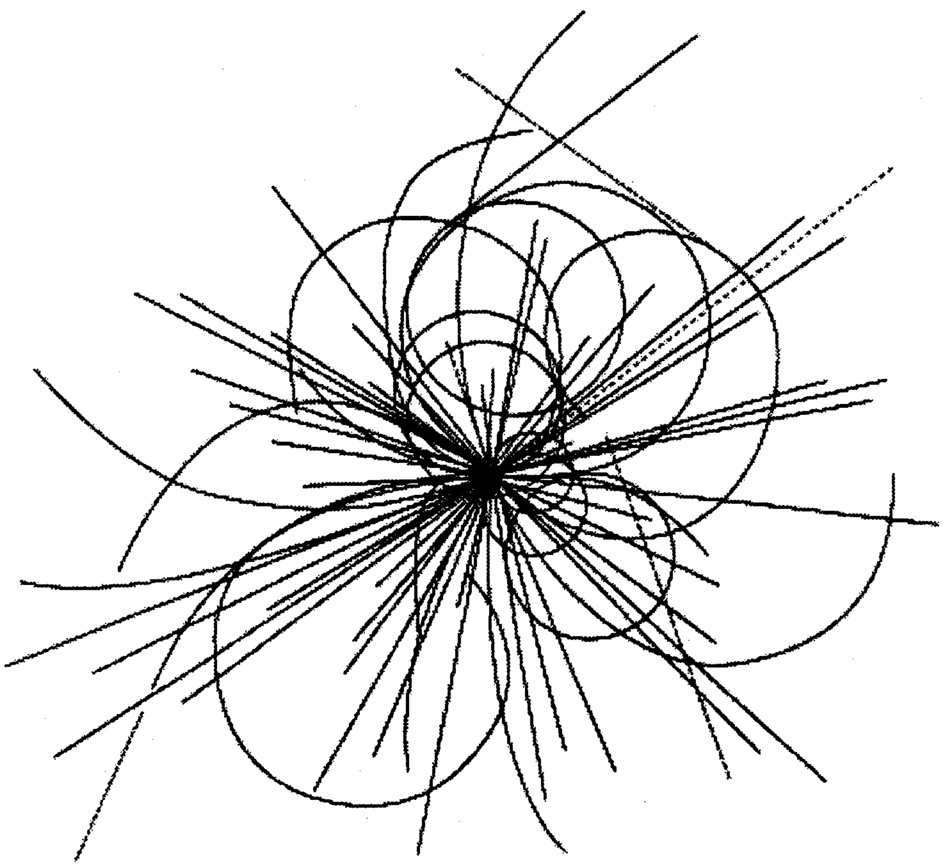
SSCL-Preprint-234

SSCL-Preprint-234
April 1993
Distribution Category: 40

B. Archer
R. Schermer
G. Snitchler
H. Kohli

A Quasi-3D Model to Predict Temperature Distribution in SSC Magnets Due to 3D Heat Loads



Superconducting Super Collider Laboratory

To be published in *Supercollider 5* SSCL-Preprint-234

A Quasi-3D Model to Predict Temperature Distribution in SSC Magnets Due to 3D Heat Loads*

B. Archer, R. Schermer, and G. Snitchler

Superconducting Super Collider Laboratory†
2550 Beckleymeade Ave.
Dallas, TX 75237

H. Kohli

Department of Engineering Mechanics
The University of Texas at Austin
Austin, TX

April 1993

*Presented at the Fifth Annual International Symposium on the Super Collider, May 6–8, 1993 San Francisco, CA.
†Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

A QUASI-3D MODEL TO PREDICT TEMPERATURE DISTRIBUTIONS IN SSC MAGNETS DUE TO 3D HEAT LOADS

B. Archer, R. Schermer, and G. Snitchler

SSC Laboratory*
2550 Beckleymeade Ave.
Dallas, TX 75237

H. Kohli

Dept. of Engineering Mechanics
The University of Texas at Austin
Austin, TX

INTRODUCTION

Hadronic and electromagnetic cascades in the vicinity of the interaction regions deposit energy into the final focusing superconducting magnets as a heat load that varies radially, azimuthally, and axially. The helium used to cool the magnets convects heat axially as it flows, thus, the temperature distribution at any point in the magnet depends on the previous history of the helium. A detailed map of the temperature distribution of the superconducting coils is required to determine if the cooling is sufficient to prevent the magnet from quenching.

A three-dimensional model is required to analyze the magnet temperature distribution due to the 3D heat load and the axial helium flow. A 3D finite element thermal model of a 15 m magnet is not practical due to the large amount of CPU time that would be required. Therefore, a quasi-3D model has been developed that divides the magnet into a large number of segments axially, then calculates the temperature distribution for each segment using a 2D finite element model with boundary conditions derived from the previous segment by conservation of energy.

