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AN INNOVATIVE DESIGN OF A FLEXIBLE TEMPERATURE-MAPPING SYSTEM*

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Abstract

A temperature-mapping (T-Map) system is an essential tool for fundamental SRF research as it provides spatial information of RF power dissipation and so allows localizing hot-spots on a cavity surface at cryogenic temperatures. However, the temperature sensors are mounted on rigid boards in most current systems, so each can only work for one specific cavity size and shape. In this paper, we proposed a flexible design, which allows this temperature mapping system to work for different cavity shapes.

INTRODUCTION

Superconducting radio-frequency (SRF) cavities are a key component of a state-of-the-art accelerator, because their ultra-low surface loss can dramatically reduce operating costs compared to normal-conducting cavities. The quality factor of a SRF cavity, defined by the cavity angular frequency (ω) multiply the stored energy (U) divided by the power dissipated on surface (P_c) (see Eq. 1), measures the efficiency of a cavity, i.e. higher Q_0 represents lower power loss on surfaces at a certain stored energy level.

$$Q_0 = \frac{\omega U}{P_c}. \quad (1)$$

The P_c can be written as an integral of the local surface resistance multiplied by the square of the magnetic field, integrated over the entire cavity surface,

$$P_c = \frac{1}{2}\int_A R_s(\vec{x})\,|H(\vec{x})|^2 da. \quad (2)$$

Eq. 2 manifests that a weighted summation of the local surface resistances determines the power loss of a cavity. A temperature-mapping (T-Map) system, which consists of a thermometer array positioned precisely on an exterior cavity wall, is capable of detecting small temperature increases on the surfaces. Therefore, it is an essential tool for SRF research, e.g. for studying localized hot-spots of an SRF cavity as well as studying quench mechanisms, etc.

Cornell University is one of the early developers of T-Map systems, has used a single-cell T-Map system since the 1980s [1, 2], and has constructed a multi-cell T-Map system [3, 4]. Today many SRF labs are equipped or plan to build a sophisticated T-Map system. Most existing T-Map systems, however, mount the temperature-sensors on rigid T-Map boards, which can only fit for one specific cavity size and shape. But the SRF cavity family has a quite large frequency range for different accelerator applications, e.g. the Cornell B-cell's frequency for the CESR is 500MHz [5], while the FLASH 3rd harmonic cavity [6] operates at a frequency of 3.9 GHz. Even at the same frequency, e.g. 1.3GHz, cavities have different shapes e.g. ILC-shape [7], Cornell ERL-shape [8], and re-entrant shape [9], etc.

In this paper, we proposed a flexible design based on the current Cornell T-Map systems, which allows it to work for different cavity sizes and shapes.

REVIEW OF THE CORNELL T-MAP SYSTEM

Before discussing the design of the flexible T-Map, we will review the Cornell T-Map systems.

T-Map Sensor and Board

The Cornell T-Map systems adopt Allen–Bradley carbon resistors (56 or 100 Ω, 1/8 W). The carbon resistor is embedded in G10 housing, which is 1 cm long by 0.4 cm wide; see Fig. 1. The leads of each resistor are connected to a Manganin wire. A clear phenolic varnish is painted on the resistor side and a spring loaded pogo stick is installed on the back side of the G10 housing hold in place by Stycast 2850 epoxy. The spring presses the sensor against cavity wall and APIEZON type N grease or Dow Corning vacuum grease is applied between the varnished side of the sensors and the cavity outside surface prior to T-Map installation. The grease fills the small gaps between the flat sensor and the curved cavity wall and so prevents superfluid helium from cooling the sensors and thereby improves thermal contact. With the grease, the thermal efficiency of the sensor is 25%-30% [2].

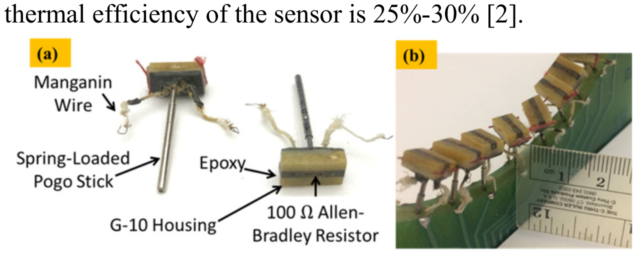

Figure 1: (a) Schematic of a carbon resistor based sensor; (b) Photograph of T-Map sensors with a ruler for size reference.

