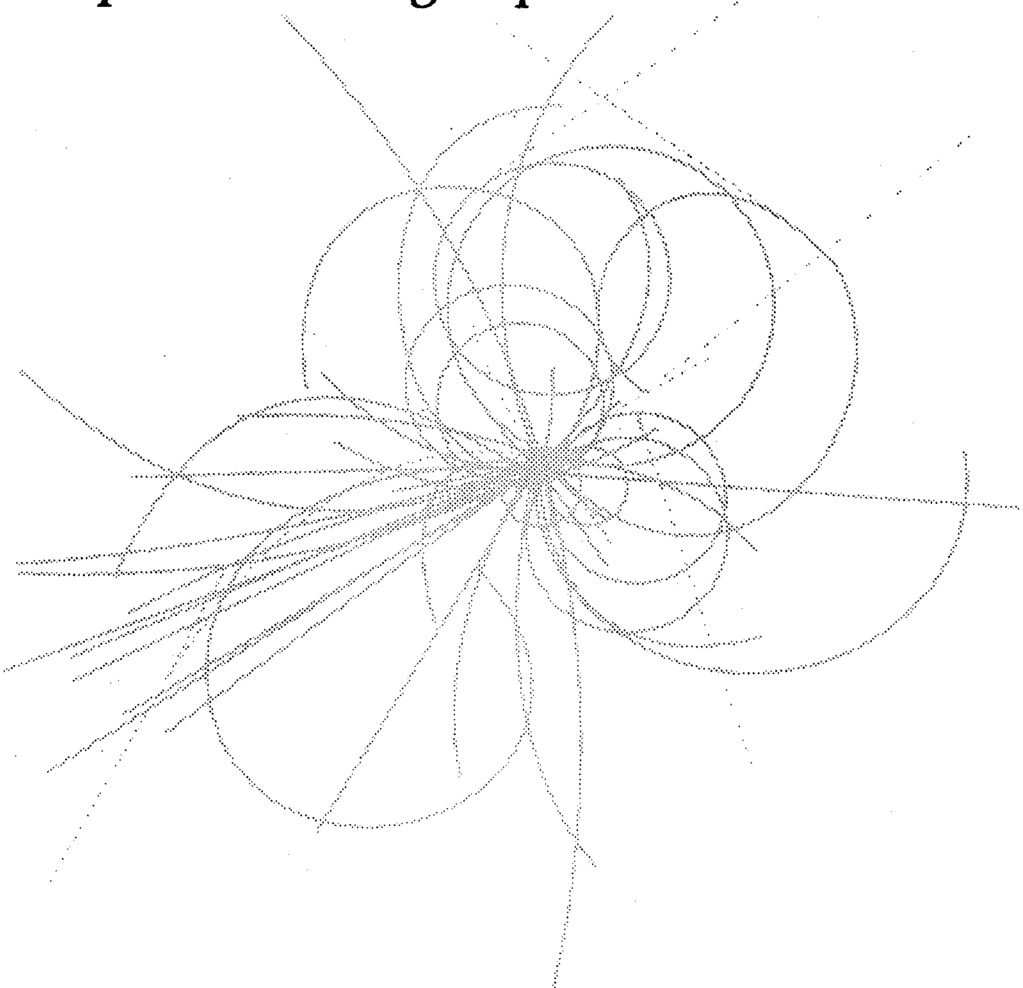
SSCL-Preprint-59

SSCL-Preprint-59

Superconducting Super Collider Laboratory



Analytical Study of the Thermal Insulation System in the Interconnect Region of the SSC Collider Magnets

A. R. Jalloh and D. Baritchi

March 1992

To be published in *Supercollider 4*

SSCL-Preprint-59

Analytical Study of the Thermal Insulation System in the Interconnect Region of the SSC Collider Magnets*

A. R. Jalloh and D. Baritchi

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

March 1992

---

*Presented at the International Industrial Symposium on the Super Collider, New Orleans, March 4-6, 1992.

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

ANALYTICAL STUDY OF THE THERMAL INSULATION SYSTEM IN THE INTERCONNECT REGION OF THE SSC COLLIDER MAGNETS

A. R. Jalloh and D. Baritchi

Magnet Systems Division
Superconducting Super Collider Laboratory*
2550 Beckleymeade Ave.
Dallas, TX 75237

ABSTRACT

The superconducting nature of the Superconducting Super Collider (SSC) collider magnets requires extremely low operating temperatures. As a consequence, a heat leak budget with very stringent tolerances must be maintained during operation. Violating the heat leak budget could result in loss of superconductivity and quenching of the magnets. To ensure that the magnets operate at the appropriate temperature levels, the interconnect region should be maintained at similar operating temperature levels. To this end, a very efficient thermal insulation system is required in the interconnect region. This study presents a finite-element model of the insulation systems in the interconnect region that serves as a tool to investigate the thermal efficiency of candidate insulation system in the interconnect region. Temperatures predicted by the model showed good correlation with experimental results.

