CONSTRUCTION, EVALUATION, AND APPLICATION OF A TEMPERATURE MAP FOR MULTI-CELL SRF CAVITY*

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Abstract

Temperature mapping (T-map) system is able to locate hot-spot of SRF cavity; therefore it is a very powerful tool for cavity Q-value research. Recently Cornell University is developing a T-mapping system for multi-cell SRF cavities. The system includes nearly two thousands Allen-Bradley resistors. Electronic of the system uses a new scheme of multiplexing sensors which dramatically reduces wire numbers for multi-cell cavity application. A new cavity testing insert for T-map has been constructed. The system has low noise and decent resolution.

INTRODUCTION

Temperature mapping system is a powerful and useful tool to investigate local as well as global surface effects of superconducting Radio-Frequency (SRF) cavity. It's able to detect temperature rising of cavity wall caused by Quench, Q-slope, Field Emission, and Multipacting during feeding RF power into cavity. Thus useful information can be concluded from T-map for cavity performance study.

T-mapping history can be traced back to 1980s. Cornell University was a pioneer to develop 1-cell T-mapping system for 1.5GHz SRF cavity research [1, 2, and 3]. Now many labs built T-mapping system, DESY and Los Alamos have T-map for 9-cell ILC cavity [4, 5]. Recently Cornell University adapted one-cell system for 1.3GHz single-cell cavity research [6].

The development of multi-cell T-mapping system is for Cornell ERL 7-cell as well as ILC 9-cell SRF cavity high-Q-value research. Cornell ERL project requires 7-cell cavity's Q_0 to achieve 2×10^{10} at accelerating gradient 16MV/m [7]. Therefore to understand surface losses mechanism is ultra-important.

MULTI-CELL T-MAPPING

For high-Q research, it requires T-map to have high-resolution. To a 1.3GHz SRF cavity, the temperature rising of exterior wall is about 10mK at 25MV/m in 2K helium bath [9]. Hence the resolution of T-map is required to be approximately 1mK.

Thermometers and Boards

Cornell multi-cell T-mapping system has nearly two thousands thermometers. The temperature sensor is a 100Ω carbon Allen-Bradley resistor (5% 1/8 W). Figure 1 shows the schematic and a picture. Dow Corning vacuum grease is applied on the varnished side of the thermometers prior to inserting the boards in cages. Silicon-based Dow Corning grease has similar thermal performance to traditional APIEZON grease in superfluid helium, but much cheaper than APIEZON grease [6]. When the thermometers press to cavity wall, the grease spreads into remaining gaps and prevents superfluid helium from cooling the sensors. The sensor is able to detect 25% efficiency of temperature rising [3].

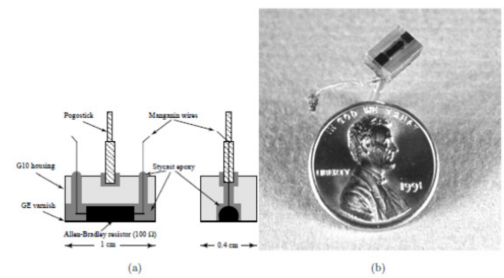

Figure 1: (a) Thermometer schematic, (b) Image of a thermometer. [3]

Two sets of 3-cell boards and one set of 1-cell boards were used for 7-cell SRF cavity. A 3-cell board has two channels addressed to the sensors for 3-cell. The sensor boards are spaced azimuthally every 15° around the cavity; totally it has 24 boards around the azimuth. Each cell is covered by 11×24 thermometer array. Figure 2 shows 3-cell and 1-cell boards installed on a multi-cell SRF cavity. The quantity of thermometers for 7-cell cavity is 1848.

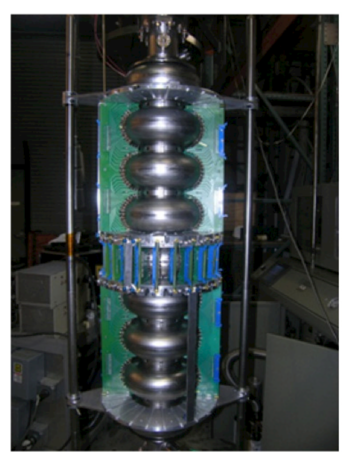

Figure 2: Boards attached on a multi-cell cavity.

