

QUENCH STUDIES OF A SUPERCONDUCTING RF CAVITY *

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Abstract

In tests of superconducting RF cavities, it is important to understand the cause of high field quenches. Quenches at high field above 25 MV/m are a limiting factor in the performance of high accelerating field cavities but their causes are currently not well understood. An ILC shaped single cell cavity with quench field near 40 MV/m was tested with temperature mapping to determine the cause of its hard quench. Prior to quench, heating on the order of 25 mK was concentrated in two hot spots. After a quench, these two hot spots remain and a new one appears with much higher heating (about 40 mK). The quench location was found by the temperature mapping system to be centered at the new hot spot, not at the two hot spot locations before that dominated quench. By studying the quench location and heating on the surface of the cavity, some hints were gained as to the cause of this quench.

INTRODUCTION

Superconducting RF cavities are one of the main driving forces for modern particle accelerators. Quenches in superconducting RF cavities severely limit the maximum accelerating field that can be reached. A quench occurs when a superconducting cavity transitions from superconducting to normal conducting, causing the loss of the stored energy within the cavity. Quenches below 25 MV/m typically result from defects or impurities on the surface of the cavity. The causes of quenches above 25 MV/m however, are not well understood. It is important to understand the cause of these quenches so that high accelerating fields can be reached reproducibly for future machines.

An ILC shape single cell cavity was tested with temperature mapping near its quench field. The cavity was prepared by vertical EP, 2 hour 800°C bake, micro-EP, and 48 hour 120°C bake. Heating patterns were measured before and after quench and flux trapping was observed. The heating was measured as a function of magnetic field for various hot spots and the quench location was studied. These measurements provide insight into the possible causes of the hard quench.

EXPERIMENTAL METHOD

A temperature mapping system was built consisting of 646 Allen and Bradley carbon resistors. Groups of 17 resistors are arranged on 38 boards surrounding the cavity. Collectively, they provide a complete grid of the cavity, allowing the temperature at each point on the surface to be measured. The layout of the resistors is shown in figure 1.

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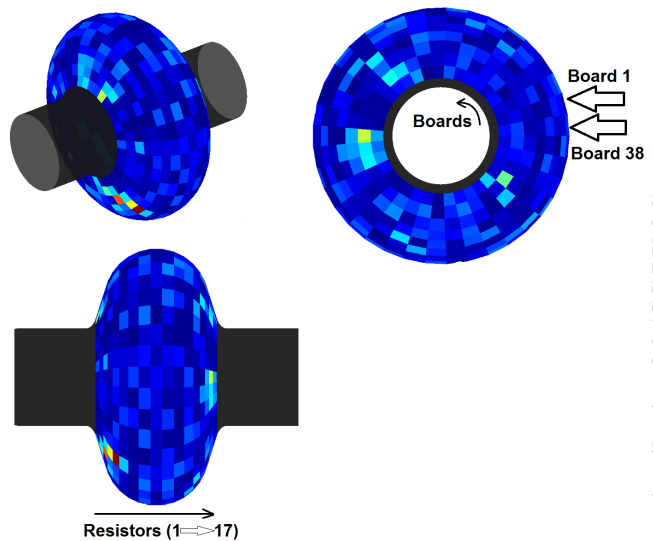


Figure 1: The layout of the 646 resistors on the surface of the cavity. They are organized in 38 boards of 17 resistors.

The cavity was brought to resonance at 1.6 K and temperature maps were taken at 1 MV/m intervals from 30 MV/m to 37 MV/m (approximately 0.2 MV/m below the quench field). The cavity was then quenched and this data was taken again. A temperature map was also taken at 37.12 MV/m, very close to the quench field, in order to see if heating occurs at the quench location just before quench.

The temperature mapping system was also used to find the quench location. During quench, sections of the cavity will become normal conducting. This can be measured with our system by observing large voltage drops across the resistors when a resistor warms. Therefore, by measuring the length of time that a given resistor is at a low resistance value, the duration of warming for that resistor can be found. The point on the cavity that stays warm the longest is hypothesized to be the quench location.

Heating was measured as a function of magnetic field for various “hot spots” on the cavity. This information is useful for understanding the mechanism of the heating at each hot spot. Traditional, ohmic, heating should scale linearly with magnetic field squared.

