6th International Particle Accelerator Conference IPAC2015, Richmond, VA, USA JACoW Publishing
ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPTY010

ELECTROPOLISHING FOR LOW-BETA AND QUASI-WAVEGUIDE SRF CAVITIES*

T. Reid[#], P.N. Ostroumov, M. P. Kelly, Z.A. Conway, S. M. Gerbick, M. Kedzie
Argonne National Laboratory, Argonne, IL 60439, U.S.A.

Abstract

Argonne National Laboratory (ANL) has extended high quality electropolishing techniques based on those developed for the International Linear Collider to several more complex superconducting RF cavities. These include the co-axial TEM-mode quarter-wave and half-wave cavities as well as a 2.815 GHz quasi-waveguide structure for beam bunch rotation. This system is an improved version of the one developed for 1.3 GHz 9-cell cavities and includes easy provision for direct water cooling using the helium jacket. The performance of these SRF cavities both in terms of RF fields and losses equals or exceeds that of most 9-cell elliptical cavities built and tested today.

INTRODUCTION

The Superconducting Surface Processing Facility (SCSPF) at ANL is a 200 m^2 laboratory which houses a pair of class 100 clean rooms for HPR and clean assembly, a class 1000 anteroom, and two separate chemistry rooms. The facility was originally designed to support processing of 1.3 GHz 9-cell cavities for the ILC, but has since expanded its capabilities to chemically process accelerating structures of various geometries.

In this paper we present the electropolishing and subsequent cold test results of three distinct cavity geometries. The first of which are β= 0.077, 72.75 MHz quarter-wave resonators (QWR) developed for the ANL ATLAS efficiency and intensity upgrade completed in 2014. The second are β= 0.11, 162.5 MHz half-wave resonators (HWR) currently being developed and fabricated for the PXIE injector experiment at Fermilab. Finally we will briefly review the tooling used to electropolish a 2.815 GHz deflecting cavity for novel beam manipulations.

LOW-BETA CAVITIES

Quarter-wave Cavities for ATLAS

A cryomodule containing seven 72 MHz quarter-wave resonators (QWRs) was recently installed into the ATLAS heavy-ion accelerator as part of the ATLAS Intensity Upgrade (AIU) project [1]. The prototype 72 MHz QWR was the cavity used to commission the newly built low-β EP tool at Argonne in 2011 [2], and developed the procedures generically employed for all of our cavities. The remaining six production cavities followed in 2012 [3]. The low-β EP tool was based on Argonne's experience with the horizontal electropolishing of 1.3 GHz 9-cell cavities for the global ILC effort [4]. One of the unique features of the ANL low-β tool is its versatility which enables the chemical polishing of many different cavity geometries. A QWR is shown in Figure 1. QWRs were the first cavities processed with this tool and the processing sequence used is described below.

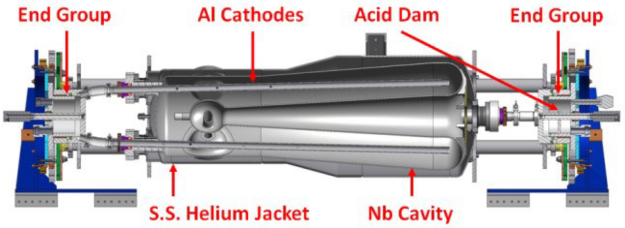

Figure 1: Section view of the low-β EP tool with 72 MHz quarter-wave cavities.

Prior to installation into the low-β EP tool, the finished cavities are ultrasonically cleaned for 60 minutes at 120°F in a 2% liquinox, 98% DI water solution. After the QWR is installed in the ANL low-β EP tool it receives a 20 µm buffered chemical polish (1:1:2; 48% HF: 70% HNO_3: 85% H_3PO_4) 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 process has several similarities to the EP. The first is the helium jacket of the QWR is used for direct water cooling to keep the temperature of the niobium cavity below 17°C, minimizing the risk of contaminating the bulk niobium with hydrogen. Second, the BCP is done in the horizontal position and the cavity is rotated at 0.5 rpm. Since the cavity is not completely filled with the BCP electrolyte, the hydrogen gas which evolves during the procedure bubbles up through the bath and not along the cavity surface. This eliminates the surface pitting and groove formation inherent to the process when the hydrogen gas bubbles travel along the niobium surface.

