

OPTIMIZATION OF VERTICAL ELECTRO-POLISHING PROCESS: EXPERIMENTS WITH UPDATED CATHODE ON SINGLE-CELL CAVITY AND PERFORMANCE ACHIEVED IN VERTICAL TEST

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Abstract

Marui Galvanizing Co. Ltd, KEK and CEA have been studying Vertical Electro-Polishing (VEP) on Nb single-cell superconducting cavities with the goal of mass-production and cost-reduction for large accelerator projects such as ILC. Marui has invented and patented a rotative cathode called 'i-Ninja'. The version 5 has been tested for the first time in Europe at CEA Saclay. The four wings of the cathode remove efficiently bubbles of hydrogen and the chosen parameters make it possible to achieve better surface and uniform material removal compared to VEP with a fixed cathode. The effect of the temperature of the cavity walls on current oscillations has been precisely studied. Two single-cell cavities have been electro-polished and tested at 1.5 K in vertical cryostat and the results will be presented.

INTRODUCTION

CEA Saclay has been developing Vertical Electro-Polishing (VEP) since 2012 [1, 2]. The treatment used up to now involved a fixed cathode with different shape for improving the electric field distribution inside the cavity. However some drawbacks remained inherent to the process: asymmetry of the removal and some features generated on the niobium surface (pits, stripes) due to insufficient removal of hydrogen bubbles generated at the cathode. In order to improve on the process and participate in the cost reduction effort for ILC project, a collaboration has been strengthened between KEK, Marui Galvanizing Co., Ltd and CEA Saclay. The goal is to demonstrate the feasibility of the VEP process as a key technology and its scalability to industry mass production of SRF cavities. Marui Galvanizing Co. Ltd has developed and continuously improved on the design of a rotating cathode "i-cathode Ninja" [3-12]. For the first time, this cathode (version 5) has been tested in Europe at CEA on two different single-cell Tesla shape cavities. The cavities were tested in vertical cryostat at 1.5 K and the results will be presented.

NINJA CATHODE AND VEP SETUP

Ninja v5 cathode is characterized by its four Teflon wings and four additional rods in aluminum, in order to extend the cathode active electrical area (see Fig. 1). Adaptation parts have been designed by Marui to fit the CEA Saclay set-up.

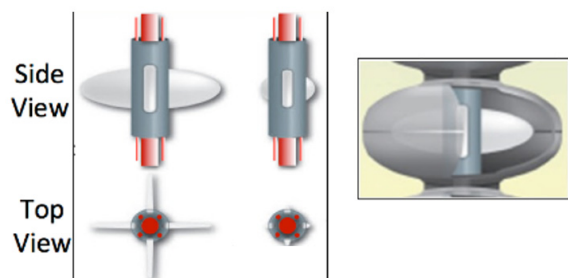


Figure 1: Schematic of Ninja cathode (v5) in unfolded/expanded positions. The parts in red are in aluminum.

For the treatments, the characteristic of the set-up were:

- 200 L of HF (40%)-H₂SO₄ (96%) with volume ratio 1-9
- Nitrogen blowing on the top of the cavity to avoid risk of explosion due to hydrogen production
- A specific system has been designed to control the temperature of the cavity external surface. The cavity is tightly surrounded by a box in PVC filled with water, connected to a chiller (Fig. 2).

The targeted parameters during the VEP treatment were:

- Acid temperature in tank: 18 °C
- External cool down temperature: 12 °C
- Acid flow: 10 L/min
- Rotation cathode: 20 Hz
- Voltage cathode: 17.3 V
- N₂ flow: 6 L/min

An I(V) curve has been plotted and confirms the usual 'plateau' for voltage above 5 V.

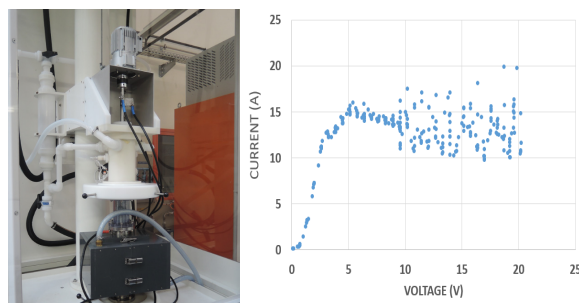


Figure 2: single-cell cavity during VEP at CEA Saclay and I(V) curve. The cavity is surrounded by a PVC box, filled with water and connected to a chiller.

