ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL030

VERTICAL ELECTROPOLISHING OF 1.3 GHZ NIOBIUM 9-CELL CAVITY: PARAMETER STUDY AND CAVITY PERFORMANCE

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Abstract

VEP parameters and process have been already optimized with single-cell 1.3 GHz niobium cavity at Marui Galvanizing Company working in collaboration with KEK. A unique cathode called “Ninja cathode” with an optimized shape was applied to single-cell cavities. The cathode was effective to stop the bubble accumulation in the upper half-cell of the cavity and yielded smooth sur-face and uniform removal in the cell. This work shows parameter study with the Ninja cathode and a 9-cell coupon cavity which contains totally 9 coupons and viewports in the first, fifth, and ninth cells. Effects of temperature and acid flow in the cathode housing were studied using coupon currents and by observing bubbles through the viewports. The adequate parameters found with 9-cell coupon cavity were applied on a 9-cell cavity to be tested in vertical cryostat. The VEP and vertical test results are reported.

INTRODUCTION

The vertical electropolishing (VEP) attracted researchers’ interest owing to low cost setup and simple operation compared to horizontal electropolishing (HEP) technique. However, the VEP process of a niobium cavity usually results in rough surface with bubble traces and removal asymmetry. Bubbles accumulation on the cavity surface was found to be the main cause of removal asymmetry [1]. Our previous study on single cell cavity using a unique cathode namely Ninja cathode revealed that a smooth surface and symmetric removal can be obtained with VEP [2,3]. However, achieving a uniform EP in each cell of a nine-cell cavity is still a challenging job. In this paper, we show VEP parameter study, VEP of a nine-cell cavity and its performance in vertical test.

EXPERIMENTS

VEP parameter study was carried out with a 9-cell coupon cavity and a Ninja cathode. The cavity contains removable coupons, which are electrically isolated with the cavity, at the iris and equator positions of the first (top), fifth (center) and ninth (bottom) cells of the cavity. These cells also have viewports at the top and bottom irises [4,5]. The cathode is covered with a meshed hous-ing to stop the bubble diffusion in the cavity cell. VEP setup, Ninja cathode and 9-cell coupon cavities are dis-cussed elsewhere [5]. The VEP system was modified to flow acid in the Ninja cathode housing and cavity separately so as to enhance an acid flow speed in the cathode housing.

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EFFECT OF ACID FLOW

The modified setup allowed us to flow acid in the cathode housing and cavity with different flow rates. Acid flow rates were varied from 0 to 20 L/min in both cavity and cathode housing to find out an adequate combination of flow rates to remove H_2 gas bubbles quickly from the cathode housing. During the tests, coupon currents were recorded and gas bubble behavior in the cavity cells were observed from the viewports. Coupon currents in the top cell are compared for the acid flow rates of 0, 5, 10 and 20 L/min in the cathode housing and a fixed flow rate of 5 L/min in the cavity (see Fig. 1). During all these tests, cathode was rotating at 20 rpm.

It has been observed from the top iris viewport that at acid flow rates of 0, 5, and 20 L/min in the cathode housing, bubble diffused from the cathode housing to the cavity cells. The diffused bubble accumulated on the upper half-cells of the cavity especially in the upper cells and enhanced the EP rate [1]. The top iris coupon current in the top cell was increased due to the bubble accumulation. At 10 L/min, the bubbles moved along the cathode and bubble diffusion was not noticed. In this case, the bottom and top iris coupon currents were found to be very simil-ar. The coupon current comparison under different com-binations of the flow rates revealed that flow rates of 10 L/min in the cathode housing and 5 L/min in the cavity are adequate to significantly reduce bubble accumulation in the cavity cells.