Scan Scheme

The traditional scheme for single-cell system is each sensor connects two wires. Multiplexer scans each sensor one by one. However, in multi-cell T-mapping application

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the wires number would reach approximately four thousands, if single-cell T-mapping scheme is adopted. A simple scheme is proposed [8] to reduce wire number. Figure 3 is the schematic of multi-cell T-mapping system scanning scheme.

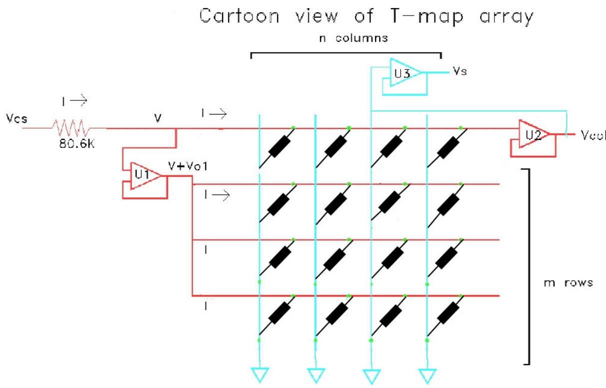

Figure 3: Schematic of multi-cell T-mapping system scanning scheme.

In the scheme, one lead of thermometer connects to horizontal wires; the other one connects to vertical wires. For each measurement, voltage applies one horizontal and one vertical wire, then the electronics captures voltage drop across the sensor. Multiplexer scans column and row wires one by one to complete whole scan of T-map. If there are n columns and m rows of thermometers, the number of wires is n+m which is less than 2×n×m wires in the traditional T-mapping scheme. In our case, we use 5×IDC-50-wire cryogenic ribbon cables for 1848 thermometers covering whole 7-cell cavity.

Electronics

The analog sensing and digital control for the signal processing board is provided by a National Instruments PXI-1033 chassis. In the chassis is a PXI-6123, 8-channel analog input, 500 kHz DAQ module, and a PXI-6509, 96 DIO module for thermometers addressing, signal conditioner gain select, carrier waveform select, and reference thermometer control. Labview software on a Windows PC with a PCI slot will control the PXI chassis.

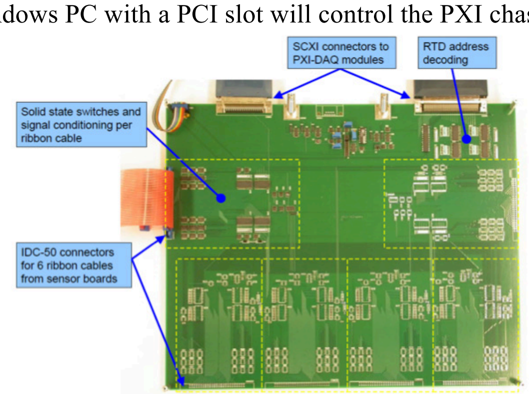

Figure 4: Pictures of electronics.

The switching and signal processing board fabricated for multi-cell cavity is shown in Figure 4. It is an 8- layer board with surface-mount components on both sides. There is a section for decoding the thermometer address and 6 duplicated channels to process the signals from 6 ribbon cables.

New Test Insert

Cornell constructed a new test insert for hanging multi-cell cavity with full T-mapping system. It has a feed-through on top-plate for extracting T-mapping cables out of Dewar. A coupler motor and Iron pump were built on the insert as well, which allows to adjust coupler position as well as to keep cavity under high-vacuum during cold RF test. Three well calibrated Cernox thermometers were attached on insert for T-mapping system calibration.

COMMISSIONING TEST AND RESULT ANALYSIS

We use a 1.3GHz single-cell SRF cavity to commission T-mapping system for saving liquid helium sake. Figure 5 shows the tests set-up. A set of 1-cell boards was attached on a single-cell cavity NR1-2. A set of 3-cell boards was assembled in cage without touching cavity wall. The other two channels were populated with testing boards (The small picture in Figure 8) which was made by 11 kΩ chip-resister arrays to simulate 3-cell T-map.

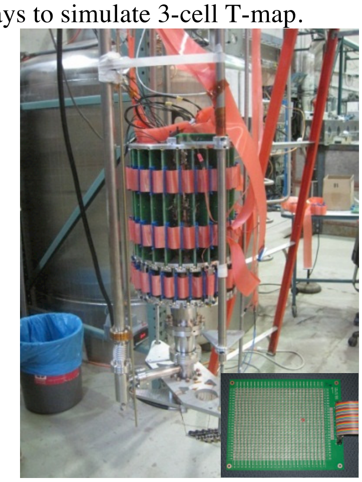

Figure 5: Picture of commissioning-test set-up.

