

RAISING THE BAR ON SUPERCONDUCTING CAVITY PROCESSING AND PERFORMANCE*

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Abstract

This paper will give an overview of recent results on the highest gradient superconducting radio-frequency (SRF) cavities, including new, improved surface treatments and cavity repair techniques. Significant recent progress has been made in understanding gradient limiting effects and how to cure them. Several of these results will be reviewed here.

INTRODUCTION

Due to major R&D efforts by many laboratories within the TESLA Technology Collaboration (TTC), DESY, JLAB, and KEK have now successfully tested more than 20 cavities with peak accelerating gradients over 35 MV/m [1, 2]. Nevertheless the means for reliably producing cavities which achieve accelerating gradients >35 MV/m with a yield >90% remains to be demonstrated as one of the International Linear Collider's (ILC) highest priority R&D goals.

The rest of this paper is divided into two parts to cover several examples of current research and development efforts focused on attaining the ILC's 90% yield goal. The first part will review recent cavity polishing progress. The second part will review cavity defect location and repair techniques being employed to repair/recover SRF cavities.

CAVITY POLISHING

Electropolishing (EP) is a critical treatment step for the production of niobium cavities with accelerating gradients > 35 MV/m. The majority of EP facilities are using the continuous EP method developed at KEK [3] with the cavity held in the horizontal orientation during polishing. To further increase the number of cavities reaching accelerating gradients > 35 MV/m many laboratories have ongoing research and development programs focused on developing our basic understanding of the electropolishing process and on developing alternate techniques to supplement the traditional electropolishing process.

Understanding Electropolishing

Recent improvements in ILC 9-cell cavity processing and testing [2] led to the use of analytic chemistry to aid in the understanding of the SRF cavity electropolishing procedure. By applying analytic electrochemistry to the electropolishing of samples, new explanations have been proposed to explain an optimized procedure for repeatable high-performance cavity processing [4]. Two of the most

relevant points which can be rapidly applied to current electropolishing installations without significant changes are:

- Control the process temperature carefully to obtain a controllable and repeatable procedure [4].
- For electropolishing temperatures greater than approximately 30°C there are two material removal processes acting in parallel: a polishing process and an etching process [4]. Limit the polishing temperature to less than 30°C to avoid the undesirable etching process [2, 4].

For more information refer to reference [4].

Alternative Techniques

Cornell [5] and JLAB [6] are developing an alternative polishing method, vertical electropolish (VEP), which was designed to be less expensive and easy to install to support the mass-processing of cavities during ILC construction, refer to. The continuous VEP procedure:

- Eliminates rotary acid seals
- Eliminates sliding electrical contacts
- Eliminates the cavity vertical/horizontal position control fixturing
- Simplifies the acid plumbing/containment

Cornell has employed the VEP procedure in the past two years during the processing of several 9-cell cavities and numerous 5-cell, 3-cell, and single cell cavities. The aim of this work is to successfully process and test 9-cell ILC cavities with accelerating gradients > 35 MV/m. Defects have prevented the 9-cell ILC cavities processed with VEP from reaching the gradient goal in the π -mode. However, we have demonstrated, in individual cells, accelerating gradients which exceed 35 MV/m in two different 9-cell cavities processed with VEP: a reentrant 9-cell cavity fabricated by AES/Cornell [7] and the TESLA-style 9-cell cavity ACCEL-9 [8].

DEFECT LOCATION AND REPAIR

Defect Location

Superconducting RF cavity quench location is presently a cumbersome procedure requiring two or more expensive cold tests with large arrays of thermometers. One cold test identifies the cell-pair involved via quench field measurements. A second test follows with numerous fixed thermometers attached to the culprit cell-pair to identify the particular cell. A third measurement with many localized thermometers is necessary to zoom in on the quench spot. By operating superconducting RF cavities at temperatures below the lambda point the second sound wave emanating from the location where quench occurred

*Work supported by The U.S. Department of Energy and The National Science Foundation.