RESULTS AND DISCUSSION

Temperature Mapping

Prior to any quenches, temperature maps were taken at fields from 30 MV/m to 37 MV/m with a bath temperature of 1.6 K. Temperature maps at 34, 35, 36, and 37 MV/m are shown in figure 2. Heating is contained in two hot

spots, both near the irises. The first one is located at board 19, resistor 16 and shows heating on the order of approximately 25 mK at 37 MV/m. The second hot spot, at board 13, resistor 2 shows heating of approximately 40 mK at 37 MV/m. This heating, even just below (0.2 MV/m) the quench field, is too small to be causing the quench. This suggests that the quench is not triggered by pre-quench heating. Measurements of the actual quench location confirm this.

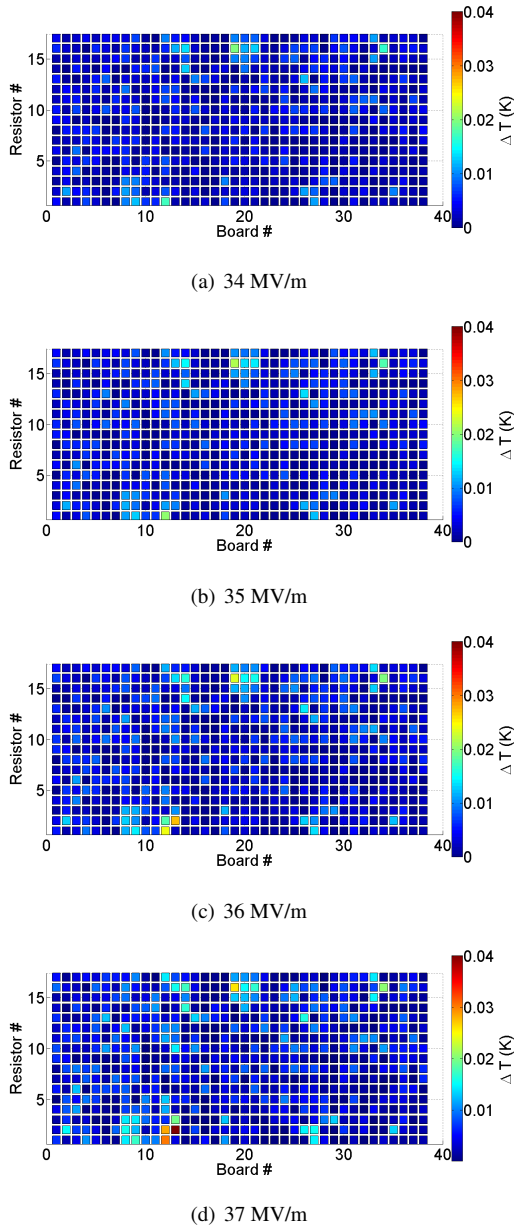


Figure 2: Temperature maps from 34 MV/m to 37 MV/m (approximately 0.2 MV/m below quench) with a bath temperature of 1.6 K. Heating is centered in two hot spots on the irises (Board 13 resistor 2 and board 19 resistor 16).

After a single quench, the two hot spots at the irises remain but a new one appears with more dominant heating.

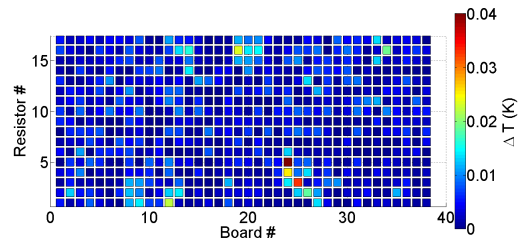


Figure 3: Heating at 36 MV/m after 1 quench. The two hot spots from before quench remain with the same heating but a new, dominant hot spot appears centered on board 24, resistor 5 with heating on the order of 40 mK.

Figure 3 shows this heating pattern at 36 MV/m, plotted on the same scale as figure 2. The new hot spot is centered at board 24 resistor 5 and shows heating on the order of 40 mK. For comparison, the other hot spots at this field show a maximum heating of 25 mK. After many quenches, this hot spot remains the dominant heating on the cavity. Since it was not present prior to quenching and appears and remains consistently after quenching, it is reasonable to believe that magnetic flux is being trapped at the new hot spot. When a superconductor transitions to normal conducting, magnetic flux from thermal currents tends to be trapped after transferring back into the superconducting regime. This heating is characteristic of such phenomena. This implies that the region centered around the new hot spot is the location of the quench. Notice that the quench location shows no unusual heating just below the quench field before the first quench (Fig. 2).

