IEEE Transactions on Nuclear Science, Vol.NS-22, No.3, June 1975

THERMAL CONDUCTANCE MEASUREMENTS OF MECHANICAL SUPPORTS FOR SUPERCONDUCTING MAGNETS

M. Kuchnir and P. Sanger
Fermi National Accelerator Laboratory*
Batavia, Illinois

Introduction

The space confinement and warm iron shielding envisioned for the superconducting magnets of the Fermilab Energy Doubler impose high demands on the insulating support system with regard to stiffness and thermal conductance. In order to adjust the minimum heat load to a reasonable refrigeration power a study of the heat conduction through the support was undertaken. The use of multilayer insulation can reduce the infrared radiation load to a small fraction of the conduction load. This study involved the design of several possible supports, steady-state thermal analysis calculation for two supports, and the development and use of a new method for measuring their thermal conductances. In this contribution we stress the thermal conductance measurements.

Support Description

In the present magnet configuration the radial space available for vacuum insulation is limited by two concentric cylinders, the inner one at liquid He temperature with 13.72 cm OD and the outer one at room temperature with 20.32 cm ID. Piped He gas is available in this space for cooling heat interceptors to temperatures near 20K. The general shape of the supports tested is shown in Figure 1, a split ring with protrusions outwards contacting the wall at room temperature and inwards pressing the liquid He temperature tube.

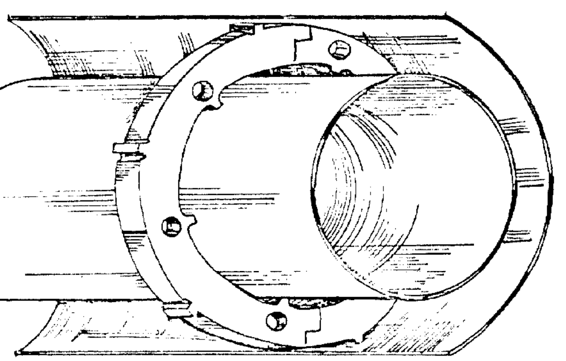

Fig. 1. Sketch of the six protrusions model support.

Holes are provided for contact to heat interceptors and the passage of their He gas piping. The ring dimensions are such that both at room temperature and at operating temperatures the support is always under a stressed condition so as to keep the magnet properly centered. The axial thickness of the support is determined by the desired modulus: 1.9 cm for model G10-2 and 1.27 cm for model G10-3.

Calculation

A computer analysis of the support was made using a Nodal Network Thermal Balance Program.[1] The support and the multilayer insulation were simulated by a set of a few hundred nodes. Each node connected by thermal conductances to every other node with which it exchanges energy; the energy exchanges being by both conduction and radiation. Some nodes act as energy sources or sinks. An energy balance equation is set up for each node whose temperature is unknown. The computer program solves the resulting set of simultaneous equations for the nodal temperatures; it also computes the energy transfers through each conductance so that relevant heat transfers are readily available. The conductances used are functions of temperature[2]; therefore, during the iterative solution process, the coefficients in the set of equations underwent changes. The effects of relatively simple changes in the geometry of the support on its thermal performance were predicted. Such studies are usually sufficient when a limited number of supports are considered. In our case, however, a few thousand supports are to be used and the actual performance of an individual support should be measured as a safeguard against the unavoidable assumptions involved in the calculation. A good knowledge of the performance of this critical element of the magnet cryostat should prove invaluable later on in the minimization of the total heat load.

Method

The method developed to measure the thermal resistance R_2 of the insulating support between the heat interceptors and the wall at liquid He temperature is based on thermal conductivity measuring techniques.[3] The cooling of the heat interceptors is accomplished by a calibrated copper strap. The thermal-resistance of the combined system (copper strap in parallel with R_2) is measured by electrically heating the heat interceptors and recording their temperature change. In a graph of interceptors temperature versus electric heating the slope at a given temperature is the thermal resistance of the combined system, from which we calculate R_2 using the formula for 2 resistors in parallel and the known (actually, independently measured) thermal resistance of the copper strap. In general the R_2 thus obtained is good only at one temperature; however, if the thermal conductivity of the material involved is temperature independent, as happens in our case[2] for temperatures below 60K, this value of R_2 can be used for calculating heat loads into the liquid He for interceptors temperatures below 60K. It should be pointed out that this method discriminates conduction heat from radiation heat. The effect of the thermal resistance R_1 of the insulating support between the heat intercepts and the wall at room temperature on R_2 is negligible to the first approximation.

The actual set up involves: (1) attaching the support with parts that simulate the outer wall, T_R, and the interceptors or shield, T_S, to a cold finger that simulates the wall at He temperature, T_H, as indicated in Figure 2, and (2) properly instrumenting these parts with heaters and thermometers. Therefore, the measurements are carried out in the vacuum space of a very simple dewar and the interpretation is guided by the thermal circuit shown in the insert of Figure 2. A good experimental value for R_1 can be obtained by adjusting the power Q_1 into the heater of T_R to a value that keeps it at the temperature of the dewar wall. Then R_1 will be given by $R_1 = (T_R - T_S)/Q_1$ where the labels T_R amd T_S have been used to indicate the temperature of the parts they represent. Infrared radiation loading of T_S and T_H is minimized by use of multilayer insulation (not shown in Figure 2) and thus long-time

*Operated by Universities Research Association, Inc., under contract with the U. S. Energy Research and Development Administration.

constants are involved in this determination of R_1.