The T-Map board of the Cornell system is made of G10 material as well. There are two kinds of T-Map board in the Cornell systems: 3-cell boards and single-cell boards, as are shown in Fig. 2. The wires connecting the sensors and the blue connector are printed on the G10 board. The curvature of the board accommodates 1.3 GHz ILC-shape cavities and Cornell ERL-shape cavities, but not a re-entrant shape.

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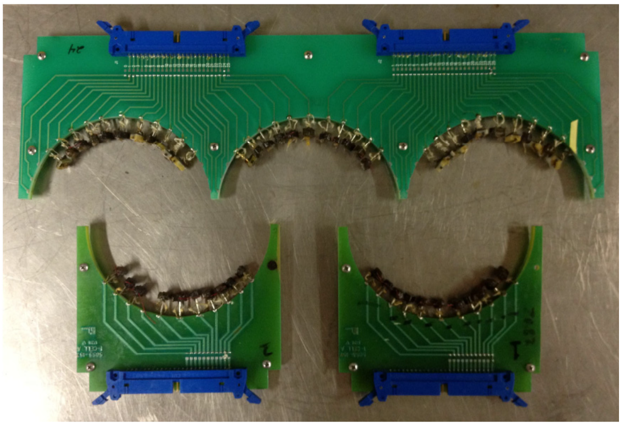

Figure 2: A 3-cell board and a 1-cell board from the Cornell T-Map systems.

Cornell T-Map Systems

The Cornell single-cell T-Map, shown in Fig. 3, has 38 boards, uniformly spaced azimuthally. Each board has 17 sensors for 646 sensors in total. The Cornell multi-cell T-Map system has 24 uniformly spaced boards around the cavity at every 15°. Each board has 11 sensors for 1848 sensors in total for a 7-cell cavity, which is depicted in Fig. 4.

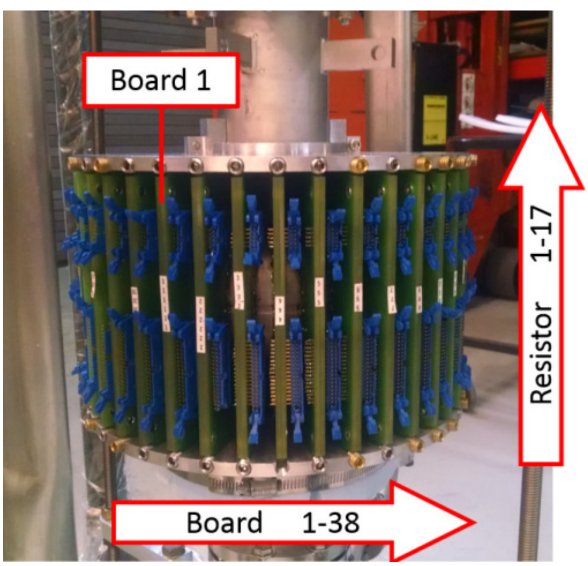

Figure 3: Photograph of the Cornell single-cell T-Map system which works for 1.3 GHz ILC-shape and Cornell ERL-shape cavities.

The noise level for the Cornell T-Map systems is very low, which gives high thermal resolution of the systems. The 3-sigma noise level is ~1-2 mK, as is shown in Fig. 5. We optimised the scan time and sampling numbers to set the total scan time of the system is about 1 min.

The T-Map is capable of quench detection using a special scan scheme in which the T-Map performs a quick scan to locate heating spots, then narrow down the scan region on those spots to extract the quench signal. Figure 6 gives an example of the quench detection of the 1.3GHz 9-cell cavity TB9AES022. The quench was detected on the cell #2 equator region, consistent with second sound (OST) measurement results. The quench pulse heated the cavity spot up to 17 K with 357 ms width.