BENEFITS OF THE ROTATING CATHODE

Two different cavities have been electro-polished vertically with the parameters described above:

- TP02: Pristine cavity. 150 μm have been removed in two sequences (546 min and 665 min) with the turning of the cavity in between.
- IAC03: This cavity has been electro-polished several times with non-optimized parameters. Its gradient was limited at 19 MV/m before the treatment (limited by power). 50 μm have been removed in one sequence.

The achieved removal rate for the treatments presented above is approximately 0.14 $\mu\text{m}/\text{min}$. We now focus on TP02 cavity which went through the longer electro-polishing process, and without prior chemical treatment.

The current is plotted as a function of time for the duration of the process in Fig. 3. Current oscillations are clearly observed, with an amplitude of approximately 12A along with fluctuations on a period of 2000 s that corresponds to the cooling system duty cycle. The amplitude of the current fluctuations increases with the temperature of the walls of the cavity. Upon stopping the rotation for a few minutes, we noticed that the current fluctuations disappeared, as it has been previously observed in VEP processes with a fixed cathode. The current fluctuations shown in Fig. 3 are similar to those achieved with horizontal EP and are thought to be a direct consequence of efficient hydrogen bubbles removal from the cavity surface.

After 150 μm removal, the surface aspect achieved on TP02 cavity is similar compared to horizontal EP. The surface is smooth and shiny. No features (pits, bubbles stripes) are visible at the cavity surface (see Fig. 3). Furthermore, VEP using a fixed cathode is characterized by a strong asymmetry in the removal. The removal in the upper half cell is at least twice as high as the removal in the lower half cell [2].

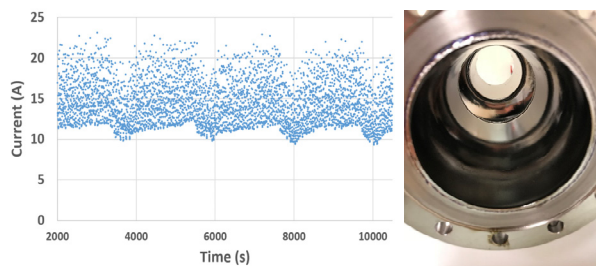


Figure 3: Left: current fluctuations during treatment. Right: inner surface of TP02 cavity after 150 μm removal.

Thickness measurements with an ultrasonic gauge have been done after each sequence for comparison. Twelve locations along the cavity are considered. The results are presented in Fig. 4 below.

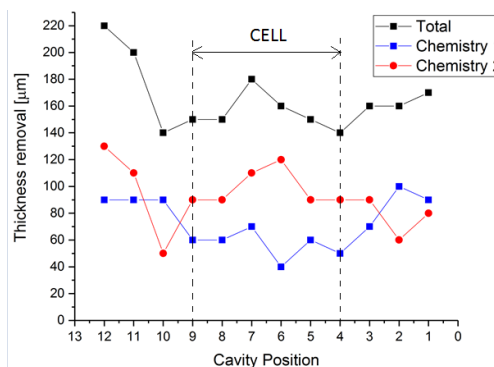
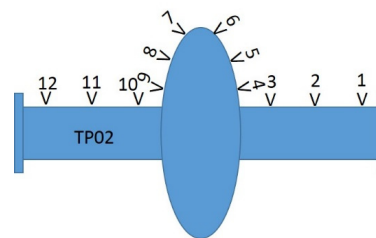


Figure 4: Removal profile achieved on TP02 cavity after the two VEP sequences.

The removal profile achieved here is uniform in the cell, in accordance with previous results from Marui [3]. It is a substantial advantage compared to VEP with fixed cathode and to standard horizontal EP. In fact, during EP in horizontal configuration, the removal at equator is half the removal at iris for Tesla shape cavity.

