UPDATES OF VERTICAL ELECTROPOLISHING STUDIES AT CORNELL WITH KEK AND MARUI GALVANIZING CO. LTD*

F. Furuta, M. Ge, T. Gruber, J. Kaufman, M. Liepe, J. Sears,
CLASSE, Cornell University, Ithaca, New York, USA,
H. Hayano, S. Kato, T. Saeki, KEK, High Energy Accelerator Research Organization,
Tsukuba, Ibaraki, Japan
V. Chouhan, Y. Ida, K. Nii, T. Yamaguchi, Marui Galvanizing Co. Ltd., Himeji, Hyogo, Japan

Abstract

Cornell, KEK, and Marui Galvanizing Co. Ltd have started a Vertical Electro-Polishing (VEP) R&D collaboration in 2014 to improve removal uniformity. MGI and KEK have developed their original VEP cathode named i-cathode Ninja®, which has four retractable wing-shape parts per cell. One single cell cavity has been processed with VEP using the i-cathode Ninja at Cornell. Cornell also performed a vertical test on that cavity. Here we present process details and RF test result at Cornell.

INTRODUCTION

Electro-Polishing (EP), especially Horizontal EP, is applied on niobium SRF cavities in many projects as a high-performance surface treatment procedure. As an alternative, Cornell's SRF group has led the development of Vertical Electro-Polishing (VEP) which requires a much simpler setup and is less expensive compared with the conventional Horizontal EP [1]. Cornell has successfully demonstrated the capability of VEP on high gradient cavities for the ILC project, which require cavity specification for the accelerating field (Eacc) of >35MV/m with cavity quality factor (Q_0) >$0.8x10^{10}$ at 2K [2]. In addition, VEP was done on the high-Q cavities for the LCLS-II project at SLAC, which requires Q_0>$2.7x10^{10}$ at Eacc=16MV/m, 2K [3]. The EP process in vertical direction is affected by gravity, resulting in a removal difference between upper and lower half cells. In addition, the top cell of a multi-cell cavity during the VEP has a much larger removal than the end cell located on the bottom. To compensate for the removal non-uniformity, the cavity needs to be flipped and additionally processed after finishing half of the target removal. Marui Galvanizing Co. Ltd (Marui) has focused on VEP application targeted mass-production and has been developing their original cathode named "i-cathode Ninja®" (Ninja cathode) to improve polishing quality, especially removal uniformity during the VEP process [4]. Marui's work matches Cornell's research on VEP removal uniformity, and a collaboration between Cornell and KEK-Marui was started in 2014 to improve removal uniformity. In this paper, we present VEP processes using two types of the Ninja cathode at Cornell on a single cell cavity in addition to the result of a RF test. [5].

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#ff97@cornell.edu

VEP SYSTEM AT CORNELL

Figure 1 shows a 1.3GHz TESLA shape single-cell cavity installed into the Cornell VEP system with the Ninja-cathode. Two types of the Ninja cathode and top and bottom EP sleeves were shipped from Marui to Cornell. The Cornell VEP system received a couple of upgrades to enable acid circulation during the VEP process.

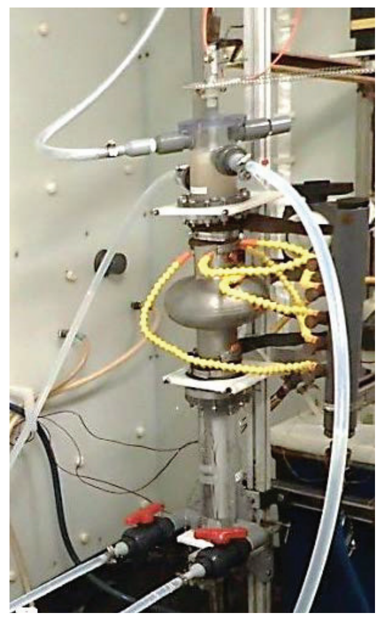


Figure 1: Cornell VEP system with "Ninja" cathode.

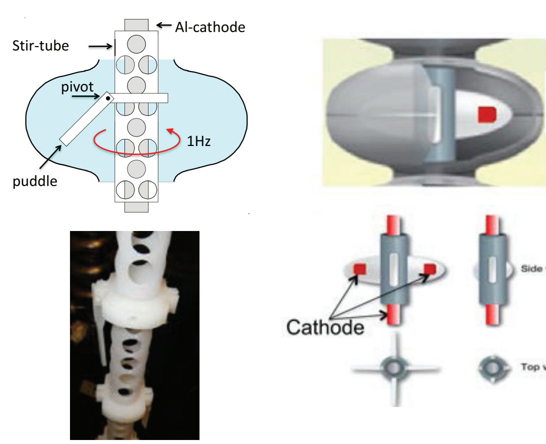


Figure 2: Images of Cornell VEP cathode (left), Images of Marui's i-cathode Ninja type-I and retractable wings (right).