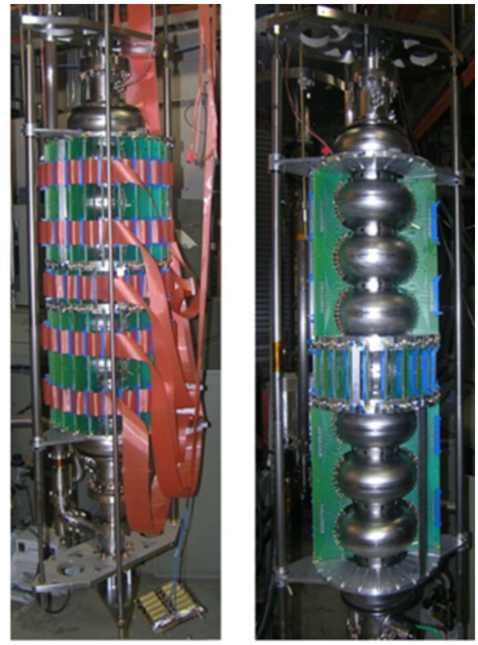

Figure 4: Photograph of the Cornell multi-cell T-Map system.

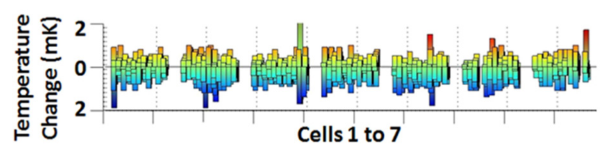

Figure 5: The 3-sigma noise level is ~1-2 mK; 1-sigma is about 0.2 mK.

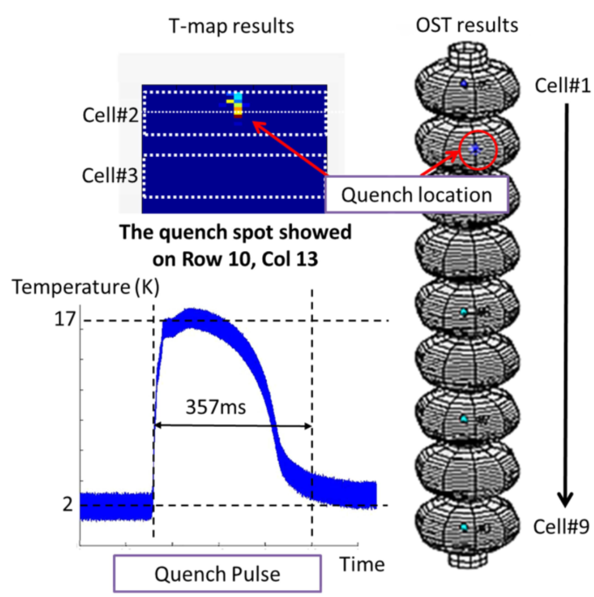

Figure 6: Quench location with TB9AES022 detected by the OST system and the Cornell T-Map with the quench recorded by the T-Map system shown in the inset on the left.

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DESIGN OF THE FLEXIBLE TEMPERATURE-MAP SYSTEM

The flexible T-Map system is based on the current Cornell systems, i.e. the temperature sensor, electronics, and scan software of the current system will be used in the flexible system. The rigid T-Map board is replaced by a chain-style aluminium link which is consists of the T-Map sensor holding piece and a linking piece, as is shown in Fig. 7 (a) and (b) respectively. The two types of pieces are alternatingly connected by pins. One chain accommodates 11 T-Map sensors, and a signal PCB board is installed on back side of the chain to connect the sensor wires.

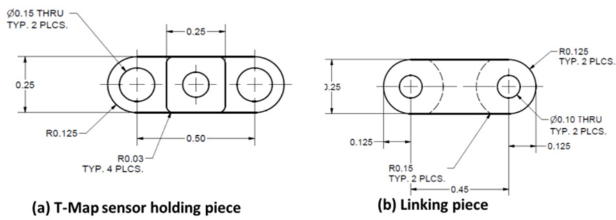

Figure 7: Two different link parts of the expandable chains of the flexible T-map system.

