ISBN: 978-3-95450-234-9 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2023-MOPMB038

TEMPERATURE MAPPING FOR COAXIAL CAVITIES AT TRIUMF

P. Kolb*, B. Matheson, J. Keir, R.E. Laxdal, Z. Yao, TRIUMF, Vancouver, BC, Canada
H. Al Hassini, T. Junginger, University of Victoria, Victoria, BC, Canada,
L. Fearn, University of Waterloo, Waterloo, ON, Canada

Abstract

Temperature mapping (T-map) on superconducting radio-frequency (SRF) cavities has been shown as a useful tool to identify defects and other abnormal sources of losses. So far T-map systems have only been realized for elliptical cavities that have an easily accessible outer surfaces. TEM mode cavities such as quarterwave and halfwave resonators (QWR, HWR) dissipate most of their power on the inner conductor of the coaxial structure. The limited access and constrained space are a challenge for the design of a temperature mapping system. This paper describes the mechanical and electrical design including the data acquisition of a T-map system for the TRIUMF multi-mode coaxial cavities, and prototyping of the system will be shown.

INTRODUCTION

Temperature mapping has been a reliable tool to detect defects in SRF cavities since the late 90s [1]. Defects or other sources of abnormal power dissipation have a strong negative effect on the unloaded quality factor:

$$Q_0 = \frac{\omega U}{P} \tag{1}$$

with ω as resonant frequency, U as stored energy in the RF fields and P as dissipated power in the cavity walls. A decrease in Q_0 results in a higher power requirement for the cryoplant.

Temperature-mapping systems have been developed in the past for elliptical cavities operating in a TM010 mode. Elliptical cavities are a widely used cavity and dissipate their heat in easily accessible areas of the cavity body. Coaxial cavities such as QWRs and HWRs on the other hand have the majority of their magnetic field distributed on the inner conductor of the coaxial structure as can be seen in Fig. 1. This poses a challenge for the T-map system as space and access is limited to the relevant surface of the cavity. The T-Map system described here is designed to fit into the TRIUMF Coaxial Multi-mode cavities [2]. In the discussed design, eight boards are used with each board hosting 19 sensors in a vertical array down the inner conductor shown in Fig. 2. The goal for the Data Acquisition (DAQ) is a sampling frequency for all 152 sensors of 1 Hz or lower.

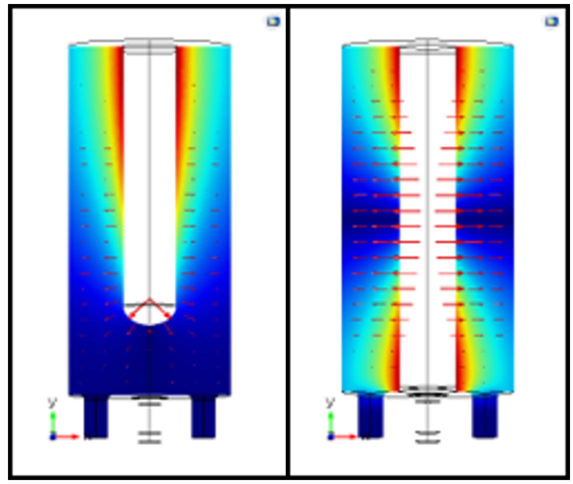

Figure 1: Field Distribution of QWR and HWR.

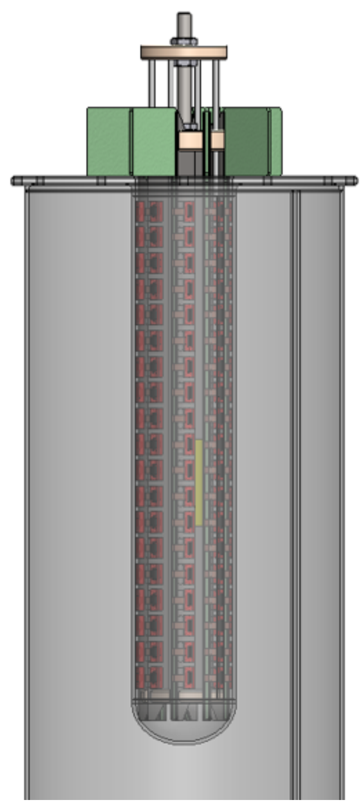

Figure 2: Conceptual setup of the coaxial Tmap system: 8 boards with each 19 sensors are arranged in a 45deg pattern to cover the inner conductor surface of the QWR. An actuation mechanism expands the system and presses the sensors against the cavity wall.