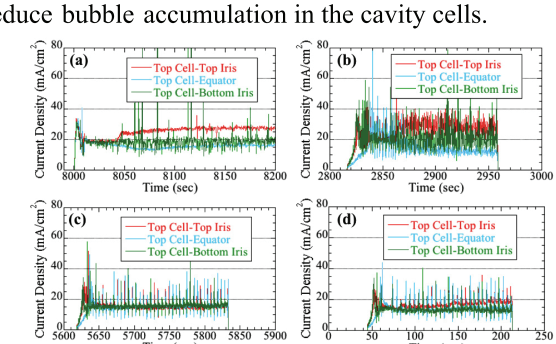

Figure 1: Current profiles of the coupons in the top cell at a flow rate of 5 L/min in the cavity and different flow rates of 0 L/min (a), 5 L/min (b), 10 L/min (c), and 20 L/min (d) in the cathode housing.

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VEP OF COUPON CAVITY

In order to decide EP parameters, I-V data was measured for all the nine coupons and cavity. In the I-V test, a cavity temperature was kept lower to be at around 15 °C since EP plateaus shift towards higher voltage at a higher temperature [5]. I-V curves for the coupons and the cavity are shown in Fig. 2. During the I-V tests, an acid flow rate of 10 L/min in the cathode housing and 5 L/min in the cavity was set. The EP plateaus for all the coupons and cavity were clearly appeared within the maximum applied voltage (20 V).

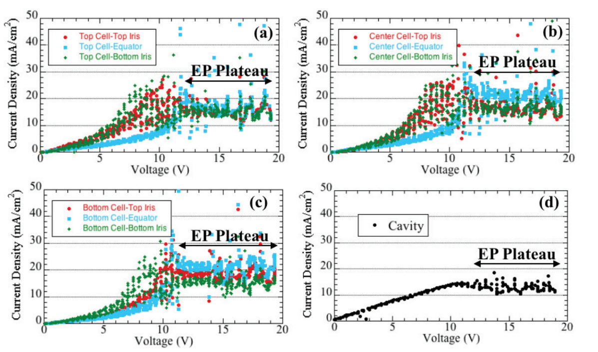

Figure 2: I-V curves for the coupons in the top cell (a), center cell (b), and bottom cell (c) and for the cavity (d).

VEP of the cavity was performed with the same acid flow condition as used for the IV measurement, at a temperature below 15 °C and a voltage of 17.5 V. An average current density was measured to be ~14 mA/cm². During the VEP, the bubbles, which move from the cavity to the acid reservoir, return back to the cavity after a few minutes of VEP. The returned bubbles started to accumulate in the bottom cell and enhanced the top iris coupon current in the bottom cell. To avoid the bubble circulation, a VEP was performed with periodic on/off voltage cycles. The on/off time was set to be 3 min. The cut-off time of 3 min reduced returned bubbles in the cavity. It has been found that some bubbles always stay on the upper iris surface and might influence the EP rate. However, a large amount of bubbles were not found under these acid flow conditions. An average removal thickness of the cavity was ~25 µm. The coupon surfaces after VEP were found to be smooth and shiny. The coupon surface roughness Rz is shown in Fig. 3.

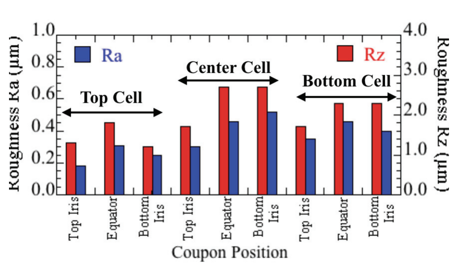

Figure 3: Roughness Rz of the coupon surfaces.

VEP AND VERTICAL TEST OF 9-CELL CAVITY

VEP Conditions

The cavity (TB9-TSB02) was VEPed with usual acid flow, in which separate acid flow streams in the cavity and cathode housing were not applied, and with separate flow as explained above. The current density, temperature and voltage profiles for both the VEPs are shown in Fig. 4. The first and second VEP processes (VEP-1 and VEP-2) were carried out for an average removal thickness of 52.8 and 18.2 µm, respectively. In the VEP-2 the similar VEP parameters as found with the coupon cavity were applied.

