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PRECISION HEAT INLEAK MEASUREMENTS ON CRYOGENIC COMPONENTS AT 80 K, 4.2 K AND 1.8 K

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PRECISION HEAT INLEAK MEASUREMENTS ON CRYOGENIC COMPONENTS AT 80 K, 4.2 K AND 1.8 K

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We have built and are operating a test bench for precision heat inleak measurements and thermal qualification of components for the superfluid helium cryostats of the CERN Large Hadron Collider (LHC) project. The bench features the three temperature levels used for heat interception in the LHC cryostats. The heat loads are measured using both calibrated thermal conductances ("heatmeters") and standard boil-off methods. After validation of the measurement methods, we compare experimental results with thermal design calculations on a prototype magnet support post.

INTRODUCTION

CERN, the European Laboratory for Particle Physics, is conducting development work in view of its next high-energy particle accelerator, the Large Hadron Collider (LHC), to be installed in the 26.7 km circumference tunnel of the existing LEP machine. Key technologies for this project include high-field superconducting magnets operated in superfluid helium below 2 K [1]. The technical feasibility of the LHC cryogenic system depends critically on the ability to design, construct, mass-produce and install several thousand cryomagnets with a reasonably low heat budget [2]. To achieve this, the LHC cryostats feature several levels of heat interception between ambient and superfluid helium temperatures [3], in order to stage the heat inleaks and thus limit the entropic load on the refrigeration plants. Global calorimetry on prototype cryomagnets under test, such as reported in [4], proves difficult to precisely assess their insulation performance, due to unavoidable parasitic heat loads from the test equipment, e.g. current leads and warm bores for magnetic measurements. It is therefore essential to evaluate separately the thermal performance of critical cryostat components, such as magnet support posts, on a dedicated test bench providing the required heat interception levels, and capable of precision heat inleak measurements.

THE HEAT INLEAK MEASUREMENT BENCH

Principle

The measurement bench, sketched in Figure 1, is constructed around a standard test cryostat(*) which features three nested vessels filled respectively with liquid nitrogen, normal liquid helium and saturated helium II. Besides providing adequate temperature levels, the warmer cryogen baths act as thermal shields and guards for the colder ones. The component to be tested is mounted in the "tail" of the cryostat, and thermally bridged, through demountable copper plates, to the cryogen baths. While the warm side is maintained at ambient temperature by a controlled electrical heater, the heat loads reaching the three cryogenic temperature levels are cross-measured by several independent methods: heatmeters, liquid boil-off and transient temperature rise in the superfluid helium.

The heatmeters

Heatmeters are calibrated thermal impedances, through which the heat flow to be measured generates a small temperature difference [5,6]. The design characteristics of our heatmeters for 80 K, 4.2 K and 1.8 K measurements are given in Table 1, while Figure 2 shows their construction. Each heatmeter is equipped with its own calibration heater, thus allowing individual in situ checks.

(*) Manufactured by AS Scientific Products, Abingdon (UK).

Table 1 Design characteristics of the heatmeters

Temperature level	[K]	77	4.2	1.8
Measuring range	[W]	1-5	0.5-2	0.05-0.2
Design sensitivity	[W K^{-1}]	3	7	3
Thermal impedance		Brass	Copper	Copper
Resistance thermometers		Pt 100	Carbon 220 Ω	Carbon 100 Ω

The calibration of a typical 1.8 K heatmeter appears in Figure 3; the high sensitivity of the thermometers in this temperature range permits to detect heat flows as small as a few mW. Comparing readings from the 1.8 K heatmeters with calorimetric measurements on the superfluid helium bath shows good agreement to within ±2 mW. Absolute calibration at normal boiling point of cryogens, performed by boil–off flow measurements (see Figure 4), yielded a precision of ±0.05 W at 4.2 K, and ±0.3 W at 80 K.

Instrumentation, data acquisition and control

Readout of the thermometers is performed by a digital multimeter, connected to a 40–channel scanner. The data is acquired by a personal computer, via an IEEE-488 bus. Processing and display is handled by the LabView(*) software, in particular individual resistance–to–temperature conversions for the thermometers. A multifunctional I/O card monitors analog signals from the boil–off mass flowmeters and controls the valve regulating the saturation temperature of the helium II bath. Operation of the bench is fully automatic, thus allowing unattended long–period measurements.