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. With the low-β EP tool, cathodes are used to flow acid both into and out of the cavity, as well as flow N_2 gas into the cavity RF volume to purge the H_2 gas produced as part of the EP reaction. To accomplish this, a dam sets the acid level at ~60% of the cavity diameter, allowing there to be two cathodes submerged in the acid bath and two cathodes above the acid bath during the majority of the EP process. The two submerged cathodes are used to

---

* This work was supported by the U. S. Department of Energy, Office of Nuclear Physics, under contract number DE-AC02-06CH11357. This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility.

[#] treid@anl.gov

flow acid into and out of the cavity while the two exposed cathodes are used to flow N_2 gas in and remove the H_2 gas. Since the cavity is continuously rotating during EP, the gas/liquid transfer roles of each cathode will continually change as the cavity rotates.

The EP parameters used on the QWRs were derived from extensive elliptical cell polishing for the ILC. Using a constant voltage of 18 V with an average current density of ~ 30 mA/cm^2, the cavities are rotated at 0.5 rpm with niobium surface temperatures limited to < 35°C for the bulk polish and < 30°C for the final light EP. Direct water cooling through the helium jacket reduces the surface temperature oscillations as the cavity rotates to <5°C and can stabilize the average temperature to +/- 1°C [4]. This tight process control has been demonstrated to give superior cavity performance [5,6] by strongly decoupling the reaction temperature from the electrolyte bath temperature and is an important element in achieving our measured cavity performance. The acid flow rate is reduced to ~0.5 l/min because acid flow is not used to control the reaction temperature. This flow rate is sufficient to refresh the cavity acid.

Once polishing is complete, the QWRs then receive another round of ultrasonic cleaning in 2% liquinox/DI water followed by high-pressure rinsing (HPR) using ANL's custom built adaptable HPR tool [7]. To degas the hydrogen contained in bulk niobium the cavities are baked at 625°C for 10 hours in a high vacuum furnace at Fermilab. After baking, a final 20 µm EP is done to remove contamination from the furnace. After polishing, the cavities are ultrasonically cleaned in a 2% liquinox solution and high pressure water rinsed at the ANL/FNAL processing facility to prepare for cold testing.

Using this procedure eight QWRs have been chemically processed and subsequently cleaned for both off-line testing and on-line operation in the ANL facility. Four out of the seven 72 MHz QWR's plus one R&D QWR were tested at both 4.5 and 2.0 Kelvin [3].

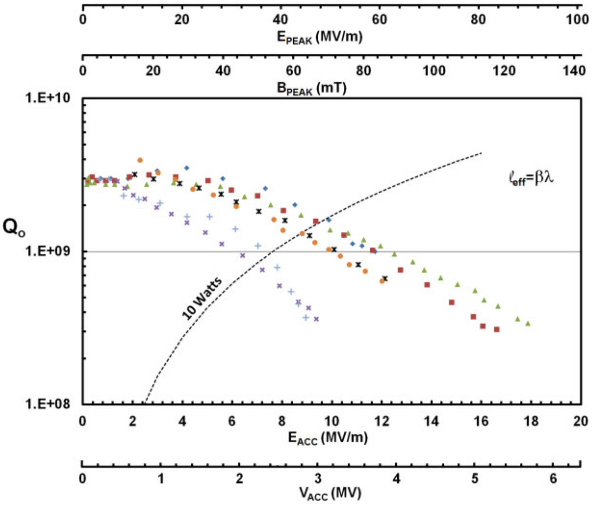

Figure 2: On-line performance of 72 MHz quarter-wave cavities in operation at 4.5 K.

As shown in Figure 2, on-line performance of all seven QWRs exceeded the design goal of V_{ACC}=2.5 MV/cavity at 4.5 K.