Calibration and Sensitivity

Calibrated Lakeshore Cernox thermometer is used as a reference of helium bath temperature during cooling down from 4.2K to 2K. Calibration points were taken at every 0.2K intervals. Figure 6 is a typical 1/T vs. Resistance curve.

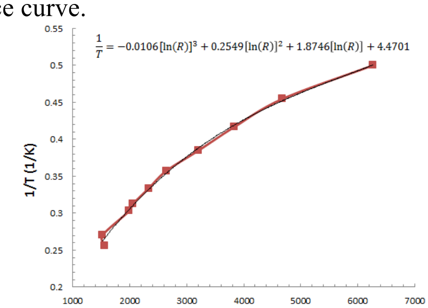

Figure 6: 1/T vs. R curve during cooling down.

A polynomial function was adopted to fit the curve,

$$\frac{1}{T} = a_n x^3 + b_n x^2 + c_n x + d_n \;; \quad x = ln(R). \qquad (1)$$

In function (1), T is the bath temperature measured by Cernox sensor, R is the resistance of Allen-Bradley resistor. a_n, b_n c_n, and d_n are fit parameters. For each Allen-Bradley resistors, it has individual calibration curve with different fit parameters.

By using fitting curves, it's able to calculate dR/dT value which represents sensitivity of T-mapping system. At 1.6K Allen-Bradley resistor is about 12kΩ, dR/dT is approximately 30Ω/mK; At 2K, dR/dT is about 10Ω/mK calculated by 6 kΩ resistance.

Noise Level Analysis

Noise comes from environment and system. Good grounding of all instruments helps to reduce noise from environment. We use a grounding line to connected signal generator, RF amplifier, T-mapping electronics, and Dewar together with building grounding point.

Increasing measurement sampling number is an effective way to reduce system noise. The sampling number for a thermometer in one scan is 2^N. The N is the parameter for setting sampling number in T-map scanning program. The program returns average value of all samples for each thermometer. Figure 7 is plot of standard deviation vs. sampling number. Each standard deviation point is calculated from 25 scans at different N value.

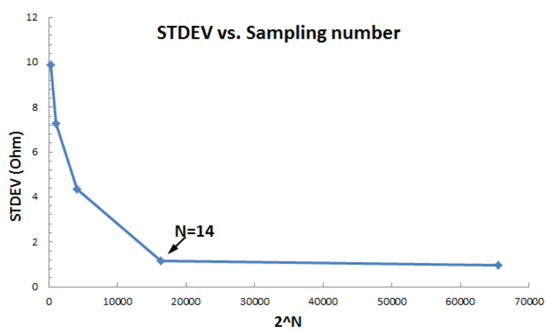

Figure 7: Standard deviation vs. sampling number.

The standard deviation achieved 1Ω, when N was set to 14, corresponding to sampling number is about 16000. The resolution of T-mapping system calculated by sensitivity and noise level; in 2K helium the resolution is about 100-300μK; and 30-100μK in 1.6K helium.

Testing Results

In the commissioning test, the T-map detected RF heating from Channel Cell 4 attached on the single-cell cavity when the cavity achieved 25MV/m and Q0 was 5×10^9. The Figure 8 is the delta-resistance map caused by cavity RF-heating. In the Cell 4 heating region, the resistance-value changed about 500 Ω smaller; therefore the detected temperature-rising was about 0.05 K.

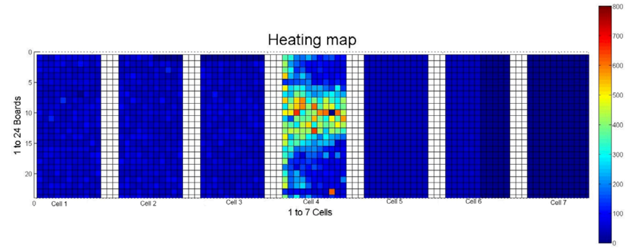

Figure 8: Heating detected from single-cell cavity.

CONCLUSION

A multi-cell T-map has been constructed at Cornell University, it has low-noise and decent resolution for high-Q research.

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