TEST OF A CRYOMAGNET SUPPORT POST

A development is under way for the low heat inleak posts, based on epoxy–fiberglass composites, which support the large cold mass of the LHC cryomagnets. The competing designs will be thermally evaluated and compared on the heat inleak measurement bench.

Table 2 displays the calculated thermal budget of a prototype post, together with heat inleak measurements performed on the bench after reaching a thermal steady–state in about 36 hours. Discrepancy between measured and calculated heat loads at 80 K requires further investigation

Table 2 Thermal performance of a prototype support post

Nominal temperature	[K]	80	5	1.8
Working temperature	[K]	87	6.5	2.5
Measured heat load	[W]	4.8	1.2	0.085
Calculated heat load	[W]	7	1.2	0.081

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(*) Produced by National Instruments, Austin (USA).

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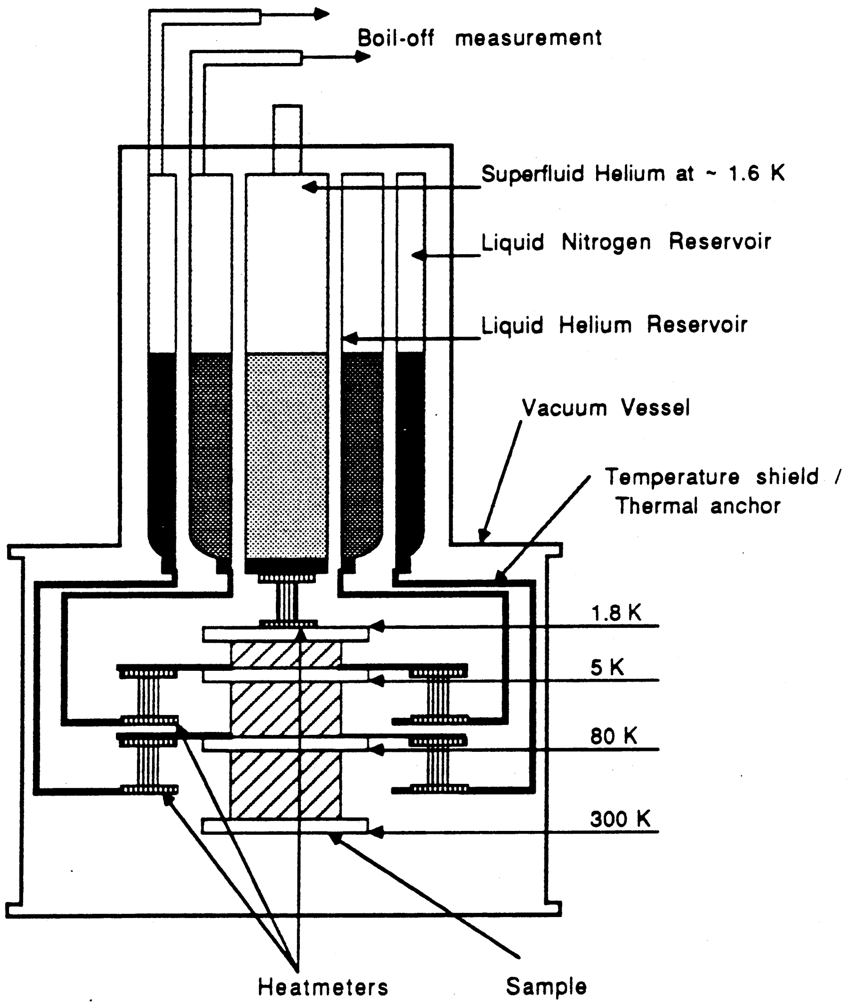

