STANDARD PROCEDURES OF ILC HIGH GRADIENT CAVITY PROCESSING AND HANDLING AT JEFFERSON LAB*

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Abstract

We describe the JLab standard procedures of ILC cavity processing and handling for reproducible high gradient, high Q_0 results. The procedure includes optimized electropolishing (EP), streamlined post-EP cleaning, updated vacuum furnace out-gassing, no-touch bead-pull tuning and slow pumping down for cavity evacuation.

INTRODUCTION

The standard ILC cavity processing recipe [1] consists of, among others, the following steps following the completion of cavity fabrication,

- Light BCP etching (10-30 μm).
- Heavy EP (100-150 μm).
- Vacuum furnace outgassing (600-800 ˚C).
- Tuning for field flatness and frequency.
- Light EP (20-50 μm).
- In-situ baking at 120 ˚C for 48 hours.

The exact implementation varies at different processing facilities. For example, the exact amount of light BCP prior to heavy EP, the exact amount of heavy EP, the exact vacuum furnace heat treatment cycle (temperature, duration and ramp up profile), and the exact light EP amount vary within a rough range as listed above. In this paper, we describe the JLab standard procedures of ILC cavity processing and handling.

The standard JLab procedure has been used in preparation of fine-grain 9-cell ILC cavities since 2009. More recently, it has been also used for processing large-grain niobium and seamless niobium 9-cell cavities. The procedure begins with mixing fresh electrolyte at a molar ratio of $HF:H_2O:H_2SO_4$ in a range that is compatible with that in the original Siemens recipe. Three key process parameters, namely the acid flow rate, the polish cell voltage and the cavity body temperature, are identified and in control. The optimal EP is achieved in the continuous current oscillation mode. The appearance of current oscillation also serves as a sensitive in-situ QA/QC indicator. The "auto polishing" procedure is introduced by continuing the acid flow and cavity rotation after the voltage is shut off. This effectively reduces sulfur-bearing niobium oxide granules, an inherent contaminant of the EP process. An elaborate post-EP cleaning procedure includes low-pressure water rinsing, HOM coupler brushing and ultrasonic cleaning with detergent. Additional ethanol rinsing is applied following the heavy EP to facilitate removal of sulfur deposit on the niobium surface. The vacuum furnace heat treatment procedure is updated. A no-touch bead-pull method is established. Slow pump down is routinely applied to prevent recontamination of the cavity surface. The repeatability of the cavity processing procedure and the reproducibility of high gradient high Q_0 results are much improved as compared to that during the initial period of ILC cavity work at JLab.

* Work supported by DOE. Authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177. The U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce this manuscript for U.S. Government purposes.

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ELECTROPOLISHING

Electrolyte Mixing

Electrolyte mixing is done at the EP machine. A volume ratio of 1:10 ($HF(48\%):H_2SO_4(96\%)$) is used for a molar ratio of $HF:H_2O:H_2SO_4$ compatible with that of the original Siemens recipe [2]. Prior to mixing, the electrolyte storage tank and acid piping are flushed with sulfuric acid (96% concentration). This eliminates any possible water left in the system. Then 55 gallon of sulfuric acid (96% concentration) is transferred into the electrolyte storage tank followed by chilling while keeping the acid in circulation (this is done by connecting the cavity acid inlet hose with the cavity acid outlet hose). Addition of the first gallon of hydrofluoric acid (48%) starts when the electrolyte temperature in the storage tank reaches 15 ˚C or lower. Acid circulation is then continued until the electrolyte temperature recovers to 15 ˚C again, followed then by addition of the second gallon of hydrofluoric acid. This process is repeated till 5.5 gallon of hydrofluoric acid is added.

Electropolishing

A horizontal EP [3] machine is used at JLab. Three key EP parameters are identified and are under control,

- Voltage. Nominal at 14.5 V as measured across the body of cavity and the cathode, allowable range 13-17 V.
- Cavity cell temperature (measured at the cavity outer surface near the equator region). Nominal at 25 ˚C, allowable range 20-30 ˚C for final light EP and nominal at 30 ˚C, allowable range up to 35 ˚C for heavy EP.
- Acid flow rate. Nominal at 3-4 liter per minute.

In addition to these key parameters, it is important to keep the purging nitrogen gas flow at the minimum level. We also changed the direction of acid supplying holes in the cathode tube. They face upward instead of downward. This reduces the disturbance of the viscous layer across the acid niobium interface.

