ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-THPOGE15

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

L. Shpani*, M. Ge, A. Holic, M. Liepe, J. Sears, N. Verboncoeur
Cornell Laboratory for Accelerator-Based ScienceS and Education (CLASSE), Ithaca, NY, USA

Abstract

The Seebeck effect plays a crucial role during the cooldown procedure in SRF based accelerators, like LCLS-II at SLAC. The temperature-dependent Seebeck coefficient quantitatively measures the strength of electric potential induced by thermal gradients in metals. This effect is present in cryomodules and drives thermoelectric currents generating magnetic fields. These fields can get trapped in cavities and cause additional dissipation in RF fields. We have therefore designed and commissioned an experimental setup that does continuous measurements of the Seebeck coefficient for cryogenic temperatures ranging from 200K down to below 10K. We present results of the measurements of this coefficient for materials commonly used in cryomodules, such as niobium, titanium, niobium-titanium, silicon bronze, and stainless steel.

INTRODUCTION

LCLS-II will be the first XFEL based on 4GeV continuous-wave superconducting RF (CW-SRF) accelerator technology. The LCLS-II-HE will increase the energy of the CW-SRF to 8GeV, increasing the photon energy range from 5keV of LCLS-II to at least 13keV at 1MHz repetition rates [1].

Nitrogen-doped niobium SRF cavities with high quality factors of 2.7×10^{10} at 4K will be used. Because of the high sensitivity to RF dissipation from trapped magnetic vortices resulting from magnetic fields in cryomodules during cooldown, reducing thermoelectric currents and their resulting magnetic fields is crucial to maintain the high quality factor of the cavities [1, 2].

The Seebeck effect is a phenomenon in which a potential difference is induced between two ends of an electrical conductor when a temperature gradient is applied across it, as carriers diffuse from the hot end to the cold end of the sample [3–5]. The Seebeck coefficient is a temperature dependent material property, which is a crucial value needed to estimate these thermoelectric currents.

MEASUREMENT SETUP

The voltage difference induced induced in a metal due to a temperatre gradient can be described by

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

where T_1 and T_2 are the temperatures of the two ends of the sample, and $S(T)$ is the temperature dependent Seebeck coefficient.

The value of the temperature-dependent Seebeck coefficient itself is the ratio of the potential difference and temperature gradient across the metal, namely

$$S_{ab}(T) = \lim_{\Delta T \to 0} \frac{\Delta V}{\Delta T}. \tag{2}$$

Measurement Method

Measurement was done using the differential method [3], using a small temperature gradient across the sample (between 1 to 5K) . We simultaneously measure the temperature on each side of the sample and the induced potential difference. Figure 1 is an illustration of the Seebeck effect on two dissimilar metals with the interfaces at temperatures T_1 and T_2 ($T_1 \neq T_2$).

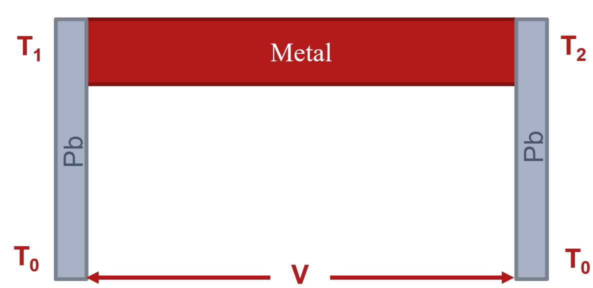

Figure 1: Seebeck effect for two dissimilar materials, namely the lead wires and the metal of interest, with the interfaces at temperatures T_1 and T_2. A proportional voltage V is generated.

We can measure the potential difference across the metal of choice using lead wires shown in Fig. 1 as leads. The measured potential difference in this case is given by

$$V = -\int_{T_1}^{T_2} [S_b(T) - S_a(T)]dT, \tag{3}$$

where S_a is the Seebeck value of the metal of interest, and S_b is the Seebeck value of the Pb wires [5].

Using the known values of the Seebeck coefficient for Pb [6] we can add a correction as follows:

$$S_a(T_{ave}) = -\frac{\Delta V}{\Delta T} + S_b(T_{ave}), \tag{4}$$

where $T_{ave} = (T_1 + T_2)/2$ and $\Delta T = T_2 - T_1$.

* ls936@cornell.edu

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-THPOGE15

Experiment Setup

The experimental setup was inspired by [4], and it consists of a copper sample holder mechanically bolted to a copper base, which is electrically insulated through 0.015" thick aluminum oxide sheets. The 3D CAD model of the setup is shown in Fig. 2 (A), and photographs of the disassembled and assembled sample are shown in Fig. 3 (A) and (B) respectively. The sample is clamped down to the holder using heaters on both ends of the sample, as well as two G10 clamps. The heaters are 5 Ω Dale resistors, and they are used to create the desired temperature gradient across the sample. The G10 clamps are also used to press the sample against the cernox sensors placed underneath, as shown in Fig. 3.

