ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-THPFDV006

SEEBECK COEFFICIENT MEASUREMENT AT CRYOGENIC TEMPERATURES FOR THE LCLS-II HE PROJECT*

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Abstract

Reducing thermoelectric currents during cooldown is important to maintain high quality factors (Q_0) of the cavities in the LCLS-II HE cryomodules. The temperature-dependent Seebeck coefficients of the materials used in the cryomodules are needed for quantitative estimation of thermoelectric currents. In this work, we present a setup for cryogenic Seebeck coefficient measurements as well as the measured Seebeck coefficients of high-pure niobium at cryogenic temperatures between 4K and 200K.

INTRODUCTION

LCLS-II will be the first CW X-ray FEL based on 4 GeV CW superconducting linac. The energy upgrade program which is referred as the LCLS-II HE will increase the beam energy to 8 GeV. The empty space in the SLAC tunnel allows to install 20 additional cryomodules in which SRF cavities operate at an average quality factor $Q_0 \approx 2.7\times10^{10}$ and accelerating gradient $E_{acc} \approx 19.4$ MV/m without exceeding the cryoplant capacity [1]. To achieve such high-Q_0 at 2K, the SRF cavities were treated by a nitrogen-doping based recipe, which in turn causes a high sensitivity to additional RF dissipation from trapped magnetic vortices resulting from ambient magnetic fields in the cryomodules during cooldown. Therefore, reducing thermoelectric currents and resulting magnetic fields generated during cooldown is important to maintain high-Q_0 of the cavities in the LCLS-II HE cryomodules. The temperature-dependent Seebeck coefficient of the materials used in the cryomodules is the key parameter in thermoelectric current estimation.

EXPERIMENT SETUP

Seebeck Coefficient

The thermoelectric effect is a phenomenon in which a voltage V between two ends of an electrical conductor/semiconductor is created by a temperature different between them. It can be described by Eq. (1),

$$V = -\int_{T_2}^{T_1} S(T)\,dT. \tag{1}$$

where $S(T)$ is temperature-dependent Seebeck coefficient, T_1 and T_2 are the temperatures of two ends of a metal respectively. In a measurement, a dissimilar metal (metal B) is used as leads to connect the two ends of a sample (metal A) to extract voltage crossing the sample, as is shown in Fig. 1. In this scenario, the Seebeck effect of the two metals has to be considered, which is shown in Eq. (2),

$$\begin{aligned} V &= -\int_{T_0}^{T_1} S_b(T)\,dT - \int_{T_1}^{T_2} S_a\,(T)dT \\ &\qquad - \int_{T_2}^{T_0} S_b(T)dT \\ &= \int_{T_1}^{T_2} S_b(T) - \int_{T_1}^{T_2} S_a\,(T)dT \\ &= \int_{T_1}^{T_2} [S_b(T) - S_a(T)]dT, \end{aligned} \tag{2}$$

where S_a is the Seebeck coefficient of the sample to be measured and S_b is the Seebeck coefficient of the reference leads.

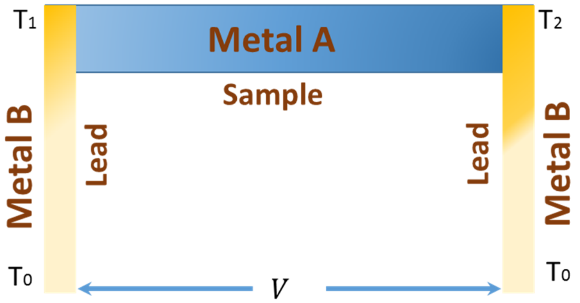

Figure 1: Sketch of the Seebeck effect of two dissimilar metals A and B at temperatures T_1 and T_2 at their contacts.

The differential method of approximating Eq. (2) is described in [2], from which the Seebeck coefficient of the sample can be written as Eq. 3,

$$S_a(T_{ave}) = -\frac{V}{\Delta T} + S_b(T_{ave}). \tag{3}$$

where $T_{ave} = \frac{1}{2}\,(T_1 + T_2)$, and $\Delta T = \; T_2 - T_1$. Since the temperature range of the measurements is 4K-200K, we choose lead (Pb) as the reference wire material (metal B). The Seebeck coefficient of high-pure lead (Pb) in the temperature range 4K-200K can be found in [3].

Experiment Setup

A 1.8W 2.8K Cryocooler (Model: CRYOMECH PT420) was employed for the setup, in which helium is circulated between the compressor and the cold head for cooldown. Figure 2 A) shows a 3D CAD model of the copper base of the experimental setup bolted to the cryocooler cold head that cools down the whole setup when the cryocooler is running. Figure 2 B) depicts the detailed view of the CAD model of the setup, which referenced the design from [4].

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* Work supported by the US DOE and the LCLS-II-HE Project.
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It has to be noted that the sample holder is mechanically bolted to the base but electrically insulated from the base by an aluminum-nitride ceramic plate and washers. Two 5 Ω Dale resistors are used as heaters and sample-clamps to heat up and retain the sample on the setup.

