton and Ion Research (FAIR), under construction at Darmstadt, Germany. These magnets will be designed, fabricated and installed at FAIR site by VECC engineers.

These magnets are super-ferric in nature having Nb-Ti superconducting coils cooled at liquid helium temperature. Iron is at room temperature. The dipole magnets require a magnetic field range of 0.15 T to 1.6 T with a field uniformity of $\pm 3x10^{-4}$ over the elliptical beam tube of ±300 mm x ±100 mm. The coil is epoxy impregnated having a cross section of 56 mm x 54 mm.

A detail quench analysis was performed to find out maximum temperature of the coil at the worst scenario and corresponding pressure rise in the liquid helium chamber was calculated. This data was used to design the helium chamber and its safety system. This paper describes the details of the analysis giving the assumptions made and the results.

INTRODUCTION

The Facility for Antiproton and Ion Research is under construction at Darmstadt, Germany with the aim to open a new arena of Nuclear, Atomic, Astrophysics and high density plasma physics. The Energy Buncher part will sit at the end of the Super-FRS low energy beam line. There are four dipole magnets, out of which one is placed separated from others to use this as high acceptance spectrometer [1]. The speciality of the dipole magnets [Figure-1] are having high acceptance i.e. large bore (±300 mm x ±100 mm) and high field quality ($\pm 3x10^{-4}$) over the elliptical bore.

Operation of the magnets at liquid helium temperature will require to ensure that in case of quench, the coil temperature do not exceed allowable limit and the produced gases are efficiently handled by the safety system to avoid any overpressure in the helium chamber.

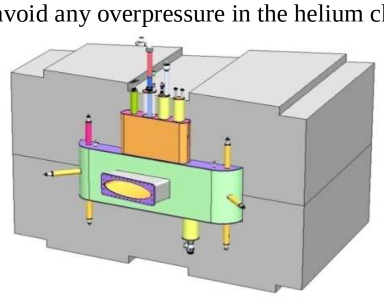

Figure 1: Dipole magnet 3-D model

DESCRIPTION

The dipole magnets are super-ferric. The iron is laminated. Nb-Ti superconducting conductor is used to make the coil. Table 1 summarizes the properties of the conductor. Coils are epoxy impregnated and sit inside a stainless steel helium chamber.

Table 1: Conductor details

Conductor specification	Data	Unit
Superconducting strands	Nb-Ti	
Dimension	1.17 x 1.93	mm
Dimension with insulation	1.43 x 2.24	mm
Cu: no Cu	14	
Critical current Ic	813	A @ 4.2K, 1.6T
Current density	109	A/mm2
Operating fraction, Iop/Ic	0.3	
Temperature margin, Tcs-Top	2.8	K

THEORETICAL MODEL

Quench happens when a part of the superconductor becomes normal (resistive). The criticality is that at very low temperature, the specific heat of material becomes very small and small heat dissipation (~ mW) inside the coil due to bad joints, conductor movement or epoxy crack lead to localised high temperature inside the coil. The conductor becomes normal when temperature goes above its current sharing temperature when current starts to flow through copper matrix. A non-linear transient thermal analysis is to be performed to predict the behaviour of the coil during a quench due to rapidly changing temperature and temperature dependent material properties. Another important point is to be noted that during quench, the large magnetic stored energy of the coil dissipates inside the resistive part of the conductor and protection for this is to be taken by using dump resistors for sharing some part of heating outside liquid helium. The governing equations [3] are given below:

$$\frac{\mathrm{d}}{\mathrm{dx}}(k_x[T].\frac{dT}{dx})+\frac{\mathrm{d}}{\mathrm{dy}}(k_y[T].\frac{dT}{dy})+$$
$$\frac{\mathrm{d}}{\mathrm{dz}}(k_z[T].\frac{dT}{dz})+G[T,t]-h[T].p/A=C[T].\frac{dT}{dt} \quad (1)$$

With *C* being heat capacity, *K* thermal conductivity, G heat generation rate per unit volume, h the heat transfer coefficient to liquid helium and T instantaneous temperature.

Heat generation is given by the following equations:

$$G[T,t] = 0, if, T < Tcs[t]$$

$$G[T,t] = \rho[T].\frac{I[t]^2}{A}.\frac{T - Tcs[t]}{Tc - Tcs[t]}, if, Tcs \le T \le Tc$$

$$G[T,t] = \rho[T].\frac{I[t]^2}{A}, if, T > Tc$$

(2)

Solution of the equations

The equation is solved assuming no cooling available for epoxy impregnated coils. The Wilson [2] method was adopted, where, equation (1) was converted into a one dimensional equation and solved with assumption that the quench propagation velocities are constant in each time step and the resultant resistive volume is of ellipsoid shape.

The analysis uses all the material properties that are temperature dependent. The results are plotted in Figure 1, Figure 2 and Figure 3.

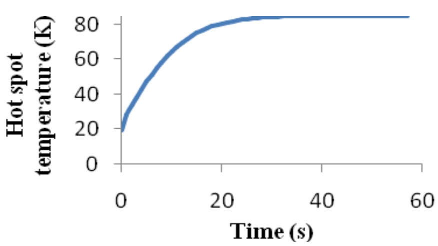

Figure 1: Hot spot temperature vs time for 25 mm x 10 K normal zone

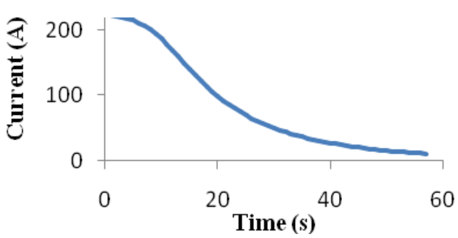

Figure 2: Coil current decay vs time for 25 mm x 10 K normal zone

The current decay depends on the dump resistance used in the circuit. A value of 0.05 ohm has been used for this simulation which was calculated to keep the current decay rate of about 2 A/s [4].

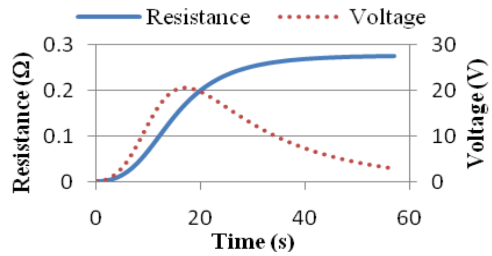

Figure 3: Coil resistance and voltage vs time for 25 mm x 10 K normal zone

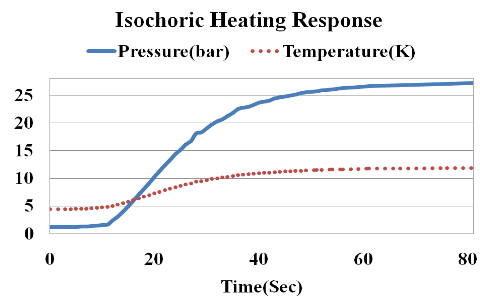

Figure 4: Pressure rise with time is case of a quench in the coil

The heat input to the coil is used to calculate the pressure rise in the helium chamber in case of a quench. Figure 4 gives a plot of pressure with time and the temperature of the bulk fluid. The assumption in this calculation is that the heating is isochoric to a homogenise fluid.

Further 3D quench analysis is being performed to predict more accurate behaviour of the coils.

ACKNOWLEDGEMENTS

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