ELECTROPOLISHING AT ANL/FNAL

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Abstract

A system for electropolishing 1.3 GHz elliptical single- and nine-cell cavities is in operation at the joint ANL/FNAL cavity processing facility located at Argonne. The system is one piece of a larger 200 m^2 complete single cavity processing and assembly facility which also includes clean rooms and high-pressure water rinsing. Recently, the electropolishing system has been used to process a series of single and nine-cell cavities. For single cell cavities a good set of EP parameters has been demonstrated based on more than a half dozen complete processing and cold test cycles at ANL/FNAL. The latest six single cell cavities each exceed E_{ACC}=35 MV/m and, at this gradient, have Q in the range $6x10^9$ - $1x10^{10}$. The first nine cell cavities electropolished at ANL have not yet reached similar fields (~23-26 MV/m) and ongoing activities are focused on demonstrating 30 MV/m or better in these cavities. Suitable nine cell EP parameters using the ANL/FNAL EP system including acid/water temperatures, flow rates, current, voltage, air flow etc. are all substantially different than for single-cell cavities and are discussed here.

INTRODUCTION

A new superconducting rf (SRF) cavity processing facility has been in operation at Argonne National Laboratory (ANL) for more than one year [1]. The facility is part of a broader accelerator physics collaboration between ANL and Fermi National Accelerator Laboratory (FNAL). It has in one location all of the hardware required to process cavities as received from industry and produce in the end cavities suitable for either vertical testing or installation into a cryomodule. Manpower and material costs are being shared roughly equally by ANL and FNAL. The facility, sized to process multiple cavities per week, has already been used to electropolish cavities for the recently installed ATLAS energy upgrade [2] at Argonne and will likely also support development for the next-generation light source and hadron linacs.

Figure 1: An electropolishing system for single- and multi-cell 1.3 GHz elliptical cavities at ANL.

SYSTEM DESCRIPTION

Background

The electropolishing hardware shown in Figure 1. has been designed, built and operated thus far by ANL personnel. A pre-construction review at ANL in February 2007 was attended by many of the world's experts on cavity EP and design input has been incorporated into the system.

Training of additional ANL and FNAL operators is underway and it is planned that five trained operators will be qualified by early 2010. Typical operating parameters for the 1.3 GHz single- and nine-cell cavity electropolishing system are listed in Table 1. Most of these parameters are similar to those described elsewhere [3]. Notable exceptions are discussed.

Materials

Materials used in the EP system are based on more than three decades of continuous experience performing niobium electropolishing at ANL, going back to the original development of the Siemens process [4]. Materials with proven compatibility with the electrolyte include Teflon (PTFE), PFA, HDPE, and high-purity aluminum. Cathodes for single- and nine-cell cavities were fabricated from high-purity aluminum tubing provided by Jefferson Lab and more recently from 3003 aluminum tubing purchased commercially. No difference in cathode performance or wear is apparent for the two materials.

Table 1: Electropolishing Parameters used at ANL for Nine-cell Cavity Electropolishing

ANL Electropolishing parameters for 9-cell cavities	
Pre-cleaning	Ultrasonic, 1% Liquinox, 1 hour, 50 °C
Electrical connection	Copper braid on cells 2, 5, 8
Cavity rotation speed	1 rpm
Acid reservoir/inlet temperature	20 °C
Acid outlet temperature	30-35 °C
Heat exchanger capacity	10 kW
Heat exchanger material	3003-O Aluminum
Acid flow rate	8 liter/minute
Air flow rate	9 liters/minute
Cathode geometry	3.3 cm OD Al tube
Cathode masking	Teflon tape w/ 40mm openings at cell location
Cathode holes	One 6 mm hole downward into each cell
Electrolyte	9:1 of 96% sulfuric, 48% HF
Volume of rinse water	200 liters
Final pH	5
Post-cleaning	Ultrasonic, 1% Liquinox, 1 hour, 50 °C

