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Thermal conductivity of RHIC superconducting magnet insulation materials at low temperatues

J. Lu, S. Verdu-Andres

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DISCLAIMER

THERMAL CONDUCTIVITY OF RHIC SUPERCONDUCTING MAGNET INSULATION MATERIALS AT LOW TEMPERATURES

Jun Lu†, National High Magnetic Field Laboratory, Florida State University, Tallahassee, FL
Silvia Verdú-Andrés, Brookhaven National Laboratory, Upton, NY

Abstract

The Electron-Ion Collider (EIC) is planned to be built upon the Relativistic Heavy Ion Collider (RHIC), which vacuum chamber will need to be upgraded to host the EIC hadron beams. For the beam pipe section running through the RHIC superconducting (SC) magnets, the baseline is to insert a screen that will get cooled by thermal contact to the 4.55 K beam pipe of RHIC. Knowing the material properties of the cold mass is thus crucial to understand which is the final temperature that the screen and the superconducting coils in the magnets will reach during the passage of the EIC beams. The thermal conductivities of two insulation materials in the RHIC superconducting magnets and a reference material were measured at cryogenic temperatures at the Magnet Science and Technology division of the National High Magnetic Field Laboratory (NHMFL). The measurements were performed in a Quantum Design physical property measurement system. This report explains the motivation behind this work and summarizes the measurement method and results.

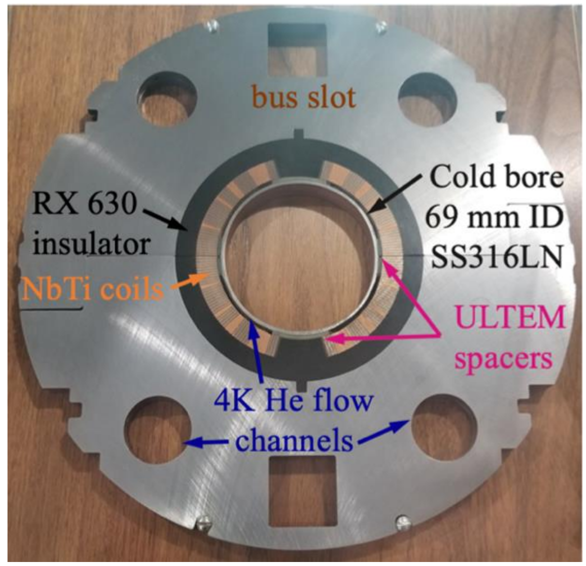

Figure 1: Cross section of RHIC arc dipole magnet.

MOTIVATION

The Electron-Ion Collider (EIC) will be built upon the Relativistic Heavy Ion Collider (RHIC) of Brookhaven National Laboratory (BNL) [1]. The vacuum chamber of RHIC was not designed to host the EIC hadron beams and will need to be updated to show a lower resistive-wall impedance and suppress electron cloud. For the cold bore or beam pipe running through the RHIC superconducting magnets, the baseline solution is to insert a screen that will be passively cooled by thermal contact to the 4.55 K beam pipe [2].

Knowing the cryogenic thermal properties of the electrical insulators in the RHIC superconducting magnets is crucial to understand the operational temperature of the screen – which determines the resistive-wall heating and the vacuum level attained in the vacuum chamber – and the expected temperature reached at the superconducting coils to identify if cooling is sufficient to prevent magnet quench [3]. The electrical insulators are ULTEM® 6200 and RX® 630. Figure 1 shows the cross section of the RHIC arc dipole (superconducting) magnet and the location of these two electrical insulators.

TEST METHOD

The measurements were performed in a physical property measurement system (PPMS) (Fig. 1(a)) which is equipped with the thermal transport option. See reference [4] for the detailed description of the measurement method. The ULTEM-6200 and RX-630 materials were received from BNL; the cast Nylon-6 material were purchased from McMaster Carr. They were machined to a size of approximately 2 x 4 x 10 mm^3. The exact size of each sample was measured by a digital calliper. ECCOBOND 286 thermally conductive epoxy (Henkel Loctite) was used to attach the leads to the samples in a four-leads configuration. (Fig. 1(b)). The distance between two thermometer leads was measured by the Nikon NEXIV measuring microscope.

The thermal conductivity κ was measured at different temperatures in the steady-state mode (single mode). In this mode, after a propriate level of heating power was turned on, the system waited for the sample to reach steady state defined as stability $dT/T < 0.1\%$. Once the steady state was reached, the temperature difference between the hot and the cold thermometer was measured and used to calculate κ.

† Primary author. E-mail address: junlu@magnet.fsu.edu

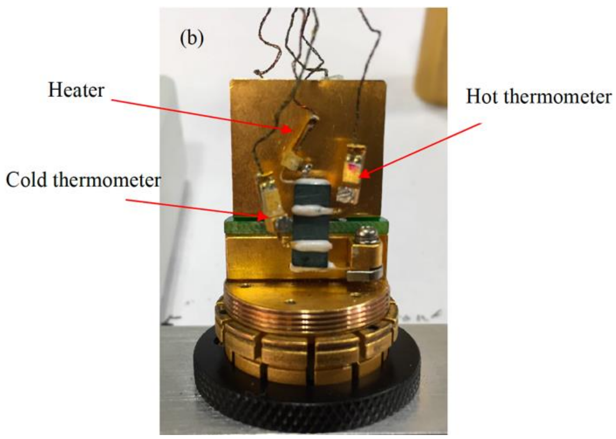

Fig.1 (a) The Quantum Design PPMS system. (b) The thermal conductivity measurement puck with a RX-630 sample. Two temperature sensors and a heater can be seen attached to the leads that were glued to the sample by EC-CONBOND 286 thermally conductive epoxy.

