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HEAT LEAK MEASUREMENTS FACILITY*

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ABSTRACT

Heat leak measurements of superconducting magnet suspension systems, and multilayer insulation (MLI) systems are important for the optimum design of magnet cryostats. For this purpose, a cryogenic test facility was developed having a versatile functional end in which test components of differing geometrical configurations can be installed and evaluated.

This paper details the test facility design and operating parameters. Experimental results of heat leak measurements to 4.5 K obtained on a post type support system having heat intercepts at 10 K and 80 K are presented. Included are measurements obtained while operating the 10 K intercept at temperatures above 10 K, i.e., in the 10-40 K range. Also reported is a description of the test facility conversion for a heat load study of several MLI systems with variations of MLI installation technique. The results of the first MLI system tested are presented.

INTRODUCTION

The Superconducting Super Collider (SSC) refrigeration requirements are very stringent and result in low heat leak budgets. The heat leak contribution of suspension systems, multilayer insulation, and other cryostat components must be understood for optimum cryostat design.

A program to measure the heat leak of various cryostat components was developed and is being implemented.¹ Critical to the measurement program is a liquid helium research dewar. The purpose of the dewar is to provide a facility that can be used to measure the heat load of various test samples and to evaluate their use for the SSC Cryostat Development Program.

LIQUID HELIUM RESEARCH DEWAR DESCRIPTION

The research dewar (illustrated in Figure 1 with a post type support installed) utilizes a functionally adaptable end that permits a wide variety of test geometries. Available within the functional end are temperature connections to 4.5 K, to a controlled intermediate temperature (regulated between 10-40 K), a connection to 80 K and to 300 K. Shown in

