ADVANCE IN VERTICAL BUFFERED ELECTROPOLISHING ON NIOBIUM FOR PARTICLE ACCELERATORS*

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Abstract

Niobium (Nb) is the most common material that has been employed for making superconducting radio frequency (SRF) cavities for use in particle accelerators over the last couple of decades. One of the most important steps in fabricating Nb SRF cavities is the final chemical removal of 150 µm of Nb from the inner surfaces of the SRF cavities. This is usually done by either buffered chemical polishing (BCP) or electropolishing (EP). Recently a Nb surface treatment technique called buffered electropolishing (BEP) has been developed at Jefferson Lab. It has been demonstrated that BEP can produce the smoothest surface finish on Nb ever reported in the literature while realizing a Nb removal rate as high as 10 µm/min that is more than 25 and 5 times faster than those of EP and BCP(112), respectively. In this contribution, recent advances in optimizing and understanding BEP treatment technique are reviewed. Latest results from RF measurements on BEP treated Nb single cell cavities by our unique vertical polishing system will be reported.

INTRODUCTION

After more than four decades of development, superconducting radio frequency (SRF) technology based on niobium (Nb) has matured gradually. Accelerating gradient as high as 59 MV/m has been demonstrated on a Nb SRF single cell cavity [1]. Currently there are two major challenges for the SRF community. One is how to consistently fabricate high performance multiple cell Nb SRF cavities with a high reproducibility and a gradient higher than 35 MV/m. The other is how to reduce the fabrication costs of Nb SRF cavities. For the first challenge, progress has been made in the direction of looking for improved surface treatment techniques that would produce better and smoother surface finish [2-6], improved quality control of Nb materials, improved cavity assembly procedure and environment, and better understanding of the mechanism that produces the high field Q-slope [7]. For the second challenge, researchers have developed techniques of hydro-forming and spinning to produce seamless cavities [8,9], explosive bonding [8] or hot rolling [10] to make Nb/Cu sheets to fabricate the cavities, and thin film deposition technique [11-13]. In fact, the two challenges are interrelated. For instance, a Nb surface treatment technique called "buffered electropolishing" (BEP) that was initially developed [2] by scientists at JLab in collaborations with Peking University [14,15] and CEA Saclay [16] can not only produce better and smoother surface finish but also reduce fabrication costs of Nb SRF cavities. It has been shown [4,14,15] that Nb surface treated by BEP is an order of magnitude smoother than that by the conventional electropolishing (EP). Furthermore, the polishing rate of BEP can be as high as 10 µm/min [17]. This high Nb removal rate will reduce the surface chemical treatment time, leading to significant savings in Nb SRF cavity fabrication costs as discussed in Ref.17. In this contribution, the latest progress in R&D on vertical BEP since IPAC2010 is reported.

* Authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177. andywu@jlab.org

CATHODE SHAPE

The first comprehensive experimental study of electropolishing mechanism for the superconducting radio frequency (SRF) cavities in a macroscopic scale especially for the effects of cathode shape on the polishing results during vertical BEP and EP has been done recently by employing a unique JLab home-made demountable single cell niobium SRF cavity [18]. Different cathode shapes such as, for instance, small bar, large bar, ball, ellipsoid, and wheels were employed in this study. Detailed electropolishing parameters at different locations inside the demountable cavity were measured, including I-V characteristic, removed rate, surface roughness, polishing uniformity and so on. Similar studies were also done on EP for comparison. It was revealed that cathode shape had dominant effects for BEP especially on the obtaining of a suitable polishing condition and a uniform polishing rate in a Nb SRF single cell cavity. The conventional EP appeared to have the same tendency. It was demonstrated that a more homogeneous polishing result could be obtained by optimizing the electric potential distribution inside the cavity through the modification of the cathode shape given the conditions that temperature and electrolyte flow were kept constant.

