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NEW SRF STRUCTURES PROCESSED AT THE ANL CAVITY PROCESSING FACILITY*

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Abstract

Argonne National Laboratory (ANL) has extended high quality cavity processing techniques based on those developed for the International Linear Collider to several more complex superconducting RF cavities. Recently, these include a bunch lengthening harmonic cavity, a crabbing rf-dipole cavity, a compact half-wave cavity, and both medium and high frequency elliptical cavities. These systems are an improved version of the one originally developed for 1.3 GHz 9-cell cavities and include a second rotating electrical contact that can support multiple cathodes, necessary for optimum polishing in difficult cavity geometries. All include the possibility for external water cooling.

INTRODUCTION

The Superconducting Surface Processing Facility (SCSPF) is a 200 m^2 laboratory that houses a pair of class 100 clean rooms for HPR and clean assembly, a class 1000 anteroom, and two separate chemistry rooms [1]. The facility was originally designed to support processing of 1.3 GHz 9-cell cavities for the ILC, but has since been expanded to chemically process accelerating structures of various geometries. In this paper we present the cavity processing techniques used on several new SRF structures.

BUNCH LENGTHENING CAVITY

4th Harmonic Cavity for APS-U

A bunch lengthening cryomodule operating at the 4th harmonic is being assembled at Argonne as part of the Advanced Photon Source Upgrade Project (APS-U) [2].

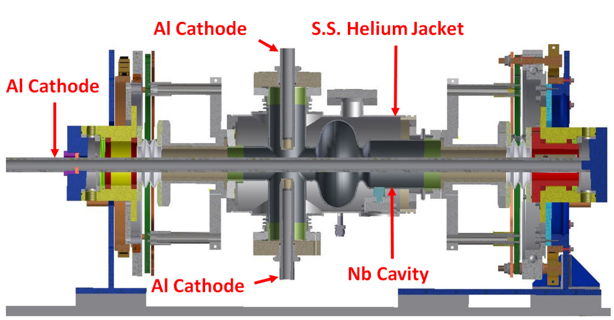

Figure 1: Section view of the EP tool with 1.4 GHz harmonic cavity.

The 1.4 GHz single-cell elliptical cavity includes two large power coupler ports oriented 180 degrees apart with respect to the beam axis, as well as, two different size beam tubes as required, for the higher-order mode damping scheme. A stainless steel helium jacket surrounds the complete cavity.

Prior to installation into the EP tool, the cavity receives ultrasonic cleaning for 60 minutes at 120°F in a 2% Liquinox, 98% DI water solution. To make certain we get good cleaning in all areas, the cavity is flipped 180 degrees and the process repeated. To avoid any trapped detergent, the cavity is rinsed with DI water and the ultrasonic cleaning process is repeated again in 100% DI water.

To ensure good polishing of the entire cavity surface, two additional 3003 series aluminium cathodes were inserted in each power coupler port, in addition to the main cathode that runs through the cavity along the beam axis, as shown in Figure 1. A second rotating electrical contact allows the supplementary cathodes to rotate with the cavity, as the primary cathode remains stationary. The annular space between the niobium cavity and the stainless steel helium jacket offers the opportunity to function as a water jacket for external water cooling. Both helium ports were sealed off and the helium jacket was filled with DI water. A thermocouple attached to the cavity cell wall through a watertight feedthrough on the helium port monitored cavity surface temperature. External water-cooling spray, connected to a 10 kW chiller, showered over the water filled helium jacket to control cavity surface temperatures during EP.

A 120 µm EP (9:1, 96% H_2SO_4: 48% HF) was done to remove the damage niobium surface layer, keeping cavity surface temperatures below 25°C. To degas the hydrogen dissolved in the bulk niobium the cavity was baked at 625°C for 10 hours in a high vacuum furnace at Michigan State University (MSU). A final 20 µm EP was done to remove any contamination picked up by the furnace followed by ultrasonic cleaning. The cavity was high pressure rinsed (HPR) through both beam ports using Argonne's HPR tool [3] and assembled in a class 100 clean room.

CRAB CAVITY

RF-Dipole Cavity for LHC High Luminosity

A 400 MHz superconducting rf-dipole crabbing cavity is under development for the High Luminosity Upgrade of the LHC [4]. This proof-of-principle cavity is intended to crab the proton beam in the horizontal plane as part of the High Luminosity Upgrade at CERN.