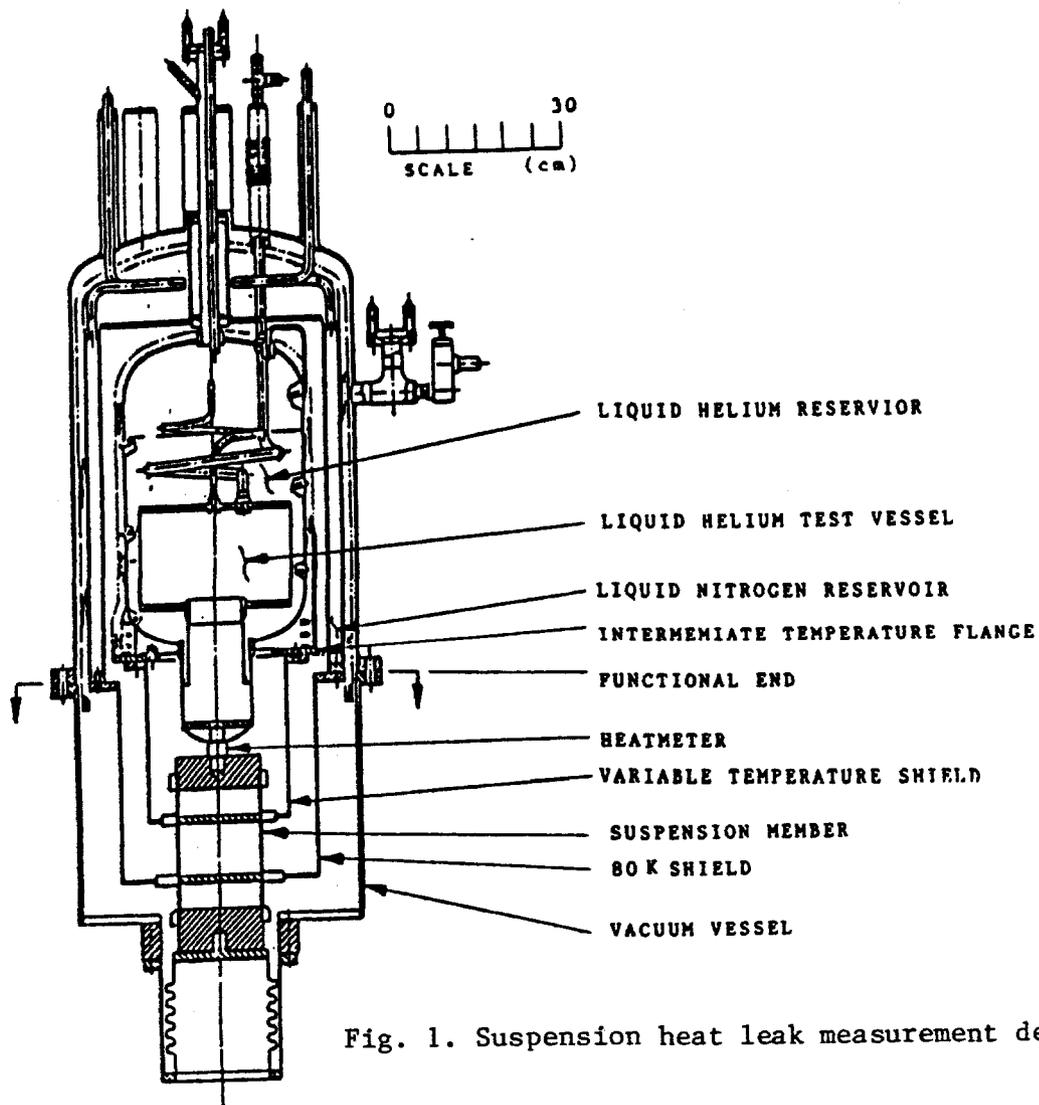


Fig. 1. Suspension heat leak measurement dewar

Figure 1 is the helium test vessel which provides the connection to 4.2 K helium. The vessel has a 10.6 L capacity and is equipped with redundant helium sensors to monitor liquid level. Heaters were installed within the liquid volume for calibration of boil-off measurements. Outside the test vessel and located near its spherical end are temperature sensors. Carbon resistors are used for measurements near 4.2 K and cryogenic linear temperature sensors (CLTS) for temperatures near 80 K.² A four lead wire system is employed. The sensors are connected in series with a current source whose polarity is manually controlled. 10 μ A of current is used for measurements near 4.2 K, and, for increased sensitivity, 100 μ A is used for temperature measurements near 80 K. Sensor voltage leads are connected to a high impedance data logger.

The helium reservoir encapsulates all but the lower end of the test vessel. The reservoir serves to reduce the heat load to the test vessel by bathing the test vessel in the liquid volume of the reservoir. The capacity of the helium reservoir is 26 L with a 16 L inventory above the test vessel. Helium liquid sensors monitor the level. Mounted to the outside of the reservoir are heaters that can be used to increase the boil-off rate of gaseous helium. The boil-off gas exits the helium reservoir through its main vent and also through a 6.35mm o.d. stainless steel tubing. Boil-off gas through the stainless tube provides cooling for the intermediate temperature connection.

The intermediate temperature connection consists of a copper flange to which the stainless steel tubing is soldered. Temperature control of the flange is accomplished by throttling the gas exiting the flange through a flowmeter. Circular heaters are imbedded in a groove in the

flange and carbon resistors and CLTS sensors monitor the flange temperature.

A 14.5 L capacity liquid nitrogen reservoir surrounds the helium reservoir, test vessel, and intermediate temperature flange. The nitrogen reservoir, which serves to shield thermal radiation to 4.5 K, also provides the 80 K connection for the test component. Automatic fill of the reservoir is maintained by a liquid nitrogen level sensor and liquid level controller.

The functional end vacuum closure provides the test component's 300 K connection to the facility. A bellows attachment to the vacuum vessel allows for thermal contraction of the test component and is sized to provide a compressive load, due to atmospheric pressure, on the test component. A heater and thermostat on the bellows pressure plate control the 300 K temperature connection.