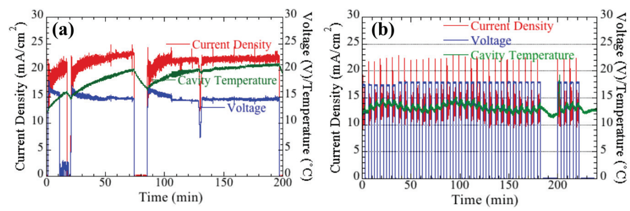

Figure 4: Current, voltage and cavity temperature profiles in (a) VEP-1 and (b) VEP-2.

Removal Thickness and Field Flatness

Removal thickness trends along the cavity length in both the VEP processes are shown in Fig. 5. VEP-1 resulted in strong asymmetric removal with higher removal in the upper five cells. VEP-2 performed with separate acid flow significantly reduced the removal asymmetry along the cavity length. A difference in removal at the top and bottom irises of cells was found. However, all the cells show a similar removal trend. The higher removal at the top iris position in each cell might result of circulating bubbles between the cavity and the acid reservoir.

Field flatness was reduced from 90% to 67% after VEP-1. This large degradation in the field flatness was attributed to the asymmetric removal. The cavity was tuned again with a field flatness of 97% before the VEP-2 was performed. No degradation in the field flatness was seen after VEP-2. This proves that VEP with removal of around 20 µm, which is the standard adopted thickness for final EP, does not degrade field flatness and can replace HEP for the final EP.

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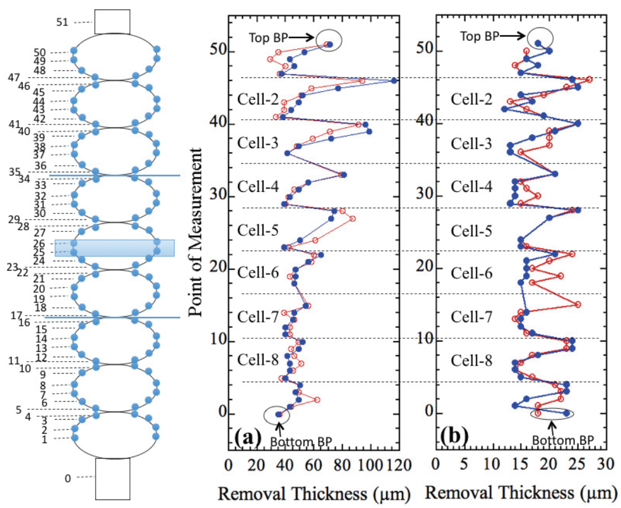

Figure 5: Removal thickness trends along the cavity length in (a) VEP-1 and (b) VEP-2. The schematic shows positions of thickness measurement.

Cavity Surface

The equator surface in each cell was observed with a Kyoto camera. Images of the equator surface of the top six cells after both the VEP processes are shown in Fig. 6.

The VEP-1 yielded a rough equator surface in the top four cells. The surface was smoother for the rest five lower cells. The rough surface was the result of etching due to uncontrolled temperature during VEP which shifts EP plateaus towards higher voltage, accumulation of a large amount of H_2 gas bubbles in the upper cells, and the lower applied voltage for VEP-1. VEP-2 yielded smoother surface as shown in the images. The surfaces in the upper cells were still rough because the average removal thickness in VEP-2 was only 18.2 µm.

