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IMPACT OF VERTICAL ELECTROPOLISHING WITH FLIPPING SYSTEM ON REMOVAL UNIFORMITY AND SURFACE STATE: STUDY WITH 9-CELL NIOBIUM COUPON CAVITY

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Abstract

We have been developing a vertical electropolishing (VEP) method for niobium superconducting RF cavities using a novel setup that allows periodic flipping of the cavity to put it upside down in the VEP process. The purpose of using the novel setup named as flipping system is to achieve uniform removal and smooth surface of the cavity. Previously, we have already introduced the VEP system and showed the preliminary results of VEP performed with the flipping system. In this article, we report VEP results obtained with a nine-cell coupon cavity. The results include detail on coupon currents with I-V curves for coupons, and impact of the cavity flipping on removal uniformity and surface morphology of the cavity.

INTRODUCTION

Marui Galvanizing Co., Ltd has been developing Niobium SRF cavity vertical electropolishing (VEP) technologies in collaboration with KEK. We developed new VEP methods of "2-flow VEP" and "cavity flipping VEP" with Ninja cathode so far. In case of 2-flow VEP, acceptable polished surface and accelerating gradient were achieved as the same level of horizontal electropolishing (HEP) [1]. In case of cavity flipping VEP, cavity removal uniformity was significantly improved, however IV curves and EP current of forward position and reverse position were different and polished surface was somewhat rough [2]. It is thought that the cause is the influence of EP temperature and inner hydrogen bubbles. To solve these problems, cavity flipping VEP experiment using 9cell coupon cavity with improved EP temperature and inner bubble status was performed and IV curves, EP condition, polished surface and removal uniformity were evaluated.

CAVITY FLIPPING VEP

Cavity flipping VEP was performed with dedicated cavity holder that can rotate around the central strut. Figure 1 shows a photo and a schematic of the cavity flipping VEP equipment, and Figure 2 shows a continuous photo of cavity flipping. It is defined that the case that a Ninja cathode rotation motor is at upper side is the forward position (F), at lower side is the reverse position (R). And it is defined that the cell close to the motor is the top (top cell (TC), top iris (TI) etc.), far from the motor is the bottom (bottom cell (BC), bottom iris (BI) etc.). Nb coupons were set at top iris position (TI), equator position (EQ) and bottom iris position (BI) of top cell (TC), center cell (CC) and bottom cell (BC), a total of 9 coupons were installed. Flipping was performed using semi-automatic motor drive. In this experiment, we modified the EP acid tank to improve the inner bubble status. This is to reduce the number of bubbles returning to the cavity during EP acid circulation by connecting a new tank to the conventional tank to increase the capacity and increasing the number of mesh filters. Figure 3 shows the modified EP acid tank.

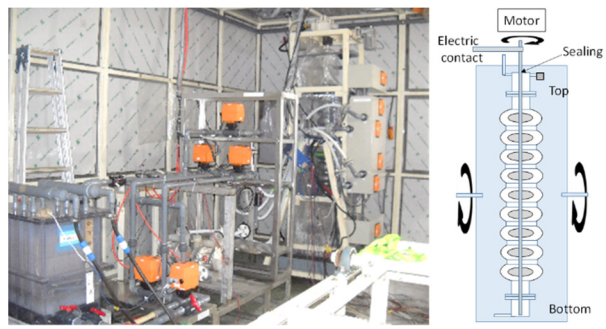

Figure 1: A photo and a schematic of the VEP equipment.

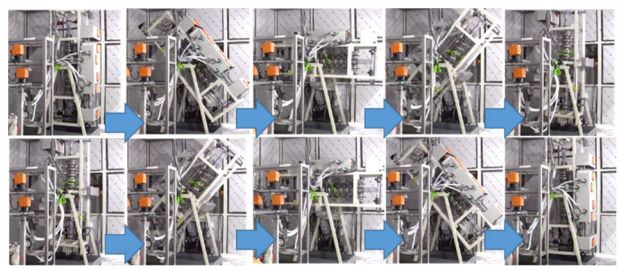

Figure 2: A continuous photo of the state of flipping (Upper: F to R, lower: R to F).

