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ABSTRACT

A method suitable for measuring the thermal conductivity of good thermal conductors at low temperatures was implemented. It successfully served its purpose: to detect the effect of doping with manganese the interfilament part of the copper matrix of the superconducting wire used in the magnets of the Superconducting Super Collider. It uses two heaters and one thermometer per sample reducing the accuracy requirement on the thermometers, automatically compensating for zero offsets and reducing the number of critical thermal contacts. Commercially available strain gauges are used as heaters.

INTRODUCTION

In the development of the NbTi multifilamentary wire for the Superconducting Super Collider (SSC) magnets an elegant solution was found,[1] to reduce interfilament coupling when the copper thickness between filaments is reduced: doping this interfilamentary copper with manganese. The reduction in filament size and copper thickness between filaments were needed in order to reduce the low field magnetization of these magnets. In order to evaluate how this solution (manganese doping) affects the stability against quench of these magnets it became relevant to quantify how it changes the thermal conductivity of the wire.

The comparison of thermal conductances in the 4 K to 10 K range of high conductivity materials, if carried in the usual fashion (two thermometers on the sample), involves measuring rather small temperature differences with highly accurate thermometers aside from the usual care about thermal isolation, steady state conditions and thermal contacts. By using one carbon composition thermometer and two strain gauges as heaters[2] per sample, one can accomplish the comparison in a very satisfactory way as is described below.

EXPERIMENTAL SETUP

A cryostat usually used for calibration of resistance thermometers[3] was used for these measurements. Inside the thermally isolated thick copper wall container (calorimeter) vacuum instead of exchange gas was used. This calorimeter is contained in a container that can be evacuated and

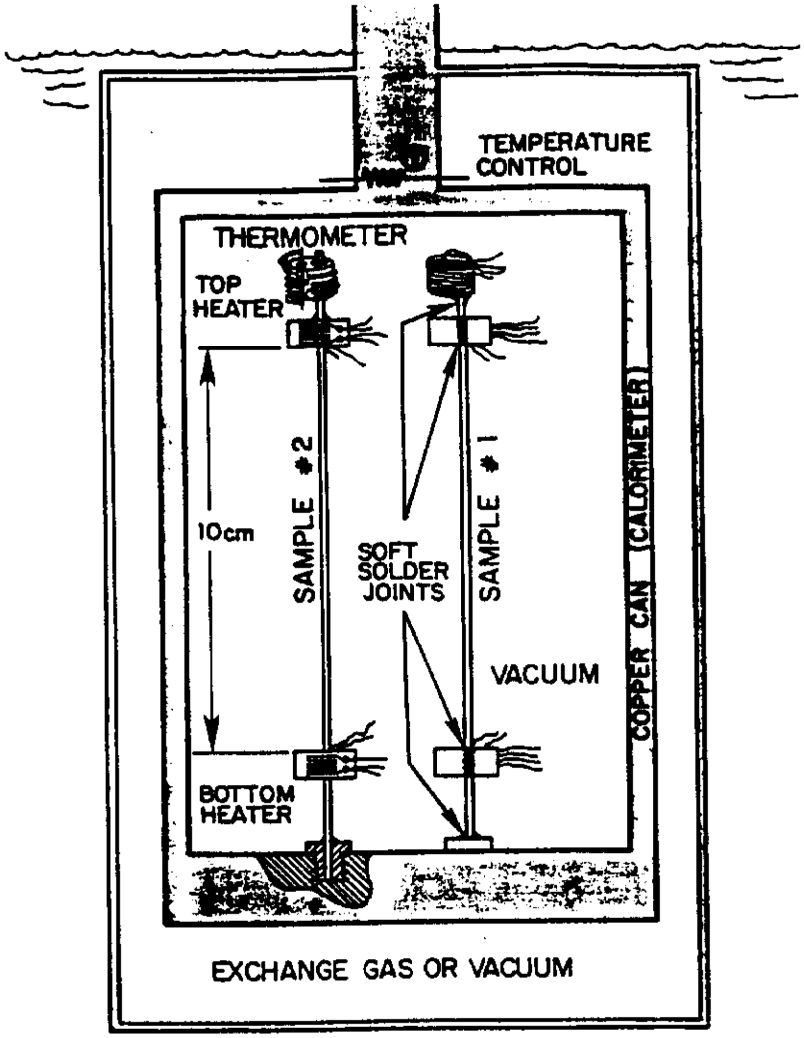

Fig. 1. Schematic representation of the two instrumented samples in the calorimeter.

stays immersed in liquid Helium, furthermore, the calorimeter is mechanically connected to it via a temperature controlled stage. A model DRC-82C Lake Shore Cryotronics temperature controller is used to maintain this stage and the calorimeter at the so called heat sink temperature. A schematic representation is shown in Fig. 1. Not shown is a copper structure inside the calorimeter in good thermal contact with it and the stage. This copper structure holds thermally heat sunk electrical connectors and has a platform with threaded holes to which the samples are heat sunk.