Techniques for reducing radiant heat leak were used throughout the test dewar construction.³ Aluminum tape is used to lower the emissivity of the 4 K and 80 K surfaces. Superinsulation consisting of aluminized mylar with a fiberglass mat spacer is used as the facility's MLI. The insulating vacuum is initiated by a turbo-molecular pumping station. System vacuum is monitored by an ionization gage and controller which is read-out on the data acquisition data logger with each log entry.

HEAT LEAK MEASUREMENT METHODS

The primary method of determining heat leak in this facility is by means of a heatmeter.^{4,5,6} The heatmeter (shown in Figure 2) employs a thermally resistive reference section sandwiched between thermally conductive ends. For measurements to helium temperatures, a pair of carbon resistors sense the temperature across the reference section. When making measurements to 80 K, platinum resistors are used. A calibration heater is located at the warm end of the heatmeter. Calibration of the heatmeter is accomplished by calibrating the temperature difference across the reference section for a given heat flow through the meter as generated by the calibration heater.

Heat leak measurements by conventional gas metering methods are used as a back-up to the heatmeter. Boil-off from the test vessel is monitored by a helium mass-flowmeter and totalizer in series with a wet test meter.

The heatmeter has distinct advantages over the gas metering method in that: (1) the data acquisition time is greatly reduced, since reservoir

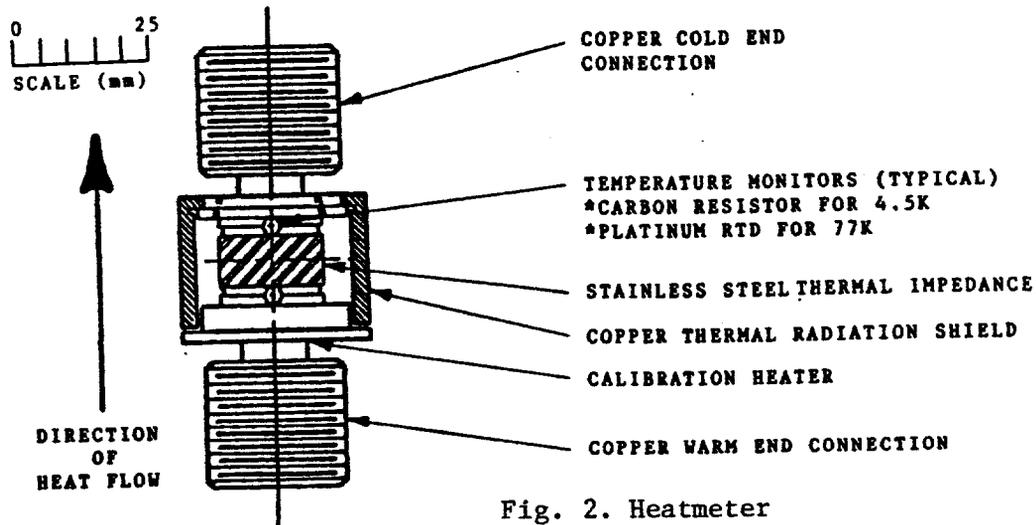


Fig. 2. Heatmeter

equilibrium is no longer necessary (as with the gasmeter)—only test sample steady-state is required; (2) the heatmeter is independent of any heat transfer between the helium reservoir and the test vessel; and (3) the resolution of the heatmeter is in micro-watts versus milli-watts for the gasmeter.

FACILITY OPERATION AND CALIBRATION RUNS

For ease of test component installation, and for convenience during cryogenic operations, the test dewar is supported on a trunnion base. A manually cranked gear box provides 360° of rotation of the test dewar. The trunnion allows the dewar to be locked in an inverted position for test component installation.

Engineering runs for operational shake-down of the facility were conducted and measurements were taken of the "no-load" or base-line heat leak to the facility's three cryogen containing vessels. Measurements were made by monitoring the boil-off from the vessels using a mass-flowmeter in series with a wet test meter. No test component was installed in the facility at the time of these measurements. The results are given in Table 1 along with an estimate of the no-load operational running time for each vessel.