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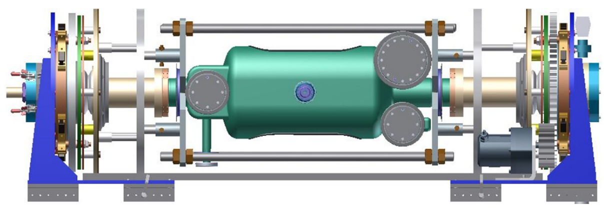

Figure 2: RF-dipole cavity in the “low-β” EP tool.

Before installation in the “low-β” EP tool [5, 6], the cavity received the same pre-EP ultrasonic cleaning procedure described in the previous section. The cavity is flipped and cleaned in both directions due to the tendency of air to be trapped in the square coupler ports when vertical.

150 µm was removed by BCP (1:1:2, 48% HF: 70% HNO_3: 85% H_3PO_4) over three etches in an effort to improve the previously BCP’d surface. The BCP is done horizontally in the “low-β” EP tool using the existing electropolishing hardware. For this BCP the aluminium cathodes were replaced with a high-density polyethylene (HDPE) tube, see Figure 2. Two 10 kW chillers are used to keep the temperature of the BCP below 17°C to minimize the risk of contaminating the bulk niobium with hydrogen. One chiller supplies external cooling water to the cavity and the other actively cools the acid during processing through a custom made PFA heat exchanger. Since the cavity is not completely filled with BCP the gases, which evolve during the procedure, bubble up through the acid bath and not along the cavity surface. This reduces the surface pitting and groove formation inherent to the process when hydrogen gas bubbles travel along the niobium surface

Cavity rinsing is more complex than elliptical shaped cavities due to the trapped volumes of acid in the vertical orientation of the more complex rf-dipole cavity. After the acid completely drains from the cavity, DI water fills the cavity and overflows to a dilute waste tank. At this stage, with water continuously flowing through the cavity, we lower the cavity down to the horizontal orientation while rotating, and then back up to the vertical position before draining. This rinsing process repeats five times to minimize the risk of acid staining on the cavity surface.

After etching and rinsing is complete, the cavity received another round of ultrasonic cleaning. Final high-pressure rinsing (HPR) is performed using Argonne’s HPR tool. With the cavity horizontal and the coupling ports facing downward, the cavity is rinsed through both beam ports for 30 minutes each, dumping the rinse water from the cavity every 5 minutes. A final vertical HPR is performed through both beam ports and on all the hardware used in the clean assembly for testing.

LOW-BETA CAVITY

Half-Wave Cavity for Heavy Ions

A 337 MHz half-wave cavity optimized for β = 0.285 ions was previously developed as a potential upgrade of the post-stripper section of the Facility for Rare Isotope Beams (FRIB) [7].

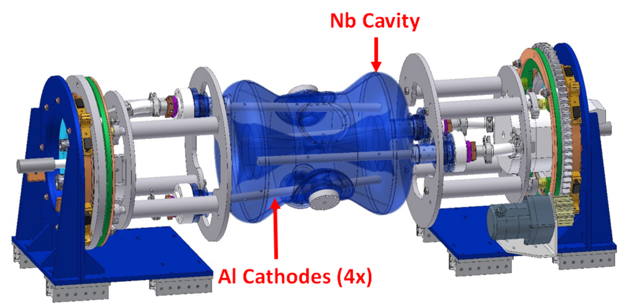

Figure 3: Half-wave cavity in the “low-β” EP tool. Note the stainless steel helium jacket is not shown on the cavity.

The cavity receives the same pre-EP cleaning previously described before installation into the EP tool. A 20 µm BCP is done initially to remove the oxide layer formed during the final electrostatic discharge machining (EDM) of the cavity. This BCP step is necessary because the EDM oxide layer is not removed during EP. The BCP is done horizontally in the “low-β” EP tool using the existing electropolishing hardware with the exception of using short high-density polyethylene (HDPE) tubes. The helium jacket of the HWR, not shown in figure 3, is used for direct water cooling to keep the temperature of the BCP below 17°C. A pressure regulator is installed on the chiller water supply to the cavity to ensure the water pressure inside the helium jacket don’t exceed the yield point of niobium and cause permanent deformation of the cavity

After the BCP, a bulk 150 µm EP (1:9; 48% HF: 96% H_2SO_4) is performed using four 3003 series aluminium cathodes to achieve uniform polishing of the rf surface. Due to the tapered geometry of the cavity, special attention needs to be paid to how the cathodes are loaded/unloaded to ensure the cathodes do not come into contact with the rf surface, possibly causing unrepairable damage. Properly aligned cathodes come very close, within less than 1 inch of the re-entrant noses. This is achieve by using carefully machined HDPE guide flanges installed in the ports to keep the cathodes aligned for loading and hold them in place during processing.