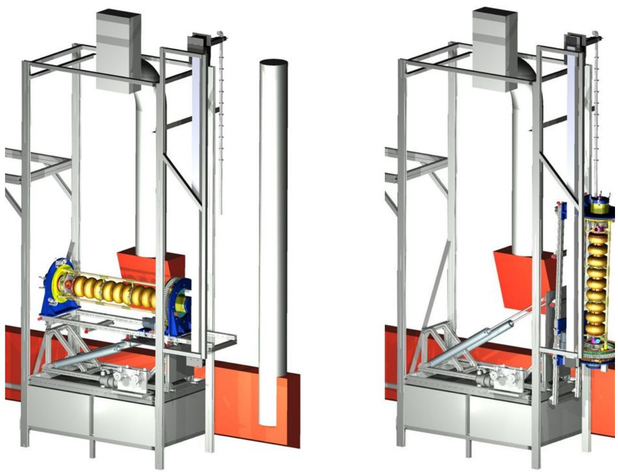

Figure 2: Horizontal orientation (left) as during EP and vertical orientation (right) as during acid dumping, water rinsing and loading and unloading of the cathode.

Non-acid-wetted structural materials located inside the chemistry room are constructed from chemical- and deionized water resistant materials including stainless steel, aluminum, HDPE and Type II PVC. Electrical leads and contacts are fabricated from copper, copper-graphite, aluminum and bronze. To the extent possible delicate components such as electrical leads are coated or covered in order to minimize corrosion.

Orientation

The horizontal orientation was the preferred design choice since it avoids many well established problems in niobium electropolishing. Some of these include an intrinsic difference in polishing rates between upward and downward facing surfaces (downward surfaces polish ~2X faster) and the natural tendency to have temperature and bubble density gradients in tall vertically oriented systems. Likewise, there is long experience [5] with horizontal systems at DESY, KEK and JLab. During EP the cavity is rotated slowly about the beam axis. After EP the system is rotated vertically, as depicted in Figure 2, in order to dump the acid and then rinse the cavity interior with deionized water.

Acid Dumping and Rinsing

The EP system permits the rapid drainage and rinsing of the cavity interior at the end of the procedure. Typically, the elapsed time from the shut off of the applied voltage to the condition with the cavity fully upright and drained is 1-2 minutes. Approximately 2 minutes are required to fill the cavity for the first rinse. Water enters the cavity both from the bottom and through the holes in the cathode. It was found experimentally that allowing the water to overflow and spill into the waste tank for a couple of minutes during the initial rinse prevents staining near the top of the cavity due to residual acid. Allowing the water to overflow on the first rinse is now routine procedure.

Acid Seals

The electropolishing system requires several acid tight seals. All but two of these seals are between fixed surfaces and perform reliably with standard Viton gaskets, o-rings and/or Teflon encapsulated Viton o-rings. The flat 3 mm Viton B gaskets used to seal to the (easily damaged) cavity flange faces provide very robust seals and are recommended.

The seal between the rotating cavity assembly and the fixed EP end groups is, however, more challenging. Here we use a double- Teflon-lip seal available from industry and developed previously for automotive and petroleum applications. The design of the end group is such that the weight of the EP apparatus is never applied directly to the lip seals but is taken by the cavity holding fixture. Any misalignment between the rotating cavity and the fixed end groups are accommodated using a pair of flexible Teflon bellows at each end of the cavity. Lip seals are intended to be replaceable, however, there are no signs of wear or leakage after more than a dozen procedures.

Heat Exchanger

In order to maintain the acid temperature close to the nominal operating temperature of 30 ^{o}C, a heat exchanger fabricated from 30 meters of 1 cm diameter high-purity (3003) aluminum tubing is used to regulate acid stored inside the external tank labeled "Acid Dump" in Fig. 1. The heat exchanger is based on those used for electropolishing of TEM cavities at ANL for more than three decades and is different than the Teflon heat exchangers in use elsewhere. A water chiller with a capacity of 10 kW at 5^{o}C is used to circulate cold water through the aluminum coil. It is noted that the high purity