Heatmeter calibration was performed at both liquid helium and liquid nitrogen cold end temperatures for the ranges of 0-3.0 watts to 80 K and 0-0.250 watt to 4.5 K.

FACILITY CONVERSION FOR MLI STUDIES

Conversion of the functional end of the test dewar for studies of multilayer insulation systems is illustrated in Figure 3. A copper cold plate is connected through the heatmeter to the test vessel. A hot plate, also of copper, lines the functional end vacuum can. Insulating spacers separate the liner from the vacuum can. The surface areas of both the cold plate and the hot plate are coated with a black paint to approximate a surface emissivity of 1. Cold plate temperature is monitored by carbon and platinum sensors. A calibration heater on the cold plate is also provided.

To limit thermal radiation to the cold plate from sources other than the hot plate, a guard plate is employed. The guard plate operates at 77 K and serves to trap-out extraneous radiation. Thermal communication between the cold plate and guard plate is reduced by superinsulation in the space between the two plates.

The hot plate temperature is controlled by using an electronic temperature controller. A 28 gage double Formvar coated copper wire is

Table 1 Helium Test Dewar Base-Line Heat Load

Vessel	Capacity (L)	Cryogen	No-Load	
			Heat Leak (W)	Running Time (Hrs)
Test Vessel	10.6	Liq. He ⁴	0.03	248
Helium Reservoir	26.0	Liq. He ⁴	0.7	27
Nitrogen Reservoir	14.4	Liq. N ₂	9.4	Automatic Fill

