RESIDUAL RESISTANCE STUDIES AT CORNELL*

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Abstract

The Cornell single-cell temperature mapping system has been adapted for use with ILC and Cornell ERL-shape superconducting accelerator cavities. The system was optimized for low-noise, high-precision measurements with the goal of measuring resistances as low as 1 nohms. Using this system, a T-map of an ILC single cell was obtained at accelerating fields below the onset of Q-slope and at temperatures at which BCS resistance is small, producing a measurement of the distribution of residual resistance over the surface of the cavity. Standard procedures were used in preparing the cavity to avoid Q-disease and trapped flux caused by cooling the cavity through its transition in the presence of magnetic fields. Studying the T-map gives clues to the source of residual resistance, so that steps can be taken to reduce it, thereby lowering losses and increasing Q_0. The temperature map noise-reduction studies as well as the residual resistance results are presented in this paper.

INTRODUCTION

Understanding how to achieve high Q_0 in superconducting RF cavities at relatively low accelerating gradients is becoming increasingly important as more and more CW SRF linac applications arise, such as the Cornell and KEK ERLs and Project X. At low temperatures and low fields, the BCS resistance and Q-slope are small, so the residual resistance R_{res} is the primary detriment to Q_0. Finding a procedure that can reliably produce very small R_{res} would substantially decrease in the load on the cryogenic plant, saving millions of dollars in power and infrastructure costs. To investigate the sources of R_{res} in a cavity that has undergone the standard preparation, temperature mapping was performed at very high precision. The methods used, the results, and the implications are presented here.

PREPARATION

A single cell ILC cavity was prepared using standard methods. It was treated with 300 μm vertical EP, degas at 800 C, micro-VEP, and baked at 120 C for 48 hours. The cavity and its Q vs E curve is shown in Fig. 1.

A temperature mapping system based on [1] was developed to fit on ILC and Cornell ERL shape single cell cavities. Surrounding the cavity are 38 boards, each with 17 Allen-Bradley resistors, as well as 3 resistors sitting in the

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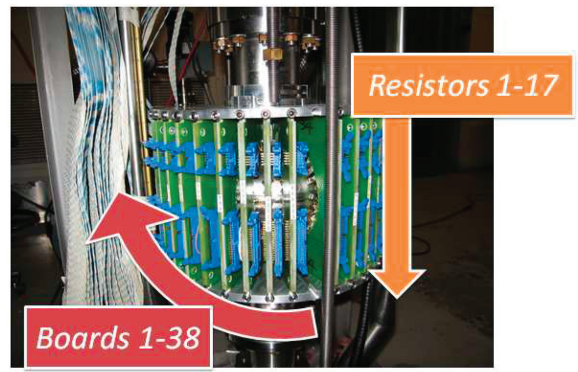

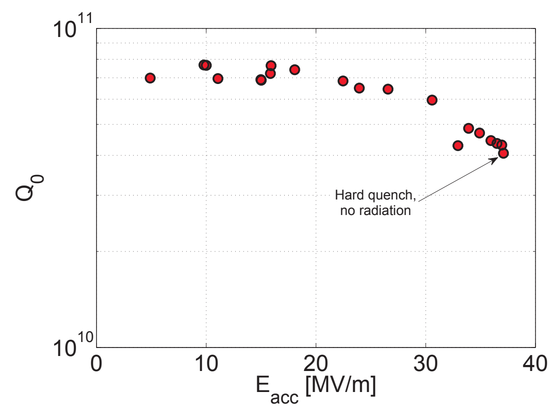

Figure 1: Cavity showing T-map setup (top) and its Q vs E curve at 1.6 K (bottom).

helium bath. A national instruments DAQ system is used to measure the resistance of the resistors. The resistors are calibrated using Cernox sensors.