Ref. 18 also demonstrated that simulation of electric field distribution via Poisson Superfish was a powerful tool in optimizing the cathode shape so that a more uniform polishing on the entire inner surface of a Nb SRF cavity could be obtained. This study implied that it would be possible to intentionally polish some localized spots in a SRF cavity by designing a special cathode shape using simulations from Poisson Superfish. Fig.1 shows the optimized cathode shape and the simulated electric field

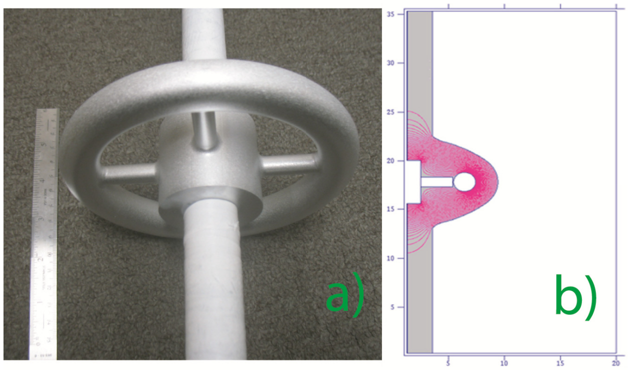

Figure 1: Optimized cathode for BEP and EP treatments on single cell Nb SRF cavities of CEBAF shape. b) is the simulated electric field distribution by Poisson Superfish. The red lines are the potential lines.

distribution inside the cavity. The photo of the cavity treated by BEP using the optimized cathode is given in Fig.2. Based on the experimental results obtained from Ref.18, a shaped cathode is proposed for doing horizontal EP on a Nb single cell SRF cavity as shown in Ref.19. Similar cathodes can be designed for multi-cell cavities.

Figure 2: Photo of the demountable cavity treated by the optimized cathode shown in Fig.1a). Left is the upper half cell. Right is the lower cell.

POLISHING OPTIMIZATION VIA SIMULATIONS

Simulations via Poisson Superfish and Solidworks were employed to optimize the vertical polishing process in terms of cathode shape design (see Fig.1b) for example), hydrogen bubble management, and uniform electrolyte flow in the cavity [20].

Hydrogen bubbles are an inevitable product during BEP and EP. They can not only create movement traces on the inner surface of a cavity making it rougher but also degrade its RF performance via the well known Q-disease. Fig.3 shows that by using a special cathode it is possible to guide the movement of hydrogen bubbles generated during BEP and EP so that the effects of the bubbles on the surface of the cavity can be minimized.

Performance of a Nb SRF cavity is determined by the weakest spot in its inner surface. To achieve high performance, it is important that the polished cavity has a uniform finish on its inner surface. A special piece of Teflon is also designed to make the electrolyte flow inside the cavity more uniform as showed in Fig.4.

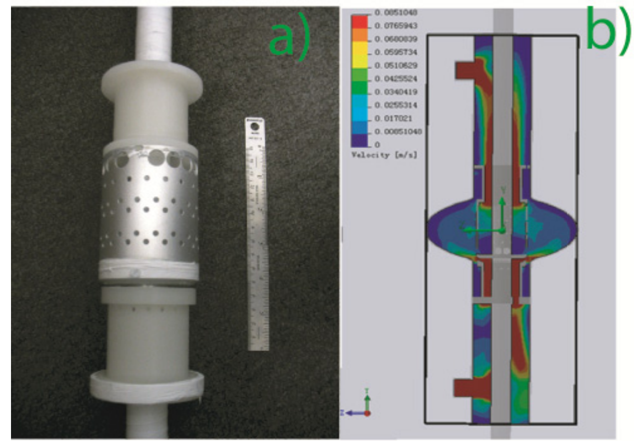

Figure 3: Special cathode designed by simulation via SolidWorks for guiding the movement of hydrogen bubbles during vertical BEP and EP. a) Fabricated cathode. b) Simulated electrolyte flow pattern to minimize the effect of hydrogen bubbles on Nb surface.

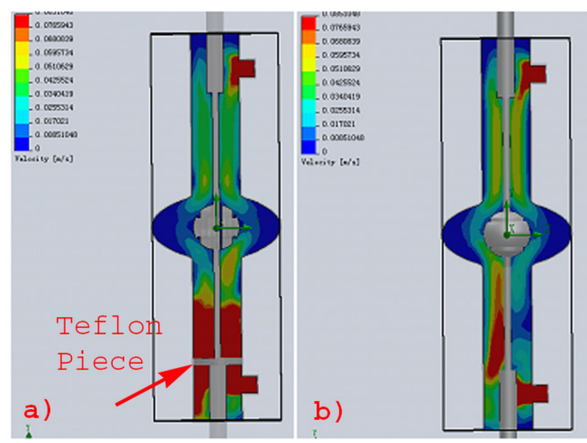

Figure 4: A special Teflon piece designed by simulation via SolidWorks to make the electrolyte flow in the cavity more uniform. a) Flow pattern after using the Teflon piece. b) Flow pattern before using the Teflon piece.