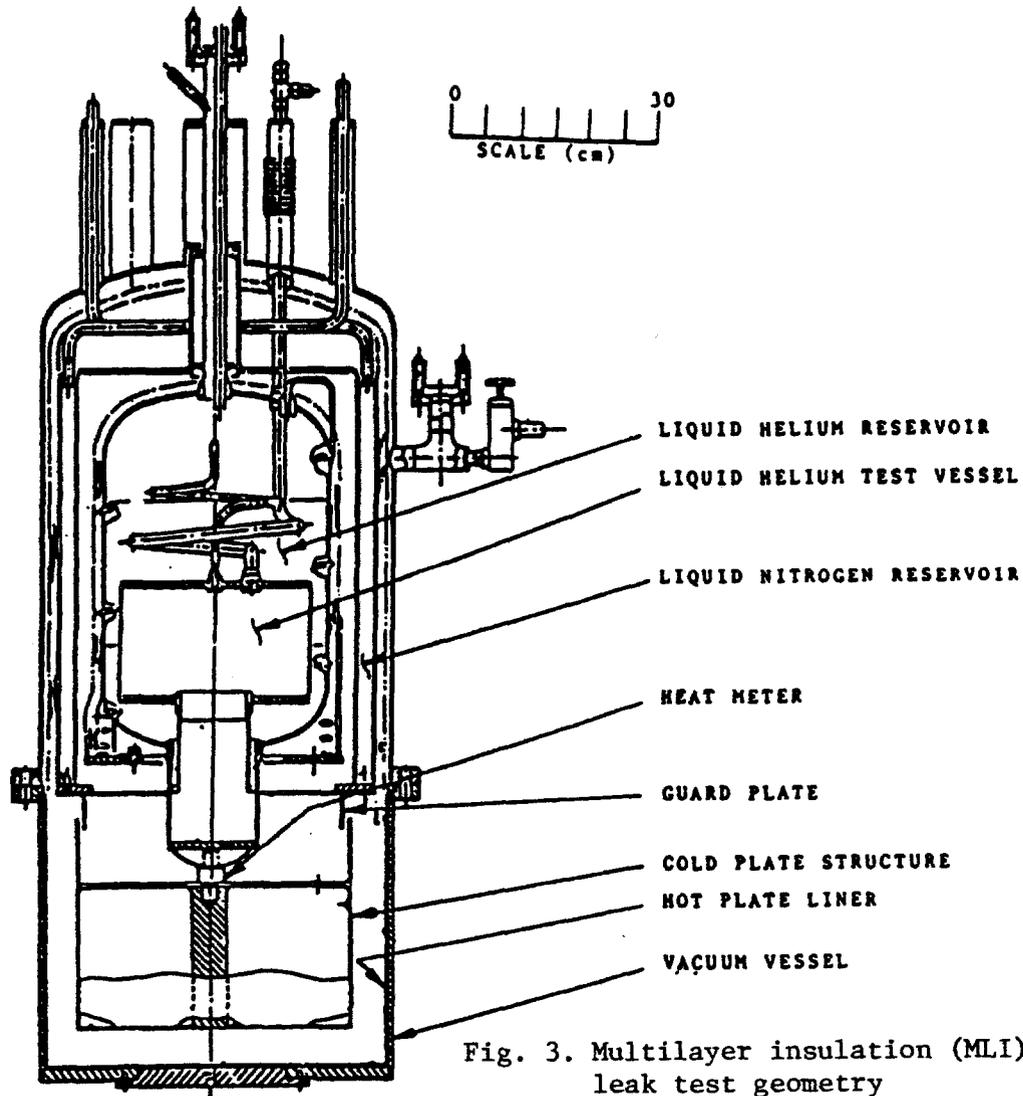


Fig. 3. Multilayer insulation (MLI) heat leak test geometry

used as the hot plate heater. The heater wire is wrapped in a 1.25cm pitched spiral groove around the outer cylindrical and flat bottom surfaces of the hot plate. A 36 gage double Formvar coated copper sensing wire is located midway between heater wire turns in a second spiral groove. The sensing wire provides an average temperature measurement of the hot plate for the electronic temperature controller. A platinum resistor monitors the steady-state temperature of the hot plate.

Qualitative heat leak measurements of an MLI system to 80 K are conducted with liquid nitrogen in the three test dewar reservoirs, and with a known thickness of MLI installed around the cold plate area. The "mean apparent thermal conductivity" or K-factor of the MLI is determined at cold plate with hot plate temperature equilibrium. By observing the plate temperatures, and the measured heat load of the cold plate, via the heatmeter, the K factor of the MLI can be derived from the relationship as given by Equation 1.

$$\bar{K} = \frac{Q\Delta X}{A\Delta T} \quad (1)$$

where, \bar{K} = mean apparent thermal conductivity ($Wcm^{-1}K^{-1}$)
 Q = measured cold plate heat leak to 80 K (W).
 A = cold plate test area = 5000 cm^2
 ΔT = hot plate minus cold plate temperature (K)
 ΔX = MLI thickness (cm)

polyester flat film with .025 cm random oriented fiberglass mat spacers. This system provided 20.5 reflective layers per centimeter and was fabricated in a blanket of eleven layers. This MLI system has been used successfully in a full section model cryostat as part of the SSC Cryostat Development Program.⁹

The MLI blanket was installed around the cylindrical portion of the cold plate test area using a single butt seam. Aluminized reflective polyester tape was used to close the seam on only the outermost reflective layer by taping along the direction of the seam. The circular flat bottom of the cold plate was covered using discs of MLI material. Individual reflective layers around the cylinder were overlapped onto a reflective disc, and secured in several places with reflective tape. The fiberglass mat in the blanket around the cylindrical area of the cold plate was trimmed to minimize overlapping of the spacer material as fiberglass discs were sequentially installed between reflective disc layers.

The MLI system was evaluated between 300 and 80 K. The mean apparent thermal conductivity (K-factor) was compared at three successive hot plate temperatures; i.e., 273 K, 288 K and 294 K which corresponded at thermal equilibrium to cold plate - hot plate temperature differences of 190 K, 205 K and 210.5 K, respectively. The mean apparent thermal conductivity remained constant at $6 \times 10^{-7} \text{Wcm}^{-1}\text{K}^{-1}$. Facility vacuum concurrent with the hot plate temperatures were 8×10^{-5} Torr, 1×10^{-5} Torr and 8×10^{-6} Torr, respectively.

