# CURRENT STATE OF ELECTROPOLISHING AT ANL*

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*Abstract*

An electropolishing system for 1.3 GHz elliptical single- and 9-cell cavities is in full operation at the joint ANL/FNAL Superconducting Cavity Surface Processing Facility (SCSPF) located at Argonne. Currently, the facility is processing an average of one cavity per week. Single-cell cavities are routinely achieving accelerating gradients exceeding 35 MV/m and several recent 9-cell cavities have operated in the region of 34-35 MV/m. Process improvements are continuing with the intent to improve overall yield at 35 MV/m and to improve cavity Q-values. Electropolishing on dressed 9-cell cavities is being explored as a technique for recovering previously good performing bare cavities where performance has degraded, for example, after RF processing. A new electropolishing tool for co-axial half- and quarter-wave cavities has been recently commissioned and work is ongoing to adapt this new tool for 650 MHz elliptical shaped cavities for Project X.

## INTRODUCTION

The SCSPF is a 200 $m^2$ facility that houses a pair of class 100 clean rooms for HPR and clean assembly, a class 1000 anteroom, and two separate chemistry rooms along with a 3000 scfm air scrubber to remove hazardous fumes generated from electropolishing (EP) and buffered chemical polishing (BCP) processes [1]. The facility has now been electropolishing 1.3 GHz elliptical shaped superconducting niobium RF cavities for the International Linear Collider (ILC) since May of 2008. Currently, the SCSPF is electropolishing 1.3 GHz cavities at an average pace of one cavity per week with a total of 42 processes in 2010. A second EP tool, along with a new high pressure rinsing (HPR) tool, were designed and built to process quarter-wave resonators (QWR) for the Intensity Upgrade of the Argonne Tandem Linac Accelerator System (ATLAS). Both the new EP and HPR tools were built with the flexibility to accommodate cavities of various geometries, such as 650 MHz tesla shaped cavities for Project X.

## ILC

### *Evolution of EP Parameters*

Since the inception of the elliptical cell EP tool at the SCSPF, continuous process improvements and system upgrades have subsequently led to an evolution of our EP parameters. The original parameters were chosen based on what was known to reliably produce good performing cavities at the time [2]. These original parameters steered the electropolishing process by controlling the acid return temperature, which is the temperature of the acid exiting the cavity.

Discussions with KEK, JLAB, and FNAL in March 2010 led to adjustments in some of our EP parameters. The EP process was then operated at a lower voltage and driven by controlling the cavity surface temperature instead of the acid return temperature (see Table 1). An increase in accelerating gradient and a decrease in $Q_o$ were immediately observed for several cavities electropolished under these adjusted conditions. One explanation for this observation is that by lowering the voltage, the process is no longer occurring on the current-limited plateau region of the I-V curve; therefore the cavity was not receiving optimum polishing.

Table 1: Evolution of EP Parameters.

| | Original Parameters | Adjusted Parameters | Current Parameters |
|---|---|---|---|
| Voltage | 18 V | 14.5 V | 18 V |
| Acid Return Temp | 30-35°C | No Longer a Control Parameter | |
| Cavity Equator Temp | N/A | Bulk: 30-35°C<br>Light: 25-30°C | Bulk: 30-35°C<br>Light: 25-30°C |

Reverting back to the original EP voltage of 18 volts while still regulating the process by cavity surface temperature improved $Q_o$ and has now become part of the standard EP parameters used to process all 1.3 GHz cavities for the ILC.

### *1.3 GHz Cavity Results*

The SCSPF has recently processed numerous single- and 9-cell cavities that have surpassed the ILC cavity performance specification of $E_{ACC}$ = 35 MV/m at $Q_o = 8 \times 10^9$.

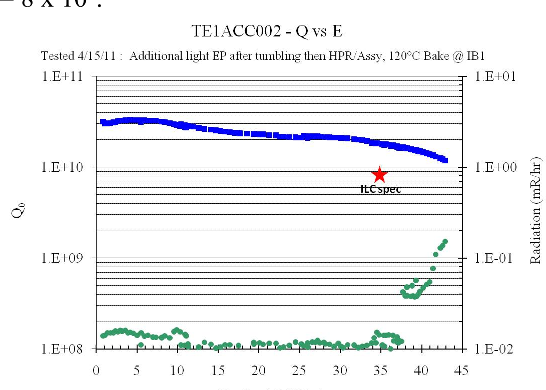


Figure 1: Cold test results for TE1ACC002.