TEST RESULTS

The thermal conductivity results are tabulated in Table I and plotted in Fig. 1 and Fig. 2. As shown in Fig. 1, the measured κ values of two Nylon-6 samples are consistent with one another, but slightly higher than those in Martelli paper [5]. This is likely due to the variations in the Nylon material.

The systematic error estimation in a thermal conductivity measurement is rather complex. The random measurement error comes mainly from the uncertainty in the measurement of the distance between two thermometers, as well as the uncertainty in the radiation heat losses. Although the microscope allows us to measure distance more accurately than a calliper, the relatively large size of the thermal leads (width~0.6 mm) and the epoxy used to attach the leads inevitably introduces significant uncertainty. It is advised that the data presented in the report are used with caution within an uncertainty of 10%.

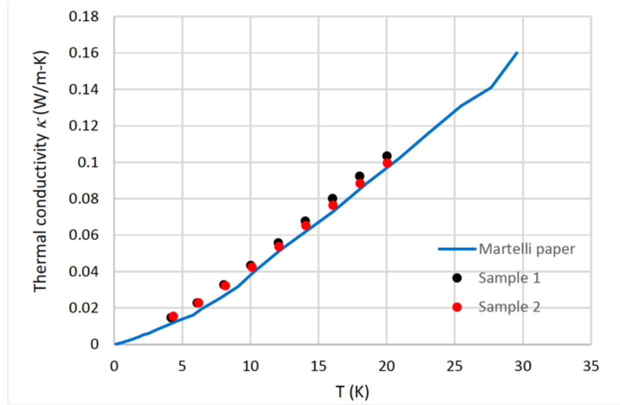

Fig. 1. Nylon-6 data, in comparison with those in Martelli paper [5].

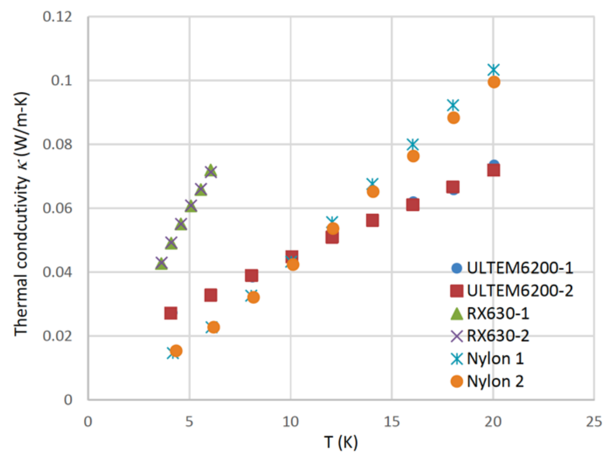

Fig. 2. κ vs. T of ULTEM-6200 and RX-630. Nylon-6 data are also presented for comparison.

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Table 1: Thermal conductivity of Nylon-6, ULTEM-6200 and RX-630 samples

Nylon-6			
Sample 1		**Sample 2**	
T (K)	κ (W/K-m)	**T (K)**	κ (W/K-m)
4.187	0.0147	4.350	0.0154
6.099	0.0228	6.206	0.0228
8.058	0.0327	8.172	0.0321
10.031	0.0433	10.129	0.0424
12.055	0.0557	12.103	0.0537
14.042	0.0676	14.082	0.0652
16.037	0.0800	16.072	0.0764
18.029	0.0923	18.060	0.0883
20.031	0.103	20.056	0.0995
RX-630			
Sample 1		**Sample 2**	
T (K)	κ (W/K-m)	**T (K)**	κ (W/K-m)
3.617	0.0427	3.629	0.0430
4.101	0.0491	4.109	0.0493
4.580	0.0551	4.589	0.0551
5.079	0.0608	5.086	0.0609
5.568	0.0659	5.575	0.0660
6.058	0.0720	6.066	0.0713
ULTEM-6200			
Sample 1		**Sample 2**	
T (K)	κ (W/K-m)	**T (K)**	κ (W/K-m)
4.085	0.0272	4.155	0.0273
6.058	0.0328	6.116	0.0326
8.076	0.0390	8.126	0.0384
10.064	0.0449	10.107	0.0443
12.056	0.0510	12.094	0.0506
14.046	0.0563	14.079	0.0564
16.042	0.0611	16.067	0.0621
18.022	0.0667	18.065	0.0658

AUTHOR CONTRIBUTIONS

Jun Lu conducted the measurements of the samples. Silvia Verdu-Andres defined the scope of the research, coordinated the exchange of samples, and wrote the “Motivation” section of this report. Jun Lu wrote the rest of the report.

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