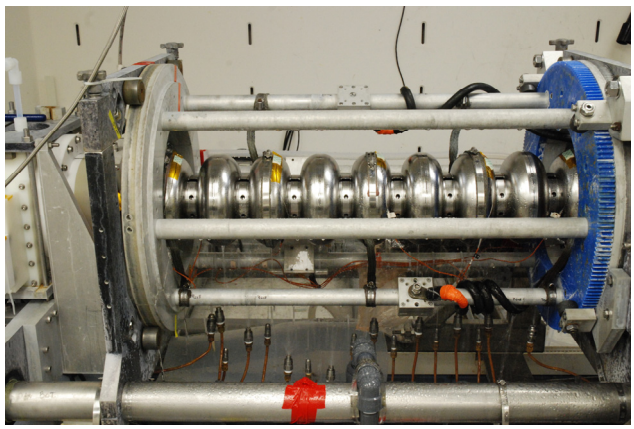

Figure 1: Cavity outer surface water irrigation setup added to the JLab EP machine. An array of nozzles spray chilled water at selected iris and/or equator regions.

Several provisions are available for cavity cell temperature control: by steering the chilled water set-point; by duty-cycling the voltage; by irrigating the hot spot of the cavity outer surface. Typically, by using one or more of these methods, a standard fine-grain 9-cell cavity EP can be operated within the allowable temperature ranges. Following the active external irrigation cooling used in Cornell's vertical EP system [4], a cavity outer surface water irrigation setup (Fig. 1) has been added to the JLab EP machine. An array of nozzles spray chilled water at the iris and equator regions from the bottom of the cavity. Because of cavity rotation, uniform whole-cavity cooling is achieved. This chilled water irrigation system has been used routinely for electropolishing of 7-cell CEBAF upgrade cavities in which case a lower cell temperature (20 ˚C) is desired. Recently, a 9-cell seamless cavity was electropolished by irrigating the iris regions.

The optimal EP is achieved in the continuous current oscillation mode [5]. Our experience has shown that the appearance of current oscillation also serves as a sensitive in-situ process QA/QC indicator. The disappearance of current oscillation is correlated to excessive loss of HF or excessive addition of H_2O in the electrolyte, in which case abandoning the electrolyte is warranted.

The "HF Auto Rinse" procedure is introduced by continuing the acid flow and the cavity rotation after the EP voltage is shut off. Under this condition, HF continues to react with the top layer of the cavity inner surface while the anodization process is stopped. An effect similar to that of HF rinsing is expected. We believe that HF Auto Rinse effectively removes the sulfur-bearing niobium oxide granules, an inherent contaminant on finished niobium surface due to the EP process itself [6].

Post Cleaning after Heavy EP

The post cleaning after heavy EP consists of the following steps:

- Low-pressure water rinsing. Immediately after the cavity is dismounted from the EP machine, the cavity inner surface is irrigated with copious amount of de-ionized water.
- HOM can and cavity end group brushing and wiping with soapy water. This procedure cleans the inner surface areas that lack direct line-of-sight access by the high pressure water jets.
- Ultrasonic cleaning for 1 hour. The entire cavity is immersed in a bath of hot (50 ˚C) de-ionized water with 2% Liquinox mixed.
- Ethanol rinsing. About one gallon of high purity ethanol is transferred into the sealed cavity. The cavity is tilted and flipped for 10 minutes.
- High pressure water rinsing for two passes, each for about 2 hours.

Vacuum Furnace Heat Treatment

Following post-heavy-EP cleaning, the cavity is heat treated in a vacuum furnace for hydrogen degassing. The baseline furnace vacuum is typically in the mid-10^{-8} Torr after over-night pumping. The furnace temperature ramps up at a rate of 5 ˚C/min, soaks at 800 ˚C for 2 hours [7], then ramps down naturally by turning off the heating elements. Fig. 2 shows a typical furnace cycle, displaying the temperature profile and the partial pressure of two species (H_2 and H_2O).

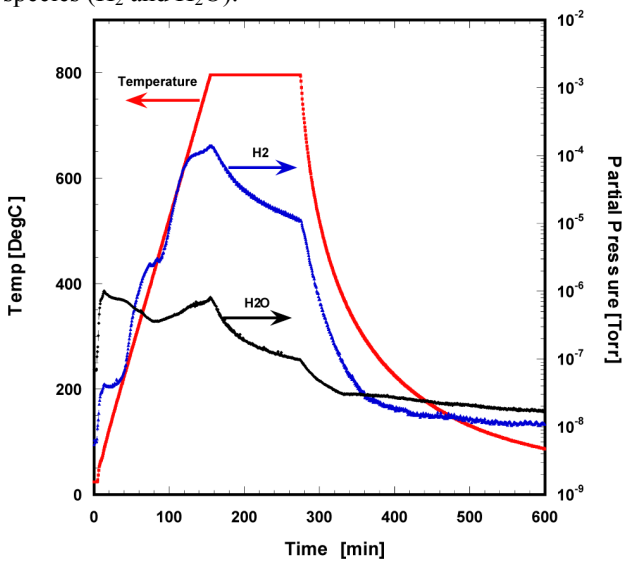

Figure 2: Standard ILC cavity vacuum furnace heat treatment temperature profile. The partial pressure of H_2 and H_2O of a typical 9-cell heavy-electropolished cavity is also shown.