VERTICAL TEST RESULTS

After the VEP process, high pressure rinsing and clean room assembly, TP02 has been tested at 1.5 K in vertical cryostat. The quality factor Q_0 was plotted as a function of the accelerating gradient E_{acc} . The result is quite unusual for a non-baked cavity since the gradient reaches 37 ± 2 MV/m (Q_0 of $4.9 \cdot 10^9$), limited by quench whereas non-baked cavities are usually limited by power around 30 MV/m, due to the high field Q-slope (HFQS). The cavity subsequently received a low temperature baking (LTB) under vacuum at 120 $^\circ\text{C}$ during 48 h prior to an additional test at 1.5 K. The high field Q-slope was removed and the cavity was limited by quench at 35 ± 2 MV/m with a Q_0 value of $1.25 \cdot 10^{10}$ (see Fig. 5). The absence of clear HFQS along with the moderate performance improvement by the mild baking step up to accelerating voltage of 35 MV/m is indicative of a reduced hydrogen contamination in the first penetration depth of Nb [13] as compared to standards EP processes. This result seems to be correlated with the efficient removal of hydrogen noticed during the VEP process. The continuous mixing of the acid bath insured by the wings rotation close to the cavity inner surface might improve the surface dynamic of the electro-polishing process and contamination, prompting further experimental investigations. The temperature dependence of the surface resistance before and after low temperature baking

is represented in Fig. 5. The residual resistance after baking raised from 6 nΩ to 10 nΩ.

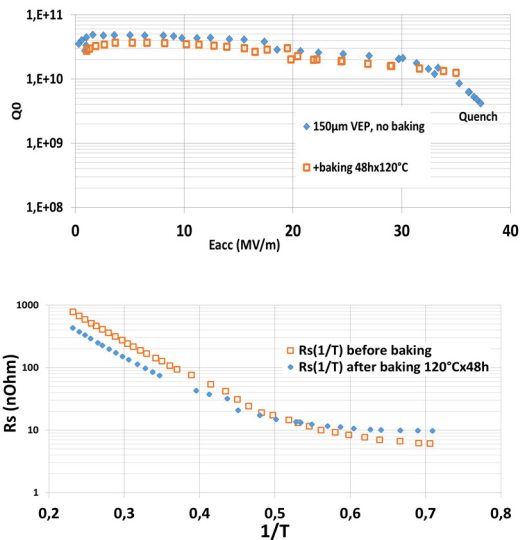


Figure 5: summary of the RF tests on cavity TP02. Top: $Q_0=f(E_{acc})$ at 1.4-1.6 K for TP02 cavity before and after baking (120 °C x 48 h). Bottom: surface resistance measured as a function of the temperature before and after the LTB.

The VEP process was tested on another cavity, 1AC3. The baseline test in blue in Fig. 6 reveals a pronounced Q slope above 12 MV/m and a quench of 19 MV/m.

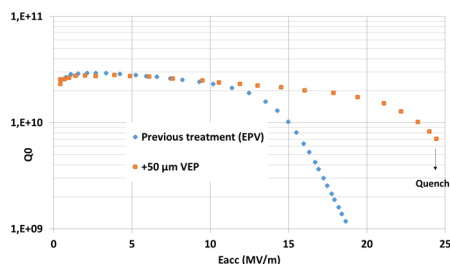


Figure 6: $Q_0=f(E_{acc})$ at 1.4-1.6 K for 1AC3 cavity before and after VEP with Ninja cathode (50 μm removal).

Upon removing 50 μm the performances were significantly improved; the Q slope onset was shifted to 21 MV/m followed by a quench at 24 MV/m. In order to fully reset the cavity history, it will be reprocessed to remove another 100 microns.

SUMMARY

Ninja Cathode technology (v5) has been implemented at CEA Saclay and two different cavities have been electro-polished vertically. The removal along the cavity surface is uniform and the achieved surface very shiny, similarly to horizontal electropolishing. 150 μm have been removed on TP02 pristine cavity into two steps. The cavity reached 37 MV/m limited by quench without baking. After baking, the high field Q-slope was removed. A second cavity has been tested which performance was

improved substantially after treatment. Both results demonstrate the efficiency of vertical electro-polishing using optimized Ninja cathode. Future work involve scaling up the technology to 9Cell ILC cavity.

ACKNOWLEDGEMENTS

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