A NEW DEMOUNTABLE CAVITY

A new demountable cavity was fabricated to allow two more button samples to be installed at locations near iris and equator on the lower half cell. The first experiment has been done using the new cavity and the optimized cathode (Fig.1) as well as the Teflon piece (Fig.4). The

Figure 5: Photo of the new demountable cavity after treated by BEP. a) Upper half cell. b) Lower half cell.

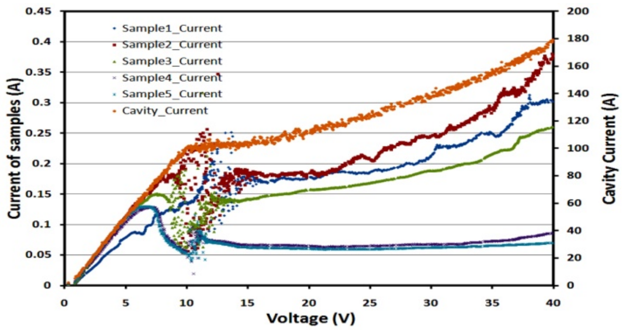

Figure 6: I-V curves of the whole cavity and button samples 1 to 5. Button samples 1-3 are from iris to equator for the upper half cell. Button samples 4 and 5 are located near iris and equator for the lower half cell respectively.

photo of the cavity after BEP removal of 75 μm is shown in Fig.5. The corresponding I-V curves of the whole cavity and the five button samples are shown in Fig.6. It is interesting to note that the positions of the I-V curves for the two button samples on the lower half cell overlap. This explains why the lower half cell generally has more homogeneous Nb removal between iris and equator. This experiment also reveals for the first time that the removal rate of the lower cell is significantly less than that of the upper half cell. This fact can be crucial in determining the RF performance.

LATEST RF TEST RESULTS FROM BEP TREATED CAVITY

Although the optimized cathode shape is known for BEP and EP, how to implement it in a real cavity treatment is still an issue since the cathode size is always limited by the size of the beam pipe. Nevertheless, this is a less important engineering issue and should be able to be resolved sooner or later. One way to realize a more uniform surface electric potential distribution in a cavity is to use the umbrella mechanism. The other is to make an aluminium balloon cathode with a shape like Fig.1. After putting the balloon cathode into a cavity, then pressure some inner gas into the balloon to form the special shape.

Our systematic investigation on vertical BEP and EP [20] has shown that good I-V curves with the clear four areas [2] can only be obtained when the cathode shape is optimized and the ratio between the surface areas of cathode and anode excesses a certain threshold. So far, the best RF performance has been obtained employing a ball cathode [Fig.4]. Several single cells of CEBAF shape have reached ~25 MV/m with Q_o close to $5X10^9$. All of them were quench-limited. It is highly plausible that these are the performance limits of the cavities since RRR values of those cavities are not high. Typical excitation curves of a BEP treated Nb single cell cavity of CEBAF shape are shown in Fig.7. This cavity reaches 28.4 MV/m and Q_o of 1.2×10^{10} at the quench point.

New cavities of TESLA shape using high RRR Nb materials are under fabrication and will be treated by vertical BEP. The experimental results from the new cavities will be reported soon.

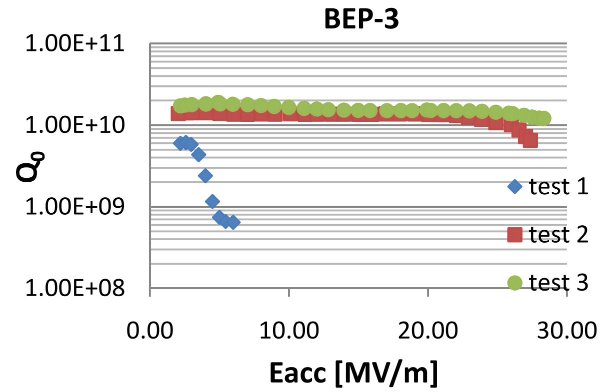

Figure 7: RF test results of BEP-3 at 2K before and after high pressure water rinsing as well as after the 120°C baking.

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