A NEW ELECTROPOLISHING SYSTEM FOR LOW-β SC CAVITIES*

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Abstract

A new electropolishing system designed for a completed low-beta niobium superconducting cavity with integral helium vessel was installed and operated at Argonne National Laboratory (ANL). The design was based on that used for the electropolishing of 1.3 GHz 9-cell elliptical cavities for the global ILC development effort at ANL, with the addition of direct water cooling to the cavity surface. This design also allows for repeated chemistry on the cavity, if needed, without producing the rougher surface associated with buffered chemical polishing.

INTRODUCTION

An upgrade at the Argonne Tandem Linac Accelerator System (ATLAS) uses a new cryomodule of seven superconducting (SC) 72.75 MHz quarter-wave resonators (QWR) to increase the intensities for both stable and exotic beams [1,2]. These seven new QWR's will provide an accelerating voltage of 2.5 MV per cavity, for a total of 17.5 MV. The electropolishing (EP) of each QWR is performed on a complete, fully jacketed cavity, and includes direct water cooling through the helium jacket to control the cavity temperature during the procedure. This differs from the previous generation of QWR's installed for the ATLAS Energy Upgrade where EP was performed as two subassemblies, followed by a final electron beam weld of the cavity, installation of the helium jacket, and a light buffered chemical polish (BCP) [3]. Using this method of EP, chemistry is decreased to two man-days per cavity, with EP being the final step before high pressure rinse (HPR) and clean assembly.

NEW EP SYSTEM FOR LOW-β SC CAVITIES

A new low-β EP tool for superconducting cavities was designed and built in the Physics Division of ANL. This tool was built to EP the QWR's required for the ATLAS Intensity Upgrade. The single most important technical improvement for these new cavities is that the EP is performed after all cavity fabrication is completed. This new EP tool is located in the chemistry room next door to the existing elliptical cell EP tool at ANL. The low-β EP tool closely resembles the elliptical cell EP tool currently in use at ANL (see Figure 1), and was designed and built over 8 months for ~$95k and with 4 man-months of effort.

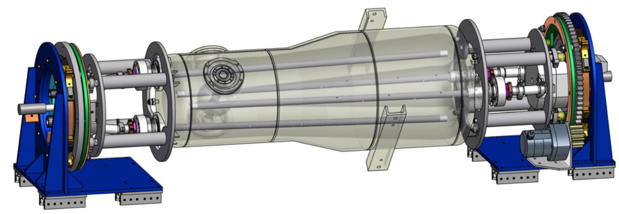

Figure 1: 3-D model of new low-β EP tool.

Design Goals

In order to maximize the accelerating gradient per cavity for the ATLAS Intensity Upgrade, many design changes were put into place for cavity EP. Some of the major design goals for the new EP tool were:

- ability to EP a complete, fully jacketed cavity
- two electrical slip ring assemblies to allow rotation of both anode and cathodes during EP
- direct water cooling through cavity liquid helium (LHe) jacket (while the cavity is rotating)
- enough cathodes to provide adequate polishing
- cathode loading system to ensure correct cathode alignment inside the cavity rf space
- ability to circulate acid during EP
- nitrogen gas purge to evacuate hydrogen gas

The end result was a new horizontal EP system (see Figure 2) modeled after the ANL elliptical cell EP tool with the addition of direct water cooling to the cavity surface through the helium jacket. Four cathodes are used to flow both the acid as well as the N_2 to evacuate the H_2, and also includes an integrated cathode loading system. The time required to load and unload the cavity into the EP tool is ~1 hour.

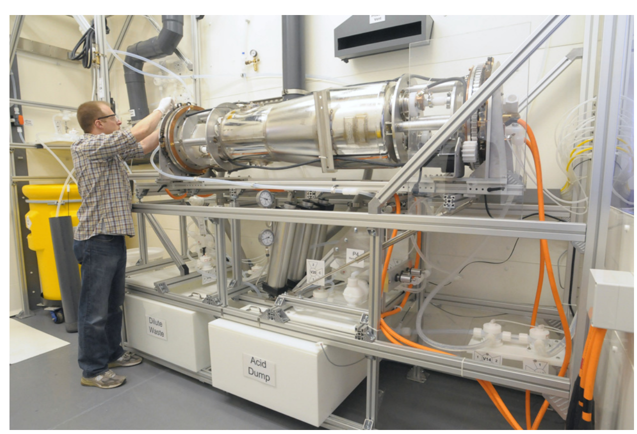

Figure 2: Prototype QWR installed in the new EP tool.