Cornell VEP cathode

The Cornell VEP cathode (Figure 2, left) consists of a aluminium rod and a stirring tube with paddles (one paddle per cell). Teflon mesh lapped around the stir tube (not shown in the figure) guides hydrogen bubbles produced on the cathode during EP process to prevent the hydrogen bubbles from attacking the niobium surface.

Marui i-cathode Ninja

Marui's Ninja cathode (Figure 2, right) consists of a aluminium cathode rod, polyvinyl chloride (PVC) tube, and retractable Teflon wings (four wings per cell). PVC is an acid resistance material, and especially inexpensive. It is therefore suitable for the early stage of the Ninja cathode development and for capital cost reduction of VEP. The retractable wings are kept inside the PVC tube when the cathode is inserted into the cavity. After cathode installation, the wings are opened into the cell. After the VEP process, the wings need to be closed into the tube before pulling the cathode out from the cavity. The gap between the wing edge and the cell surface are designed to be equal from iris to equator. Marui has developed several types of the Ninja cathode so far. For the first trial of a Ninja cathode at Cornell, Marui shipped the type-I and type-II Ninja cathodes to Cornell. The type-I is designed for having the field uniformly from iris to equator by putting an Al coupon on top of each wing (Fig. 2). The type-II has no Al coupon on the wings, but has more cathode surface inside the tube. The type-II is also designed to protect the Nb surface from hydrogen bubbles by covering the opening between the wings and the tube with Teflon mesh.

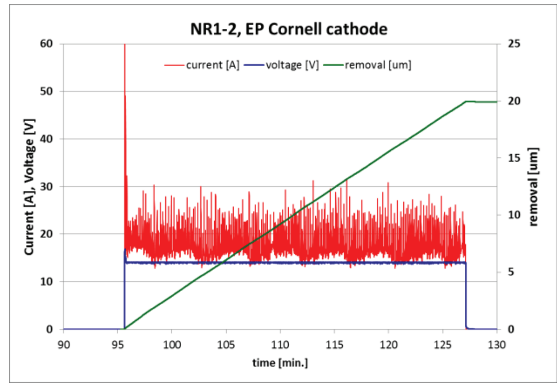
EXPERIMENTS

Ninja cathode VEP at Cornell

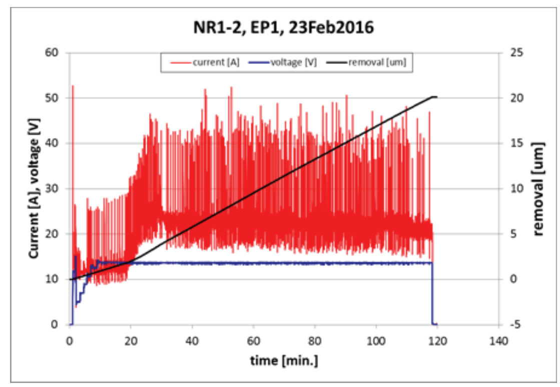
Cornell had performed two VEPs using the Ninja cathode of type-I and type-II on a TESLA shape single-cell cavity, NR1-2. NR1-2 has been processed by VEP using the Cornell cathode and tested preciously. Prior to the Ninja cathode VEP, NR1-2 had mechanical polishing (30µm) and Buffered Chemical Polishing (BCP, 60µm) to reset the RF surface. In addition, furnace degassing (800degC, 2hrs) was also applied. New electrolyte was mixed and used for each VEP with the Ninja cathode. Figure 3 shows EP current vs. time profiles for each cathode. The average current depends on the temperature. The Ninja cathode had a higher temperature set point than the Cornell cathode, so average current was higher. The Ninja cathode has a larger current oscillation than the Cornell cathode. Acid circulation and the wings of the Ninja cathode could result in more effective agitation and might result in the larger current oscillations.

VEP parameters

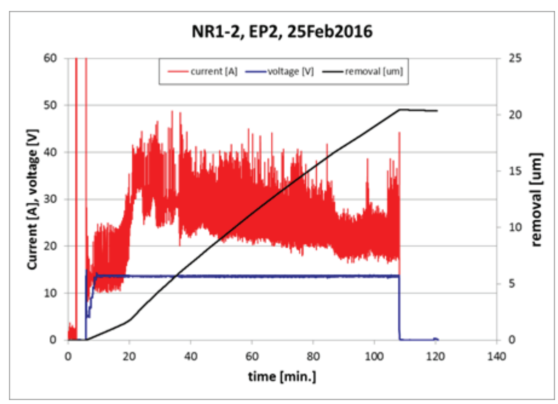
Table 1 summarizes the VEP parameters for the Ninja cathode and the Cornell cathode. Those were set based on the parametric studies at Marui, but not optimized yet for the Cornell VEP system. The target removal was calculated and monitored from the current integration during the process. The actual removal was measured by ultrasound thickness gauge after the process.