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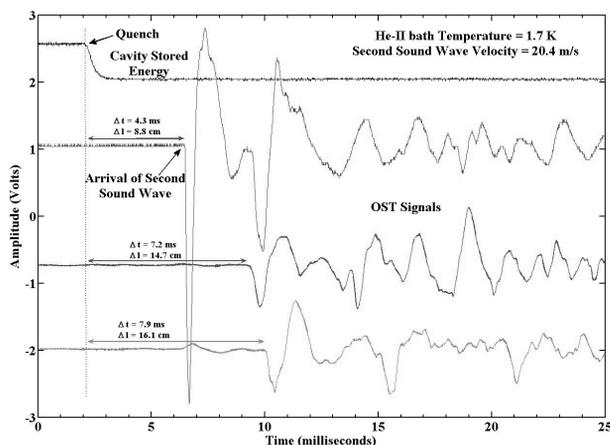


Figure 1: A typical quench event observed with three different transducers. The top trace is the amplitude of the cavity RF field. The lower three traces are the second sound signals measured with 3 distinct OST. The variation in the second sound wave time-of-arrival is well correlated with the variation in propagation distance to each transducer.

can be utilized to triangulate on the quench-spot. Here, we focus on pure three dimensional systems and on oscillating superleak transducers (OST). OSTs measure the fluctuating superfluid helium counterflow velocity to detect the time of arrival of second sound waves [9].

Figure 1 shows the experimental data from an observed quench at 1.7 K. The top, step-like, trace shows the cavity field amplitude in a single-cell TESLA-style cavity, which was excited with an RF pulse to $E_{acc} = 28$ MV/m. At this accelerating gradient the resonator quenched and the RF field decays. The lower three traces show the signals measured with three unique OSTs immersed in the superfluid helium bath with the cavity. For clarity the other five transducer signals are not shown. In figure 1, the OSTs detect the arrival of the second sound wave 4.3 ms, 7.2 ms, and 7.9 ms after quench. This indicates that the defect in the cavity is 8.8 cm, 14.7 cm, and 16.1 cm from each OST respectively. Please note, this picture is representative of many quench events and the process is highly repeatable.

Using this method the defect location is determined to an area within an approximate radius of 2-4 cm. Alternatively, using the second sound wave velocity as a free parameter and searching for the point where the signals converge improves the defect location estimate by a factor of ~ 3 . Once the defect location is known (via second sound or temperature mapping) the cavity interior is optically inspected and a course of repair can be determined.

Defect Repair

Cornell's work with single cell cavities [10] has shown that "bump-like" defects can be fixed with additional etching, e.g. BCP. However, there is mounting evidence that there are pit-like defects which cannot be fixed with heavy EP. Several ideas are currently under investigation to fix such defects: centrifugal barrel polishing, local

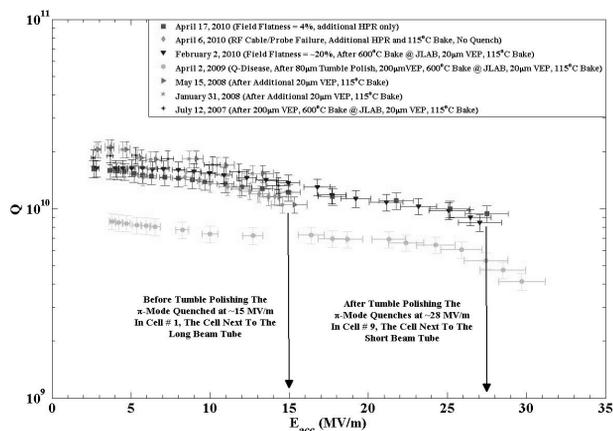


Figure 2: Reentrant 9-cell cavity test results. Initially, the cavity was found to quench at 15 MV/m. Additional, heavy electropolish did not increase the accelerating gradient. After tumbling the cavity we attained $E_{acc} \sim 30$ MV/m.

grinding/polishing, electron-beam melting, laser melting, tumbling, etc. In this section we will discuss these techniques and give examples of their effectiveness.

Tumble Polishing

Cornell employ's a simple cavity tumbling apparatus which is cheap and simple to operate. The apparatus was initially developed to tumble two-cell cavities for the ERL Injector cryomodule. It was modified to tumble cavities with one to nine cells. In this configuration the Cornell tumbling apparatus removes ~ 10 μm of surface material per day at the equator weld. This removal rate is significantly less than centrifugal barrel polishing but the system is lower in cost and easier to implement.