MECHANICAL DESIGN

The QWR and HWR share a large number of dimensions. This includes the inner diameter of the inner conductor. This allows the design of a common Tmap system used for both cavities. An early design choice was to make one T-map

* kolb@triumf.ca

ISBN: 978-3-95450-234-9 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2023-MOPMB038

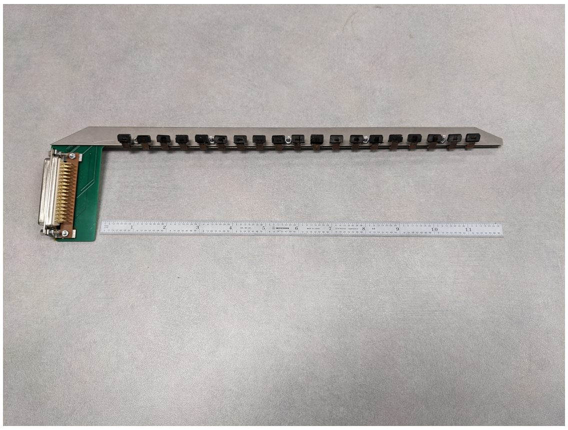

Figure 3: 'Cold' PCB with sensor-spring assemblies soldered in and sandwiched into reinforcing Ti sheets.

system for both cavities meaning the full height of the HWR is not covered with the device. If it is deemed necessary, the design can be adopted to cover the larger height of the HWR inner conductor.

As can be seen in Fig. 3, the 'cold' printed circuit board (PCB) has a long narrow shaft which holds 19 temperature sensors. The spacing between sensors is 14 mm. BeCu springs, soldered to the PCB, hold the sensor resistor. For the sensor Allen-Bradley 100 Ω 1/8 W resistors *ID* are chosen. Traces are laid out in four layers and lead to a DB50 pin connector at the top of the PCB. Angled edges at the top and bottom of the cavity provide a sliding surface for the holding mechanism. To ease insertion and removal of the assembly into the inner conductor, the sensors are retracted from the cavity walls by a actuation mechanism as shown in Fig. 4. Due to the relative structural weakness of the PCB alone and the goal contact force of 2 N between the sensor and cavity wall, the PCB has to be reinforced to prevent bending of the PCB. This reinforcement is done via the construction of a Ti-PCB-Ti beam, shown in a cross-section view in Fig. 5. The beam is assembled by clamping the PCB between two sheets of Ti. Washers provide space between the Ti and the solder points to prevent shorted electrical contact. To increase the strength of the beam, the bottom Ti sheet has a 50° bend in it, as is seen in Fig. 5. Ansys simulations show a maximum bend of 0.4 mm of the beam at its center. This is less than the nominal 2.3 mm compression of the springs. The Ti also has extended stops for the mechanical actuation mechanism. The BeCu springs are 0.2 mm thin and tempered to 1/2HT to reach the desired spring constant for the goal force and deformation.

The sensors themselves are held and potted into the BeCu springs using Stycast 2840 cat 9. A small spacer, also made from Stycast, between the resistor and spring ensures the position of the resistor is reproducible. Moulding forms for both the spacer and the sensor potting have been designed and manufactured in the TRIUMF machine shop. The sensor potting not only holds the sensor in position, but also

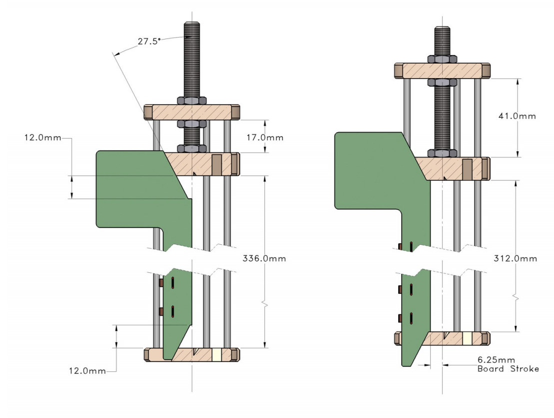

Figure 4: The vertical actuation mechanism causes a horizontal spread of the sensor boards, pressing the sensors against the cavity wall. Left: compressed state; Right: expanded state.

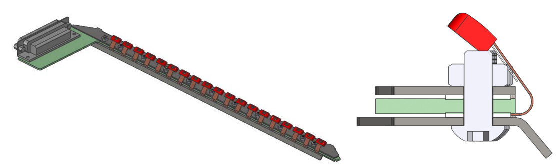

Figure 5: The PCB is 'sandwiched' between two strips of Titanium to provide mechanical stability. The angled part of the bottom Ti strip increases the mechanical stability. Left: perspective view of the full board; Right: cross section through the assembly.

shields the sensor from the LHe bath. After potting the epoxy is grounded off to expose the contact surface. A radius is worked into that grinding to match the cavity inner conductor radius. A varnish afterwards prevents electrical contact between resistor and cavity. A finished sensor-spring assembly is shown in Fig. 6. The springs are soldered to the PCB as well as the resistor leads.