NOISE REDUCTION

To measure resistances on the order of 1 nΩ with good resolution, a voltage resolution on the order of a few tens of uV was necessary. To achieve this, several steps were taken:

- A battery was used as a power source instead of a voltage supply to reduce electronics noise
- The DAQ system used a differential rather than single ended measurement scheme
- Each channel was read 1000 times in a row at 25 kHz then averaged
- A Cernox sensor was used to keep track of fast bath temperature drifts (order of seconds) and Allen-

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Bradley resistors in the bath were used to keep track of slow drifts (order of hours)

- T-maps were taken both with and without RF to remove calibration offsets
- Several 10s of T-maps were recorded and averaged to reduce noise even further, as shown in Fig. 2

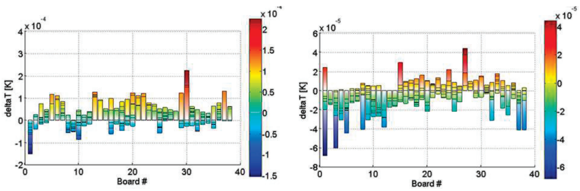

Figure 2: Approximate noise level for 1 measurement is 2×10^{-4} K (left), but by averaging 16 measurements, it drops to 4×10^{-5} K (right)

OBSERVATIONS AND ANALYSIS

A T-map taken at 1.6 K with the cavity at 10 MV/m with a Q_0 of 6×10^{10} is shown in the top of Fig. 3. To achieve high temperature resolution when the cavity was only dissipating approximately 0.16 W, 36 T-maps were recorded (both RF on and RF off) and averaged. The surface resistance R_s was calculated from the RF parameters and the surface magnetic field distribution, as shown in the bottom of Fig. 3. The temperature maps show that R_{res} is relatively uniform over surface, with several locations with R_{res} higher by a factor of 2-4 peppered throughout. However, R_{res} is not concentrated in just a few hot spots– Removing the resisters that have the highest 10% of ΔT only increases Q_0 by 26%.

After several warmup-cooldown cycles, additional T-maps were recorded under various circumstances. They are shown in Fig. 4. Comparing the low-field T-maps in Fig. 4 to those in 3, it can be seen that many of the high-R_{res} locations remain the same, even after several warmup-cooldown cycles.

Comparing the T-maps at 15 and 37 MV/m before quench in Fig. 4, it is clear that many of the high field hot spots are at high R_{res} locations, though not all of them are. In addition, the locations with the highest R_s are different at low and high fields. This suggests that the sources of R_{res} might be related to the sources of hot spots at high fields, but that there is a strong field dependence on the behavior.

Comparing the T-maps at 15 MV/m before and after quench in Fig. 4, it can be seen that there is increased R_s at the quench locations. See [2] for more information about the quenches and how the quench locations were determined using fast T-mapping. The increased R_s in the quench locations is likely due to trapped flux from thermocurrents. It is worth noting that other than these locations, the high R_s locations remain approximately the same after quench, suggesting that they are relatively stable.

OUTLOOK

To gain a better understanding of R_{res} that might lead to new preparation methods, several next steps are possible. It would be interesting to perform an HF acid rinse on this cavity and then test again with T-map to see if R_{res} distribution changes after oxide layer is regrown. Since the R_{res} distribution stays roughly the same from test to test, it would also be informative to cut out high and low R_{res} spots and do surface studies such as SEM, XPS, EBSD to look for differences.

ACKNOWLEDGEMENTS

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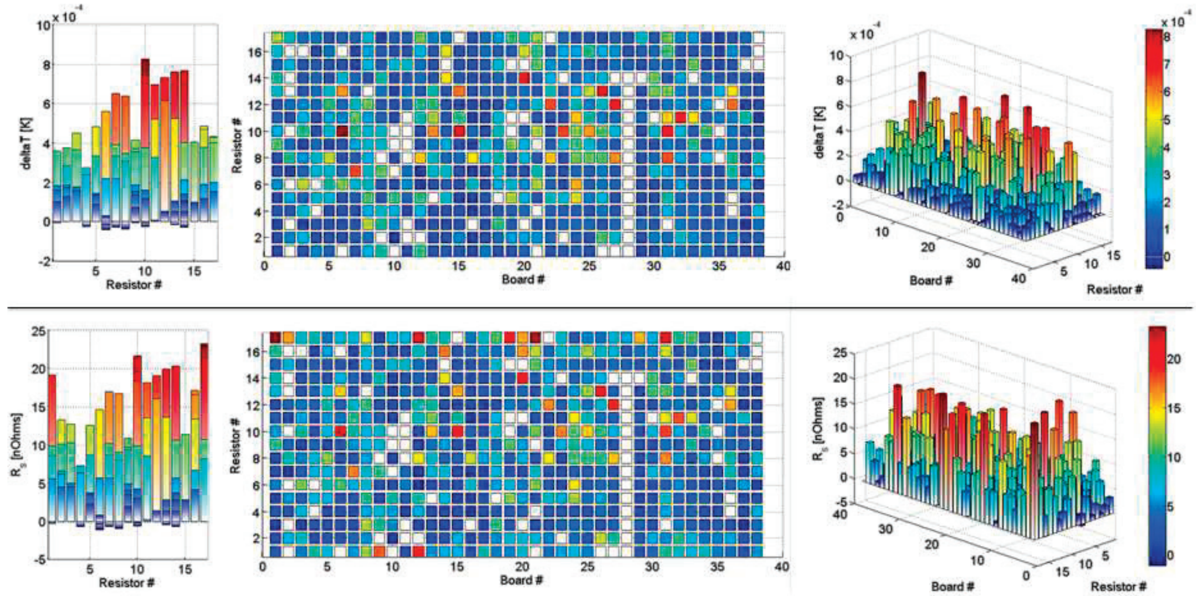