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Cathodes/Cathode Loading

Four cathodes made of 3003 series aluminum are used to achieve uniform polishing of the cavity rf surface. Due to the geometry of the QWR (or a half-wave resonator in the future), great care must be taken when loading/unloading the cathodes in the cavity to ensure that the cathodes do not come into contact with the rf surface, possibly causing unwanted damage that EP will not be able to repair. Since the cathodes are cantilevered inside the cavity rf space once loaded, a fixture is used to hold the cathodes in the correct orientation inside of the cavity, while also ensuring that the cathodes will not shift during EP and contact the rf surface.

Both of these issues were solved with the same piece of hardware. A precision plastic flange machined out of ultra-high-molecular-weight polyethylene (UHMWPE) is attached to the port flanges on the cavity (see Figure 3), allowing both the precision installation of each of the cathodes while also keeping the cathodes aligned inside of the cavity rf space during EP.

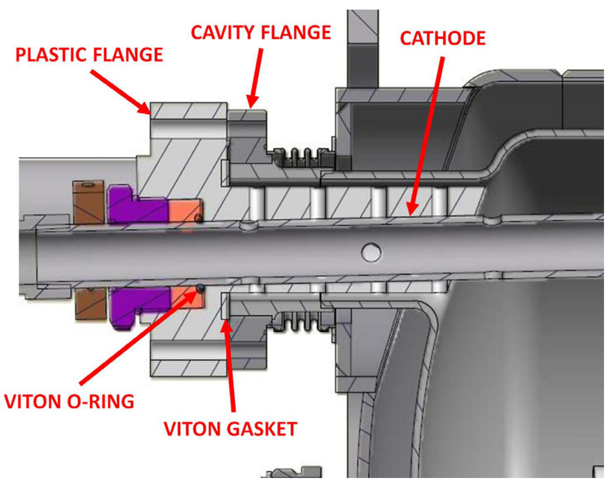

Figure 3: Precision plastic flange for cathode loading and proper alignment inside of cavity rf space.

Installation of the plastic flange is very straight forward. The plastic flange is bolted onto the cavity flange with a Viton gasket acid seal between the cavity flange and the plastic flange. The cathode is then inserted through the plastic flange to a depth determined by the cavity length. The hole in the plastic flange through which the cathode is inserted is precision machined to match the diameter of the cathode, ensuring proper alignment during EP. Finally, the cathode is secured in place with a Viton o-ring compression fitting to form an acid seal between the cathode and the plastic flange. No cathode bag is used with this method of EP.

Bookends/End Groups

The bookends and end groups on either end of the EP tool are very similar (see Figure 4). Each "bookend" consists of an aluminum and stainless steel frame, custom rotating electrical slip ring, a bearing assembly or bearing/gear assembly, and the aluminum framework that is used to mount the cavity into the EP tool.

Each "end group" consists of a non-rotating UHMWPE shaft, a rotating UHMWPE bolted assembly, a Teflon bushing which allows the bolted assembly to rotate on the shaft, a large Teflon lip seal that forms an acid seal between the body assembly and the shaft, and a high-density polyethylene (HDPE) shaft and a small Teflon lip seal used to circulate chilled water into and out of the cavity jacket. One of the end groups also includes an HDPE acid dam which is used to set the height of the acid inside the cavity to be ~60% of the cavity diameter.

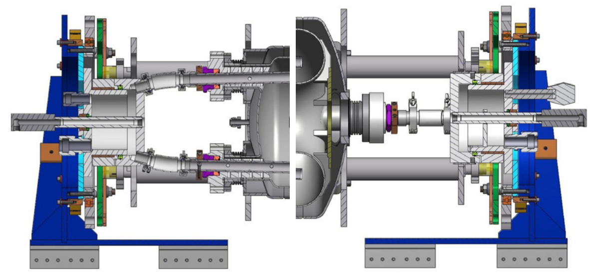

Figure 4: Section view of bookends and end groups.

The cathodes are connected to the end groups with ISO-KF Teflon bellows manufactured by EVAC. The acid seals are also ISO-KF and manufactured by EVAC, with a centering ring made of Teflon and a Viton o-ring. Both the seals and bellows are manufactured for use in vacuum systems, but due to the materials used they were able to be repurposed for acid transfer. Custom HDPE ISO-KF style fittings were made to permit connection of the bellows to the end groups and cathodes.

Water Cooling

Cavity temperature during EP is controlled by circulating chilled water through the LHe space of the cavity, enabled by the fact that EP is performed on a completed, fully jacketed cavity. This offers a major improvement over the ANL elliptical cell EP tool which chills the acid in order to control cavity temperature. Also, the possibility of accidentally mixing water with acid due to a heat exchanger failure is eliminated with this method.