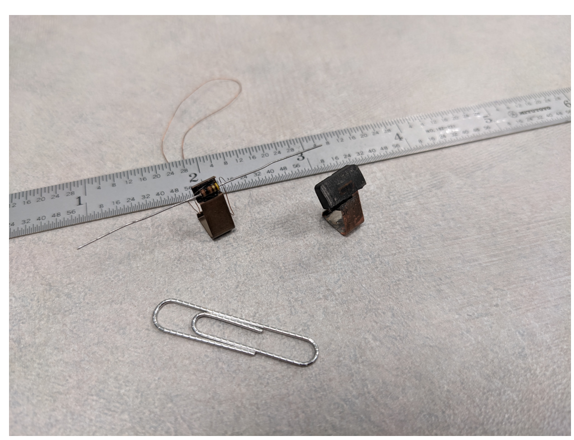

Figure 6: Spring with a temperature sensor resistor glued in (left) and fully potted in epoxy (right).

ISBN: 978-3-95450-234-9 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2023-MOPMB038

The eight cold PCBs are arranged so that the sensors are evenly distributed every 45° along the circumference of the inner conductor. The mechanical assembly also allows for the installation of a three-axis Bartington CryoMag fluxgate probe [3] with a diameter of 21 mm.

DATA ACQUISITION

The data acquisition is done via NI Labview [4]. Each cold PCB connects via a vacuum feedthrough to a custom designed 'warm' signal processing board, shown in Fig. 7. This warm board connects to a NI SCXI crate with SCXI-1102B modules that measure and digitalizes the voltage across the temperature sensor. It also connects to a Keithley 2400 source meter, which provides the required voltage and current to all sensors. Two 1 MΩ resistors are in series with each temperature sensor resistor to provide a large enough, temperature constant resistance in the circuit. The voltage measurement happens only across the sensor resistor. All 152 sensor circuits are in parallel to each other. A schematic of the circuit layout is shown in Fig. 8. The power supply is also controlled using Labview, setting a constant current and reading back the provided current and voltage. Several VI's have been developed which (1) collect data of R from all Tmap sensors and the temperature from two Cernox sensors for calibration during the cooldown without RF, (2) fit the measured T(R) calibration data to a predefined function, and (3) use this calibration to determine the temperature at the resistor for each sensor during RF operation. Two Cernox sensors located at the top and bottom of the cavity are used to calibrate the Tmap sensors to known and reliable temperature values during the cooldown from 4.4 to 1.5 K. With the RF off, it is assumed that all sensors submerged in LHe have the same temperature and the Cernox reading can be used as calibration. The calibration of the Cernox sensor is verified via physical properties of LHe like the super-fluid transition at 2.17 K and its vapour pressure to temperature relation.

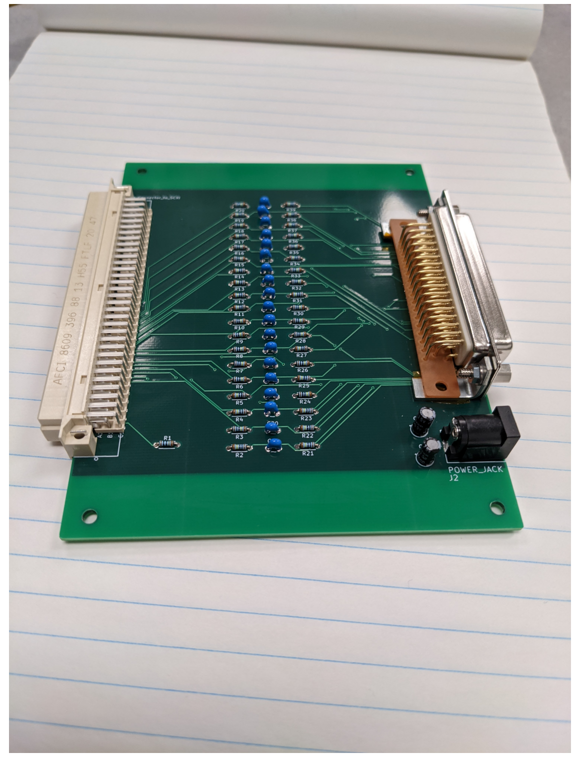

Figure 7: Photo of the warm PCB that interfaces to the NI-SCXI DAQ, Keithly power supply and cold sensor board.

