R & D ON VERTICAL ELECTROPOLISHING AT TRIUMF

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Abstract

Vertical electropolishing is being developed at TRIUMF. The development is being done on a single cell 1.3 GHz cavity. Various variants of cathode geometry, paddle geometry and cathode bag shape have been compared. The results of the various approaches are presented.

INTRODUCTION

Starting from the intermittent electropolishing of a niobium surface originally developed by Siemens [1], continuous electropolishing of inside surface of a cavity was developed by KEK to shorten polishing time. To reduce hydrogen bubbles accumulating in the cavity, KEK made the cavity placed horizontally and rotated on its axis during the etching [2]. Horizontal electropolishing became a popular procedure that enables field gradient of over 30 MV/m for a niobium cavity [3]. However this required complicated structure such as Teflon seals for rotating the cavity. This resulted a development of vertical electropolishing (VEP) method started at Cornell University [4]. When the cavity direction is changed from horizontal to vertical, hydrogen bubble associated problem must be solved. VEP system for a single cell 1.3 GHz cavity has been installed at TRIUMF last year [5]. A vertical method was selected to make the set-up compact. Disadvantage of the VEP is concentration of hydrogen bubbles at the upper iris of each cell and less uniform removal will be resulted. To understand the problem better and find what to do to achieve more uniform surface removal, we started from the simplest VEP and various solutions were evaluated.

EXPERIMENTAL

We had tried 4 big cathode paddles (see Fig. 1) that rotate at 30 rpm to agitate electrolyte in the cell [5]. This resulted more removal at the upper side of the cell and rougher surface. It could be the paddle configuration causing hydrogen bubbles accumulating more at the iris area.

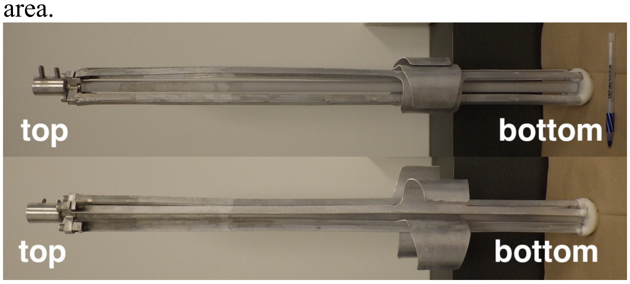

Figure 1: Expanding cathode paddles.

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We tried simpler configuration without the cathode paddles. Various configurations were evaluated by measuring thickness of the cavity wall before and after VEP using the ultrasonic thickness gauge (Olympus 38DL Plus, sensor M202). Applied voltage between anode (cavity) and cathode was adjusted so that temperature of the cell was kept at 40 degrees C or less. Parameters for VEP are shown in Table 1. The thickness measurement points are shown in Fig. 2.

Table 1: Parameters for VEP

Cathode Material	Alloy number 1100 (Aluminum > 99.5%)
Electrolyte Amount	34 L (repeatedly used)
Electrolyte Formula	H_2SO_4 (95%) : HF (48 %) = 10 : 1 (v/v)
Flow Rate	3.1 L/min (when voltage was not applied)
Temperature	40 degrees C or less on the cell
VEP Time	30 minutes (voltage applying)
Target Current Density	30~40 mA/cm^2

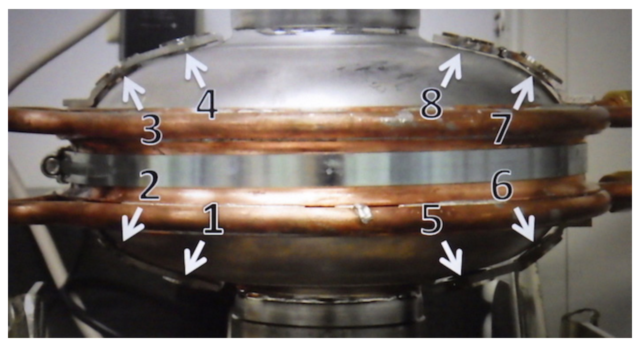

Figure 2: Thickness measurement points on the cell.

1. Thin Rod Cathode

For the first set-up, a thin rod cathode 1 cm square was selected. However this VEP had to be stopped since current density was only 24 mA/cm^2 at best during the first 4 minutes under the power supply used (12 V). The surface area of the cathode was not enough for the cavity.

2. Thicker Rod Cathode

A thicker rod cathode (cylinder of diameter 6 cm. See Fig. 3) was installed to improve current density. Removed

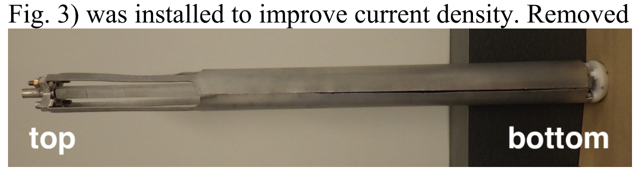

Figure 3: Thicker rod cathode.

thickness by the VEP at the measurement points are shown in Table 2. Each thickness value is an average of 3 measurements. The last value in the Table 2 is the ratio of removed thickness at the upper iris (4+8) to that of the lower iris (1+5). Average thickness of removal was 13 μm according to the integrated current value.