The full flexible T-Map consists of 24 chains spaced every 15° azimuthally. Several plastic strings connected through the holes of 24 chains are used to tighten and press the chains onto the cavity wall, as is shown in Fig. 8.

POTENTIAL APPLICATIONS OF THE FLEXIBLE T-MAP SYSTEM

Cornell University is developing state-of-the-art cavity treatment recipes via a single-cell cavity research program [10, 11]. With the flexible T-Map system, the 1.3 GHz re-entrant cavities could be included in the program. Figure 9 (a) and (b) display that two pieces of flexible chains mounted with thermometers fit to 1.3 GHz ILC and re-entrant shape SRF cavities. The figure clearly demonstrates the core concept of the flexible T-Map: accomendating different shape and frequency elliptical SRF cavities.

The chains can be easily lengthened by attaching extra pieces of link parts to fit larger cavity such as the Cornell B-cell 500 MHz cavity or PIP-II 650 MHz cavities [12], or reduced in length to fit the FLASH 3rd harmonic 3.9 GHz cavity. Figure 10 (a) depicts the flexible T-Map attached on a 3.9 GHz elliptical SRF cavity with 7 T-Map sensors, while Fig. 10 (b) shows a 650 MHz cavity installed the flexible T-Map with two chains connected together.

In addition, the flexible T-Map can fit a low- β SRF cavity such as a half-wave-resonator [13] shown in Fig. 11. The T-Map chains attached to the outer part can be tightened by strings, but the inner part can be fixed by a plug pushing through the hole at the HWR end.

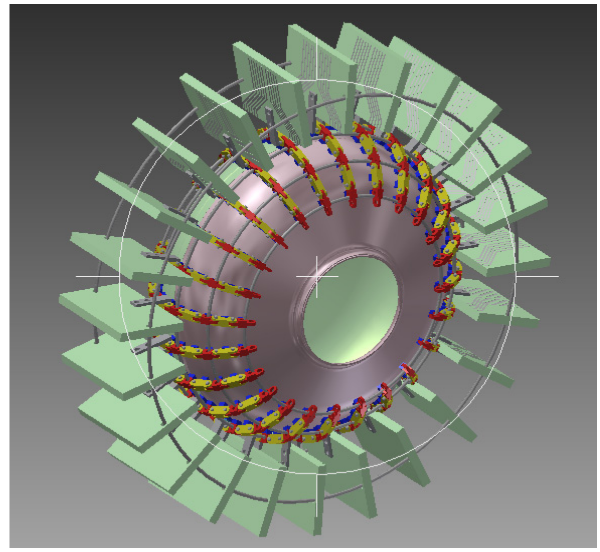

Figure 8: A flexible T-map system with a 1.3 GHz single-cell SRF cavity.

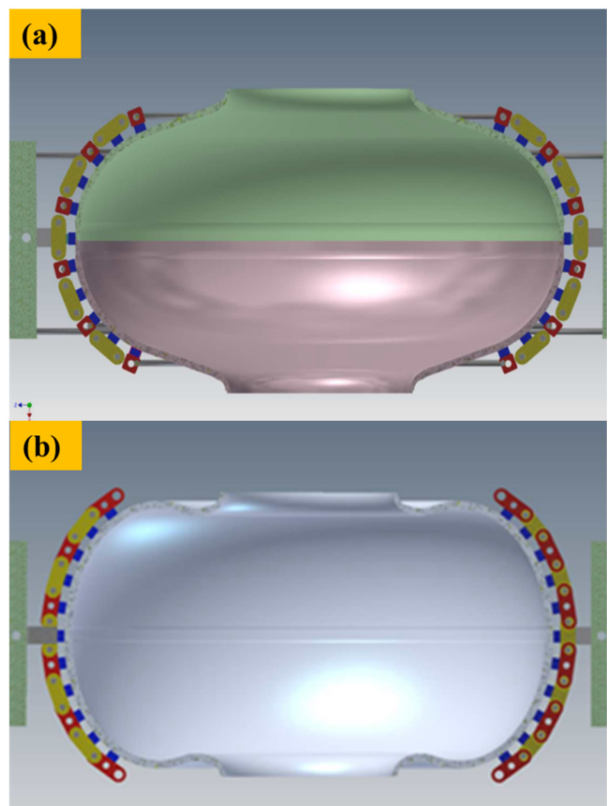

Figure 9: The flexible T-map system fits on (a) a 1.3 GHz ILC-shape SRF cavity; (b) a 1.3 GHz re-entrant shape SRF cavity.

