

MULTI-CELL REENTRANT CAVITY DEVELOPMENT AND TESTING AT CORNELL*

Z.A. Conway[#], E.P. Chojnacki, D.L. Hartill, M.U. Liepe, D.J. Meidlinger, H.S. Padamsee, J.O. Sears, E.N. Smith, CLASSE, Cornell University, Ithaca, NY, 14853, U.S.A.

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 $^{\circ}\text{C}$ 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.

Immediately following the initial test which found the

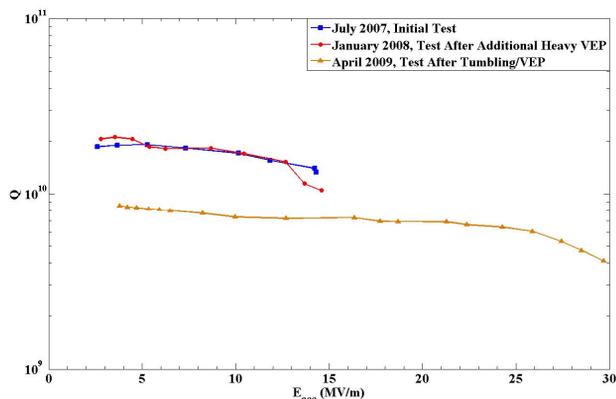


Figure 1: Reentrant 9-cell cavity test results. Initially, the cavity was found to quench at 15 MV/m. Additional, heavy electropolish did not increase the accelerating gradient. After tumbling the cavity we attained $E_{acc} > 30$ MV/m, limited only by the available RF power.

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 $^{\circ}\text{C}$ bake at FNAL. After a micro-VEP (20 μm), HPR cleaning and 110 $^{\circ}\text{C}$ 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

*Work supported by The U.S. Department of Energy

[#]zac22@cornell.edu

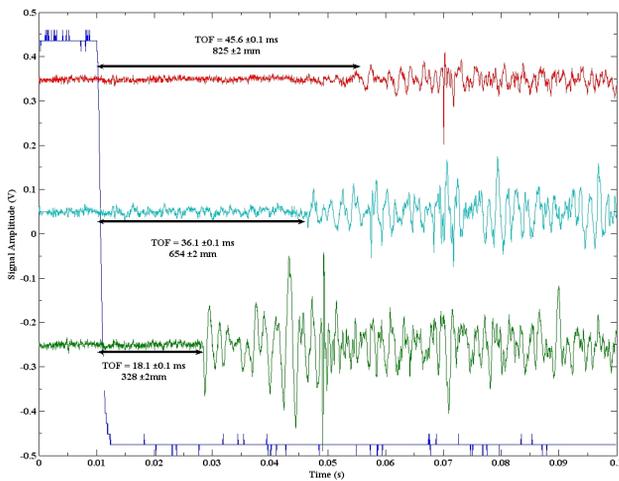


Figure 2: A representative quench event. The trace on the left (blue) shows the transmitted RF signal at quench. The upper three traces show the OST signals delayed by a time corresponding to their respective distances from the quench location.

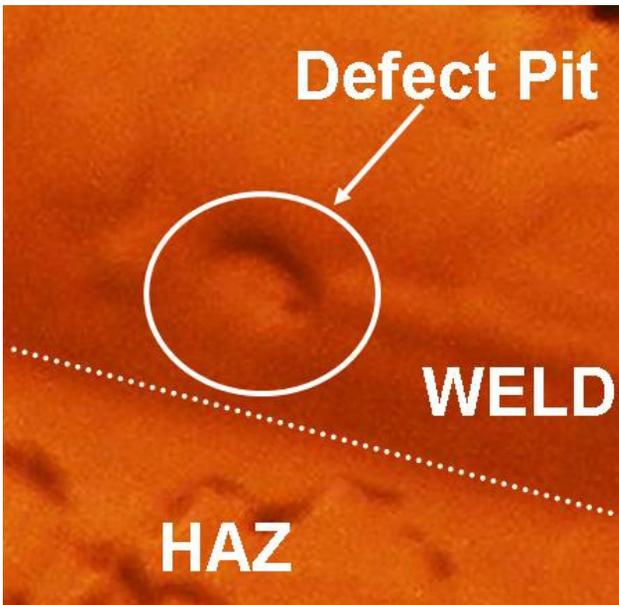


Figure 3: The defect found near the quench location is a 0.12 x 0.06 mm pit inline with a ridge on the weld (inside yellow circle). The weld appears shiny in the middle and matt at the edge due to the lighting quality.

