STATUS OF ILC CAVITY PROCESSING AND TESTING AT CORNELL*†

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Abstract

As part of the coordinated U.S. effort to build up SRF infrastructure for the ILC, the Cornell SRF lab has developed tools and procedures for 9-cell 1.3 GHz cavity processing and vertical testing. Steps performed with 9-cell cavities at Cornell include tuning for field flatness, vertical electropolishing (or BCP if desired), high-pressure rinsing in ultra-pure water, baking at 110 °C, and RF testing at 2K in a vertical cryostat. Since spring 2006, Cornell has performed ILC cavity processing/testing cycles at a rate of about one per month. We summarize methods, results, and possible next steps.

CAVITY PROCESSING

Since early 2006, Cornell has processed three elliptical 9-cell cavities fabricated in Germany by ACCEL (AC5, AC8, and AC9) and has begun processing one re-entrant 9-cell cavity fabricated in the U.S. by AES [1]. Over time, we have converged on the following processing steps.

Heavy electropolishing. In a first electropolishing (EP) step, we remove about 150 μm of the inner surface of the cavity. This step levels out the grain-boundary enhancements left by Buffered Chemical Processing (BCP) of the half cells before assembly and smooths away any surface damage incurred during fabrication and electron-beam welding in cavity assembly. Cavities are electropolished in the "vertical EP" configuration developed at Cornell [2, 3].

The EP electrolyte formula is 91% (by volume) H_2SO_4 (concentrated, 96% by weight), 9% HF (48%), 0.25% HNO_3 (70%). Other pertinent EP parameters are summarized in Table 1. Parameters shown in red have been recently adjusted. In early EP steps, we agitated the acid by stirring at a revolution rate of 0.5 Hz and cooled the cavity surface to 30–32 °C. Between March and July 2007, we experimented with higher temperatures (up to 36 °C) and stirring rates (2 Hz). In recent EP cycles, we have retreated to 30–32 °C and 1 Hz, with encouraging results. The higher temperature had been selected to keep the mean current density close to 50 mA/cm^2. The stirring rate is believed to affect the evolution of the viscous layer of electrolyte that forms at the anode surface. While further tests will be needed to draw conclusions, we suspect that stirring at 2 Hz adversely affected the viscous layer, and hence the final surface quality.

Table 1: Electropolishing parameters.

cathode	Al $> 99.5\%$
stir tube, paddles	PVDF
electrolyte	24 liters
maximum use	9 g/l dissolved Nb
EP rate at equator	≈ 0.5 μm / minute
EP rate ratio iris/equator	< 1.5
voltage	14.5 volts
current	30–50 mA/cm^2
temperature	30–32 °C
stir rate	1 Hz

Hydrogen degassing. The cavity is shipped to JLAB or FNAL for heat treatment in a vacuum furnace. (A 9-cell cavity will not fit into Cornell's furnace.) Annealing at 600 °C for 10 hours under vacuum is intended to prevent "Q disease" by liberating trapped hydrogen that can be absorbed during EP. The violet and blue curves in Figure 1 illustrate (in RF tests with rapid cooldown) the effect on cavity Q of degassing after heavy EP.

Tuning. We measure the π-mode field flatness with a bead-pull apparatus. If the $E_{\rm acc}$ nonuniformity is worse than about $\pm 2.5\%$, we tune it to $\pm 1\%$ or better [4].

Light electropolishing. An additional layer of inner surface material, about 25 μm, is removed in a post-degassing EP step, to remove any surface contamination or scratches introduced while transporting, degassing, or tuning the cavity. To follow up on recent KEK results [5], we plan in upcoming tests to add a final ≈ 3 μm EP step with fresh electrolyte.

Ultrasonic cleaning. After EP, the cavity is flushed 3–4 times with ultra-pure water (UPW). Then it is drained and moved to an ultrasonic cleaner, where it is agitated for 60 minutes in a 1% solution of Liquinox® detergent[1] in UPW, at room temperature. The cavity is then flushed thoroughly (about 10 times) with UPW, agitated for an hour, drained, sealed with lint-free cloth and UHV foil, and moved from the chemistry room to the clean room.

High-pressure rinsing. In the clean room, the cavity is lifted with a pneumatic crane onto the high-pressure rinsing (HPR) stand, where it sits vertically. UPW at 70 atm sprays the inner cavity surface from 12 jets angled at 0° and $\pm 45^\circ$ from the horizontal plane. The jets rotate about twice per minute. The cavity moves up and down with a two-hour period, so that the entire inner surface is sprayed. We rinse 16 hours, then seal all flanges except the lower (short) beam tube 78 mm flange, then rinse another 16 hours. The cavity then dries—completely undisturbed—for 48 hours on the HPR stand, which is in a class 10 clean room. The long

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[1] Suggested by JLAB experience.

rinse times are extrapolated from single-cell experience and have not yet been systematically explored.

