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VERTICAL ELECTROPOLISHIG OF 1.3 GHz NIOBIUM NINE-CELL SRF CAVITY: BULK REMOVAL AND RF PERFORMANCE

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Abstract

Vertical electropolishing (VEP) technique have been successfully developed for 1.3 GHz niobium (Nb) single cell cavity to achieve a smooth surface with uniform removal and better RF performance as achieved after horizontal EP (HEP) process. VEP parameters for 1.3 GHz Nb nine-cell cavities are being studied using a nine-cell coupon cavity and our unique Ninja cathode. The investigated VEP parameters heretofore were applied on a 1.3 GHz Tesla shape nine-cell superconducting RF cavity for bulk removal of 100 μm followed by fine removal of 20 and 10 μm. The interior surface was found to be smooth and shiny after the VEP process. Our recently developed dual flow technique, in which the EP acid is flown separately in the Ninja cathode housing and cavity, yielded lower asymmetry in removal along the cavity length. The cavity was tested in a vertical cryostat after the final VEP process. The cavity achieved 28.3 MV/m at Q_0 value of 6.7×10^9. The cavity performance was almost the same as in the baseline vertical test performed after the HEP process.

INTRODUCTION

Electropolishing (EP) is now a standard method for surface treatment of niobium accelerating cavities where the EP process is carried out with a horizontal EP (HEP) system. As an alternative way, the cavity can be set vertically to perform electropolishing with a so-called vertical EP (VEP) setup which is comparatively simple and cost-effective. However, the VEP method yielded asymmetric removal and bubble traces on the interior surface of the cavity [1]. In our previous studies, we have shown the major cause of asymmetry is an accumulation of H_2 gas bubbles, generated at the aluminum cathode used for EP process, on the cavity surface [2]. We have successfully resolved the issue of the asymmetric removal and rough surface with our patented Ninja cathode and optimized VEP parameters including cathode rotation speed, operational temperature, applied voltage, and current density [3, 4]. The cathode housing covered with a meshed Teflon sheet guides gas bubbles along the cathode and reduces diffusion of bubbles from the cathode housing to the cavity. However, the removal of bubbles from ~1.2 m long nine-cell cavity is quite difficult and the accumulation of bubbles in the upper cells cannot be avoided with the process and parameters applied on the single cell cavity. We have developed a dual flow technique to remove gas bubbles from the cathode housing quickly so as to reduce bubble diffusion from the housing to the cavity. In this technique, the acid is flown separately in the Ninja cathode housing and cavity while keeping a higher flow rate in the cathode housing [5]. Effect of the technique with adequate flow rates has been presented elsewhere [5]. This paper shows the first bulk VEP of a nine-cell cavity with the Ninja cathode, vertical test result, and future work to further improve the VEP technique.

VEP EXPERIMENTS AND RESULTS

A Tesla shape 1.3 GHz Nb nine-cell superconducting RF cavity (TB9-TSB01), which was surface treated earlier with the HEP process and has a baseline vertical test result, was selected for the VEP process. VEP process was performed with our VEP system (see Fig. 1) which is equipped with auto-controlled valves and programmed acid flow direction. The system is equipped with a water spray facility for cavity cooling and a heat exchanger for acid cooling in the acid reservoir. Pure water is uniformly sprayed at the exterior of the cavity during the EP process. As a cathode for the VEP process, the Ninja cathode having 3 insulating blades in each cell of the cavity was used. The acid inlet line was bifurcated in two lines to flow acid in the Ninja cathode housing and the cavity separately. Two flow meters are set on the two lines to measure the flow rates in the cathode housing and cavity.

Three VEP processes have been carried out for the cavity TB9-TSB01 for bulk removal of 100 μm, fine removal of 20 and 10 μm. The removal thickness was calculated from the measured integrated current with a current hour meter. The cavity was annealed at 750 °C after the bulk VEP and 20 μm removal. After each VEP process, the cavity was rinsed with ultrasonic oscillators and at high pressure water rinsing.

Figure 1: VEP system with auto-valves (left) and cavity set at VEP stand (right) for the VEP process.

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VEP parameters studied with the nine-cell coupon cavity were applied for the VEP processes [5]. The cathode was rotated at 20 rpm continuously during the VEP process and the post-EP water rinsing process. The acid was separately flown in the cathode housing and cavity. The flow rates and other VEP parameters are summarized in Table 1.