Figure 3: Top: ΔT at 1.6 K, 10 MV/m, $Q_0 = 6 \times 10^{10}$, roughly 0.16 W total power dissipated! Average of 36 T-maps. Bottom: R_s calculated from ΔT using dissipated power from RF measurements and surface magnetic field distribution from simulation. The average R_s is 5.4 n Ω

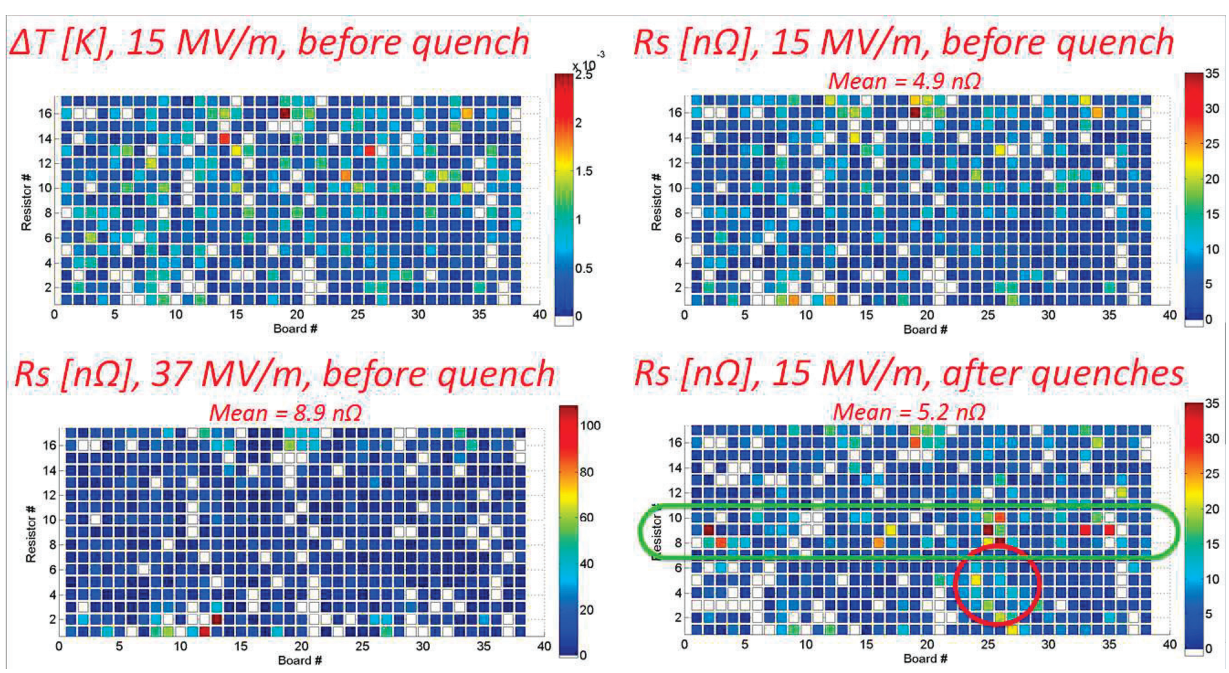

Figure 4: T-maps at low and high fields before and after quenches. The red circled area indicates the high field quench region and the green circled area indicates the mid-field quench region. Color scale in after-quench picture is forced to the same as before-quench, so some red spots may have higher R_s than indicated.

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