MULTI-CELL REENTRANT CAVITY DEVELOPMENT AND TESTING AT CORNELL[*]

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Abstract

An innovative reentrant cavity design [1] instigated the initial, highly successful, superconducting niobium reentrant-single-cell cavity tests at Cornell and KEK [2, 3]. Prompted by the success of the single-cell program a joint effort of Cornell University and Advanced Energy Systems (AES) fabricated two multiple-cell reentrant cavities: a three-cell and a nine-cell cavity. This paper reports the development status of these two cavities. First, the results of cold tests, superfluid helium defect location and repair work on the reentrant nine-cell cavity will be presented. Second, the results of cold tests, including defect location and repair efforts of the reentrant three-cell cavity will be presented.

INTRODUCTION

The best TESLA-style 9-cell cavities reach accelerating gradients of ~45 MV/m [4]. Above this level, the peak surface magnetic field approaches the RF critical field for niobium where superconductivity breaks down.

Modifying the shape of the cavity cells to reduce the ratio between the peak surface magnetic field and the accelerating gradient has proven to be effective in circumventing this fundamental limit in single-cell tests as for the low-loss and reentrant shapes [2,3]. Prompted by the success of these single-cell tests a joint effort of Cornell University and Advanced Energy Systems (AES) fabricated two multiple-cell reentrant cavities: a 3-cell and a 9-cell cavity.

The aim of the work presented here is to demonstrate the feasibility of using 9-cell reentrant cavities for high-gradient (>35 MV/m) operation in future accelerators by testing prototype cavities. The following two sections present the results of cold tests, the gradient limiting defects, and the repair status of the reentrant cavities.

THE REENTRANT 9-CELL CAVITY

The first test of the reentrant 9-cell cavity was performed in early 2007 [5]. The processing performed for this test was: a heavy 200 μm vertical electropolish, hydrogen degassing at FNAL, a final 25 μm vertical electropolish, ultrasonic degreasing, HPR, and 48 hour 110^{0}C bake. The cavity operated cw at accelerating gradients up to 15 MV/m where the cavity quenched. This accelerating gradient corresponds to a peak surface magnetic field of 564 Oe and a peak surface electric field of 36 MV/m. The RF performance is shown in figure 1, and labeled July 2007.

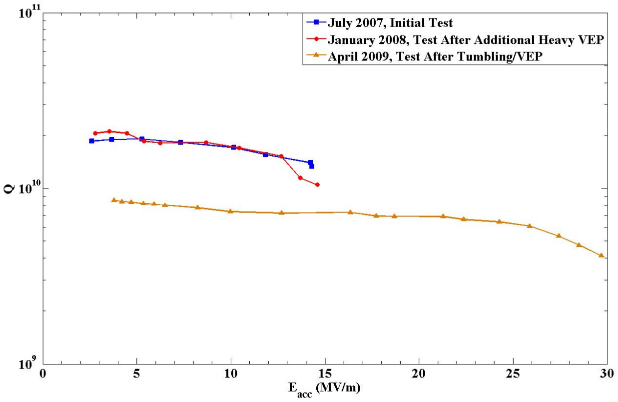

Figure 1: Reentrant 9-cell cavity test results. Initially, the cavity was found to quench at 15 MV/m. Additional, heavy electropolish did not increase the accelerating gradient. After tumbling the cavity we attained E_{acc} > 30 MV/m, limited only by the available RF power.

Immediately following the initial test which found the cavity RF field amplitude to be quench limited, two programs were implemented: 1) perform a heavy electropolish (EP), to remove enough material to repair the cavity and 2) locate the defect should the EP repair prove ineffective.

First, the cavity received a series of heavy vertical electropolish (VEP) procedures to remove 125 μm of material from the RF surface. The VEP procedures were followed with a 48 hour 600^{0}C bake at FNAL. After a micro-VEP (20 μm), HPR cleaning and 110^{0}C bake the cavity was again cooled to 2 K and tested. It was found that the cavity RF performance was unchanged (figure 1, curve labeled January 2008), requiring the determination of the defect location.

The defect was now successfully located by observing the time-of-flight of the second-sound temperature waves generated during quench [5]. A single quench event at 1.94 K is shown in figure 2. The step-like trace on the left-hand side of the figure is the transmitted power signal output from an HP 423A crystal detector. The cavity π-mode was excited with an RF-pulse to a maximum accelerating gradient of 15 MV/m, causing a cavity quench. The additional three traces display the output signal from three of the OST.