Table 1: Parameters and Conditions for VEP Process

Conditions	Value
Acid (H_2SO_4:HF)	9:1
Voltage	18.5 V
Cavity temperature	< 15°C
Cathode	Ninja cathode
Cathode rotation	20 rpm
Acid flow condition	Dual
Target flow rate in Ninja cathode	10 L/min
Target flow rate in cavity	5 L/min
Acid flow direction	Bottom to top

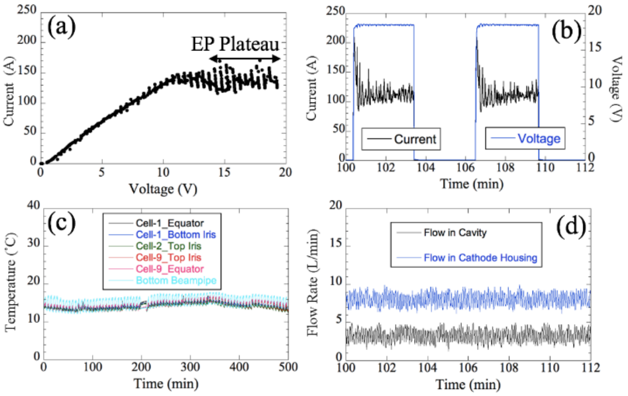

Figure 2: (a) I-V curve, (b) current and voltage cycles, (c) cavity temperature, and (d) acid flow rates in the cathode housing and cavity.

Before the VEP was started, an I-V curve at cathode rotation of 20 rpm was obtained. The I-V curve as in Fig. 1 clearly shows an apparent EP plateau starting from ~13 V. VEP was performed at 18.5 V with on-off voltage cycles. A VEP voltage was selected in the higher side on the EP plateau so that surface etching can be avoided. The on and off times were selected to be 3 min. The off-time was necessary to reduce returning of the bubbles from the acid reservoir to the cavity. Temperatures at totally six positions in the upper and lower sides of the cavity were recorded. Current, voltage, cavity temperatures, and acid flow rates are shown in Fig. 2. The flow rates in the cathode housing and cavity were measured to be around 7 and 3 L/min, respectively. The flow rates were lower than the target values as investigated with VEP experiments of the coupon cavity. The inlet acid pump required maintenance to work with its full capacity. The flow rates in the VEP process done for 20 μm removal were maintained as desired. The bulk VEP was performed totally for around 19 h including the voltage off-time to remove an average thickness of 100 μm.

Removal Thickness

Removal thickness at different positions of the cavity was measured with an ultrasonic thickness gauge. The removal trend (for 100 and 20 μm removal thickness) along the cavity length is shown in Fig. 3. In the bulk VEP, removal asymmetry was found in the cell where the removal at the upper iris was larger than the removal at the bottom iris and equator. However, the asymmetry is significantly less compared to the previous VEP performed with single flow at a flow rate of 5 L/min [5]. The asymmetry might occur due to bubble circulation from the tank, which is only 70 L in the capacity, to the cavity. Although bubbles moved along and inside the cathode, there is a possibility that a fraction of bubble amount diffused from the meshed sheet of the cathode housing and accumulated in the cells. Since the bulk VEP was performed with lower flow rates than the target values, the possibility of bubble diffusion increased. The accumulated bubbles on the upper half cells might impair the viscous layer thickness and enhances the EP rate there [2]. The asymmetry seems to be less in the VEP performed for 20 μm removal since the target acid flow rates were maintained.

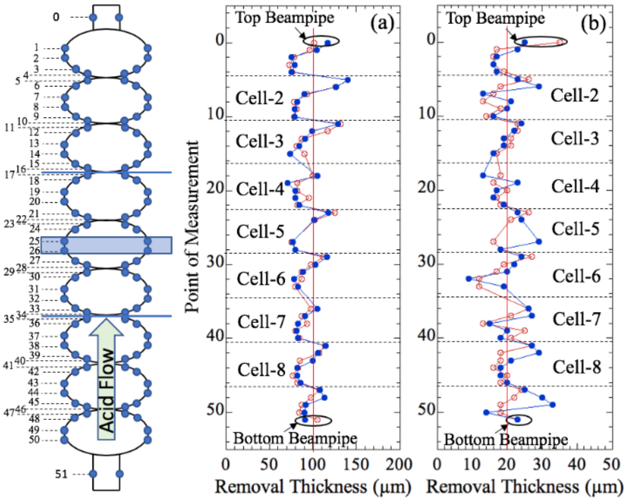

Figure 3: Removal thickness trends along the cavity length in (a) bulk VEP for 100 μm removal and (b) fine VEP for 20 μm removal. The schematic shows positions of thickness measurement. The solid vertical lines show average removal thicknesses.

Cavity Surface

The cavity surface before and after the VEP processes was observed with the Kyoto camera. Figure 4 shows images of the equator surface in the top cell (cell-1), center cell (cell-5), and bottom cell (cell-9) before and after the bulk VEP process. The cavity surface was as smooth as before VEP and no etching sign was seen. The result shows that the applied parameters are adequate to perform EP of the entire surface of the cavity without surface etching. The photograph in Fig. 5 shows the shiny surface of cell-1 and cell-9.