EP current profile, Cornell cathode



EP current profile, Ninja cathode type-I



EP current profile, Ninja cathode type-II

Figure 3: EP current profiles for Cornell cathode (top) and Ninja cathode Type-I (middle), and Type-II.

Optical inspection

Optical inspections were done after each VEP process on NR1-2. Figure 4 shows the images of the equator welding seam on the RF surface. Similar defects or features were seen on both surfaces after the Cornell and Ninja VEP.

Table1: VEP parameters

		Cornell cathode	Ninja type-I	Ninja type-II
Voltage [volt]		14	14	14
Current [amps]		~17	~22	~29
Temp. (cavity outside) [degC]		17~18	20~25	20~25
Acid circulation [L/min.]		None	5	5
Agitation speed [Hz]		0~1	0.8	0.8
Paddle type /cell		1Teflon paddle	4 Teflon wings w/ Al	4 Teflon wings
Teflon cathode bag		Yes	None	Yes
Removal	Target	20	20	20
[µm] (prelimi-	Top half cell	24	36	29
nary)	Bottom half cell	14	20	18

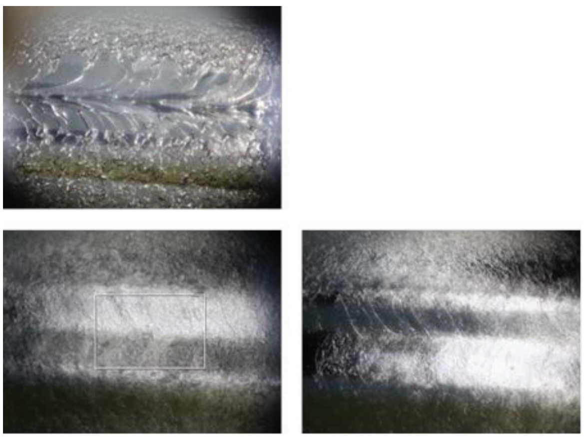


Figure 4: Optical inspection images of equator the weld seam on the RF surface; Cornell VEP (top), Ninja cathode type-I (bottom left), Ninja cathode type-II (bottom right).

Cavity RF test

After two VEPs with the Ninja cathode (20µm each) followed by the low temperature baking, 120degC for 48hrs, the cavity was tested in a vertical test pit at 2K. Figure 5 shows the RF test results as the quality factor Q_0 vs. the accelerator field gradient Eacc at 2K. The blue circles show the test result after the Cornell cathode VEP. The cavity quenched at 33MV/m with Q_0 of 1.2×10^{10} without any field emissions. The red triangles show the result after the Ninja cathode VEP. The quench field was 35MV/m with Q_0 of 0.9×10^{10} without any field emissions.

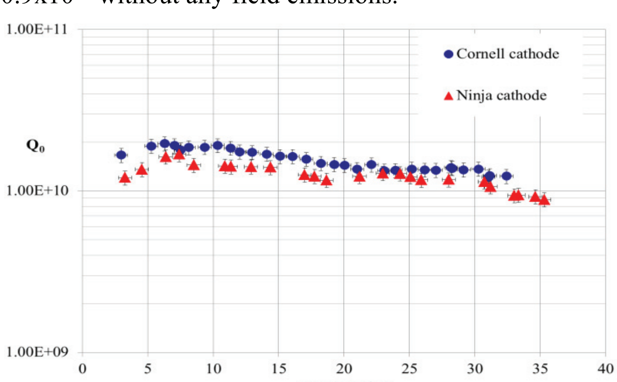


Figure 5: RF test results of NR1-2 at 2K.

SUMMARY

The integration of the Ninja cathode into the Cornell VEP system and VEP process has been done successfully at Cornell. This is the first trial to use a Ninja type cathode at Cornell. The parameters were set based on Marui's experiments, but not optimized for Cornell's system yet. RF test on single cell processed with Ninja cathodes was performed. The cavity performance was good and comparable to after a Cornell VEP. The development of a 9-cell scale Ninja cathode and a parametric study of removal uniformity for a 9-cell cavity are in progress at Marui and KEK. The 9-cell processing with a Ninja cathode at Cornell is planned for the future.

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