---

* Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

FORMULATION

Neglecting the end regions, the mechanical cross-section of the magnet is constant axially whereas the material properties and heat loads can vary radially, azimuthally, and axially. Axial conduction through the coils, collars, and yokes is assumed to be negligible. As currently implemented, the mass flow rates, or helium velocities, differ between the annulus and the bypasses, but have a constant axial flow rate. The basis of the method is to subdivide the magnet into short, and perhaps non-uniform, lengths over which the material properties can be taken as a constant. At the center of each segment a steady state 2D solution can be obtained using a finite element model if the helium temperatures in the annulus and bypass are known, as well as the interpolated heat generation rates. The helium temperature at the helium inlets (z=0) is known and the 2D steady state solution can be found for this section. An estimate of the helium temperature at the center of the next section can be found by computing the amount of heat absorbed by the helium in each flow path of length δz, assuming that the heat load conditions are constant for that length. By repeating this process the temperature distribution can be calculated for the entire length of the magnet.

If T_z and $T_{z+\delta z}$ are the absolute temperatures of the helium in a flow passage at two planes located at z and $z+\delta z$, the rate of change of enthalpy between the two planes is

$$\dot{H} = \rho A v C_p (T_z - T_{z+\delta z}) \tag{1}$$

where A is the cross-sectional area of the flow passage, v is the helium axial velocity, ρ is the helium density, and C_p is the specific heat of the helium. The distance δz between the planes is chosen so that the change in density, pressure, and specific heat is small between the planes.

In any longitudinal section of a helium flow passage energy is conserved. Neglecting the change in other forms of energy, such as kinetic and potential energies, the energy removed by the helium must equal the energy transferred into the helium across the flow passage walls. For a yoke bypass the power going through the walls for a section of length δz is

$$\dot{U} = h_{by} \pi D_{by} \delta z (T_y - T_z) \tag{2}$$

where T_z is the bypass helium temperature at z, T_y is the average wall temperature of the yoke in contact with the helium at z, D_{by} is the diameter of the bypass, and h_{by} is the heat transfer coefficient between the bypass and the yoke. Setting the sum of the input energy and the output energy to zero, then rearranging terms gives the bypass helium temperature at cross section $z+\delta z$

$$T_{z+\delta z} = T_z + \frac{h_{by} \pi D_{by} \delta z (T_y - T_z)}{\rho A_{by} v_{by} C_p}. \tag{3}$$

For the annulus the geometry is slightly more complicated because there are three heat sources: the beam tube, the coil, and the collar. Setting the sum of heat transfer into the helium and the heat transported out by the helium to zero and rearranging terms gives the annular helium temperature at the $z+\delta z$ cross section

$$\begin{aligned} T_{z+\delta z} = T_z + (\rho A_a v_a C_p)^{-1} [\alpha h_{coil} \pi D_{coil} \delta z (T_{coil} - T_z) \\ + (1-\alpha) h_{coll} \pi D_{coil} \delta z (T_{coll} - T_z) + h_{bt} \pi D_{bt} \delta z (T_{bt} - T_z) \ ] \end{aligned} \tag{4}$$

where the first term in the brackets is the coil to annulus heat transfer, the second term is for the collar to annulus heat transfer, and the third term is the beam tube to annulus heat transfer. For the coil term, α is the fraction of the circumference of the annulus that is superconducting coil, h_{coil} is the heat transfer coefficient between the coil and annulus, D_{coil} is the inner diameter of the coil (and collar), and T_{coil} is the average temperature of the coil in contact. Similarly, h_{coll} is the heat transfer coefficient between the collar and annulus, and T_{coll} is the average temperature of the collar in contact. For the beam tube term h_{bt} is the heat transfer coefficient between the beam tube and annulus, D_{bt} is the outer diameter of the beam tube, and T_{bt} is the average temperature of the beam tube in contact with the annular helium.

RESULTS

This algorithm has been used to predict the steady state temperature profile of a hypothetical QL1 quadrupole, the final focusing quadrupole nearest the interation point. The heat load due to the hadronic and electromagnetic cascade on the 15 m long QL1 is approximately 50 W, which is the highest heat load of any accelerator magnet in the SSC. Preliminary heat load data for QL1 is available[1] that varies both radially and azimuthally as shown in Table 1. The heat load is strongly peaked at the lead end of the magnet, farthermost from

Table 1. Heat deposition data for the QL1 magnet (W/kg).

axial distance from lead end	0-3 m	3-6 m	6-9 m	9-12 m	12-15 m
beam tube	1.798×10^{-1}	1.728×10^{-1}	1.486×10^{-1}	1.228×10^{-1}	1.050×10^{-1}
inner coil/collar	1.290×10^{-1}	1.240×10^{-1}	1.066×10^{-1}	8.810×10^{-2}	7.536×10^{-2}
outer coil/collar	4.050×10^{-2}	3.894×10^{-2}	3.348×10^{-2}	2.767×10^{-2}	2.366×10^{-2}
collar/yoke	6.306×10^{-3}	6.064×10^{-3}	5.213×10^{-3}	4.308×10^{-3}	3.684×10^{-4}

the interaction point, which is also the helium inlet end. A helium mass flow rate of 0.1 kg/s is used.