Recently, a 9-cell reentrant cavity was tumbled to fix equator weld defects [7]. Tumbling successfully repaired this cavity, which originally quenched at an accelerating gradient of 15 MV/m. The cavity now reaches an accelerating gradient of approximately 30 MV/m, figure 4. This shows that tumbling is a good way to repair defects, like pits.

After tumbling, processing with VEP (removed ~ 180 μm), 600°C baking for 10 hours, and micro-VEP (removed ~ 25 μm) the 9-cell reentrant cavity had a lower quality factor than expected. This was due to insufficient hydrogen-degassing of the larger quantity of hydrogen absorbed during tumbling and subsequent EP. An additional 600°C baking for 10 hours, and micro-VEP (removed ~ 25 μm) fixed this issue. A summary of all of the cavity tests is shown in figure 2.

A similar process is employed in centrifugal barrel polishing. Centrifugal barrel polishers have been in operation at DESY and KEK for many years. New systems are either being commissioned or on order at Cornell, FNAL, and JLAB to take advantage of the higher material removal rates when compared to tumble polishing.

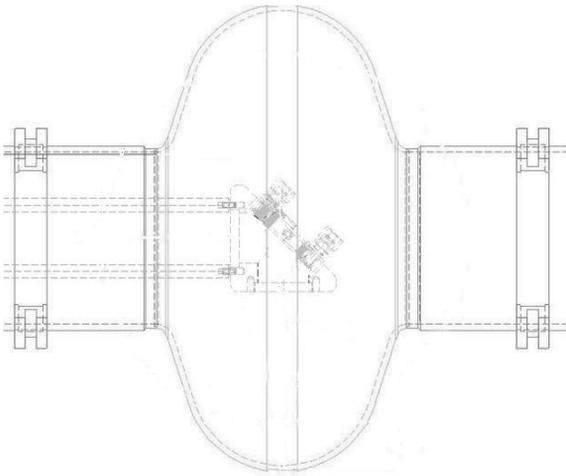


Figure 3: Schematic of the FNAL laser melting apparatus.

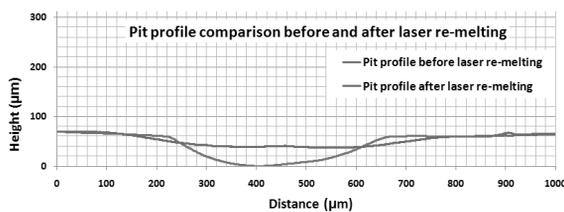


Figure 4: The profile of a defect before and after laser melting at FNAL.

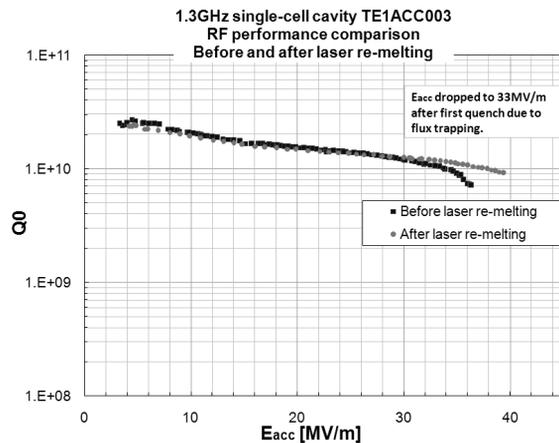


Figure 5: The RF performance of a single cell cavity before and after laser melting of a point on the inside surface. Notice that the cavity's performance does not degrade.

Laser Melting

Research at FNAL has demonstrated that if a cavity is limited by a single defect it is possible to locally change the defect's profile with a laser. This can be used to reshape a performance limiting defect by reducing the sharpness of the defect's features and thereby reducing the local field enhancement associated with the defect [11].