Assembly. We make every effort to plan carefully before removing a cavity from the HPR stand. Until the cavity is sealed onto the coupler, it is easily contaminated with dust. We keep unnecessary clutter and human activity far from the newly rinsed cavity. We wear fresh clean-room gear. We collect needed tools and parts beforehand. We move around slowly and minimally.

First, we loosely cover the cavity's lower beam tube by clipping on a thin, clean niobium plate. Then we wheel the heavy coupler, which sits on a rolling cart, from its storage area into the assembly area. The coupler, shaped like the letter Ψ, has an upward-facing antenna centered within a bellows, to allow the coupling to be varied by changing the cavity height. Two upward-facing arms, one blanked off, provide a vacuum pump-out path and a means of transmitting the weight of the coupler to the cryostat insert. The beam-tube opening of the coupler has been covered since its last use with a lint-free cloth and UHV foil.

The pneumatic crane grabs the cavity with pins inserted into two opposite holes in the stiffening ring at the third iris. The cavity is carefully removed from the HPR stand and rolled above the coupler, then lowered. The coupler is uncovered, and a new, clean aluminum gasket is placed on its 78 mm flange. The cavity is uncovered and lowered just above the coupler. The cart holding the coupler rotates to align the two 78 mm flanges until the first two bolts are inserted; then the full weight of the cavity is lowered onto the aluminum gasket, sealing the cavity. All 12 nuts and bolts are then fastened and torqued to 20 N·m.

A set of titanium and steel rods is assembled between the two ends of the cavity, to keep the cavity rigid when it is evacuated and moved up and down over the coupler bellows.

After pumpdown below 10^{-6} torr with a roughing pump and a turbomolecular pump, a leak check is performed in the clean room with helium gas and a residual gas analyzer, to sensitivity $\approx 10^{-10}$ atm $\cdot$ cm^3/s.

An all-metal valve is then closed, isolating the cavity and keeping it under vacuum. The pump-out line is bled up to atmospheric pressure and removed from the coupler. With coupler attached and sealed, the cavity is wheeled out of the clean room and into a high-bay area, where it is assembled to a vertical cryostat insert. One vacuum connection, between the coupler and the bottom of the insert, is made outside the clean room, in the clean air flow of a portable HEPA filter. The 2.5 m tall clean room door will not accomodate the insert, whose top plate lies 3.5 m above the bottom of the coupler, to match the cryostat depth.

After final pumpdown and leak check of the insert and coupler, the all-metal valve isolating the cavity is opened. With cavity pressure below 10^{-6} torr, the turbo pump is isolated and removed, and the cavity is exposed to an ion pump.

Baking at 110°C. A 30 cm $\times$ 30 cm $\times$ 125 cm box, constructed of fiberglass insulation, is fitted around the cavity. Three Leister 5000 HT heaters and a Leister Silence medium pressure blower blow hot air through three holes in the insulated box. Five thermocouples monitor the temperatures of the odd-numbered cells of the cavity. A PID servo loop, implemented with LabVIEW on a PC, regulates the temperatures via ~ 1 Hz pulse-width modulation of the 208V supplied to each heater. With the ion pump operating, the evacuated cavity is baked at ≈ 110°C for 48 hours. (We have explored the range 105–120 °C somewhat, but not yet in a systematic manner.) Through a mechanism not fully understood [6], this baking procedure reduces high-field Q slope of electropolished cavities.

RF TEST RESULTS

After the processing steps listed above, cavities are tested at 2.0K in a vertical cryostat. We list below all Cornell test results to date for 9-cell TESLA-style cavities.

Table 2: AC5 processing history.

AC5	Processing	Max $E_{\rm acc}$	Limit
Sep'06	144μm EP (0.5 Hz, 30°C)	16 MV/m	Q drop
Nov'06	degas	17 MV/m	Q drop, FE
Dec'06	3μm BCP	15 MV/m	Q drop
Mar'07	25μm EP (0.5 Hz, 36°C)	24 MV/m	quench
Jun'07	70μm EP, degas, 30μm EP (2 Hz, 35°C)	18 MV/m	quench, FE

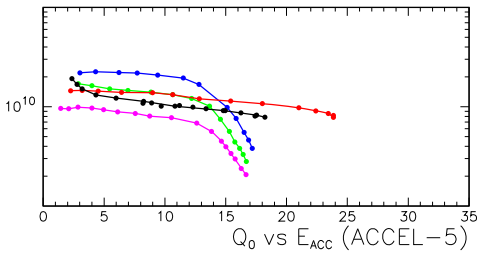

Figure 1: RF test results for AC5.