Figure 1 Schematic of the heat inleak measurement bench

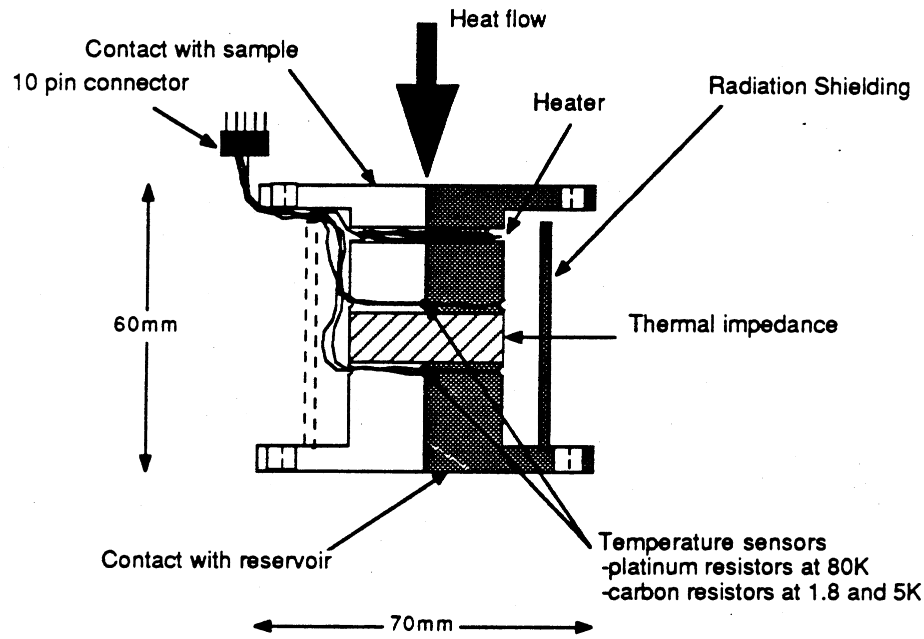

Figure 2 Heatmeter design

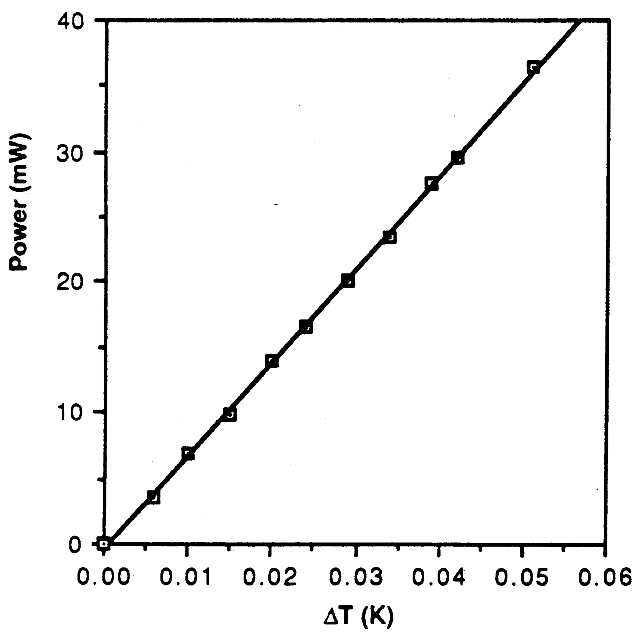

Figure 3 Detection sensitivity of a 1.8 K heatmeter

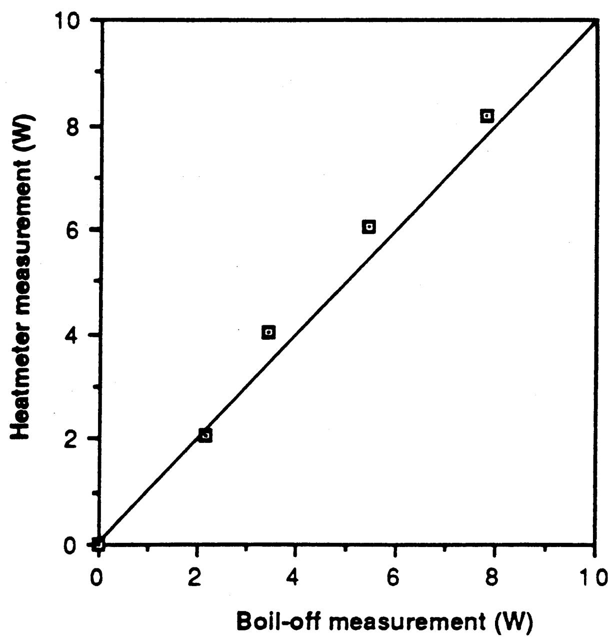

Figure 4 Boil–off calibration of a 80 K heatmeter