Half-Wave Cavities for PIP-II

The successful implementation of horizontal electropolishing with the ANL low-β electropolishing tool for QWRs has led to the development of similar techniques for half-wave resonators (HWRs), see Figure 3. The first two of nine HWRs have been processed with the ANL low-β EP tool.

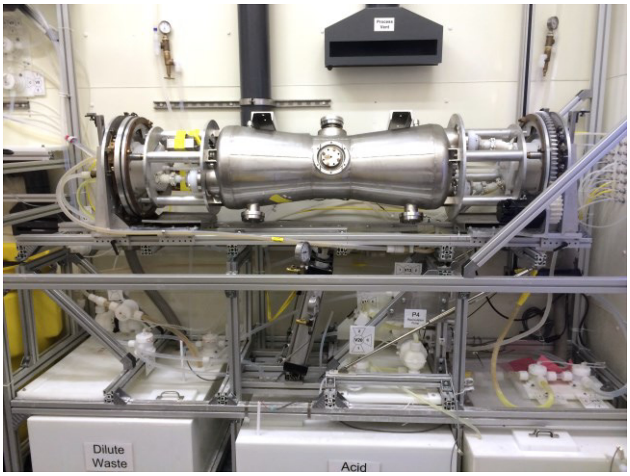

Figure 3: 162.5 MHz prototype HWR chemical polishing.

The EP of the HWR is very similar to that of the QWR, using the same EP parameters with a few exceptions. First, due to the more complex geometry of the HWR; special attention needs to be paid to how the cathodes are installed to ensure the cathodes do not come into contact with the RF surface, possibly causing damage. Properly aligned cathodes are located about 1 inch from 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, as shown in Figure 4.

It was recently found that, for non-cylindrically symmetric geometries, a differential etch rate of up to ~4X was observed between surfaces being submerged versus exposed, as in the 2.815 GHz quasi-waveguide structure which will be discussed next. To mitigate this effect, the rotation direction of the HWR was reversed half-way through the polishing process.

Both of these cavities have less than 2.5 nΩ of RF surface resistance at low fields and reach quality factors of >1×10^{10} at 8 MV/m accelerating gradient, exceeding the design goal of 8e9. Eight more HWRs are in production and will begin processing in late 2015. Given the low ~2-3 nΩ residual resistance measured in all of our low-β cavities at 2 Kelvin we are optimistic that the remaining HWRs will perform equally as well.

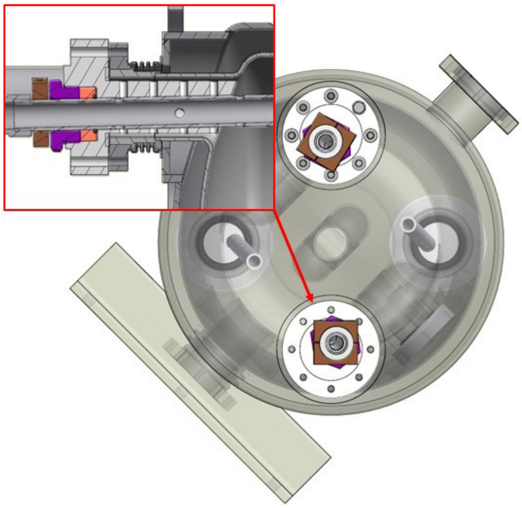

Figure 4: End view of HWR with cathodes.

QUASI-WAVEGUIDE CAVITY

Bunch Rotation Cavity for APS

A Quasi-waveguide Multi-cell Resonator (QMiR) operating a frequency of 2815 MHz has been built in collaboration with Fermilab and the Advanced Photon Source (APS) at Argonne as a possible upgrade for the manipulation of high energy electron beams [8].

The low-β EP tool was modified to enable the horizontal electropolishing of QMiR, functioning as a hybrid of the low-β and elliptical cavity EP tools. Like elliptical cavity electropolishing, QMiR has no central loading element and therefore requires only one cathode. However, due to the geometry of QMiR, the aluminum cathode is a flat plate and does not provide a means to pump the electrolyte in and out. Plastic adapter end groups that support the cathode are bolted onto the cavity flanges as shown in Figure 5.