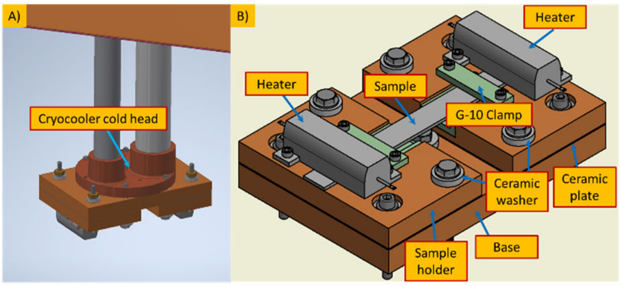

Figure 2: A) The 3D model of the Seebeck coefficient measurement setup mounted on the cold head of cryocooler; B) The detailed view of the measurement setup.

In Fig. 3, it can be seen that the lead (Pb) wires, thermocouple (TC) Type E and Cernox sensors (placed on the other side of the sample) are pressed against the sample surface tightly by G-10 clamps. We use two kinds of sensors for temperature measurements, because the Type E sensor has better accuracy at temperature 200K to 100K while the Cernox sensor is more accurate at 100K to 4K. The voltage extracted from the lead (Pb) wires is measured by a digital multimeter (Model: Keithley DAQ 65100 7700). Data taking software is programmed by using Matlab APP designer.

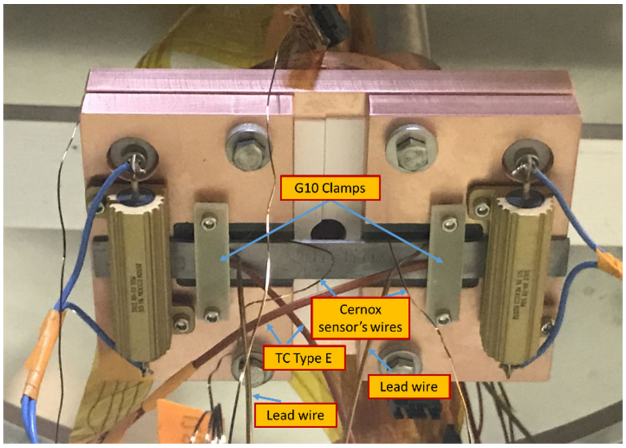

Figure 3: Photograph of Seebeck coefficient measurement setup.

EXPERIMENT RESULTS

We first measured the cryogenic Seebeck coefficient of high-purity niobium (RRR=350) to calibrate and validate our measurement system. Measurements were taken during a warm up cycle: The setup was first cooled down to ~6K, and then the cryocooler was turned off to let the setup slowly warm up. One of the heaters was turned on to generate a small (1-10K) temperature difference crossing the niobium sample. At regular intervals, a Matlab program measured the voltage and temperatures. Data taking was completed when the average temperature of the sample was above 200K. The measurement results of niobium are shown in Fig. 4, and are in general good agreement with results from Ref. [5], with small differences in the temperatures ranges from 60-100K and 120K-200K

The main systematic error in the measurements reported here comes from the temperature measurements: The surfaces of the type E and Cernox sensors were in limited thermal contact with the sample surface, requiring a long time to reach thermal equilibrium between the sensors and the sample. This caused the temperature readings to lag the actually temperatures of the sample even though the sample's warm-up was very slow. To solve this problem, we will add a small amount of indium and Apiezon grease to the type E and Cernox sensors respectively to improve their thermal contact in future tests.

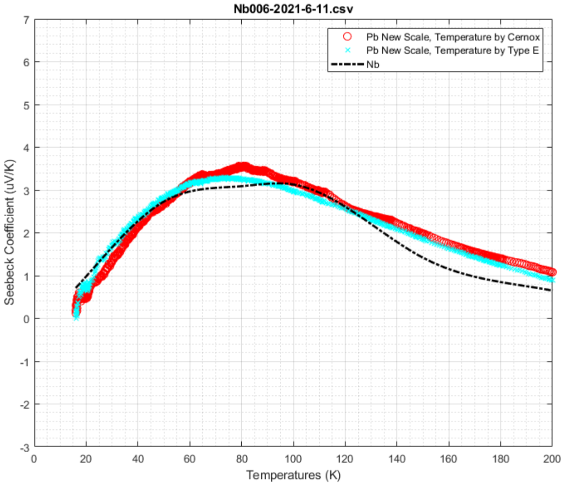

Figure 4: Seebeck coefficient measurement results of niobium compared to the result from [5].

CONCLUSION

A Seebeck coefficients measurements setup has been designed, fabricated, and commissioned at Cornell University. First cryogenic Seebeck coefficients of niobium have been successfully measured over a wide temperature range, and results validate the new experimental setup. The main source of remaining measurement error has been determined, and improvements will be implemented before measurements on a range of materials.

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