Table 2: Removed Amounts

Position	Removal [μm]
1	6
2	4
3	17
4	35
5	6
6	5
7	17
8	33
(4+8) / (1+5)	5.7 [no unit]

3. Thicker Rod Cathode + Cathode Bag

To reduce hydrogen bubbles attach to upper iris area to result more uniform removal, the thicker rod cathode was covered with the cathode bag made of PTFE mesh with holes of 0.15 mm diameter (see Fig. 4). Removed thickness at the measurement points are shown in Table 3. Average thickness of removal was 9.3 μm according to the integrated current value. Ratio of removed thickness at the upper iris to that of the lower iris was reduced by adding the cathode bag. However the removal was not sufficiently uniform.

Figure 4: Rod cathode covered with cathode bag.

Table 3: Removed Amounts

Position	Removal [μm]
1	4
2	4
3	11
4	20
5	5
6	4
7	12
8	20
(4+8) / (1+5)	4.4 [no unit]

4. Thicker Rod Cathode + Cathode Bag + 2 Teflon Paddles + Tap Water Cooling

To move hydrogen bubbles away from the upper iris, 2 thin Teflon paddles were attached to the cathode and rotated at 30 rpm. The paddles were folded for installation /removal of the rod (see Fig. 5). To increase current, tap water cooling was done (3.7 L/min. See Fig. 6). Our power supply was changed and the limit voltage became 33 V from 12 V. Removed thickness at the measurement points are shown in Table 4. Estimated average thickness of removal was 10.6 μm according to the integrated current value. Ratio of removed thickness at the upper iris to that of the lower iris was smaller. However the removal was not sufficiently uniform and we found holes on the cathode bag at the bottoms of the paddles after the VEP.

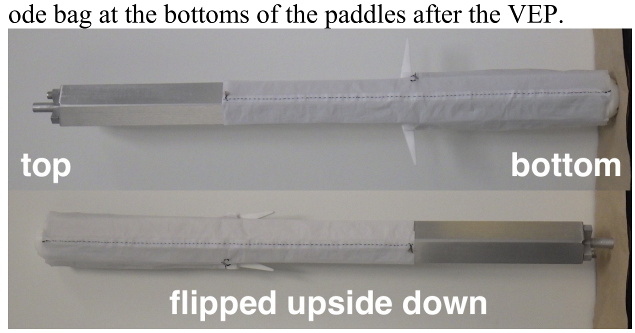

Figure 5: 2 Teflon paddles.

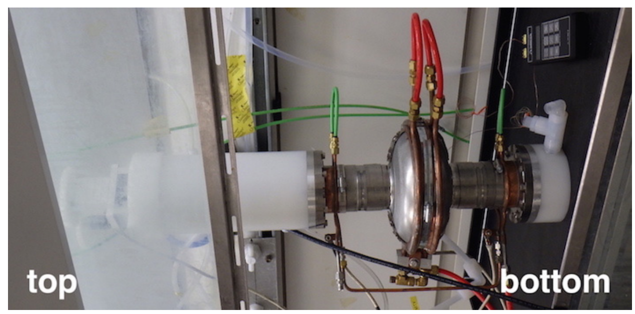

Figure 6: Cooling set-up.

Table 4: Removed Amounts

Position	Removal [μm]
1	8
2	6
3	19
4	27
5	8
6	6
7	18
8	28
(4+8) / (1+5)	3.4 [no unit]

5. Thicker Rod Cathode + Cathode Bag + 2 Teflon Paddles + Improved Tap Water Cooling

The broken cathode bag was mended. Tap water cooling area on the beam pipes was increased (see Fig. 7). The 2 Teflon paddles and the cathode were rotated at 30 rpm. Removed thickness at the measurement points are shown in Table 5. Estimated average thickness of removal was 12.8 μm according to the integrated current value. Temperature difference between the upper cell and the lower cell was 2.5 ± 1.1 degree C. Range of current fluctuation in one minute was 22 ± 11 A.

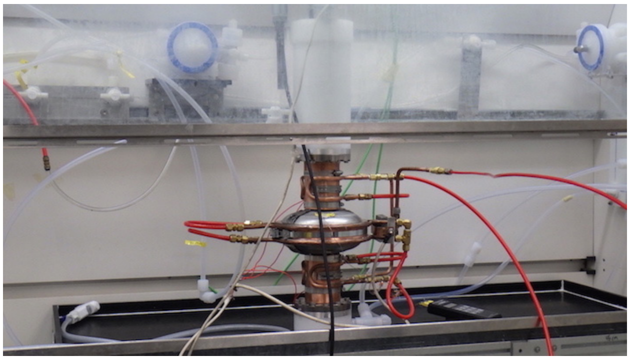

Figure 7: Improved tap water cooling.