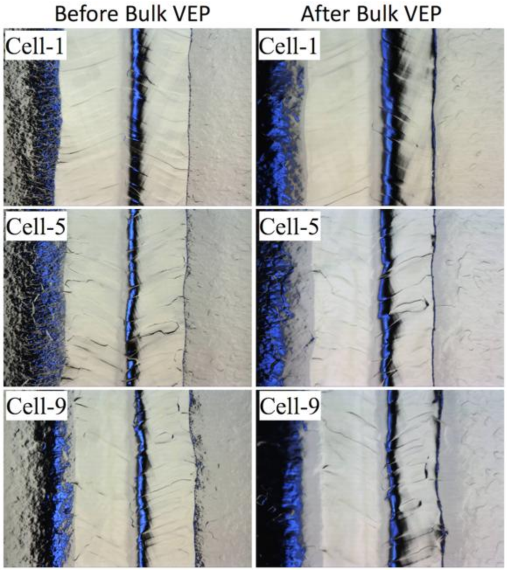

Figure 4: The equator surface in the cell-1, cell-5, and cell-9 of the cavity before (left) and after (right) the bulk VEP for 100 µm removal thickness. The image size is 12x 9 mm.

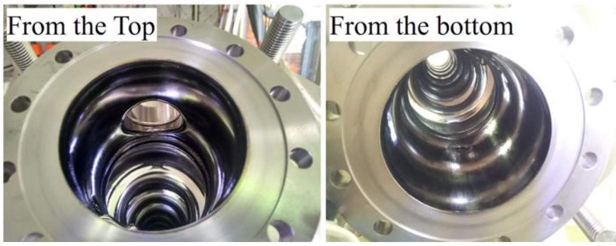

Figure 5: Cavity inner surface after the bulk VEP. Photographs captured from the top and bottom of the cavity.

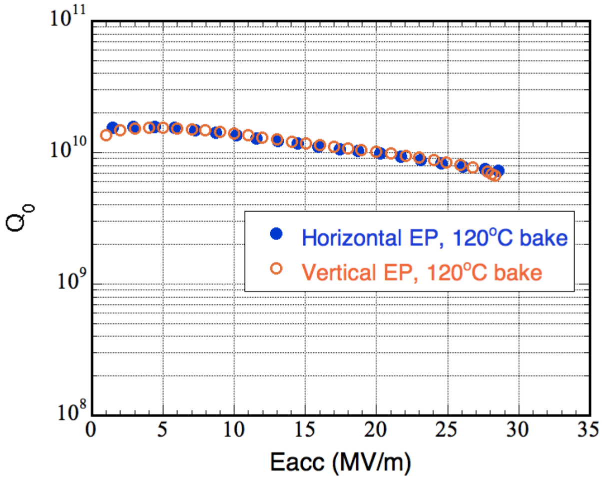

Figure 6: Cavity performance (Q_0 vs Eacc curves) in vertical tests after HEP and VEP processes.

VERTICAL TEST

The first vertical test (VT) as scheduled after the second VEP for 20 µm removal could not be performed because vacuum leak occurred while cooling down the cavity at 2 K. A vertical test was performed at 2 K after the cavity was VEPed for 10 µm removal and baked at 120°C for 48 h. Maximum field gradient (Eacc) of 28.3 MV/m at a quality factor (Q_0) of 6.7×10^9 was achieved in the π-mode. The comparison of Q_0 versus Eacc curves in vertical tests after HEP and VEP processes are shown in Fig. 6. In both the tests, the cavity performance was limited by quench. The cavity showed the similar RF performance after treated with HEP and VEP.

FUTURE WORK

In order to further improve the removal uniformity, the VEP parameters will need to be fine-tuned. The asymmetry might be reduced at higher cathode rotation as observed earlier [6]. The volume of the acid reservoir will be increased to avoid bubble circulation between the acid reservoir and the cavity. The larger tank will make it possible to perform VEP with continuously voltage-ON that will finally enhance the EP rate. Fluid flow simulation will be performed to understand fluid diffusion from the cathode housing to the cavity in dual flow condition and the effect of the acid flow rates.

CONCLUSION

VEP of a nine-cell cavity for bulk removal was successfully performed for the first time with the Ninja cathode and investigated VEP parameters with the nine-cell coupon cavity. The dual acid flow technique was applied to remove the bubbles quickly from the cathode and cavity. The separate flow resulted in less asymmetric removal compared to that with the combined flow. The VEP yielded a smooth and shiny surface and no etching sign was observed in all the cells. RF performance of the cavity was tested in a vertical cryostat at 2 K. The cavity achieved a field gradient of 28.3 MV/m at a Q_0 value of 6.7×10^9 in the vertical test. The RF performance is as good as achieved after the HEP process.

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