Heating was measured as a function of magnetic field for the two hot spots that are dominant before quench. Fig. 4 shows these plots. Heating on board 19 resistor 16 (Fig. 4(a)) and Board 13 resistor 2 (Fig. 4(b)) show $\Delta T \propto B^2$ at high fields but with non-zero intercepts. The slope of the high field points are higher than the slope of the low field points. The cause of this heating is not currently well understood.

Quench Detection

The quench location was found by measuring the length of time that given resistors were warm. It was found that the quench location exactly corresponded to the new hot spot that appeared after quench (where magnetic flux was being trapped). This is shown in figure 5. With this information along with the knowledge of flux trapping in the region, we can say that the quench occurs near board 24, resistor 5.

CONCLUSION

Temperature maps were taken at fields between 30 MV/m and 37 MV/m both prior to and after quench. Before quench, heating was confined to two regions on the irises. After quench, a new dominant hot spot appeared at board 24, resistor 5. This suggests that magnetic flux was

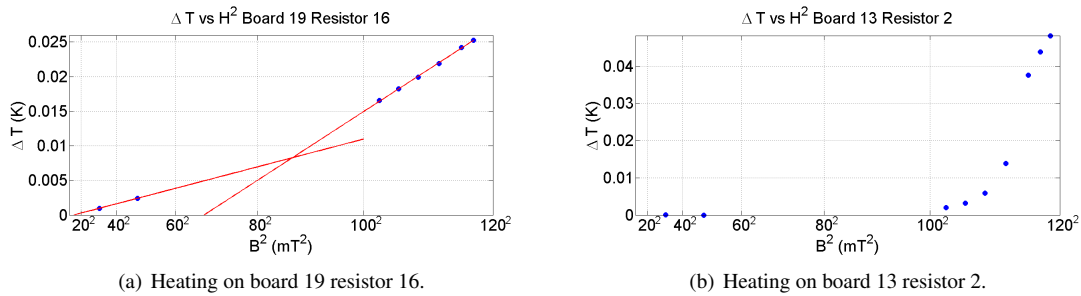


Figure 4: Heating as a function of magnetic field squared for 2 hot spots. For board 19 resistor 16, two linear fits are shown. Notice that the slope at high and low fields are different and that the high field fit does not go through zero. For board 13 resistor 2, the three highest field points are linear, again with a non-zero intercept.

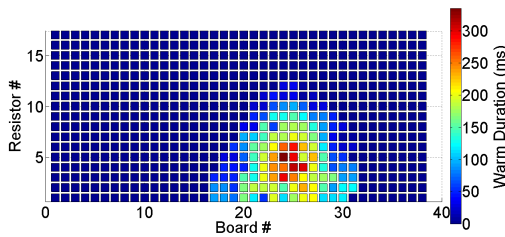


Figure 5: The quench location was found by measuring the length of time that the resistors in the temperature map were warm. The center of the quench location was found to be board 24 resistor 5, exactly corresponding to the regions of trapped magnetic flux.

trapped in the region, alluding to the possibility of this being the quench location. The exact quench location was found by measuring the length of time that given resistors were warm. From this, it was determined that board 24, resistor 5 and its neighbors, stayed warm the longest. This is consistent with the quench starting in this region. We observed no pre-quench heating at the quench location prior to the first quench. The quench was caused by the region to suddenly transition to the normal conducting state. This could be a result of the region being an area of suppressed superconductivity or magnetic field enhancement caused by the surface topology.

Heating as a function of magnetic field was measured for the two hot spots that are dominant before quench. Both show $\Delta T \propto B^2$ at high fields, but with non-zero intercepts. The cause of this heating and non-zero intercept will be investigated further in future tests.

High field quenches need to be understood in order to push the accelerating field limit in state-of-the-art accelerating cavities reproducibly to values near the theoretical maximum given by the critical magnetic surface field. By understanding the causes of quenches, we can prepare better cavities and in turn create better, more powerful accelerators and light sources.

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