Since the cavity is rotating during EP, the plumbing to circulate the chilled water into and out of the cavity jacket also has to rotate. A rotating water feed-through is used on either end of the EP tool to connect the non-rotating water plumbing from the water chiller to the rotating water plumbing on the cavity. The feed-through is attached to one end of an HDPE tube that transfers the water through the acid bath in the end group. A Teflon lip seal allows rotation of the HDPE tube through a non-rotating part of the end group, while the other end of the HDPE tube is threaded into the rotating part of the end group, using Teflon pipe tape to make an acid seal. The water is then transferred into or out of the cavity jacket, determined by the direction of water flow.

Acid/N_2 Flow

Similar to the ANL elliptical cell EP tool, the cathodes are used to flow acid into the cavity. With the new 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 space to evacuate the H_2 gas produced during the EP process. With the acid dam setting the height of the acid inside the cavity rf space to be ~60% of the cavity diameter, this then allows there to be two cathodes submerged in the acid bath and two cathodes above the acid bath during the majority of the EP process. Therefore, the two cathodes submerged in the acid bath are used to flow acid into and out of the cavity while the two cathodes above the acid bath are used to flow the N_2 gas, evacuating the H_2 gas. Since the cavity is rotating during EP, the roles of the cathodes will constantly be changing throughout the process. As seen in Figure 5, the cathodes on the left will alternate from flowing acid into the cavity to evacuating H_2 gas while the cathodes on the right will alternate from the acid flow out of the cavity to the flow of N_2 gas into the cavity.

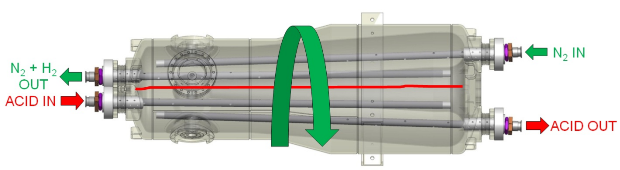

Figure 5: Diagram of the acid/N_2 flow. The red line represents the level of the acid bath inside the cavity.

RESULTS

The prototype QWR received a total of 12 hours of EP over a two day period using the new low-β EP tool. The acid flow rate into the cavity was set at 0.3 l/min. This low flow rate is used to only refresh the acid during EP, not to maintain cavity temperature. Rotation speed was set at 0.5 RPM. The other operating parameters can be seen in Table 1.

Table 1: Operating parameters during QWR EP.

Parameter	Unit	Value
Voltage	V	18
Current density	mA/cm2	30
Average temps.	C	27
Average temps. stability	C	+/- 1
Amplitude of temps. oscillations (due to cavity rotation)	C	3
Acid flow	l/min	0.3
Cavity rotation	rpm	0.5
Nitrogen flow	scfm	1.5

This method of EP proved to be very stable during operation, with an average operating cavity temperature of 27˚C which was stable to ±1˚C. Once the EP was complete, a 1 hour ultrasonic cleaning in a 1% Liqui-nox solution, high pressure rinse, and clean assembly follow. The results of the cold test of the prototype QWR can be seen in Figure 6 [4].

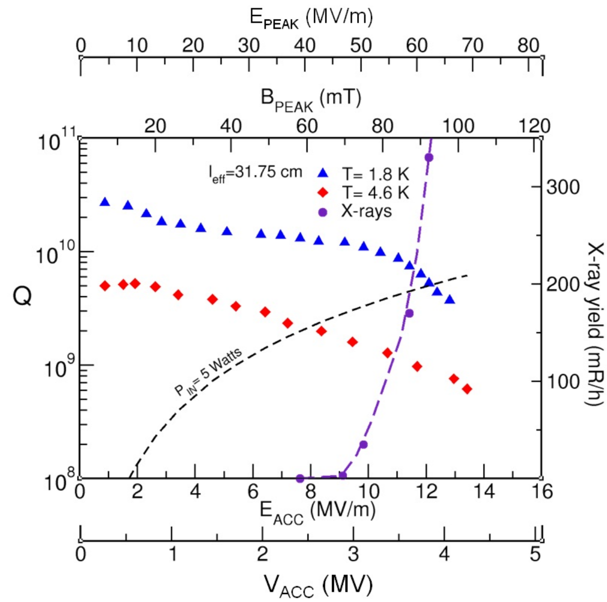

Figure 6: Results of prototype QWR cold test.

SUMMARY

With this method of cavity processing, EP is the final step in cavity fabrication. Unlike BCP, EP can be repeated, if necessary, without degradation of the cavity rf performance. Once the tool is built, EP is simple to perform, cost effective, and is broadly useful for multiple cavity geometries, e.g. quarter- or half-wave cavities. Our goal is to use this method of EP to maximize real estate gradient for ATLAS as well as the next generation of SC ion linacs.

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