In addition, to the above event other modes of the cavity 1.3 GHz pass-band were excited at various He bath temperatures (1.85 K < Temperature < 1.95 K). In each case the cavity was found to quench at the same location.

Optical inspection of the cavity RF surface using a Questar long-distance microscope found a small pit where the second sound telemetry located the defect, figure 3. This was not the only defect found during the optical

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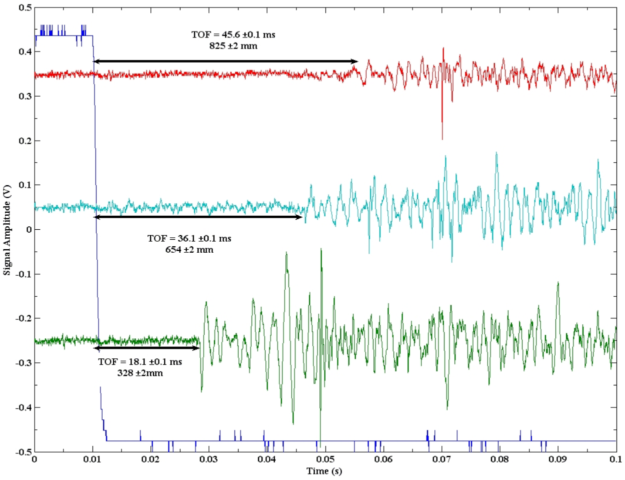

Figure 2: A representative quench event. The trace on the left (blue) shows the transmitted RF signal at quench. The upper three traces show the OST signals delayed by a time corresponding to their respective distances from the quench location.

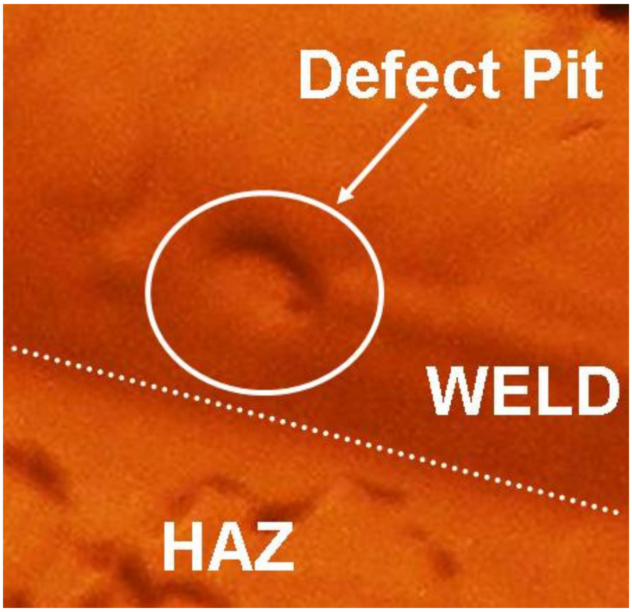

Figure 3: The defect found near the quench location is a 0.12 x 0.06 mm pit inline with a ridge on the weld (inside yellow circle). The weld appears shiny in the middle and matt at the edge due to the lighting quality.

inspection of this cavity. To avoid fixing only one defect, leaving others which may limit the maximum gradient at a slightly higher level, we decided to tumble the cavity.

The reentrant 9-cell cavity was tumbled to remove 80 µm of material from the inner surface of all cells. The tumbling was done in steps to allow for the replacement of the media and for optical inspection of the defect location. The frequent optical inspections allowed for the cessation of tumbling immediately after the defect was removed (figure 4).

Following the tumbling, the cavity was processed again with heavy vertical electropolishing (VEP), hydrogen degassing at JLAB, micro-vertical electropolishing, and a 48 hour 125^{0}C bake. The cavity RF performance is shown in figure 1 (curve labeled April 2009). The cavity reached an accelerating gradient of 30 MV/m, where we ran out of RF power to excite the cavity to higher fields. This cavity did not quench. When excited in the 5π/9-mode the cavity attained peak fields of 89 MV/m and 1400 Oe in the center cell. This corresponds to $E_{acc} > 37$ MV/m, demonstrating the effectiveness of vertical electropolishing and tumbling for the repair of pits, a common defect, in superconducting niobium cavities.

