IMPROVED PERFORMANCE OF JLAB 7-CELL CAVITIES BY ELECTROPOLISHING*

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Abstract

The great majority of experience in niobium SRF cavity processing at Jefferson Lab is with BCP etching. This has been used on CEBAF cavities and others totalling over 600 in number. With improved process quality control, field emission is now largely controlled and other factors limit performance. All of the prototype cavities developed for the 12 GeV upgrade, although meeting minimum requirements, have demonstrated a Q-drop in the 17–23 MV/m range that is not remedied by 120 C bake. Most of these cavities received >250 micron removal by BCP etch. Two of these cavities have been electropolished using the protocol under development within ILC R&D activities. The first such cavity was transformed from Q = 3×10^9 at 17 MV/m to quench from 1×10^{10} at 35 MV/m. The details of this and subsequent electropolished JLab 7-cell cavities will be reported.

INTRODUCTION

All of the niobium SRF cavities processed at the Thomas Jefferson National Accelerator Facility (Jefferson Lab) and installed for use in an accelerator have been prepared using a standard Buffered Chemical Polish (BCP) etch to obtain a clean, undamaged rf surface. Of these more than 600 multicell cavities, the majority date from the original CEBAF construction of 1991-1993 and were performance limited by field emission contamination and defect-induced quenches at accelerating gradients of less than 20 MV/m. [1]

With the technological progress of improved cleaning and handling techniques, together with improved purity of available niobium stock, as well as controlled fabrication processes, attaining cavity performance above 20 MV/m has become routine. While ever a real risk, field emission has been tamed and quench fields have been pushed up significantly.

To take advantage of this progress, the specification of the CW accelerating cavities for the CEBAF Upgrade approaches this 20 MV/m. During the development and prototyping stage 2003–2007, 15 7-cell cavities were fabricated, processed and tested. For these cavities, all constructed from "RRR-grade" fine-grain niobium stock and chemically etched with 1:1:2 BCP, there developed a performance pattern of degrading Q with fields above approximately 17-18 MV/m. [2] This Q drop did not respond to the now-typical 120 °C bake. It was also observed that this Q drop worsened with additional incremental BCP etching cycles. Figure 1 illustrates the typical Q drop with accelerating gradient.

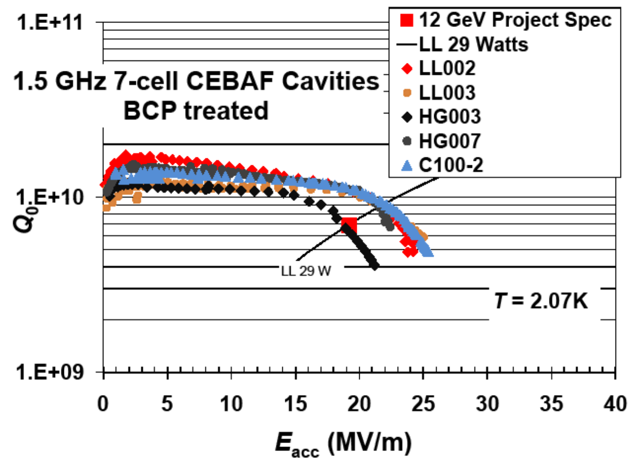

Figure 1: Characteristic Q-drop of fine-grain niobium cavities with JLab BCP etch preparation 2004-2007.

While the attained performance met the established requirements for the CEBAF 12 GeV upgrade, it has been well recognized that performance margin in the CW cryogenic load and/or acceleration capacity could be obtained by understanding and eliminating this Q-drop phenomenon.

With the inclusion of JLab in the global ILC-GDE effort to push and secure the high-gradient performance required for an energy-frontier collider, JLab began developing its capability to electropolish (EP) multicell cavities within its established system for preparing and qualifying niobium cavities. [3] We took advantage of opportunities to apply and adapt the EP process to existing idle JLab 7-cell cavities – to good effect.

PERFORMANCE HISTORY

The first 7-cell 1497 MHz cavity available for EP at JLab was cavity HG006. The parameters of this cavity design have been reported previously [2]. During the 2004 test period, this cavity was used as a vehicle for exploring the candidate causes of the Q drop. It received a series of BCP etch and test cycles, each with incrementally degrading performance.

In addition, in an effort to rule out the higher-order-mode (HOM) couplers as the source of anomalous heating, the input coupler assembly of this cavity was cut off by wire EDM and a modified endgroup lacking two HOM couplers was electron beam welded. Subsequent to this re-fabrication and additional BCP cycle, the performance was yet further degraded. One may observe the trend in the performance curves in Figure 2.