A schematic of the FNAL developed laser melting device is shown in figure 3. A high-power collimated laser beam is directed into the cavity. A mirror directs the

laser beam toward the cavity surface where the laser beam is focused. The incident laser beam heats and melts the defect on the cavity, which results in a net leveling of the defect. Throughout the procedure an argon purge is used to maintain the niobium purity on the cavity surface. Figure 4 is an example of a defect's profile before and after laser melting. Figure 5 shows the RF performance of a single-cell TESLA style cavity before and after laser melting. This result shows that laser melting of a cavity surface does not degrade the cavities performance.

Local Grinding

KEK has recently developed a local grinding machine which abrasively removes material from a small point inside the cavity [12]. This device can be used to remove defects from the cavity irises and equator regions by remove material until the defect region is level.

A picture of the KEK developed local grinding apparatus is shown in figure 6. The device shown has a horizontal grinder mounted on a jack which can be inserted into the cavity. The jack actuates out from the center of the cavity until the grinder surface is in contact with the cavity.

Figure 7 shows the RF performance of a 9-cell Mitsubishi Heavy Industries cavity which was initially defect limited but recovered with local grinding followed by several light electropolish procedures. Initially, the cavity quenched at 16 MV/m. Following local grinding and an approximately 20 μ m electropolish the cavity accelerating gradient improved to 27 MV/m at which point the cavity quenched at a bump-defect. The bump defect was removed by a subsequent electropolish and the cavity quenched at 17 MV/m. Following an additional high pressure water rinse the cavity reached 38 M/m in the fourth test.

SUMMARY

The ILC project goal of producing SRF cavities which reach accelerating gradients greater than 35 MV/m in vertical tests with an efficiency of 90% by 2012 is a daunting development goal. There is active work in the areas of improving cavity processing and repairing the cavities which do not pass acceptance testing.

ACKNOWLEDGEMENTS

I would like to thank R. Geng (JLAB), C. Reese (JLAB), C. Ginsburg (FNAL), G. Wu (FNAL), M. Kelly (ANL), E. Kako (KEK), K. Saito (KEK), F. Eozeenou (CEA-Saclay), W.D. Moeller (DESY), and D. Reshke (DESY) for their help and insight into many aspects of the work reviewed here.

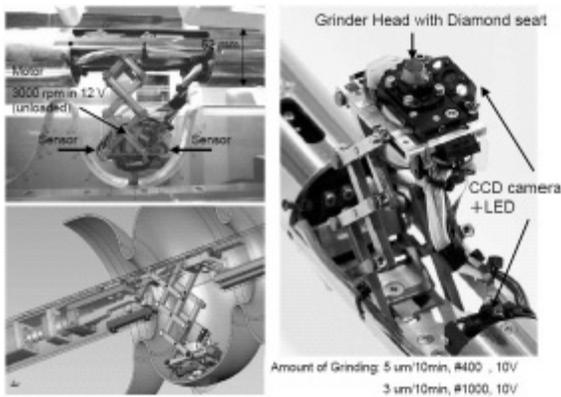


Figure 6: KEK local grinding apparatus. A different grinder is used for iris grinding and it is not shown.

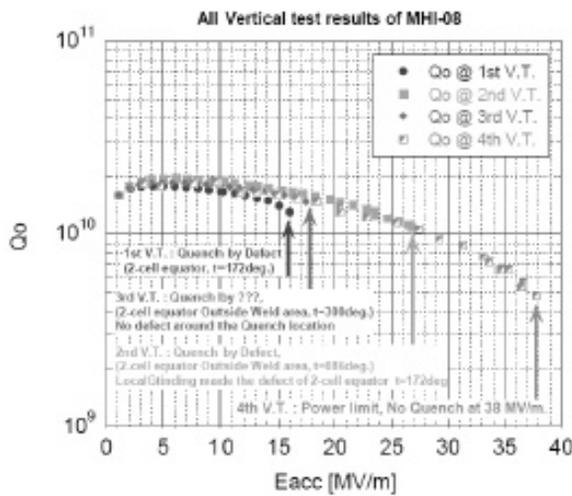


Figure 7: The RF performance of a Mitsubishi Heavy Industries cavity before and after local grinding. Notice the dramatic improvement in the cavity peak accelerating gradient after local grinding and a light electropolish.

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