Figure 4: The defect area after 80 µm of tumbling. The pit is no longer visible, even at high magnifications. The dark blemishes are deposits from the tumbling media and were removed with HPR.

Notice the low quality factor of the repaired cavity (curve labeled April 2009, figure 1). When we tumbled the cavity we added to each cell a mixture of:

1) 200 ml DI H_2O
2) 2 ml Alconox
3) 20, 3/8” dia. x 5/8” long, ceramic angle cut cylinders. Purchased from Mikro, Vernon, CT 06066.

The quantities were chosen to tumble only the equator region of each cell. During tumbling the protective oxide at the surface is removed allowing hydrogen into the bulk material. We believe the low quality factor is due to hydrogen contamination related Q-disease. A hypothesis verified with the reentrant 3-cell cavity, which we report on next.

THE REENTRANT 3-CELL CAVITY

After it was determined the reentrant 9-cell cavity quenched at a weld defect a reentrant 3-cell cavity was fabricated. The reentrant 3-cell cavity is easier to test than the 9-cell reentrant cavity and provides a test-bed for our fabrication, processing, and repair techniques.

After fabrication, an optical inspection revealed a single-cell with a groove (~320 µm deep, ~2 cm long) in the equator-weld along seam between the melted region and the weld prep seam. To repair this defect the cavity was tumbled and processed with VEP using the same procedure listed above but with more material removal. The results of the 1.65 K RF test is shown in figure 5.

Like the reentrant 9-cell the reentrant 3-cell cavity reached useful accelerating gradients without quenching and the quality factor was found to be low. The reentrant 3-cell cavity reached an accelerating gradient of 26 MV/m which was limited only by the available RF power, the cavity did not quench.

The measured quality factor in this cavity and the reentrant 9-cell cavity were low compared to those observed in other recent cavity tests at Cornell University. We tested the possibility that hydrogen Q-disease may be the cause of the low quality factor by holding the cavity temperature between 100 K and 135 K for 30 hours. Following the warm-up the cavity was again cooled to 1.65 K. The results of the Q-disease warm-up are shown in figure 5.

The results shown in figure 5 are consistent with hydrogen Q-disease. The low-field quality factor of this cavity dropped to the high 10^7 range after being held in the Q-disease temperature range. We are now preparing to post-purify the cavity at 1350^0C which will degas the hydrogen and increase the thermal conductivity of the niobium to increase the quality factor and reach higher fields.

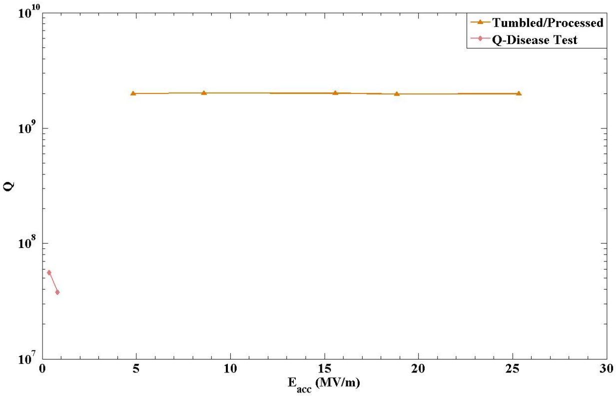

Figure 5: Reentrant 3-cell cavity test results. Like the reentrant 9-cell cavity, the reentrant 3-cell cavity did not quench and it exhibited a low quality factor. Following a warm up to the Q-disease region the quality factor dropped to ~5.5 e 7.

CONCLUSIONS AND FURTHER WORK

A joint program between the SCRF group at Cornell and AES produced and tested two multi-cell reentrant cavities. The production of these cavities is intended to demonstrate the operation of a 9-cell reentrant cavity at $E_{acc} > 35$ MV/m. This work builds upon the earlier success of the single-reentrant-cell cavities. The test results presented in this paper show that:

1) Second sound detection led us to the defect which initially caused quench.
2) Multi-cell reentrant cavity geometries are capable of attaining $E_{acc} > 35$ MV/m in individual cells.

We encountered an unexpected level of Q-disease in these cavities and further processing is required to remove the hydrogen from the bulk niobium. Future 1350^0C post-purification steps are planned for the reentrant 3-cell cavity. If this is successful it will also be applied to the reentrant 9-cell cavity.

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