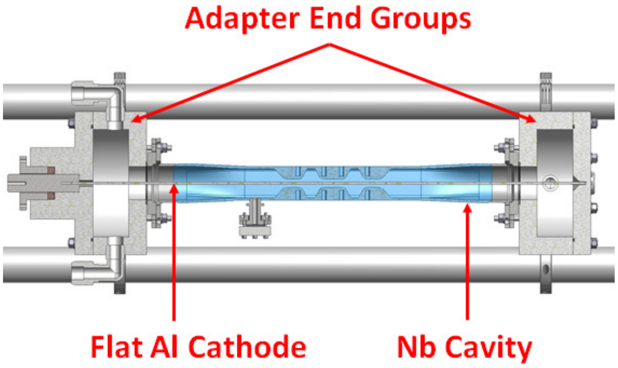

Figure 5: Section view of QMiR with EP hardware.

In this case, the cathodes are replaced with four PFA tubes, two each in two perpendicular planes, which connect the adapter end groups to the larger low-β end groups from Figure 1. These tubes move the acid and gasses in the same manner as for the cathodes described for the low-β cavities. To get uniform polishing in the waveguide coupler section, a secondary cathode is made of 3003 series aluminum wire and wrapped around a HDPE flanged insert. Again, the rotation was reversed during the process to minimize differential material removal.

Cavity processing steps applied to the low-β structures were modified slightly for QMiR. A heavier 80 µm BCP was performed, rather than 20 µm, due to initial uncertainty on the uniformity of EP removal. An 80 µm EP was done using the same EP parameters described for the low-β cavities and the polishing quality was good.

Subsequent cold testing measured a deflecting voltage of 2.7 MV, which exceeded the design goal of 2.0 MV [7]. These encouraging results demonstrate the feasibility of using such a cavity and validating our fabrication and processing techniques.

SUMMARY

Cavity processing at ANL has a long history for low-β structures for the ATLAS heavy-ion accelerator but has since expanded to include β=1 elliptical cavities for the ILC R&D effort. Building upon the ILC developments ANL has demonstrated new EP techniques for low-β cavities. These techniques have been applied to both QWR and HWR and success facilitated further applications. Examples are: (1) collaborations with Fermilab where Argonne is processing 325 MHz single spoke cavities and 650 MHz elliptical cavities for PIP-II and nitrogen doped 1.3 GHz 9-cell cavities for LCLS-II. (2) Processing of a double quarter-wave crab cavity and a large jacketed 704 MHz 5-cell elliptical cavity for Brookhaven National Laboratory (BNL).

REFERENCES

[1] M.P. Kelly et al., “Commissioning of the 72 MHz Quarter-wave Cavity Cryomodule at ATLAS,” LINAC’14, Geneva, Switzerland, p. 440, September 2014.

[2] S.M. Gerbick et al., “A New Electropolishing System for Low-β SC Cavities,” SRF’11, Chicago, U.S.A., p. 576, July 2011.

[3] M.P. Kelly et al., “Low Beta Cavity Development for an ATLAS Intensity Upgrade,” SRF’13, Paris, France, p. 850, September 2013.

[4] C.E. Reece, “Exploration and Comparison of Hydrodynamic and Thermal Properties of Electropolishing,” SRF’09, Berlin, Germany, p. 742, September 2009.

[5] M. P. Kelly et al., “Surface Processing Facilities for Superconducting RF Cavities at ANL,” LINAC’08, Victoria, Canada, p. 839, September 2008.

[6] M. P. Kelly et al., "SRF Advances for ATLAS and Other β<1 Applications," SRF'11, Chicago, U.S.A., p. 680, July 2011.

[7] R. Murphy et al., “A Flexible System for the High Pressure Rinsing of SRF Cavities,” SRF’11, Chicago, U.S.A., p. 456, July 2011.

[8] Z.A. Conway et al., “Development and Test Results of a Quasi-Waveguide Multicell Resonator,” IPAC’14, Dresden, Germany, p. 2595, June 2014.