MASTER

HEAT-LOAD MEASUREMENT OF PROTOTYPE CRYOGENIC MAGNETS AND LEADS
FOR THE ISABELLE PROJECT*

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DISCLAIMER

INTRODUCTION

A major feature in the cryogenic system development program for ISABELLE is the measurement of the heat loads of prototypical hardware. In particular, superconducting magnet assemblies, magnet power leads and magnet power lead vessels have been measured. In each of these cases it has been possible to build equipment which has a heat load equal to or less than the allowance for it in the heat load budget.

DESCRIPTION OF TEST BED

The test bed for heat load measurement consists of two "instrumented ends," flow meters and a 100 Watt helium refrigerator. The heat loads are determined by application of equation (1) for steady state conditions.

$$q = \dot{m} (h_2 - h_1) \quad (1)$$

where,

q = rate of heat transfer
 h_1 = inlet enthalpy

$\dot{m}$ = mass flow rate
 h_2 = outlet enthalpy

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Values of h_1 and h_2 are calculated from the relationships given in NBS 631¹ using the measured values for pressure and temperature at each point.

The "instrumented ends" are vacuum-jacketed vessels which contain high accuracy cryogenic thermometry.² One "end" is placed at the inlet to the load, the other at the outlet. Much of the ISABELLE hardware has a heat shield which operates at a nominal temperature of 55K. In order to accommodate the dual temperature requirement, two sets of circuits and instrumentation can be used in each "end". An electric heater system is located in the helium flow following the low temperature part of the load and it is used to raise the helium temperature to the shield temperature.

After the helium gas passes through the heat shield, its temperature is measured and it then exits from the "instrumented end," passes through a heater which brings the temperature to ambient and then through a flow meter and returns to compressor suction.

A photograph of an instrumented end is shown in Figure 1. The photograph was taken during the initial construction. The instrumented end is in the foreground. Located just behind it can be seen the magnet to be measured. The large line coming from the center of the vacuum tank is the connection for vacuum pumping. At either side are vacuum-jacketed bayonet connections and the lead-through for instrumentation wiring is in the upper center region. The flange on the far side in this picture is a flat plate and is changed (or replaced) as required to adapt to the vacuum tank of the equipment to be measured.

The flow rate through this apparatus is controlled so that a temperature rise of about 1K is observed across the load. Typically this results in about 1 g/s of flow when a magnet is being measured. A large temperature difference is desirable so that temperature measurement errors are small by comparison. Operation must be arranged so that only single phase fluid exists in the apparatus when measurements are being made. This is accomplished by operating above the critical temperature.

At all locations where the temperatures measured are used to calculate the heat load, redundant temperature sensors (either two or three) are installed. This allows some estimate of the measurement error at each point and permits easy identification of sensor drift and most types of failures. A further check of the temperature sensors was performed by flooding the apparatus with boiling liquid and comparing the offsets from the equilibrium temperature at the observed vapor pressure. Usually agreement within $\pm 0.05K$ could be attained. The best of the

Fig. 1. Instrumented End During Construction

redundant sensors were then chosen to be used in the property calculations and the offsets are entered as corrections to observed temperatures. A period of about seven days is required for a magnet to reach thermal equilibrium. A magnet was said to be at steady state when no temperature change greater than 0.2K was observed in a 24 hour period. A typical test would consist of taking readings at half hour intervals for 24 hours. A computer program was used to calculate the helium properties at each point and the magnitude of the heat load. The standard deviation from the mean of all readings taken at a point was also calculated and used as a guide to the consistency of the procedure.

TEST RESULTS

Dipole Magnets

A series of tests were run to examine the heat load characteristics of a prototypical ISABELLE magnet. One study was to determine the heat load as a function of insulating vacuum quality. Two loads are measured, the primary and the secondary. The primary load is the load at approximately 4K. The secondary load is the heat shield at 55K. The results for two test periods in April and June of 1978 are shown in Figures 2 and 3. The same dipole magnet was used in both runs.

Figure 2 shows the measurements for the primary load. The good agreement between data from the two runs indicates adequate repeatability for this method of heat load measurement. The error bars shown are drawn to scale and indicate one standard deviation above and below the mean heat load measured at a particular level of vacuum. For groups of 20 to 50 readings, standard deviations of 0.25 to 0.50 Watts were observed. The goal is for each magnet to have a heat load of less than 4.6 Watts when the insulating vacuum is 10^{-4} Torr. The measurements indicate that this goal was achieved.

Figure 3 shows the measurements for the secondary load. The data from the April run showed that the magnet exceeded the desired design heat load. The insulation was reworked and the magnet retested in June. The June data shows that the reworked insulation system was good enough to meet the heat load allowance (11 Watts) for the heat shield.

Fig. 2. Dipole Magnet Primary Heat Load

Fig. 3. Dipole Magnet Secondary Heat Load

Table 1 shows our estimate of the source of the heat loads measured. We cannot measure each of these loads separately to verify this breakdown, so the values shown are somewhat speculative except for the total.

	Allowed Dipole Load Watts	
	4K	55K
Insulation-radiation and conduction @ 10^{-4} Torr	3.0	9.0
Supports	0.3	0.5
Connecting Piping	0.8	1.5
Instrumentation	0.5	-
Total	4.6	11.0

Table 1. Dipole Magnet Design Heat Load Allowance

Heat Shield

This heat load measurement apparatus was also used to study the feasibility of inserting a heat shield between the warm and cold bore tubes of the magnets. In the ISABELLE design, which is shown in Figure 4, the beam circulates in a 9.3 cm diameter room temperature tube (the "warm bore tube"). Only a 1.03 cm wide annulus separates that tube from another tube (the "cold bore tube") which is at a temperature of approximately 4K. These tubes are about 5m in length.

4250A magnet power lead. A total of 7 leads were tested. Two leads just met the allowance. Three leads were essentially right on the design values. Two leads were 20% over the design allowance and were rejected. Variation in performance was caused by variation in the interference fit between the copper conductor and its stainless steel tube sheath. Redesign and implementation of tight quality control during manufacture has eliminated this problem.

	Conduction (W)	Mass Flow (g/s)	Total Equivalent Load (W)
Calculated Heat Load	6.1	0.24	19.1
Design Allowance	7.4	0.29	22.9
Measured Heat Load	5.1	0.25	18.6 $\pm$ 2.01

Table 3. Thermal Performance of a Single 4250A Power Lead

The design of the 100A power leads for ISABELLE incorporates "bundles" of leads. In this space-saving innovation, 12 leads are grouped together and share a common helium gas flow. The leads are, of course, electrically insulated. These have come to be known as "12 x 100A" bundles. Several of these bundles have been tested and all were well within the design heat load allowance for them. The results are presented in Table 4.

	Conduction to 4K (W)	Mass Flow (g/s)	Total Equivalent Load (W)
Calculated Heat Load	1.65	0.066	5.2
Design Allowance	2.5	0.1	7.9
Measured Heat Load	2.0	0.073	5.9 $\pm$ 1.0

Table 4. Thermal Performance of a 12 x 100A Power Lead Bundle

COMMENTS

This highly versatile package with its accurate instrumentation has proven useful in the development of equipment which meets the heat load requirements for ISABELLE. The resolution and repeatability available allow comparisons between different designs and a realistic evaluation of the overall expected heat load for ISABELLE.

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