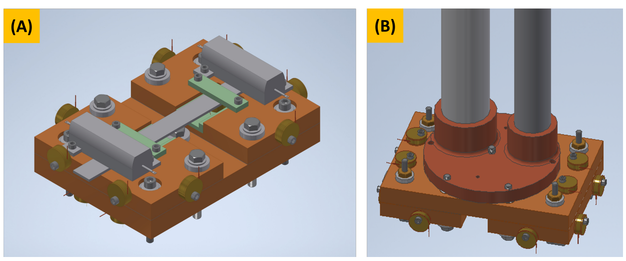

Figure 2: 3D model of the measurement setup. (A) Close up of assembled setup. Sample is mounted on the copper base; (B) Setup mounted on the cryocooler cold head.

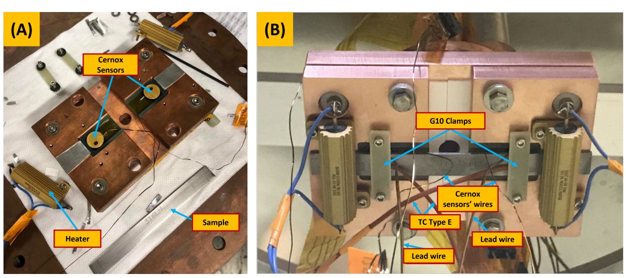

Figure 3: Pictures of the disassembled (A) and assembled (B) setup.

The cooldown was done using a 1.8W 4K Cryocooler, model: CRYOMECH PT420. Helium is circulated between the compressor and the cold head, shown in Fig. 2 (B) to reach cryogenic temperatures.

The temperatures were measured using cernox sensors which have low measurement uncertainty at low temperatures. The readings from these sensors were done using a Lakeshore 224 temperature monitor. The voltage across the sample is measured by a digital multimeter, model: Keithley DAQ 65100 7700. The data acquisition software was programmed in MatLab App Designer.

RESULTS

Preliminary results of the measured Seebeck coefficient for temperatures ranging from 10K-200K are shown in Fig. 4 for niobium, titanium, niobium-titanium, silicon bronze, stainless steel 316L and 316LN.

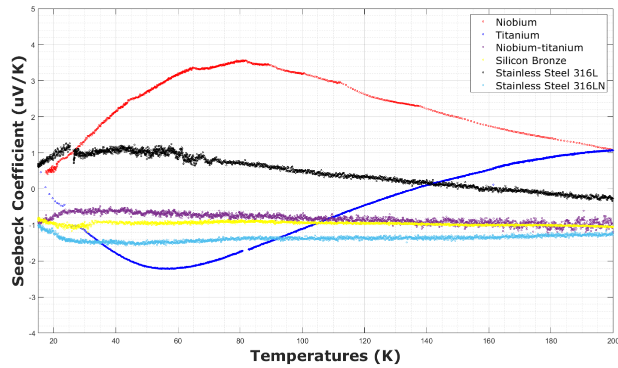

Figure 4: Measured cryogenic Seebeck coefficients for a variety of materials.

Measurements of niobium and titanium are consistent with literature [6], which validate the experimental setup. Note that our measurements are continuous in contrast to the sparse data points in the literature.

CONCLUSION

We have optimized and commissioned a system to measure Seebeck coefficients at cryogenic temperatures.
We present first-ever data for the cryogenic Seebeck coefficient for Nb-Ti, stainless steel, and silicon bronze, materials commonly used in superconducting RF cryomodules. This data is useful to compare the impact of these materials on generating thermoelectric currents.

ACKNOWLEDGEMENTS

This work is supported by the DOE LCLS-II HE Project. Special acknowledgement goes to Paul Bishop for his help in cutting the insulating sheets, as well as the implementation of the lead wire heat sink. We would like to show our gratitude to Peter Quigly for his help in setting up the temperature monitors. We also thank Greg Kulina for his help during assembly.

REFERENCES

[1] T.O. Raubenheimer *et al.*, "The LCLS-II HE, a high energy upgrade of the LCLS-II", in *Proc. 60th ICFA Advanced Beam Dynamics Workshop on Future Light Sources (FLS2018)*, Shanghai, China, 2018, pp. 6-11. doi:10.18429/JACoWFLS2018-MOP1WA02

[2] D. Gonnella, J. Kaufman, and M. Liepe, "Impact of nitrogen doping of niobium superconducting cavities on the sensitivity of surface resistance to trapped magnetic flux", *J. Appl. Phys.*, vol. 119, p. 073904, 2016.

[3] J. Martin *et al.*, "High temperature Seebeck coefficient metrology", *J. Appl. Phys.*, vol. 108, p. 121101, 2010. doi:10.1063/1.3503505

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-THPOGE15

[4] A. Guan *et al.*, "An experimental apparatus for simultaneously measuring Seebeck coefficient and electrical resistivity from 100K to 600K", *Rev. Sci. Instrum.*, Vol. 84, p.043903, 2013. doi:10.1063/1.4798647

[5] M. Ge, A. T. Holic, M. Liepe, and J. Sears, "Seebeck Coefficient Measurement at Cryogenic Temperatures for the LCLS-II HE Project", presented at the SRF'21, East Lansing, MI, USA, Jun.-Jul. 2021, paper THPFDV006, unpublished.

[6] Frank J. Blatt *et al.*, "Thermoelectric power of metals", (1st edition), New York: Plenum Press, 1976, p. 180. ISBN 978-1-4613-4268-7