Figure 3: Improved EP acid tank.

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VEP EXPERIMENT

Table 1 shows conditions of the cavity flipping VEP experiment. A Ninja Cathode v6 with metal wings and mesh covers was used for this VEP. This VEP was performed with the procedure of "repetition of 3 min EP (F) – EP stop and flipping – 3 min EP (R) – EP stop, flipping". EP stop and flipping time was around 3 min. Cavity water shower cooling was performed during VEP. The target cavity temperature during VEP was 15 ºC (last time was 20-25 ºC). The amount of EP acid was 120 L (last time was 70 L).

Table 1: Conditions of Cavity Flipping VEP

Parameters	Flipping VEP condition
EP acid	H_2SO_4(98%):HF(55%)=9:1 120 L
Voltage	17~18 V
Current density	~20 mA/cm^2
Cavity surface temperature	~15 ºC
Cathode rotation speed	20 rpm (both F and R)
Acid flow rate	5~10 L/min
EP process	3min ON (F) – OFF, flipping – 3min ON (R) – OFF, flipping 13 times
Target removal thickness	~30 um
Cathode	Ninja-v6 (With metallic wings and mesh cover)

Figure 4 shows cavity and coupon IV curves of the forward and the reverse position. The cavity IV curves of the forward position and the reverse position were almost same and a plateau region was around over 10 V. In case of IV curves of each coupon, a plateau region was around over 7 V (some coupons were excluded because of measurement failure). About the distribution of each coupon, bottom cell and center cell coupons are relatively small, whereas top cell coupons are larger. It is considered that this is because the upper side is more susceptible to the influence of bubbles.

Figures 5, 6 and 7 show the current and the voltage, the cavity surface temperature, the EP acid and cooling water temperature during VEP respectively. The current was around 200 A (the current density was around 20 mA/cm2), and the difference between the forward position and the reverse position was smaller than last time. This is the same tendency of IV curves. The cavity surface temperature during VEP was kept under 15 ºC (during flipping, the temperature was little higher because of cooling shower stop). The EP acid temperature was kept under 15°C also, both temperature was as intended. The EP acid flow rate was around 7〜9 L/min (the graph is omitted). After VEP, coupons were removed and digital camera and SEM inspection, surface roughness measurement were performed. Figure 8 shows digital camera inspection photos, Fig. 9 shows SEM inspection results and Fig. 10 shows surface roughness measurement results.

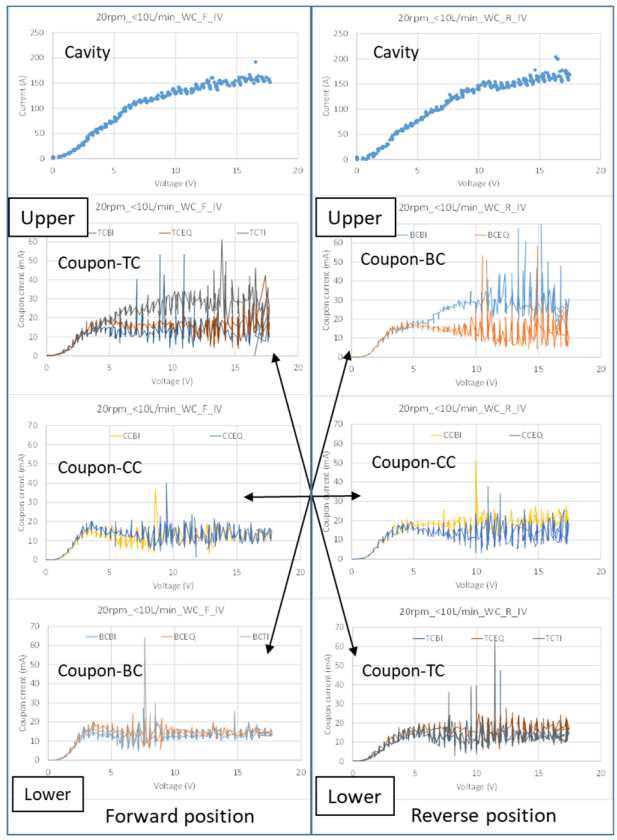

Figure 4: IV curves of a cavity and each coupon (left: forward position, right: reverse position).