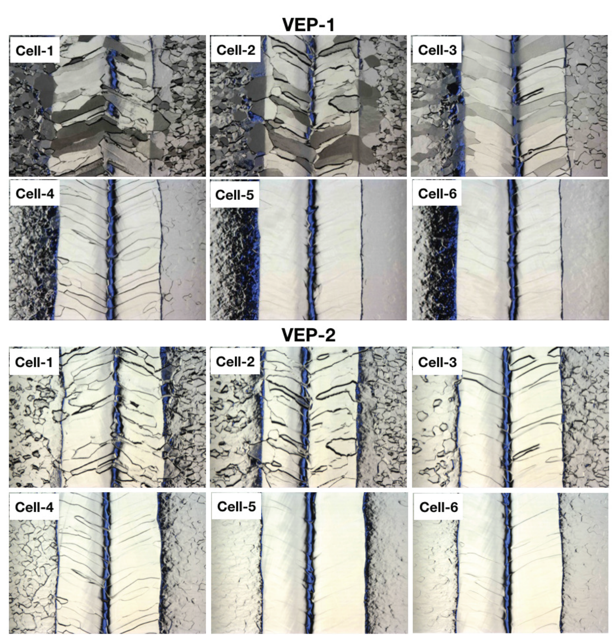

Figure 6: The equator surface of the first top six cells of the cavity after VEP-1 (top) and VEP-2 (bottom). The image size is 12 x 9 mm.

Vertical Test Result

The cavity after being treated with VEP at Marui was shipped to KEK. High pressure rinsing (HPR) of the cavity was conducted at KEK. The cavity was baked at 120℃ for 48 h. A vertical test after the VEP-1 was not performed since a leak at the feedthrough of the input coupler was found during the baking. The first vertical test after VEP-2 could not be carried out because vacuum leak occurred during the cool-down process. The cavity was disassembled, rinsed at HPR machine and baked again before a vertical test was performed.

The vertical test was performed at 1.9 K. The quality factor (Q_0) versus field gradient (E) curve is shown in Fig. 7 (a). Maximum field gradient of 19.3 MV/m with a Q_0 value of 1.2×10^{10} was achieved in the π-mode. The maximum field gradient was measured for each cell using passband-modes (8π /9, 6π/9, 5π/9, and 3π/9) as shown in Fig. 7 (b). The gradient was limited by field emission and quench. A heating spot was found at the slope region of the second cell. The heat-spot might be associated with irradiation of emitted electrons. The quench might have occurred at the heat-spot position as no other heat-spot was found.

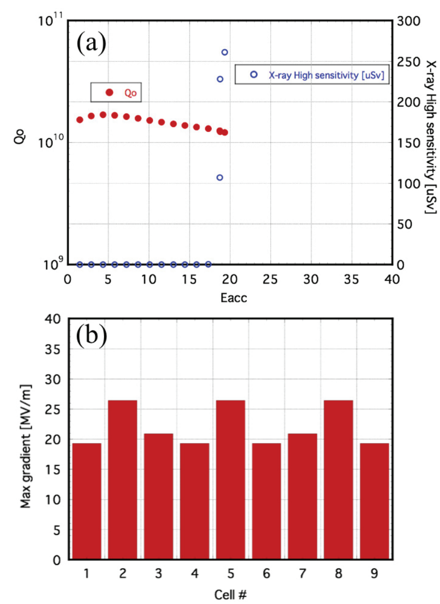

Figure 7: (a) Q_0 vs. E curve and (b) maximum gradient in each cell.

CONCLUSION

An effect of acid flow in the Ninja cathode housing was studied with coupon currents and by observing the cavity viewports. A flow rate of 10 L/min in the cathode housing in combination of 5 L/min in the cavity was found to be adequate to guide H_2 bubbles in the cathode housing. The accumulation of bubbles in the top cell was significantly reduced. The effect was also observed in the coupon currents. A VEP performed for a nine-cell cavity (TB9-TS-B02) with these flow rates and an appropriate on/off voltage cycles resulted in smooth surface and significant reduction in removal asymmetry. The cavity achieved a

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field gradient of 19.3 MV/m with a Q_0 value of $1.2x10^{10}$ in the vertical test.

The VEP facility is being modified to stop returning bubbles from the acid reservoir. In the absence of returning bubbles, VEP can be performed without voltage cut-off to enhance the EP rate.

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