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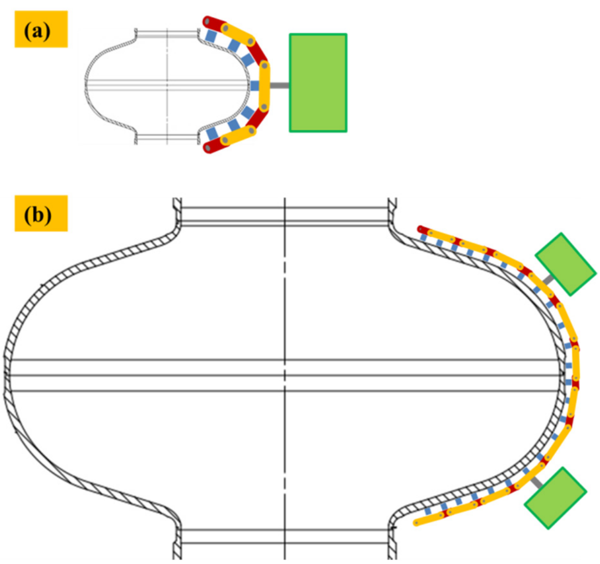

Figure 10: The flexible T-map system fits on (a) a 3.9 GHz elliptical SRF cavity; (b) a 650 MHz elliptical SRF cavity.

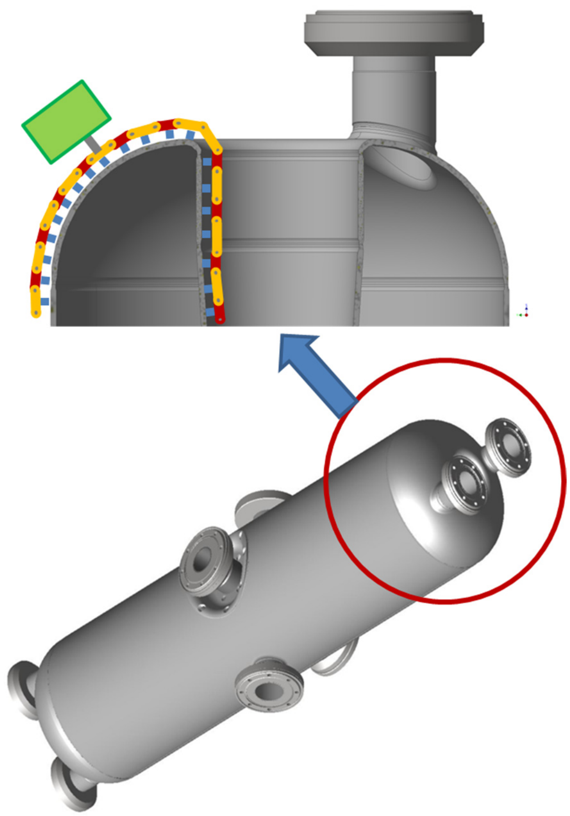

Figure 11: The flexible T-map system fits on a 162.5 MHz $\beta = 0.12$ half-wave-resonator.

CONCLUSION

A chain-style flexible T-Map has been designed based on the current Cornell T-Map systems. It can fit 1.3 GHz ILC-shape, Cornell ERL-shape, and Re-Entrant shaped cavities used in the Cornell R&D program. Beyond that, the system works for all the elliptical shape cavities from a frequency of 500 MHz to 3.9 GHz. In addition, the system can also work for low-beta cavities, e.g. a HWR cavity, etc. Since the electronics of the flexible T-Map system is same as in the current system, the same thermal resolution of ~1-2mK can be achieved. The flexible system is capable of quench detection as well.

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