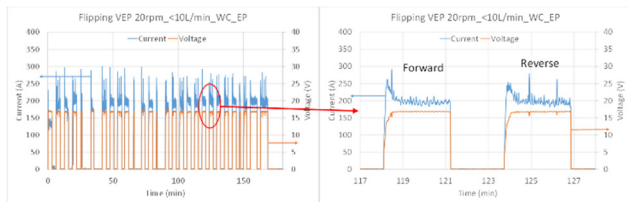

Figure 5: The current and the voltage during VEP.

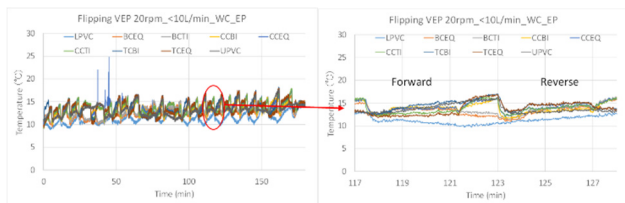

Figure 6: The cavity surface temperature during VEP.

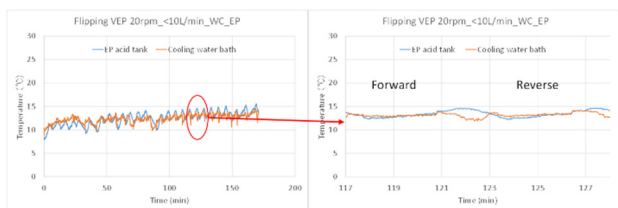

Figure 7: The EP solution and cooling water temperature during VEP.

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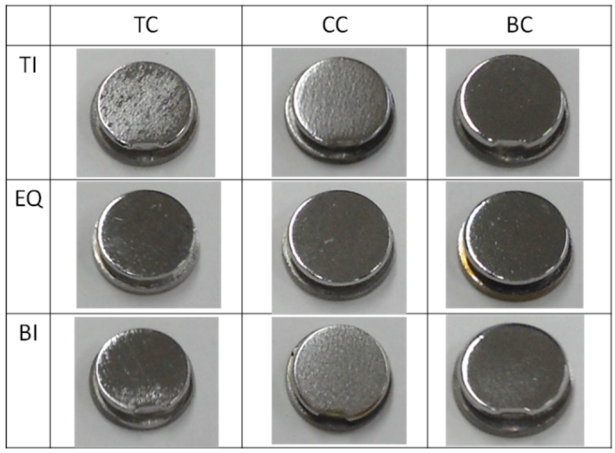

Figure 8: Digital camera inspection results of polished coupon surfaces.

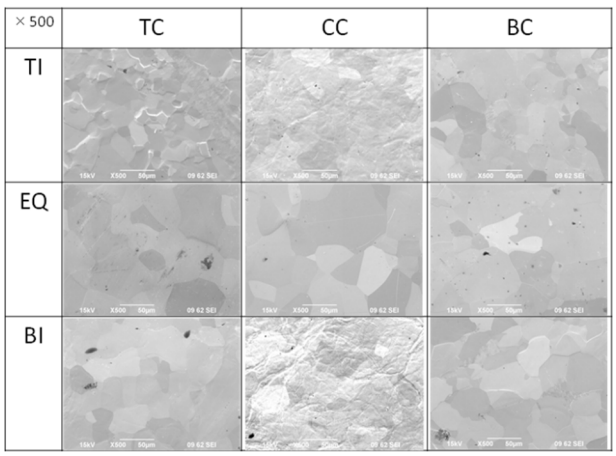

Figure 9: SEM inspection results of polished coupon surfaces.