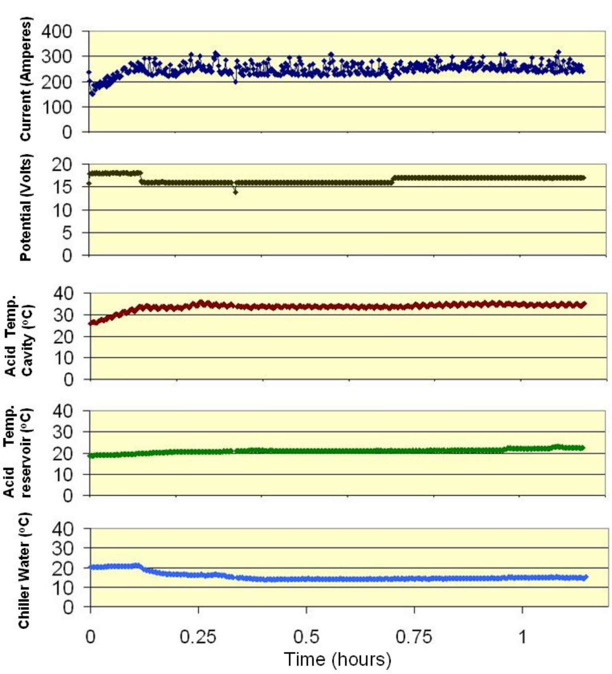

Figure 3: Electropolishing parameters for 20 micron final surface removal on a 9-cell cavity.

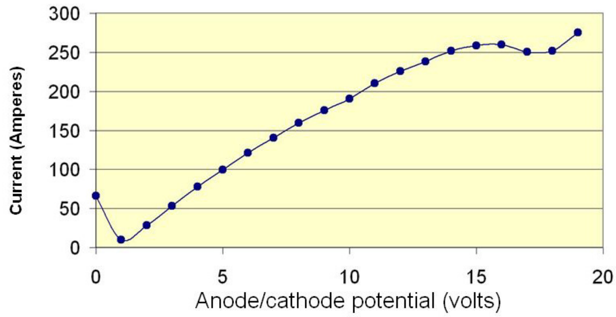

Figure 4: I-V curve for 9-cell cavity during EP.

aluminum holds up well in the fully concentrated electrolyte, as demonstrated previously in many hundreds of hours of operation. However, aluminum does corrode in dilute acid solutions and care should be made not to leave the heat exchanger immersed in such solutions. Possible external (direct) water cooling to minimize temperature gradients across the cavity during EP was initially considered and is still a possible 'upgrade' path.

EP OPERATIONS

9-cell EP

The most recently measured online parameters for electropolishing of a standard ILC-type nine-cell cavity are shown in Figure 3 for a 'light' EP procedure. The only parameters adjusted during EP are the applied anode/cathode potential (2nd panel from top) and the temperature of the chiller water (bottom panel) circulated through the heat exchanger in the external acid reservoir. The total volume of acid for 9 cell EP is 200 liters.

Parameters change slowly enough that adjustments can easily be made manually by an experienced operator. With some additional development this could be automated. Measured data show that there is an approximately 10 minute equilibration time required to bring the acid temperature from 25 ^{o}C up to the nominal operating temperature after which the parameters are fairly stable.

Current versus voltage (I-V) measured about 20 minutes after the start of the procedure is shown in Figure 4. The data shows the plateau corresponding to the 'electropolishing region' between about 15 to 18 volts though the effect is less pronounced than has been seen elsewhere [3]. Except for the first 10 minutes where the applied voltage was 18 V in order to heat the acid, this procedure was performed between 16-17 volts

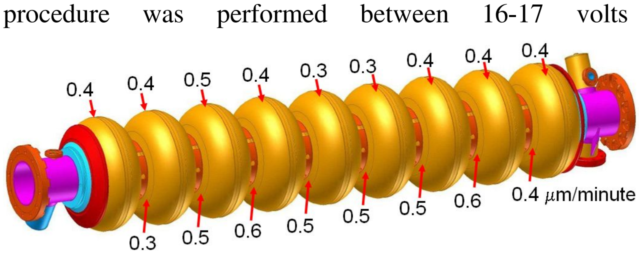

Figure 5: Measured surface removal rate at the equator and iris.

anode/cathode potential, near the middle of the plateau. We propose that because the I-V curve is clearly an 'integral' over the entire cavity inner surface, operation near the high end of the plateau should be avoided in order to avoid the possibility oxygen formation [5] near the faster polishing irises.

The total amount of surface removal is measured for each polished cavity, both near the equator and the iris regions, using a hand held ultrasonic thickness gauge. Total surface removal was verified to be just over 20 microns for this procedure. The local removal rates have been measured to be 0.35 micron/minute at the equator and 0.43 micron/minute at the iris, reasonably close to the nominal 0.3 microns/minute. The ratio of these values of about 1:1.25 is somewhat less than has been observed elsewhere [3].