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



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.

degassing at JLAB, micro-vertical electropolishing, and a 48 hour 125^oC 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 5 π /9-mode the cavity attained peak fields of 89 MV/m and 1400 Oe in the center cell. This corresponds to $E_{\text{acc}} > 37$ MV/m, demonstrating the effectiveness of vertical electropolishing and tumbling for the repair of pits, a common defect, in superconducting niobium cavities.

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 H₂O
- 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°C which will degas the hydrogen and increase the thermal conductivity of the niobium to increase the quality factor and reach higher fields.

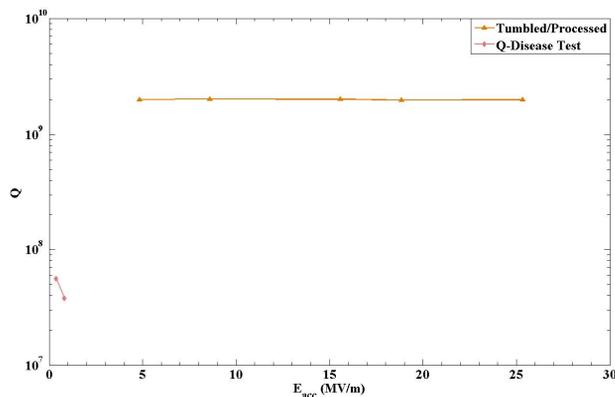


Figure 5: Reentrant 3-cell cavity test results. Like the reentrant 9-cell cavity, the reentrant 3-cell cavity did not quench and it exhibited a low quality factor. Following a warm up to the Q-disease region the quality factor dropped to $\sim 5.5 \times 10^7$.

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°C 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.

ACKNOWLEDGEMENTS

We acknowledge the contributions of Advanced Energy Systems to producing the two cavities discussed here. They formed all of the half-cells and welded the 9-cell reentrant cavity.

The authors are indebted to Anthony Crawford at JLAB for initial Q-curve measurements and for help with the cavity preparation.

John Kauffman and Brian Clasby (CLASSE, Cornell University) provided much help preparing the reentrant 3-cell cavity for cold tests.

Many thanks to Nick Szabo and Eric Smith, for their help in preparing and testing the 2nd sound transducers and electronics in the Physics 510 teaching laboratory at Cornell University.

REFERENCES

- [1] V. Shemelin, H. Padamsee, R.L. Geng, "Optimal Cells for TESLA Accelerating Structure," Nucl. Instr. and Meth. in Phys. Res. A 496 (2003) 1-7.
- [2] R.L. Geng, et. al., "World Record Accelerating Gradient Achieved in a Superconducting Niobium RF Cavity," PAC 2005, Knoxville, Tennessee, USA, July 2005, ROAC009, Pg. 653 (2005); <http://www.jacow.org>.
- [3] F. Furuta, et. al., "Experimental Comparison at KEK of High Gradient Performance of Different Single Cell Superconducting Cavity Designs," EPAC 2006, Edinburgh, Scotland, June 2006, MOPLS084, Pg. 750 (2006); <http://www.jacow.org>.
- [4] R.L. Geng, "Progress on Improving SC Cavity Performance for ILC," TU3RAI03, these proceedings
- [5] Z.A. Conway, et. al., "Oscillating Superleak Transducers for Quench Detection in Superconducting ILC Cavities Cooled With He-II," LINAC 2007, Vancouver, British Columbia, Canada, September 2008, THP036, Pg. 850 (2008); <http://www.jacow.org>.