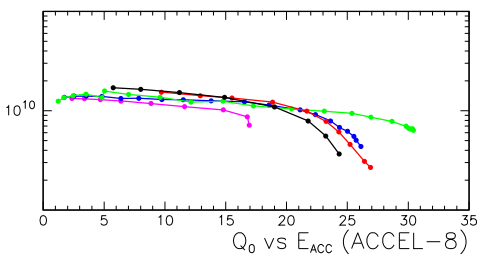

Figure 2: RF test results for AC8.

Table 3: AC8 processing history.

AC8	Processing	Max E_{acc}	Limit
Apr'06	60μm BCP	17 MV/m	quench
May'06	60μm BCP	26 MV/m	Q drop
Feb'07	25μm EP (0.5 Hz, 32°C)	30 MV/m	quench
May'07	100μm EP, degas, 30μm EP (2 Hz, 35°C)	26 MV/m	Q drop
Jul'07	7μm EP (2 Hz, 35°C)	24 MV/m	Q drop

Table 4: AC9 processing history.

AC9	Processing	Max E_{acc}	Limit
Aug'07	160μm EP, degas, 40+30μm EP (1 Hz, 31°C)	26 MV/m	quench, FE
Sep'07	30μm EP (1 Hz, 32°C)	26 MV/m	quench

We are very encouraged by these results, though additional work will be needed to reach the 35 MV/m ILC specification. Our HPR and assembly procedures seem capable of reaching high gradient without being limited by field emission.

Vertical EP followed by 110°C bake succeeds at reducing high-field Q slope, so that most of our tests have been quench-limited—though thus far at $E_{acc} \sim$ 25–30 MV/m, while we strive for 35–40 MV/m. We are also encouraged to see that 25 μm (or more) of vertical EP seems not to induce Q disease, so it is possible to carry out one or more modest EP cycles after heat treatment.

As noted above, our having varied the EP temperature and stirring rate between March and July 2007 hints that some combination of overly vigorous acid stirring and too high a temperature may degrade the smoothness of the electropolished surface.

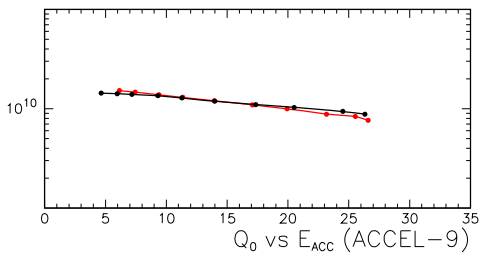

Figure 3: RF test results for AC9.

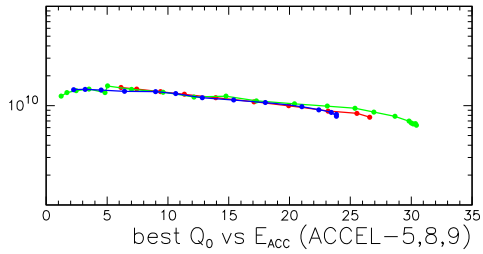

Figure 4: Best RF test results for AC5 (blue), AC8 (green), and AC9 (red).

FUTURE DIRECTIONS

The 9-cell cavity program at Cornell is ongoing. A prototype 9-cell re-entrant cavity, fabricated by AES [1], has been tested once and will be tested again after further electropolishing.

Since 9-cell tests can be expensive and somewhat laborious, we intend to collaborate with other labs on the development of thermometry systems, so that future RF tests produce more information.

The vertical EP setup is relatively new, but looks promising. This technology will be transferred to industry and to other labs. Discussions at this workshop have motivated us to consider numerical modeling and small experiments to gain a more fundamental insight into the EP process and how best to control its parameters.

SUMMARY

As the U.S. ILC program gains momentum, Cornell assists in SRF development and training by carrying out 9-cell cavity processing and testing at a rate of about one vertical test per month.

We thank the support staff of Cornell's Laboratory for Elementary-Particle Physics for their vital contributions. We also thank our JLAB colleagues for the use of their vacuum furnace for hydrogen degassing.

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