RF Tuning by No-Touch Bead-Pull

It is necessary to tune the cavity π–mode field flatness following the heavy EP and vacuum furnace outgassing. At JLab, a no-touch bead-pull procedure has been developed and used for the final tuning prior to the final EP. Through a pair of guiding holes, a titanium tube inserts into the cavity which is mounted onto the tuning machine. The bead-carrying wire is then guided through the titanium tunnel without touching the cavity inner surface. The tube then is retrieved to allow normal RF operation for tuning. After the tuning is completed, the tube is re-inserted to allow bead/wire retrieval without

touching the cavity inner surface. Finally, the tube is removed to allow cavity disassembly from the tuning machine.

Post Cleaning and Handling after Final EP

The post cleaning after light EP consists of the following steps:

- Low-pressure water rinsing. Immediately after the cavity is dismounted from the EP machine, the cavity inner surface is irrigated with copious amount of de-ionized water.
- HOM can and cavity end group brushing and wiping with soapy water. This procedure cleans the inner surface areas that lack direct line-of-sight access by the high pressure water jets.
- Ultrasonic cleaning for 1 hour. The entire cavity is immersed in a bath of hot (50 °C) de-ionized water with 2% Liquinox mixed.
- First high pressure water rinsing. 3 passes, each for about 2 hours.
- First clean room assembly of all (except the bottom flange sub-assembly) auxiliary hardware components including RF probes.
- Final high pressure water rising. 3 passes, each for about 2 hours.
- Final clean room assembly of the bottom flange sub-assembly.
- Slow pump down. The speed of pump down is controlled to avoid turbulent flow. This prevents transfer of agitated particulates in the vacuum plumbing into the cavity. Fig. 3 shows the photograph of a slow pump down unit permanently installed in the test stand between the turbo pump and the fore-line vacuum hose.
- Leak checking.
- Baking at 120 °C for 48 hours. The cavity under vacuum is enclosed in an insulated baking box. Hot nitrogen is blown into the box. The center cell temperature is used for process control.

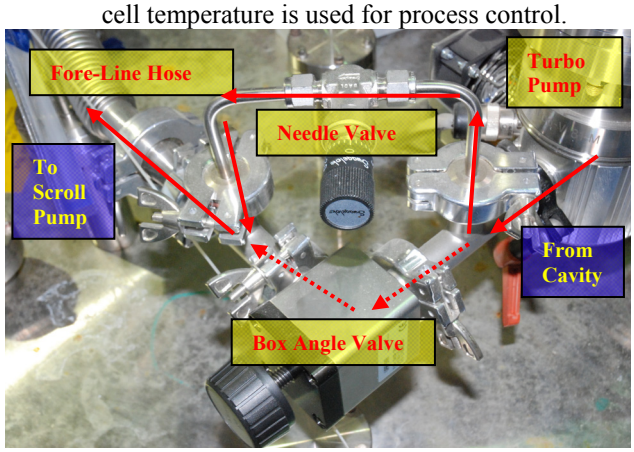

Figure 3: A slow pump down unit permanently installed in the test stand between the turbo pump and the fore-line vacuum hose. During initial pump down, a high-impedance line is formed by closing the box angle valve and slightly opening the needle valve.

CONCLUSION

We have described the standard procedures of ILC 9-cell high gradient cavity processing and handling at Jefferson Lab. Here is a summary of the procedure:

- Light BCP etching (10 μm).
- Heavy EP (100-120 μm).
- Post-heavy-EP cleaning.
- Vacuum furnace outgassing (800 °C for 2 hours).
- RF tuning by no-touch bead-pull.
- Light EP (25 μm).
- Post-light-EP cleaning.
- First HPR 3 passes (~6 hours).
- First clean room assembly.
- Final HPR 3 passes (~6hours).
- Final clean room assembly.
- Leak checking.
- In-situ baking at 120 °C for 48 hours.

This procedure has been shown to be repeatable with reproducible high gradient cavity results. It has been also shown that this procedure is transferable when adequate training and practicing are allowed. By using this procedure, an example of 90% yield at 38 MV/m has been demonstrated at JLab, based on ten real 9-cell cavities manufactured by an experienced cavity vendor. This procedure is the basis of the final surface processing procedure for the 7-cell cavity of the CEBAF 12 GeV upgrade project [8]. To some extent, this procedure has been verified or adopted at other facilities. Given these experiences, one can expect that this procedure can be ultimately transferred to the industry for processing high performance SRF cavities at a scale required by large projects such as ILC.

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