Once the polish is complete, the cavities then receives another round of ultrasonic cleaning followed by high-pressure rinsing using Argonne’s flexible HPR tool. To degas the hydrogen dissolved in the bulk niobium the cavities are baked at 625°C for 10 hours in a high vacuum furnace at Michigan State University. After the bake, a 20 µm EP is done to remove any contamination picked up from the furnace. After final EP, the cavity was ultrasonically cleaned and rinsed thoroughly followed by a final HPR through all ports of the cavity.

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ELLIPTICAL CAVITIES

644 MHz 5-cell Cavity for FRIB Upgrade

A 644 MHz, β = 0.65, 5-cell elliptical cavity was recently built in industry for a future beam energy upgrade to FRIB [8].

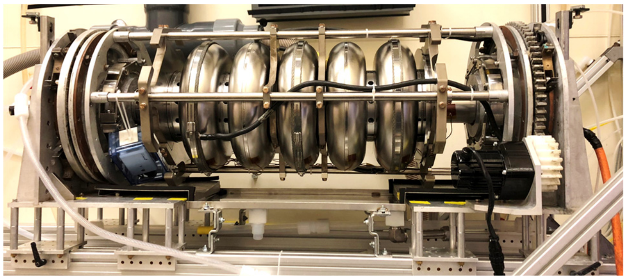

Figure 4: MSU 644 MHz 5-cell cavity in the Argonne "low-β" EP tool. The external water cooling system was installed after this picture was taken.

Electropolishing was chosen due to recent ANL experience with processing similar Fermilab 650 MHz, β = 0.9, 5-cell cavities for their Proton-Improvement Plan II (PIP-II) Project. This cavity received the standard pre-EP ultrasonic cleaning before installation into the "low-β" EP tool, as shown in Figure 4. Five 3003 series aluminum cylinders are clam-shelled around the cathode to increase the surface area in each cell and provide a galvanic current sink roughly equivalent to that used on high-performance 1.3 GHz elliptical cell resonators. 150 μm was removed during bulk EP while keeping cavity surface temperatures below 30°C using external water cooling. The cavity was hydrogen degassed at MSU before returning to Argonne for a 20 μm EP, followed by post-EP ultrasonic cleaning and high-pressure rinsing on FNAL's high-pressure rinse tool.

647 MHz 5-cell Cavity for eRHIC

A 647 MHz 5-cell cavity was recently built as part of the proposed electron-ion collider (eRHIC) at Brookhaven National Laboratory (BNL). This cavity design has large beam tubes to propagate all the HOM's but attenuate the fundamental mode [9].

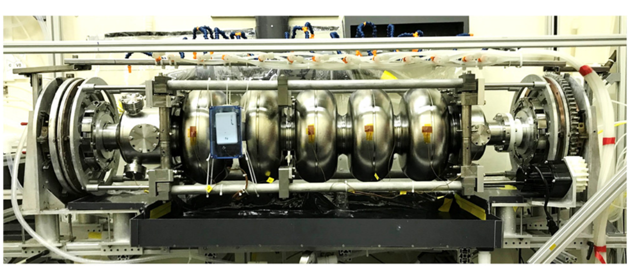

Figure 5: BNL 650 MHz 5-cell cavity in the Argonne "low-β" EP tool.

The original goal of the cavity processing was to study various post-processing methods to reach 18 MV/m with $Q_o \sim 3\times10^{10}$, with BCP chosen for the first round of post-processing. Due to the large size of the cavity and its support cage, it would not fit in our large ultrasonic cleaning tank. With the cavity vertical and all the ports sealed with Viton O-rings, except for the top beam port, the cavity was filled with a 2% Liquinox/DI water solution and a perforated plastic guide tube was inserted down along the beam axis. A 2 kW ultrasonic transducer was lowered down the guide tube and inside the cavity using an overhead crane and the internal ultrasonic cleaning ran for 60 minutes. The solution drains through the bottom port and the cavity was rinsed with DI water before installation in the "low-β" EP tool.