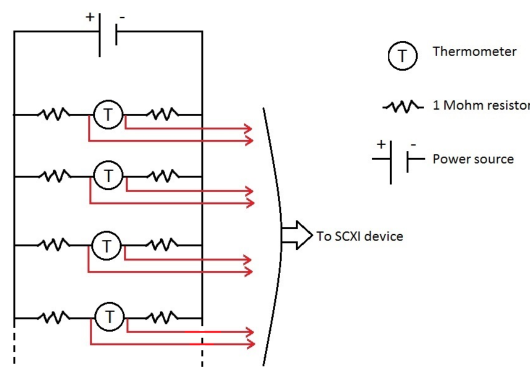

Figure 8: Schematic circuit layout for the TRIUMF Tmap system.

FIRST RESULTS

As a first step, the response of two sensor resistors to temperatures between 4 and 1.6 K was measured. The result is shown in Fig. 9. A calibration function from Cornell [5] is being adopted:

$$1/T = a_n \ln(R)^3 + b_n \ln(R)^2 + c_n \ln(R) + d_n \qquad (2)$$

with R as the measured resistance, and the coefficients a_n, b_n, c_n, d_n as fitting parameters for the n-th sensor. This provides a good agreement over a large range with the measured data. For an even better match to the data, only data below 2.2 K can be used for the fitting to get a calibration for 2.0 K. The spread in the measurement comes out due to uncertainty in the voltage measurement. Due to the fact that only two sensors were tested, the supplied current had to be reduced to 10 μA to keep the overall system voltage below 10 V. The current was stable to the specified value during the measurement to 10^{-10} A. The small current resulted in measured voltages between 5 to 50 mV. In the full setup with 152 sensors, the supplied current can be increased into the mA range due to the decreased total resistance of the circuit. This increases the measured voltage drop over the sensor accordingly, leading to a reduced measurement spread.

SUMMARY AND OUTLOOK

Temperature mapping is an established tool for detecting localized losses in SRF cavities. Systems have been widely used on elliptical cavities, while adaptations for the QWR or HWR geometry have not been done yet. The challenge

ISBN: 978-3-95450-234-9 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2023-MOPMB038

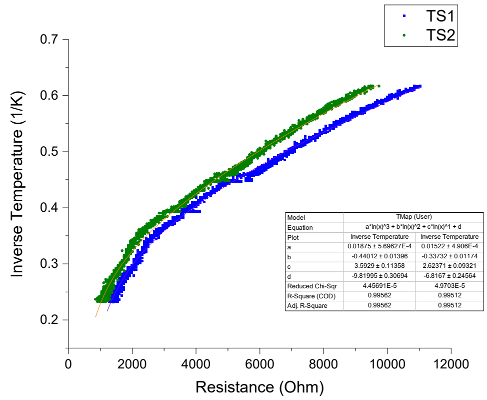

Figure 9: Calibration measurement of two sensors for the Tmap system between 4.3 and 1.6 K.

is mapping the temperatures on the inner conductor, where space is limited. A novel concept to build such a system for coaxial QWR and HWR cavities has been shown. The temperature sensors are pressed against the inner surface with a spring loaded system, that expands outwards for the measurement. The mechanical setup uses Ti strips to stiffen the printed circuit boards against bending while under tension. A labview based DAQ system has been tested by measuring the voltage response of two sensor resistors while changing the LHe bath temperature at a fixed current.

All components of the system have been tested individually. Vacuum feedthroughs, cables, and many other purchasable components are in hand and manufacturing of sensor-spring assemblies is under way. Drawings for smaller parts like the Ti-strips and actuaction rods have been made and released to the TRIUMF machine shop for fabrication. A first test of a partial or full T-map system on a cavity is anticipated for later parts of this year.

ACKNOWLEDGEMENTS

The authors would like to thank the TRIUMF electronics shop, especially Hubert Hui, for their work on the cold PCB assembly.

REFERENCES

[1] J. Knobloch, "Advanced Thermometry Studies of Superconducting Radio-Frequency Cavities", Ph.D. dissertation, Cornell University, 1997.

[2] P. Kolb *et al.*, "Coaxial multimode cavities for fundamental superconducting rf research in an unprecedented parameter space", *Phys. Rev. Accel. Beams*, vol. 23, p. 122001, 2020. doi:10.1103/PhysRevAccelBeams.23.122001

[3] https://www.bartington.com

[4] NI Labview, http://www.ni.com

[5] G. M. Ge and G. H. Hoffstaetter, "A Temperature-Mapping System for Multi-Cell SRF Accelerator Cavities", in *Proc. NAPAC'13*, Pasadena, CA, USA, Sep.-Oct. 2013, paper WEPAC09, pp. 805–807.