To date, two nine-cell cavities electropolished at the joint ANL/FNAL facility have been cold tested. However, the very first cavity was polished with parameters substantially different from those described here. In particular, the anode/cathode current was in the range of 400-500 Amperes due to difficulties regulating the acid temperature, clearly above the nominal value of about 275 Amperes (30 mA/cm^2). The cold test following the first EP showed global heating throughout the cavity and had a quench at 23 MV/m. The second cavity was electropolished with more optimal parameters similar to those in Figure 3. However, this cavity was field emission limited at 26 MV/m likely due to contamination after HPR. Additional cavities already electropolished at the facility are awaiting cold test.

Singe-cell EP and Test Results

In order to commission the EP system, and at the same time, commission the new rinsing and assembly facilities, a series of single cell cavities was processed in the joint facility. For single cell EP the total electrolyte volume is 40 liters. In order to maintain the nominal 37 Amperes anode/cathode current the temperature of the acid in the external tank is held at 26-30 ^{o}C, much warmer than for 9-cell EP.

Figure 6. shows the hardware reconfigured to hold a single-cell cavity. The reconfigured system requires

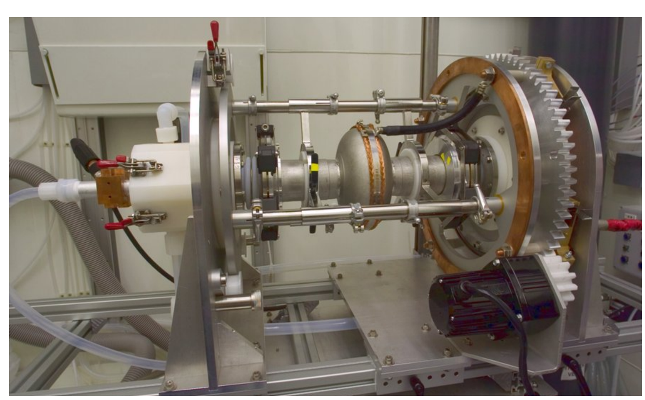

Figure 6: The electropolishing system re-configured for a 1.3 GHz single-cell elliptical cavity.

Table 2: Maximum Accelerating Gradients for Single-cell Cavities after EP/HPR and Cold Testing at FNAL.

Cavity	Eacc [MV/m]
NR-1	26.5
TE1AES004	39.2
TE1AES005	36.3
TE1ACC002	37.1
TE1ACC001	41.3
TE1ACC003	42.1

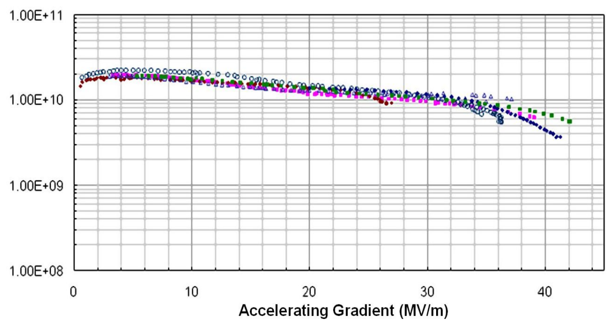

Figure 7: The electropolishing system re-configured for a 1.3 GHz single-cell elliptical cavity.

installation of a shorter cathode, changing of three acid handling lines and adjusting the length of the mounting fixture. Total effort for this is about a man-day.

For single cell cavities the EP parameters used here appear to be reproducible and are now reasonably well established based on more than a half dozen complete processing and cold test cycles at ANL/FNAL. The lastest six single-cell cavities each exceed E_{ACC}=35 MV/m and, at this gradient, have Q in the range $6x10^9$ - $1x10^{10}$ as shown in Table 2. and Figure 7.

CONCLUSION

An electropolishing system for processing elliptical cell cavities has been built at Argonne in collaboration with Fermilab. The system has been used to electropolish a series of single-cell cavities which have shown good performance in cold tests. The first nine cell cavities electropolished at ANL have not yet reached similar fields (~23-26 MV/m) and ongoing activities are focused on demonstrating 30 MV/m or better in these cavities.

ACKNOWLEDGEMENTS

This work was supported by the U. S. Department of Energy, Office of Nuclear Physics, under contract number DE-AC02-06CH11357.

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