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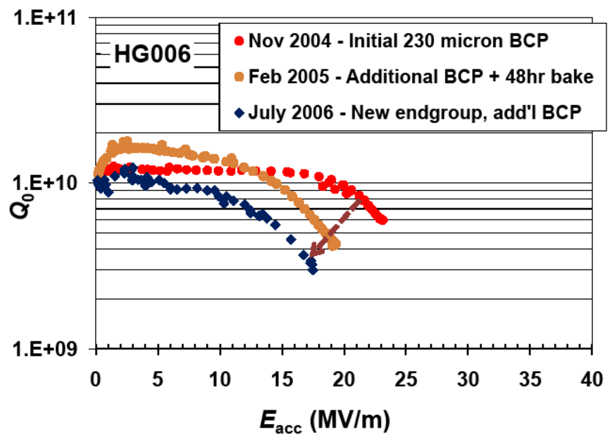

Figure 2: Sequence of degrading performance of cavity HG006 with incremental BCP cycles.

ELECTROPOLISHING PROCESS

Cavity HG006 was electropolished in the JLab horizontal electropolish machine. See Figure 3. The design of this machine follows the basic concept developed by Kenji Saito for KEK and Nomura Plating [4]. The JLab implementation is a custom unit. It should be noted that the electropolishing conditions were not optimal for this cavity. The electrolyte solution used was unintentionally diluted with water after previous use. The conditions for "Siemens" electropolishing of Niobium, i.e. current oscillations, were not achieved [5]. The fact that the subsequent rf performance of the cavity was quite good demonstrates that realizing the signature characteristic of "Siemens" electropolishing is not necessarily required. The logged process parameters for this cavity's EP operation are displayed in Figure 4.

Figure 3: 1.5 GHz 7-cell cavity HG006 being assembled into the JLab horizontal electropolish machine.

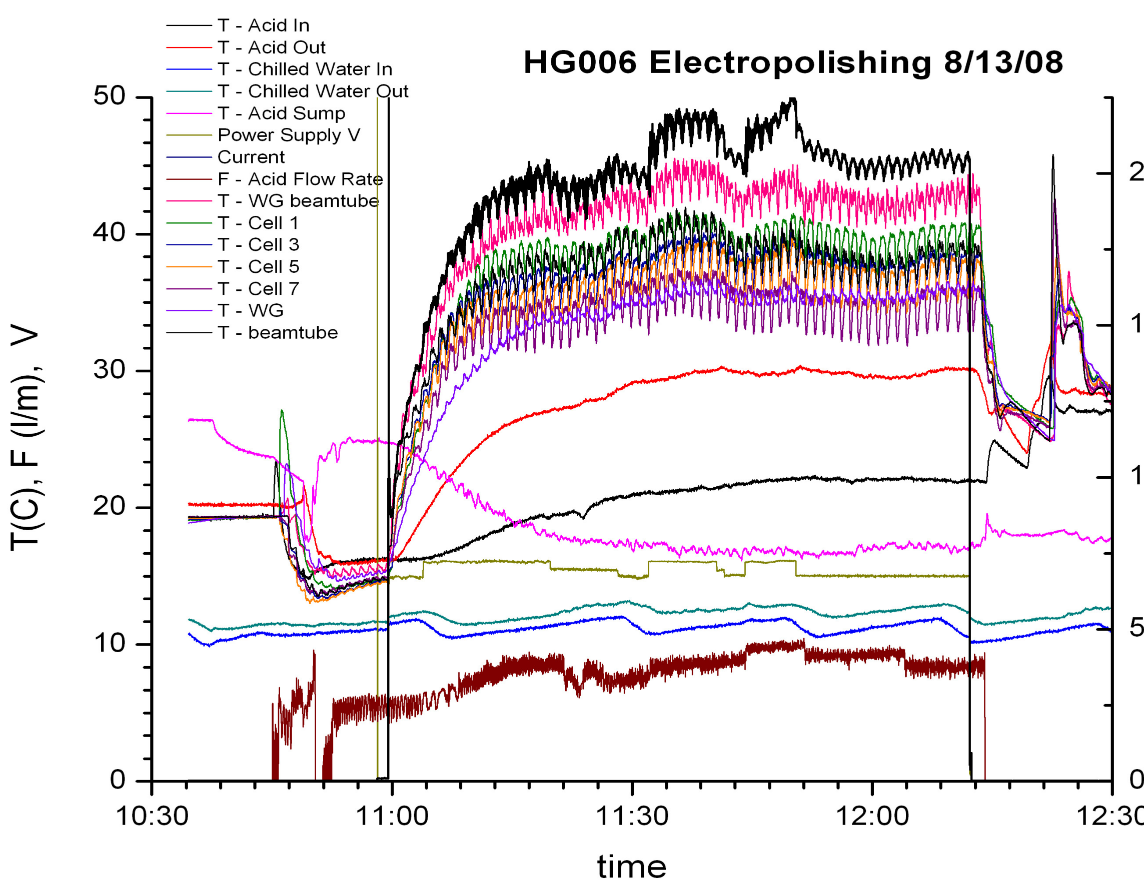

Figure 4: Electropolishing process parameters for removal of 30 microns from the JLab 7-cell cavity HG006.