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Cavity TE1ACC002 is a single cell cavity that was centrifugal barrel polished (CBP) at FNAL and then received a 20 μm light EP at ANL. Figure 1 shows the excellent result achieved by the combination of these processes. This promising outcome indicates the possibility of replacing bulk chemistry with CBP, a cheaper and much safer procedure.

Cavity TB9RI022 is a 9-cell cavity that received bulk (120 μm) EP at Research Instruments (RI). A total of five light (20 μm) EP processes where carried out at ANL to achieve $E_{ACC}$ = 38 MV/m with high field emission as seen in Figure 2. Subsequent HPR cycles eliminated field emission but did not improve cavity performance.

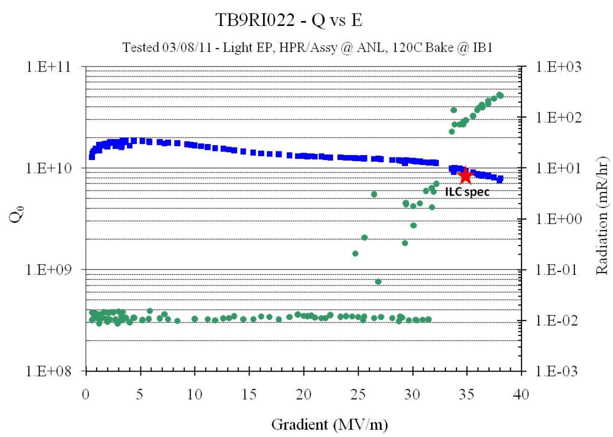


Figure 2: Cold test results for TB9RI022.

### *Horizontal EP of a Dressed 9-cell Cavity*

Cavity TB9AES002 is a 9-cell cavity that was processed and tested at JLAB, achieving 33 MV/m and subsequently chosen for dressing. After the helium vessel was welded on, the cavity received ultrasonic cleaning, HPR and was assembled for vertical testing at FNAL. Accelerating gradient was then reduced to 19.8 MV/m with no field emission.

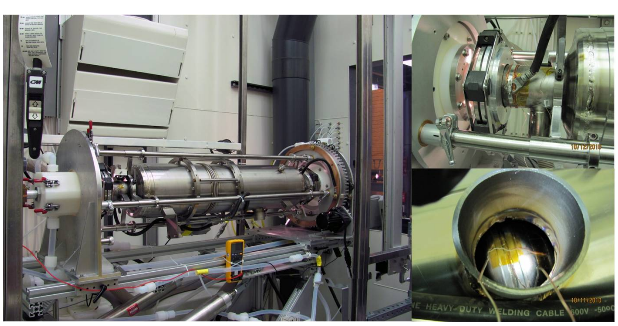

Figure 3: Dressed cavity mounted in EP tool (left). Anode connection (upper right) and thermometry (lower left).

In effort to repair cavity performance, a 20 μm EP was performed. Figure 3 shows that in order to fit the cavity with the helium jacket in the EP tool, the tuner and 2-phase helium pipe first had to be removed. This proved beneficial in the aspect that it provided the opportunity to monitor the surface temperature of one of the cells inside the helium vessel and as a result the ability to apply our standard ILC EP parameters. Without full access to the cells of the cavity, the anode connections were made on the beam tubes. Temperature of the beam tubes at the anode connection was monitored and no excessive heating was observed.

As seen in Figure 4, cavity performance after EP improved to 27 MV/m, limited due to field-induced quench. After several HPR cycles to eliminate field emission and a 120 °C bake to improve high-field Q-slope, cavity performance reached 35 MV/m with $Q_o = 1 \times 10^{10}$. This result demonstrates the possibility to use horizontal EP as a repair technique to recover cavity performance after cryomodule dressing.

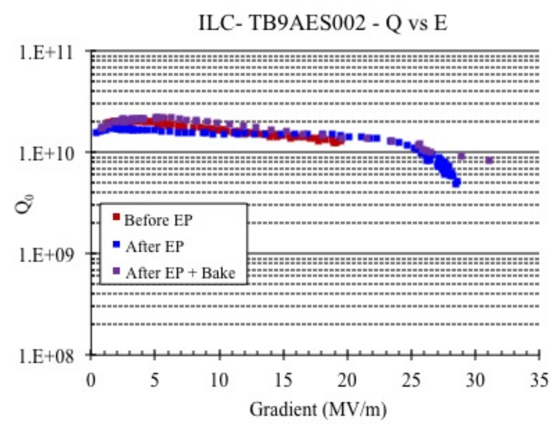


Figure 4: Cold test results for TB9AES002.