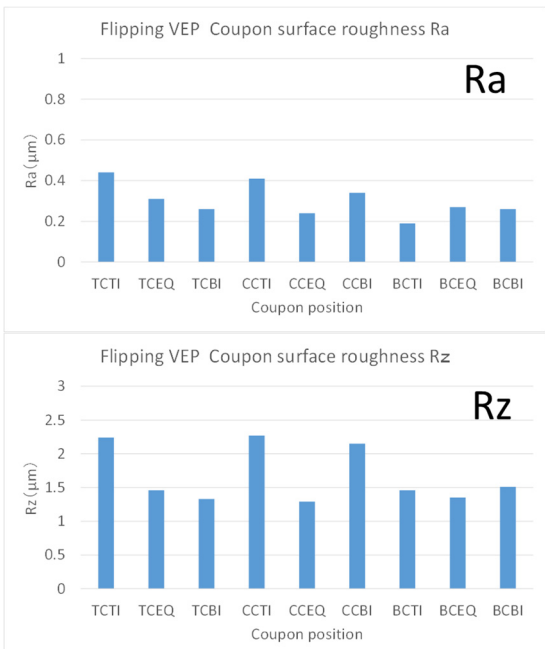

Figure 10: Polished coupon surface roughness Ra and Rz.

Polished coupon surfaces are very shiny and greatly improved compared to the previous flipping VEP. Flat surfaces were observed in the SEM inspection. The surface roughness Ra is around 0.2～0.4 um and Rz is around 1～2 um, greatly improved too. However, surfaces of TCTI, CCTI, CCBI coupons were somewhat rougher and Ra, Rz were larger. The cause is not sure now, however it is necessary to review the cathode structure and VEP condition to achieve flat and shiny cavity inner surface overall. Figure 11 shows the cavity removal thickness distribution after VEP. The measurement was performed by measuring the thickness before and after VEP with an ultrasonic thickness gauge and taking the difference. The numbers in the graph upper side show the average removal thickness for each cell. Two deferent vertical direction lines of the cavity were measured.

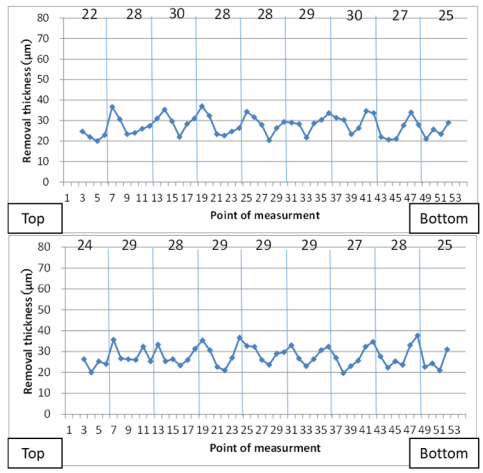

Figure 11: Removal thickness distribution after VEP.

The distribution is very uniform and there are no prominently large or small points. The removal thickness average of each cell is 27～30 um (excludes cells at both ends because of few measurement point) and it is very good distribution. The average removal thickness of all measurement points are 27.8 um.

SUMMARY

At cavity flipping VEP, to improve the current difference between forward position and reverse position and polished surfaces, EP temperature and bubble status were improved. Flipping VEP experiment was performed using a 9cell coupon cavity with lower EP temperature (15 ºC) and added EP acid tank and mesh filters. About IV curves, the difference between forward position and reverse position was little and there was a plateau region over 10 V. The IV curve distribution between coupons was slightly larger on the upper side. The EP current difference was also small. Polished coupon surfaces were flat and shiny, it was much improved than last time, however some coupons have relatively rough surfaces like bubble traces. The removal thickness distribution was very uniform. After this, we will review the cathode structure etc. to improve the polished surface and proceed with the evaluation of the acceleration performance of the cavity.

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REFERENCES

[1] V. Chouhan *et al.*, "Vertical Electropolishing for 1.3 GHz single- and nine-Cell superconducting niobium cavities: A parametric optimization and rf performance" in *Phys. Rev. ST Accel. Beams*, vol. 22, p. 103101, 2019.

[2] K. Nii *et al.*, "Vertical electropolishing of niobium nine-cell cavity with a cavity flipping system for uniform removal" in *Proc.19th Int. Conf. on RF Superconductivity (SRF'19)*, Dresden, Germany, July 2019, paper TUPO027, pp. 467−469.