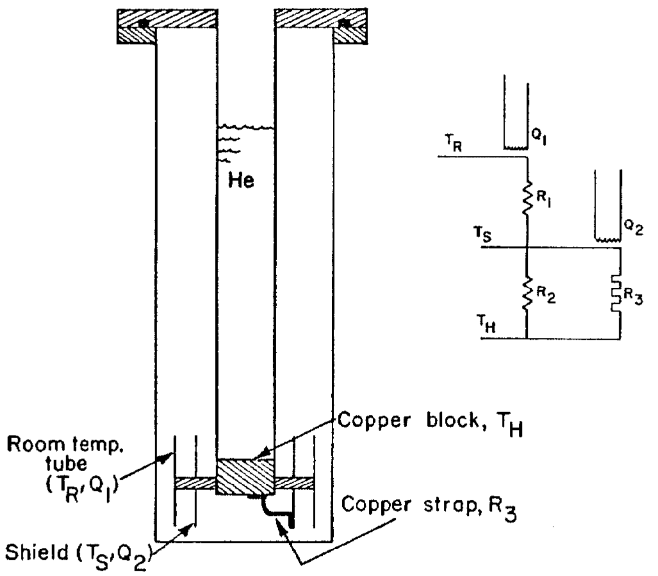

Fig. 2. Simplified drawing of the apparatus and related thermal circuit.

Results

Computer calculations and experimental data obtained from 4 different conditions are presented in Table I. The geometry of the 2 model supports used are similar to the one shown in Figure 1, except for the fact that one has four-fold symmetry instead of six-fold. Included with the thermal data is a modulus parameter[4] related to the mechanical strength of the support. Later mechanical tests determined that six-fold symmetry would be required to achieve the necessary strength modulus. The experimental data, defined throughout the text, is used to present the results in terms of the heat loads that the measured thermal conductances (R_1 and R_2) would conduct to interceptors at 20K and to the wall at 4.2K assuming the room temperature wall at 300K. The use of Indium gaskets at contact surfaces allows us to compare the experimental results with the computed calculated data. We recently measured the thermal conductivity of the fiberglass epoxy (G10) material actually used and found it to be different (larger by factors like 1.3 at 20K, 3.0 at 90K) from the one used in the calculations.[2] With this correction the agreement is expected to be excellent. The thermal resistance to the 4.2K wall is very sensitive to the positioning of the interceptors and is responsible for the small value of R_2 in the model G10-3. Electrical analogical simulation of this region[5] of the support leads to this conclusion. From these results we can conclude: (1) that the computer calculations give valid results if the contact resistances can be well determined as seen in case G10-2-1, (2) that contact resistances actually cause dramatic changes in the thermal resistances of the support, and (3) that proper aluminization of the support above the interceptor temperature improves substantially the thermal resistance to room temperature (as seen by the values of T_S and R_1 between G10-2-2 and G10-2-3); while aluminization at the low temperature portion might be detrimental.

Acknowledgement

We would like to acknowledge R. J. Houkal's contribution in the preparation of the set up for the measurements and help in the data taking.

References

1. R. B. Jacobs, unpublished.
2. F. H. Schwartzberg, et al., "Cryogenic Materials Data Handbook" (revised), Vol. 2, p. 418, July 1970, AD713620, NTIS, Springfield, VA 22151
3. M. Kuchnir, "Method for Measurement of Thermal Conductance," submitted to 1975 Cryogenic Engineering Conference, July 22-25, Kingston, Ontario.
4. The authors are indebted to G. Biallas for these values.
5. M. Kuchnir, Fermilab Internal Report, unpublished.

TABLE I

Support Model and Condition	G10-2-1	G10-2-2	G10-2-3	G10-3
Number of Symmetric Protrusions	4	4	4	6
Special Treatment	Contact Using Indium Gaskets	None	Glazed and Aluminized	Glazed and Aluminized
Experimental Data				
Q_1 (watts)	3.7	2.85	2.15	2.74
T_S (Q_2=0)(K)	25.2	27.8	17.9	27.2
R_2 (K/w)	87.8	316.0	112.0	37.6
R_1 (K/w)	75.1	92.1	128.0	97.9
Modulus (lb/mil)	50.7	50.7	50.7	132.0
Heat Load into 4.2K wall (watts)				
Calculated (Ref. 1)	.13	-	-	-
$(20-4.2)/R_2$	.18	.05	.14	.42
Heat Load into 20K Intersepts (watts)				
Calculated (Ref. 1)	2.6	-	-	-
$(300-20)/R_1$	3.55	2.99	2.05	2.44