Figure 1 shows the annular helium temperature and the average inner coil temperature for two cases in which the bypass diameter is either 3.2 cm or 2.25 cm. The primary effect of changing the bypass diameter is to redistribute the mass flow so that more helium goes down the annular space. For the 3.2 cm bypass the annular mass flow rate was 0.0056 kg/s, with a total pressure drop of 42 MPa, whereas the 2.25 cm bypass resulted in an annular mass flow rate of 0.0129 kg/s and a total pressure drop of 206 MPa.

The model predicts that for a 3.2 cm bypass the maximum temperature rise in the inner coil is 0.70 K, which leaves the magnet with an unacceptably low quench margin, 0.3 K to 0.7 K, depending on the inlet helium temperature supplied by the cryogenic system. Increasing the annular helium flow by decreasing the bypass to 2.25 cm results in a peak inner coil temperature rise of 0.51 K, a significant improvement in performance. Better performance is achieved principally because of the larger mass flow which keeps the annular helium temperature below the temperature of the inner coil.

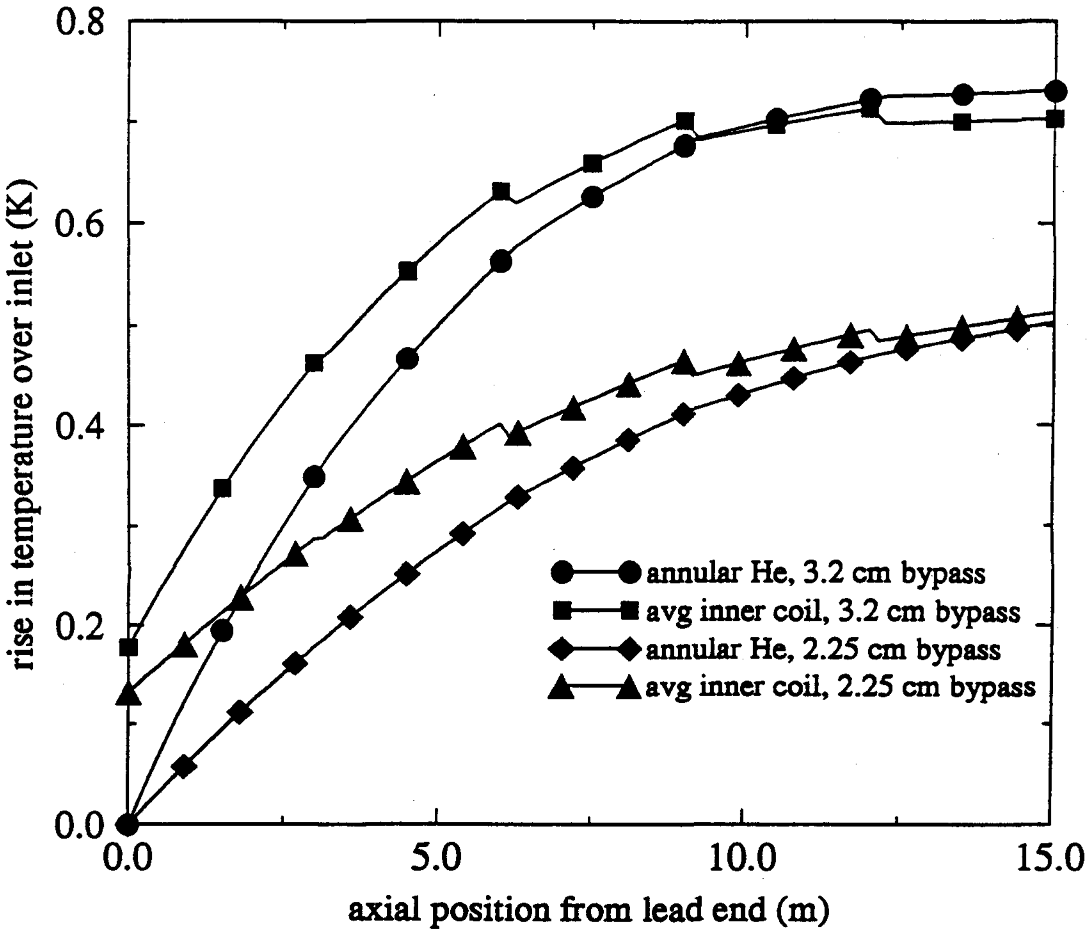


Figure 1. Inner coil average temperature versus axial position for a 3.2 cm diameter bypass and a 2.25 cm diameter bypass. Also shown is the annular helium temperature versus axial position for each case.

This method is being extended to allow analysis of alternative cooling designs such as cross-flow cooling and multiple bypass channels for use in QL1.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the valuable contribution of Dr. Bulent Aksel to this work.

REFERENCES

1. N.V. Mokhov, R. Schermer, and R. Stiening, private communication, June 4, 1991.