As shown in Figure 5, the BCP is done horizontally using the existing EP hardware with the exception of using a long HDPE tube in place of the aluminium cathode. By actively cooling the acid, we were able to keep the BCP <9°C during processing and with external water cooling spray we were able to keep cavity surface temperatures to <14°C for the 120 μm bulk etch. The cavity received a post-etch internal ultrasonic cleaning before transport back to BNL for hydrogen degassing. The cavity returned to Argonne for a 30 μm BCP to remove any contamination from the furnace followed by internal ultrasonic cleaning before transport back to BNL for HPR and testing.

5 GHz Cavity for Quantum Computing

Argonne is constantly developing new hardware to support different cavity frequencies and geometries. An example of this is our recent collaboration with FNAL on the eletropolishing of a 5 GHz single-cell TESLA shape cavity. This cavity supports FNAL's quantum computing initiative and was used to investigate photon lifetimes at very low fields [10].

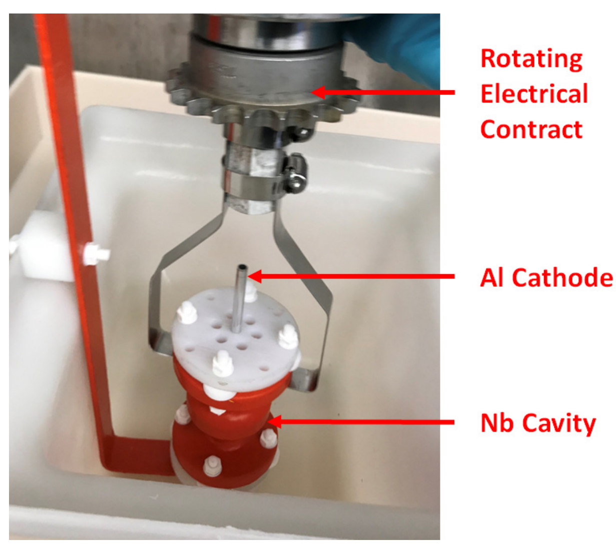

Figure 6: 5 GHz single-cell cavity EP.

The cavity is much too small to fit in any of our existing horizontal EP tools so the cavity was electropolished vertically in a small plastic bucket. With the entire cavity submerged in the electrolyte during EP all surfaces except for the inner cavity rf surface had to be masked using a

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removable acid-resistant masking (Miccro Super XP 2000 Stop-Off Lacquer). HDPE flanges bolt to the cavity ports with Teflon hardware, which keeps the aluminium cathode rigid and allows for gases generated at the cathode to escape to the acid surface. Two pieces of niobium shim-stock bolt to the cavity flange and attach to a rotating electrical contact, as shown in Figure 6. Rotation is provided by a rubber O-ring that connects the electrical contact to a small gear motor.

After the 120 µm removal, the masking is peeled from the outer surfaces of cavity followed by ultrasonic cleaning and high pressure rinsing using Argonne's hand-held HPR system. The cavity returned to Fermilab for hydrogen degassing before coming back to Argonne for a final 20 µm EP.

SUMMARY

Cavity processing at Argonne is historically rooted in low-β structures with the ATLAS heavy-ion accelerator. This success led to the development of β=1 elliptical cavity polishing tools for the ILC R&D effort. Building upon these ILC developments ANL has demonstrated new EP techniques for new and unique low-β cavities. These techniques have been applied to both quarter-wave and half-wave cavities and success facilitated further applications. Examples are: (1) collaboration with Advanced Photon Source where we are building a bunch lengthening cavity and cryomodule for APU-U. (2) Processing of an rf-dipole cavity in collaboration with Fermilab for the High Luminosity Upgrade at CERN. (3) Processing of a 337 MHz half-wave cavity with highly optimized geometry. (4) Processing of a 644 MHz 5-cell cavity as part of a future energy upgrade at FRIB. (5) Processing of a 647 MHz 5-cell cavity for eRHIC. (6) Processing of several high frequency single-cell cavities in collaboration with Fermilab for quantum computing applications.

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