SAMPLE PREPARATION AND INSTALLATION

The wire samples are cut 15 cm long and 4 small copper parts are soft soldered to each of them. These copper parts have holes or grooves that fit to the sample. They are: Two plates (14.3 mm X 6.3 mm X 1.6 mm) accurately soldered leaving 100.0 mm length of sample between them and on which the 350 Ω strain gauges (MicroMeasurements EA-03-250BF-350) are installed, a screw for attaching one extremity of the sample to the heat sink, and a cylinder (6.3 mm diameter X 4.8 mm long) with two off-centered holes. Of these one (1.7 mm diam.) is for housing a .125 W, 100 Ω Allen Bradley carbon composition resistor and the other (0.8 mm diam.) is for soldering to the free extremity of the sample. This carbon resistor with its original leads shortened to 2 mm and each soldered to two manganin wires was previously calibrated. Enamel coated 0.1 mm diam. manganin wires are used for all leads attaching to the sample. Their lengths from the sample to their connection to the calorimeter are such that the calculated heat flow through them or heat generated in them do not compromise the measurements. The extra lengths are accomodated into the confines of the calorimeter by spiraling. Care is taken to insure against touching. A maximum of 16 leads per sample are used. Groups of 4 leads are used to permit measurements of resistance or power that are free from corrections due to lead resistance. The set of 4 leads going to the carbon resistor thermometer are heat sunk to the cylindrical surface with GE 7031 varnish. Two sets are connected to the heaters and a fourth set is used to measure the electrical resistance of the sample segment itself.

MEASUREMENTS

The measurements are carried out by recording as a function of time the temperature of the two thermometers on the samples and the heat sink. After verifying the existence of thermal equilibrium inside the calorimeter and recording the zero offsets of the thermometers a typical procedure would consist of the following steps: A constant current is applied to the bottom heater of the first sample (a power dissipation of 1.0 mW is typical here). After a steady state is reached this power is switched to the upper heater of the same sample. A new steady state is reached in much less then 10 minutes in the 4-12 K temperature range. The power is then switched off for verification of the initial condition. The same procedure is then repeated with the second sample and the entire process is carried out again with a different power into the heaters. The calorimeter base temperature can then be changed and the measurements repeated at a new temperature if that is of interest. Fig. 2 shows a typical set of measurements where the measured temperatures are joined by straight lines and the samples are heated first with 1.00 mW and later with 0.50 mW. Of interest to the SSC magnet development program was the comparison of two NbTi multifilamentary composite wires made by

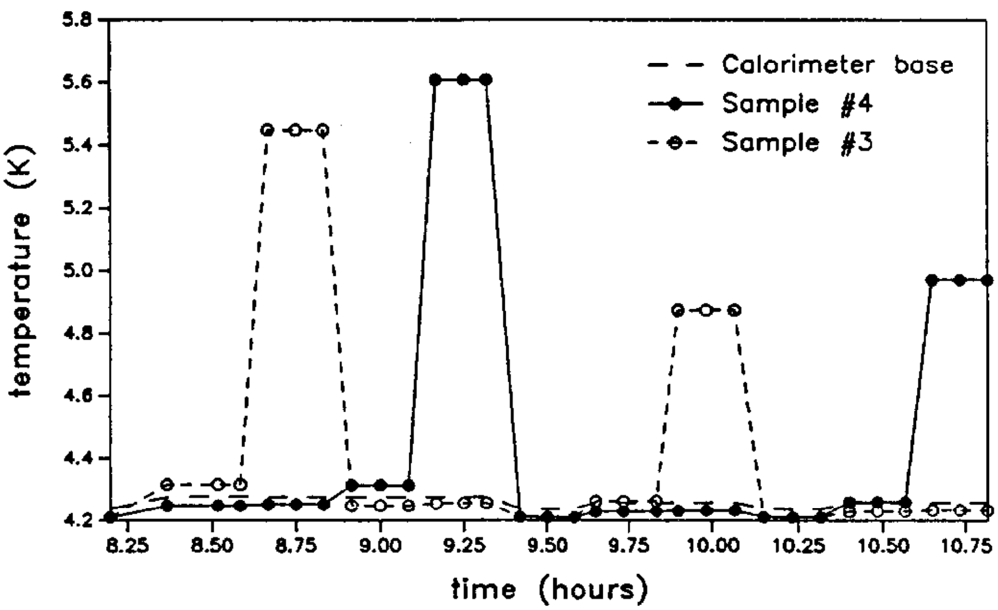

Fig. 2. Temperature points connected by strait lines during a typical sequence of heatings first with 1.00 mW and then with 0.50 mW.

Supercon Inc. labeled as SCN335E (sample #3) and SCN335E-2B2E (sample #4), supposedly identical except for the interfilamentary copper of the latter being doped with Mn. These wires have 11000 filaments, no twist, no anneal and 0.808 mm diameter. Their thermal conductances were found to be $.883\pm.009$ mW/K over the temperature range 4.315 K to 5.448 K and $.772\pm.008$ mW/K over 4.313 K to 5.608 K respectively.

DISCUSSION

This method of measuring integrated thermal conductance is a natural one for measuring thermal conductivity. Using smaller power dissipations will cause smaller temperature excursions more in conformity with the differential nature of this property. The dependence on the thermometer accuracy is somewhat relaxed since the measurement depends mainly on the slope of the calibration curve, justifying the use of the cheaper carbon composition resistors. Also temperature errors due to imperfect thermal contacts are minimized since only one thermometer is used and its thermal contact error if any is cancelled out. It is worth noting that the two critical commercial components used here, the carbon composition resistors and the strain gauges are both manufactured by highly automated processes leading to high uniformity from unit to unit.

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