## ATLAS INTENSITY UPGRADE

### *72 MHz Quarter-Wave Resonators*

A new low-β EP tool has been constructed for co-axial half- and quarter-wave cavities, in the chemistry room neighboring the existing elliptical cell EP tool in the SCSPF. This tool was developed in order to apply the same cavity process (horizontal EP) used to generate high performing ILC cavities to maximize the cavity performance of low-β structures.

Figure 5: Prototype QWR mounted in the new low-β EP tool (left) and in the new HPR tool (right).

Recently commissioned in March 2011, the design was largely based on the existing EP tool for 1.3 GHz cavities. As shown in Figure 5, the first cavity electropolished using this tool was the prototype QWR for the Intensity Upgrade of the ATLAS accelerator at Argonne [3]. The innovative cavity design presents the opportunity to EP a QWR in a single step after all machining and welding has been completed, minimizing risks of contaminating the cavity and reducing the number of processing steps. This differs from the previous generation of QWR's installed for the ATLAS Energy Upgrade where EP was performed as two subassemblies, which then required a final electron beam weld of the cavity, installation of the helium jacket, and a final light BCP of the complete cavity [4]. In addition to the new EP tool, a new high-pressure rinse tool was designed and built to clean the prototype QWR. Like the low-β EP tool, this HPR tool is also easily adaptable for various cavity geometries [5].

Cold test results (see Figure 6) for the first electropolished QWR exceeded the ATLAS accelerator's requirements for cavity performance and also set a world record for any cavity in the velocity range of β<1 [6].

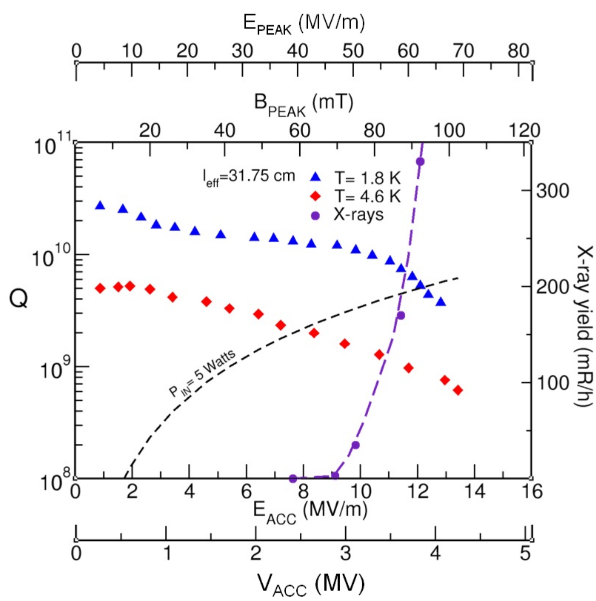


Figure 6: Cold test results for the prototype QWR.

## PROJECT X

### *650 MHz Elliptical Shaped Cavities*

Recently, a complete design (see Figure 7) has been finished to modify the low-β EP tool for 650 MHz elliptical shaped cavities for Project X. The design is essentially a scaled up copy of the ANL 1.3 GHz cavity EP tool and will be able to accommodate single-, five-, and five-cell dressed cavities. Component procurement and fabrication is underway and the first EP of a single cell cavity is planned for late 2011.

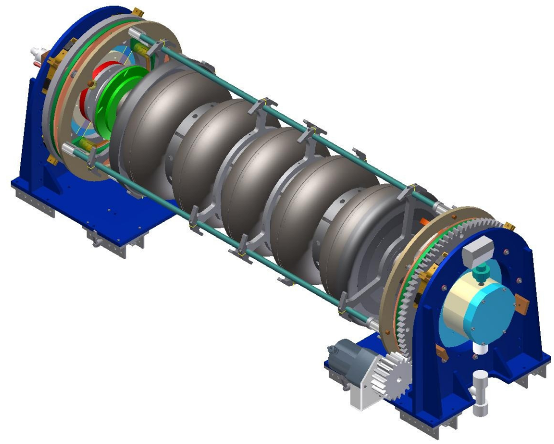

Figure 7: Complete 3-D model of the low-β EP tool adapted for 650 MHz elliptical cavities.

## SUMMARY

The SCSPF is now regularly electropolishing both single- and 9-cell cavities with accelerating gradients exceeding 35 MV/m. Process improvements will continue with the goal to improve yields above 35 MV/m. Horizontal EP on a dressed 9-cell cavity has been shown to be a possible repair technique for previously good performing cavities. A new low-β EP tool and HPR have been built. Highly optimized cavity design and decades of electropolishing experience have put ANL on the verge of demonstrating the breakthrough needed in SRF technology to realize a future compact proton accelerator.

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