For this run, the input and output flow temperatures of the electrolyte approached steady-state values of 20 °C and 30 °C respectively. Thermocouples placed near the equators and on beamtubes and the input waveguide show temperatures in the 32-42 °C range, with fluctuations at the 1 rpm cavity revolution frequency. The power supply voltage was ~14 V and the total current was ~200 A. Total processing time was less than 75 minutes.

PERFORMANCE RESULTS

After the above EP preparation the cavity was ultrasonically cleaned with detergent, high pressure rinsed with ultra pure water, assembled for test, and evacuated, HG006 was 120 °C baked for 48 hrs, then subjected to cryogenic rf testing. Performance was markedly improved. This cavity had transformed from the worst-performing JLab 7-cell cavity to the best. The testing was rf power limited at 2.0 K to 32 MV/m. Upon lowering the helium bath temperature to 1.8 K, the quench limit was encountered at 35 MV/m, with a Q_0 at that gradient of 1×10^{10}. See Figure 5.

It is interesting to note that the change in Q_0 between 2.0 and 1.8 K is approximately proportional over the whole range of fields from 1 – 32 MV/m, suggesting the effective absence of field-dependent loss mechanisms other than thermal. In addition, since for the HG cavity design B_{pk}/E_{acc} = 4.26 mT/(MV/m),[2] the peak magnetic field at quench corresponds to 150 mT.

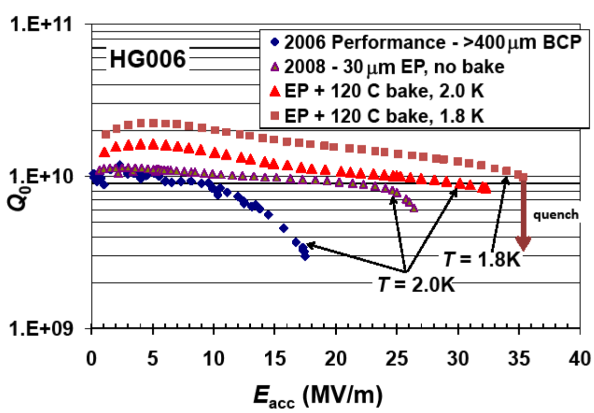

Figure 5: Performance of HG006 with initial light electropolishing treatment.

A second spare cavity of the same design, HG007, was subjected to more normal routine preparation treatments and exhibited the now typical characteristic Q drop near 20 MV/m. See Figure 6. This cavity received a similar light electropolishing treatment to that given to HG006, although with corrected standard electrolyte, which yielded the "Sieman's" process current oscillations.

The cavity performance was subsequently limited by quench at 26 MV/m; however, the Q was significantly improved up to the quench field and, similar to HG006, showed a consistent fractional dependence with rf field level over the full accessible dynamic range.

Pass-band measurements indicated end cells being responsible for quench. Subsequent optical inspection identified a particular localized fabrication flaw as a candidate source of the quench in this cavity.

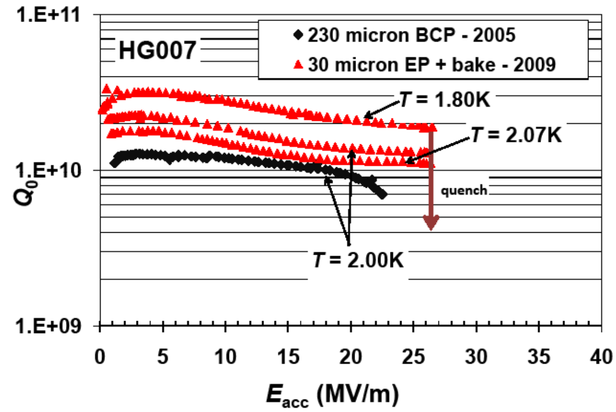

Figure 6: HG007 rf test data before and after EP.

DISCUSSION

The results obtained from the first electropolishing treatment of JLab cavities at JLab are quite encouraging, transforming the worst-performing prototype upgrade cavity into a record performer. The beneficial effects of light removal from even a significantly degraded cavity suggest that the general EP processing technology is not yet optimized.

We note that the electropolished rf surface impedance demonstrated by HG007 at 25 MV/m and 2.07 K, the 12 GeV Upgrade specified operating temperature, is 24 nΩ and would generate 30 W or 43 W/m CW in the LL cavity geometry. Alternatively, the heat load at the gradient specification of 19.2 MV/m would be 17 W, approximately half of the design load. Incorporation of EP processing into plans for CW SRF accelerators fabricated from fine-grain niobium would seem quite worthy of consideration.

ACKNOWLEDGMENTS

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