Thermal Expansion of Nb_3Sn and JK_2LB Steel at Cryogenic Temperatures

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ABSTRACT: Thermal expansion measurement is important in the ever-advancing area of low temperature physics and its applications. I have designed a low temperature probe which uses an extensometer in a PPMS to measure thermal expansion in the 10 K to 300 K range. A computer program automates data acquisition. Using this probe, I measured thermal expansion of the superconductor Nb_3Sn and the JK_2LB alloy. The data of JK_2LB is the first measurement of this kind and very valuable for ITER project.

INTRODUCTION: The main purpose of this experiment is to measure the thermal expansion of materials used for large scale superconducting magnets. Specifically, we want to get data for the superconductor Nb_3Sn and the JK_2LB alloy. The JK_2LB is one of the foremost alloys being considered for the ITER project as a conduit material for superconducting cable-in-conduit conductor. The thermal expansion difference between Nb_3Sn and JK_2LB will provide scientists with information about how the Nb3Sn superconductor wires inside the JK2LB jacket perform at low temperatures.

EXPERIMENTAL SETUP: To perform this experiment, it was required that a new probe for the physical property measurement system (PPMS) be designed and built. We used the design shown in Figure 1B for this experiment. This probe is put in the PPMS sample chamber which provides temperature control from 10 K to 300 K and the expansion is measured by an extensometer attached at the bottom of the probe, shown in Figure 1A. The extensometer sends a measurement that is translated by a strain indicator and then recorded by the voltmeter. The probe also features a thermometer near the sample to achieve higher temperature accuracy instead of relying on the thermometers in the PPMS. I then wrote a LabVIEW program that recorded and plotted the temperature versus the thermal expansion signal. The program also determined how often data was recorded and gave the current temperature.

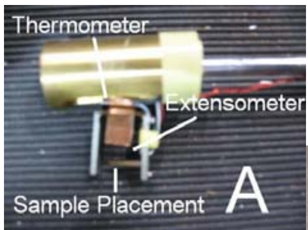

Figure 1A: This is a close-up view of the extensometer used to measure the thermal expansion of the sample. The sample is placed between the two calipers.

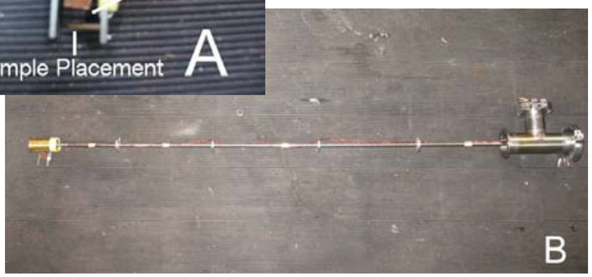

Figure 1B: This figure showcases the probe that was designed and used for this project. It features two connectors, a thermometer, and an extensometer.

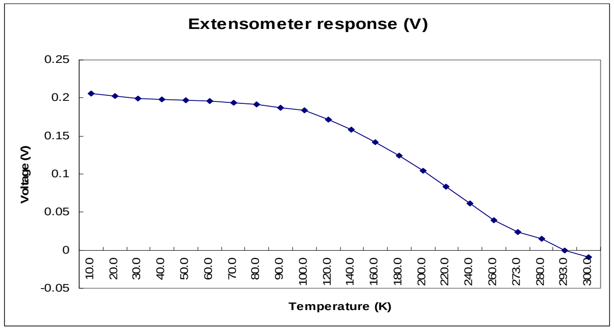

Figure 2: This Graph shows the voltage due to the extensometer during the experiment. Even with no sample the apparatus would shrink the amount shown in the graph due to the meter.

CALIBRATION:

- Calibration of the gage factor *G*:
  G = output signal (volt)/ displacement (mm) at room temperature.
- Extensometer temperature response R

$$R = V_A - \Delta L_{A\text{-std}} \times G \qquad (1)$$

where *V*(volt) is the measured signal, ΔL(mm) is thermal displacement of the standard obtained from reference [1], and *G* is the gage factor. The *R* vs. *T* based on an Aluminum standard is shown in Figure 2. The thermal expansion of a sample B, *TEB*, can be obtained by measuring a standard sample A with known thermal expansion *TEA* using,

$$f_B = \frac{f_A L_A G - V_A + V_B}{L_B G} \qquad (2)$$

where L_A and L_B are the length of sample A and B respectively, V_A and V_B are the extensometer signals of sample A and B respectively.

RESULTS:
I measured the TE of brass, Nb_3Sn, and JK_2LB using aluminum as a standard. The relative change in length $(L_{293K}-L)/L_{293K}$ versus temperature can be seen in Figure 3. Data is taken by ramping the temperature up and down at 2 K/min. Then the average of ramping up and ramping down curves is presented here. The difference between ramping up and ramping down curves is typically ~ 10^{-4}. This difference is due to the different temperature gradient between ramping up and ramping down. To minimize this effect, I have also used a temperature step and soak sequence with a soak time of 40 min. The difference between the step-and-soak and the 2 K/min ramp methods is insignificant.

My preliminary data shows that the JK_2LB has a relatively small thermal expansion compared to that of 316LN stainless steel, confirming the material developers' claim.[2]

ERROR ANALYSIS:
•Main sources of error

- temperature
- gage factor
- Extensometer controller drift
- Error in handbook values used for calibration

•Using my preliminary data I estimate an error in the TE of ~ ± 2×10^{-4}.

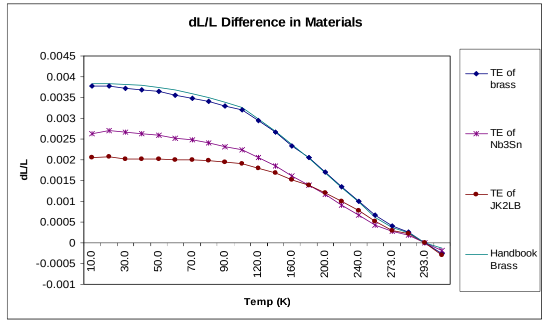

Figure 3: This graph shows the calibration curve configured using the Data Handbook, raw data, and the gage factor. For each function Aluminum was used as the control.

CONCLUSION: I developed hardware and software to measure the thermal expansion of materials at low temperatures with good accuracy using PPMS. I measured thermal expansion of materials important to the design of large scale superconducting magnets, such as Nb_3Sn and JK_2LB alloy whose low temperature thermal expansion data is not available in the literature. The thermal expansion of JK_2LB will be very valuable for the ITER project and it also has implications for the conduit material selection for the future magnets of the NHMFL.

Reference
[1] Brookhaven National Laboratory Selected Cryogenic Data Notebook
[2] K. Hamada *et al*., Cryogenics 47 (2007) 174–182

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