INTRODUCTION

The interconnect region (ICR) links the cryostats of two adjacent magnets of the SSC particle beam accelerator.[1,2] The insulation system in the ICR is similar to that in the cryostat. It consists of heat shields, multilayer insulation (MLI) blankets, and cryogenic pipes. A cross-sectional view of the dipole magnet that connects to the ICR is shown in Figure 1. The ICR cross section has to match this exactly, except for the re-entrant support post. An elevation view of the ICR is shown in Figure 2. This shows the cryogenic pipes and their connections to two neighboring magnets. The vacuum vessel, heat shields, and insulation blankets have been removed from the figure for clarity.

Extremely stringent heat leak budgets must be maintained in the SSC collider ring magnets to ensure that the operating temperatures of the magnets do not exceed the 4.25 K

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

threshold. If this threshold is exceeded, superconductivity is lost and quenching of the magnets occurs. A poorly insulated ICR could become a convenient route for heat to flow into the magnets from the outside, where the nominal temperature in the tunnel is about 300 K. Therefore, a highly efficient insulation system is required not only in the magnets but also in the ICRs. Several candidate insulation components and systems may have to be evaluated before a final design is adopted. This would require much effort and time if it were done empirically, since each component change would require a complete assembly and test of the entire system. A computer model of the system will considerably reduce the effort and time required to evaluate the relative performance of components and systems.

In the present study, a heat transfer, finite-element computer model of the ICR insulation system was developed and analyzed. The model accounted for conduction and radiation heat transfer only. Residual gas conduction could not be accounted for because the software used in the development and analysis of the model does not lend itself to handling this phenomenon. The model also included the thermal effects of the fluid flow in the cryogenic pipes. Only one insulation system was analyzed because of the lack of additional MLI thermal data. Temperature distributions throughout the ICR were obtained. Average temperatures on the exposed surfaces of the MLI and heat shields are presented as the evaluation parameter. The temperature distribution for a different insulation system, say different MLI blankets, would result in different average temperatures on the surfaces. The more efficient system then would be the one that results in lower average temperatures.

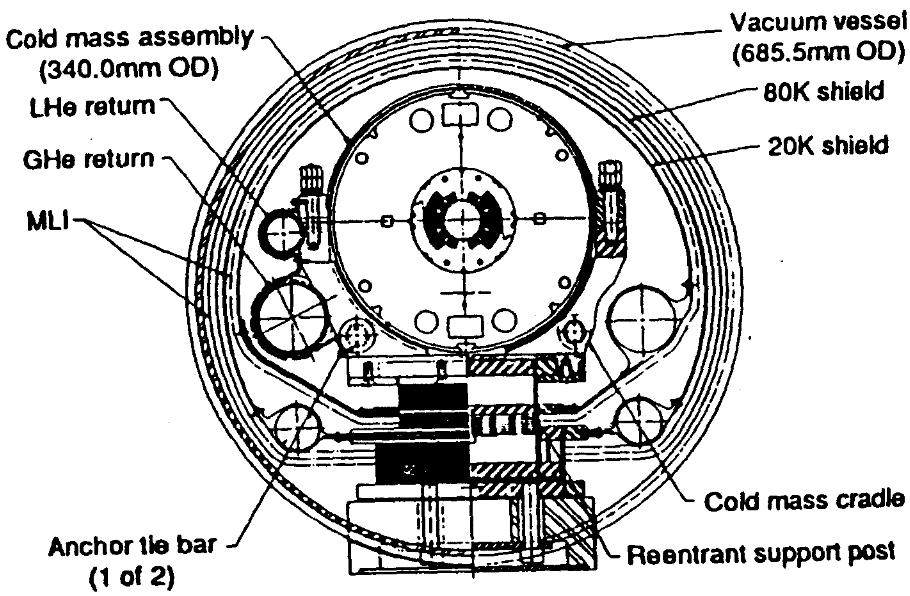


Figure 1. 50-mm Collider Dipole Cryostat Cross Section.