Facility vacuum was isolated from the turbo-molecular pump and allowed to equilibrate for 23 hours. The mean apparent thermal conductivity was determined as the pressure equilibrated at 3.3×10^{-4} Torr. Gaseous nitrogen was then used to degrade the facility vacuum to 10^{-3} Torr. The system was allowed to equilibrate at 10^{-3} Torr for 50 hours before determining the K-factor. The facility vacuum was again degraded and allowed to equilibrate at 10^{-2} Torr for 48 hours. A plot of the results from these tests is shown in Figure 4.

CONCLUSIONS

A viable test facility has been established for measuring heat leak of SSC cryostat components. The test dewar functional end is adaptable to different test geometries at reasonable costs and modification times. The heatmeter is an accurate and expedient means of obtaining heat leak measurements to 80 K and 4.5 K. The excellent agreement of measured with predicted performance for the two components tested have confirmed component design concepts.

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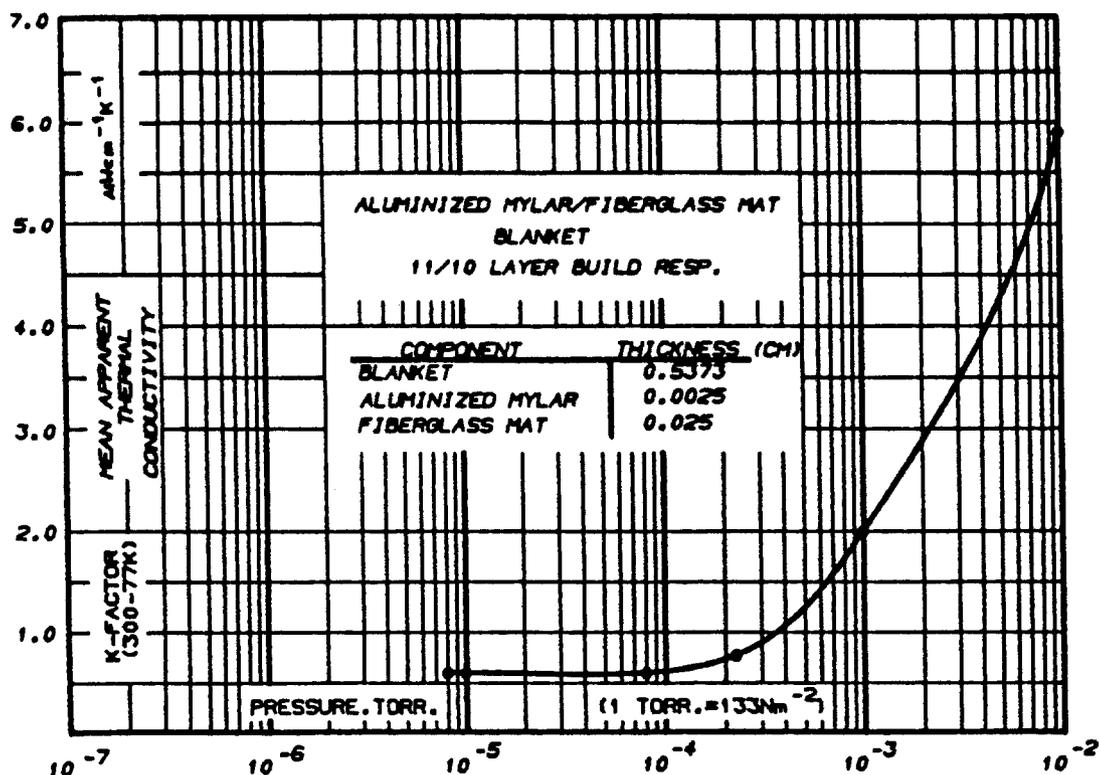


Fig. 4. Mean apparent thermal conductivity vs. pressure for fiberglass mat MLI

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