Table 5: Removed Amounts

Position	Removal [μm]
1	14
2	10
3	23
4	23
5	12
6	10
7	23
8	24
(4+8) / (1+5)	1.8 [no unit]

6. Thicker Rod Cathode + Cathode Bag + 4 Teflon Paddles + Improved Tap Water Cooling

To get more electrolyte agitation, another pair of Teflon paddles was added (see Fig. 8). The 4 Teflon paddles and the cathode were rotated at 30 rpm. Removed thickness at the measurement points are shown in Table 6. Estimated average thickness of removal was 14.3 μm according to the integrated current value. With the additional paddles, temperature difference between on the upper cell and the lower cell was reduced and 1.5 ± 1.0 degree C as well as range of current oscillation in a minute became a half and 10 ± 8 A. These show that the added paddles improved agitation of the electrolyte.

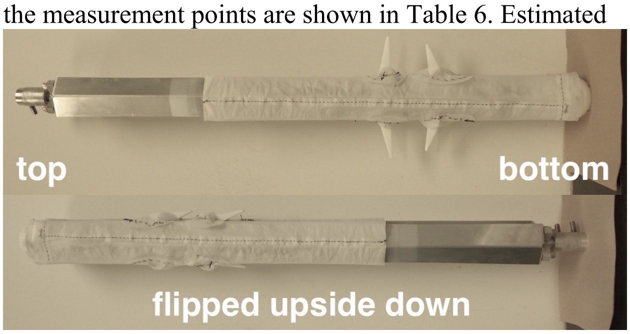

Figure 8: 4 Teflon paddles.

Table 6: Removed Amounts

Position	Removal [μm]
1	17
2	14
3	23
4	28
5	15
6	14
7	23
8	26
(4+8) / (1+5)	1.7 [no unit]

The results of Table 2, 3, 5 and 6 are shown in Fig. 9.

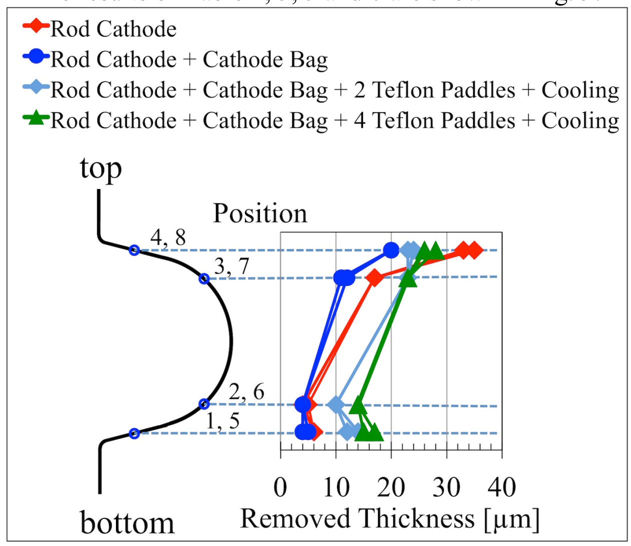

Figure 9: The results show the tendency that upper area is etched more. Paddles and cooling resulted more uniform etching.

CONCLUSION

To achieve uniform inner surface removal with vertical electropolishing, we started from the rod cathode and added a cathode bag, cooling and Teflon paddles. While they were effective, uniformity of surface removal was not sufficient. To achieve more uniform removal and smoother surface, faster electrolyte flow at the upper area of a cell are desired. We are considering further investigation through the next experiment.

ACKNOWLEDGEMENT

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REFERENCES

[1] H. Diepers *et al.*, A New Method of Electropolishing Niobium, Phys. Lett. 37A, Nov. 1971, pp. 139-140.
[2] K. Saito *et al.*, R & D of Superconducting Cavities at KEK, in Proc. Fourth Workshop on RF Superconductivity, Tsukuba, Ibaraki, Japan, Aug.1989, pp. 635-694.
[3] E. Kako *et al.*, Improvement of Cavity Performance by Electropolishing in the 1.3 GHz Nb Superconducting Cavities, in Proc. 1999 Particle Accelerator Conference, New York City, NY, USA, Mar. 1999, pp. 432-434.
[4] R.L. Geng *et al.*, Vertical Electropolishing Niobium Cavities, in Proc. 12th International Workshop on RF

Superconductivity, Ithaca, NY, USA, July 2005, THP04.

[5] J.J. Keir *et al.*, Vertical Electro-polishing at TRIUMF, in Proc. 17th International Conference on RF Superconductivity, Whistler, BC, Canada, Sep. 2015, pp. 378-380.