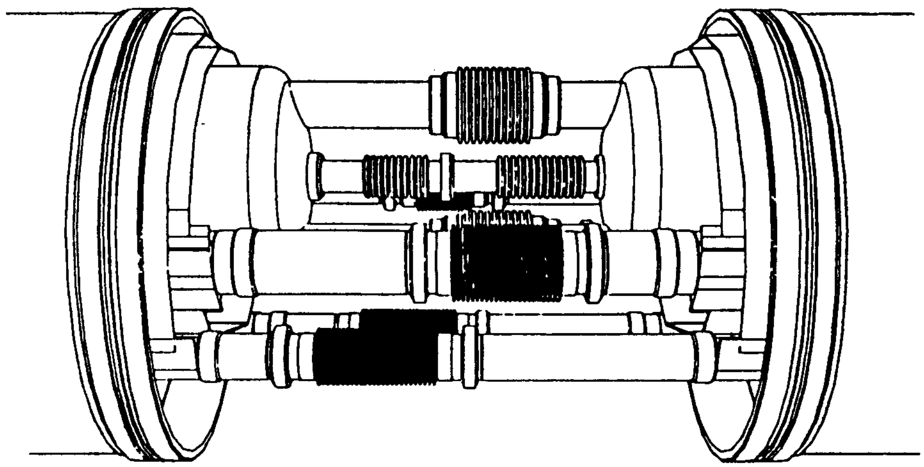


Figure 2. Interconnect Region (elevation view).

MODEL DEVELOPMENT AND ANALYSIS

The major components of the collider magnets ICR are the heat shields, MLI insulation blankets, vacuum vessel, the protrusions of the cold masses, and the cryogenic pipes[1,2] as shown in Figures 1 and 2. Heat flows from the tunnel by conduction through the vacuum vessel wall and by radiation from the inner surface of the vacuum vessel to the outer surface of the 80-K MLI. Conduction takes place through the MLI and 80-K heat shield. Then radiation occurs from the inner surface of the 80-K shield to the outer surface of the 20-K MLI. Conduction occurs through the MLI and 20-K shield. Finally, radiation takes place between the inner surface of the 20-K heat shield and the outer surfaces of the cold mass protrusions and the cryogenic pipes. It should be noted that liquid and gaseous helium and liquid nitrogen flow through the cryogenic pipes to cool the magnets. In addition to these modes of heat transfer, there is residual gas conduction that results from the fact that a perfect vacuum in the cryostat cannot be achieved. This mode of heat transfer was not represented in the model because of software limitations.

The interconnect region was modeled by the finite-element method and analyzed using ANSYS, a commercial finite-element program.[3] The basic conduction and radiation equations of heat transfer[4,5] are used to develop the finite elements. The flow in each pipe was investigated to determine whether it was laminar or turbulent before an appropriate design correlation was applied. Laminar flow was modeled by an empirical correlation, and turbulent flow was modeled by the Petukhov-Popov design correlation for turbulent flow.[5]

A three-dimensional, eight-node heat transfer element, ANSYS element stif70, was used to model conduction through the vacuum vessel wall, heat shields, and MLI blankets. The apparent thermal conductivity of the MLI was used in the analysis. Stif57, the ANSYS thermal shell element with four nodes, was used to model the radiating surfaces. The procedure for handling radiation in ANSYS consists of developing a radiation super-element from the geometry and material properties of the elements of the radiating surfaces. A section of the finite element mesh is shown in Figure 3. All thermal properties were input as temperature-dependent quantities. The analysis was highly non-linear because of the quartic nature of the temperature term in the heat transfer equation. A steady state analysis was carried out since it represents the worst-case scenario. Model development and analysis was carried out on a SPARCstation 2.

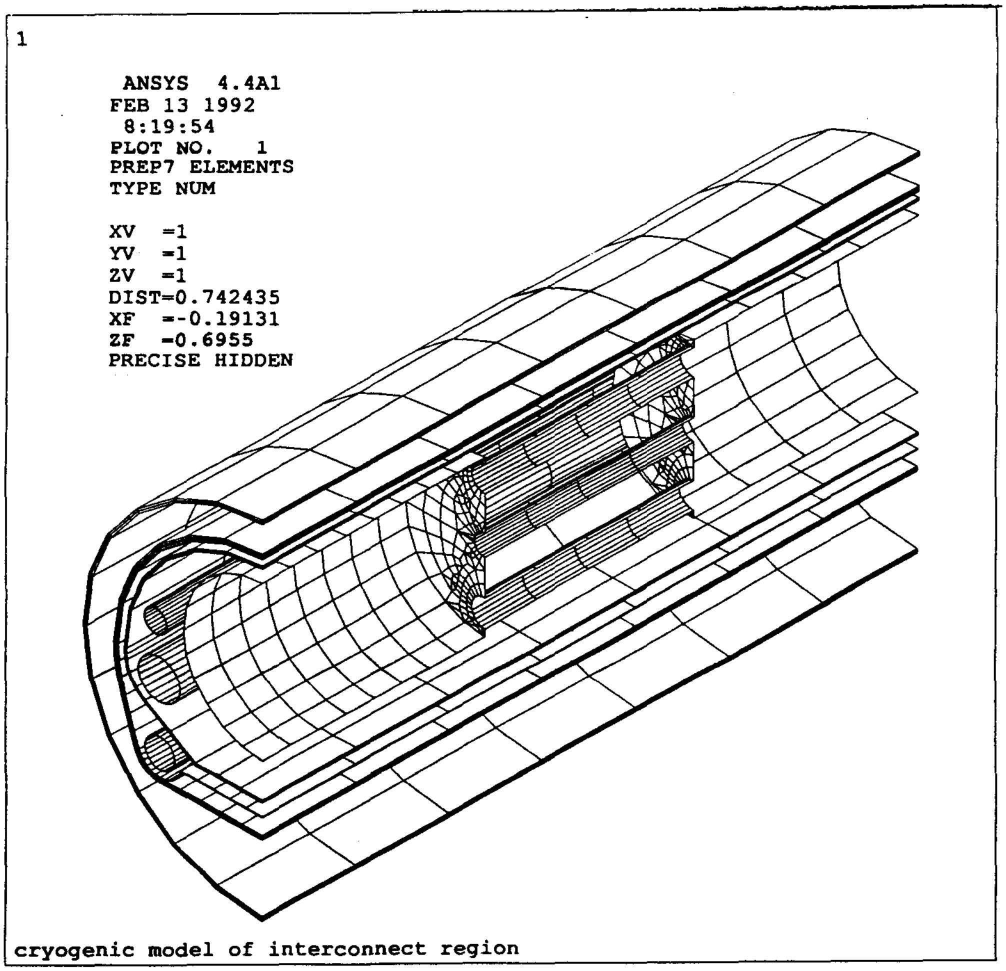


Figure 3. Finite Element Mesh of the Interconnect Region.

RESULTS AND DISCUSSION

Temperatures predicted by the model were compared with experimental data obtained from the Fermi National Accelerator Laboratory ER Dipole String Test.[6] There is very good correlation between the experimental data and the analytical data obtained by the model. The differences could be due to the fact that residual gas conduction was not included in the model and because the thermal conductivity of the MLI used was the apparent value. A more rigorous analysis that treats the MLI blankets as several layers of insulation instead of a bulk material could yield a better correlation. Finally, another reason for the slight discrepancies between the experimental and analytical results could be due to the fact that the cooling effects of the cryostats and insulation systems of the magnets that attach to the ICR were not considered.

Table 1. Comparison of experimental and analytical temperatures on exposed surfaces of MLI and heat shields in the interconnect region insulation system.

Component	Experimental Data (K)	Analytical Data (K)
80 K MLI	275	262
80 K Heat Shield	136	121
20 K MLI	32	29
20 K Heat Shield	18	21

This model would be very useful in carrying out comparative analysis using several different insulation systems and studying the resulting insulation efficiency. This was not done in the present study because thermal data for MLI, other than that used in this model, was not available.

SUMMARY

A finite-element heat transfer model of the interconnect region of the SSC collider ring magnets was developed and analyzed using ANSYS. The model considered only solid conduction and radiation between the exposed surfaces of the insulation system. Residual gas conduction could not be represented in the model because of software limitations. The MLI blankets were modeled with their apparent thermal conductivity. The cooling effects of the magnets that attach to the interconnect region were not included in the analysis. A steady state analysis was carried out since it represents the worst-case scenario. The results showed good correlation with experimental data. This model could be used to compare the thermal efficiencies of various insulation systems by varying the appropriate parameters in the model and carrying out the analysis.

REFERENCES

1. Superconducting Super Collider Laboratory, "Site-Specific Conceptual Design," SSCL-SR-1056, July 1990.
2. D. Baritchi, T. Nicol, and W. Boroski, "Conceptual Design for the Thermal Bridges and Multilayer Insulation in the Interconnect Region for the SSC," *SuperCollider 3*, Plenum Press, 1991.
3. F. Kreith, and M. S. Bohn, *Principles of Heat Transfer*, Harper & Row, 1986.
4. B. V. Karlekar, and R. M. Desmond, *Heat Transfer*, West Publishing Company, 1982.
5. G. J. Desalvo "ANSYS Engineering Users Manual," SASI, Houston, PA, 1989.
6. FNAL ER Dipole String Test Results, 1991.