VERTICAL ELECTROPOLISING STUDIES AT CORNELL*

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Abstract

Vertical Electro-Polishing (VEP) has been developed and applied on various SRF R&Ds at Cornell as primary surface process of Nb. Recent achievements had been demonstrated with nitrogen doped high-Q cavities for LCLS-II. Five 9-cell cavities processed with VEP and nitrogen doping at Cornell showed average Qo value of 3.0e10 at 16MV/m, 2K, which satisfied the required cavity specs of LCLS-II. We will report the details of these achievements and new VEP collaboration projects between Cornell and companies.

INTRODUCTION

Cornell has leaded the development of VEP and processed many single-/multi-cell cavities [1,2]. The benefits of vertical EP compared with standard horizontal EP are: 1) No rotary aids seal on sleeve joint; 2) No sliding electrical contact; 3) No cavity vertical/horizontal position control fixtures for the rinsing post process; 4) active DI water cooling on the outside of cavity which provides better temperature control during the process; and 5) lower capital equipment cost on simplified system components. In this paper, we will describe about system, details of procedures, RF test achievements, and recent updates of Cornell VEP studies.

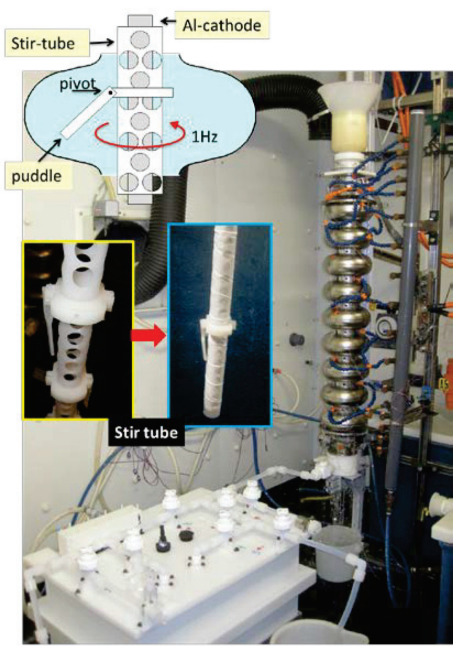

Figure 1: Cornell's VEP system.

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CORNELL'S VEP SYSTEM

Figure 1 shows the images of Cornell's VEP system with 9-cell cavity. The system is designed to process 1.3GHz single-/multi-cell Nb SRF cavities. The system could process various shapes of cavities with TESLA/re-entrant/low lows shape.

Table 1: VEP Parameters at Cornell

Parameters	
Cathode	Aluminium > 99.5%
Stir-tube, puddles	PVDF
End group	PVDF, HDPE
Electrolyte volume	24 litres / 9-cell
Electrolyte composition	10:1 (H_2SO_4:HF)
Maximum use	9 g/L dissolved Nb
Current-voltage source	500 A – 20 V max.
Ave. current for 9-cell	80-120 A
EP voltage	12 V
Temp. (cavity outside wall)	15~19 deg. C
Stir frequency	0~3 Hz
EP removal rate (ave.)	~0.3 microns/min.

VEP Process and Parameters

EP electrolyte was mixed in the mixing tank (a big white tank with plumbing shown in Figure 1) and transferred into cavity via bottom sleeve joint. After filling the electrolyte, the valve on bottom sleeve joint was closed. No electrolyte circulation was made during the process. The circulation system has been added into the system, but it is under development. EP process was performed by turning the cathode voltage on. Typical EP process voltage was 12 volts. EP acid agitation was controllable with puddle on stir tube during the process. The temperature during EP process was controlled by sprayed DI water from cavity outside and kept around 15 deg. C. Total current was monitored via I-V supply source. Total removal was calculated from current integration. This calculated removal showed the average surface removal of cavity. Once the removal reached the half of target removal, process was stopped. Cavity was rinsed with DI water, and fully disassembled from the system. Quick eye inspection was done on inner RF

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surface and flange sealing surface. If any contaminants were seen on flange surfaces, scrubbing was done to remove them. Cavity had the 2^{nd} process in upside down orientation compared with the 1^{st} process. The reason is un-uniformity of surface removal on upper and lower half-cells. Details of removal will be described later. After VEP process, cavity had Ultra-Sonic Cleaning (USC) with DI water and soap water followed by High Pressure DI water Rinsing (HPR). Table 1 shows the recent parameters of Cornell VEP. Figure 2 shows typical current profile during 9-cell EP.

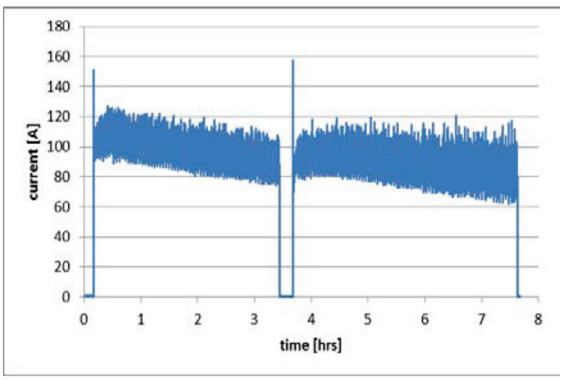

Figure 2: Current profile, EP voltage=12 V.

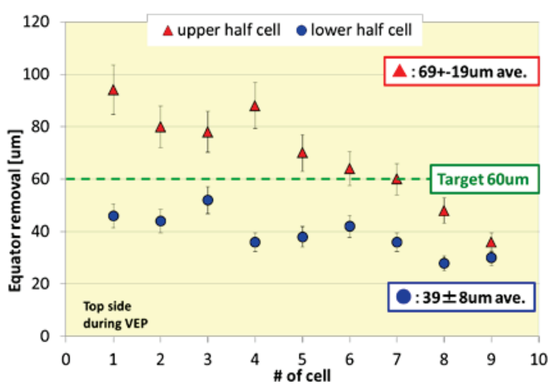

Figure 3: Removal measurements by ultra-sonic thickness gauge.

VEP Removal

Figure 3 shows the removal measurements by ultra-sonic thickness gage after 60um removal as average. Red dots shows the removal on upper half cells, blue dots shows that of lower half cells. Both data were taken near equator. The upper half cell has larger removal than lower half cell. Top cell (cell #1 in Fig. 3) has larger removal than bottom cell (cell #9 in Fig. 3). Against the calculated average removal of 60 um, the actual removal of upper half cells was 70±20 um, and 40±8 um for the bottoms. This difference came from gravity effect. Because of the vertical orientation during the process, upper half cells had less viscous layer on that surface than lower half cells. This brought the high current density, high removal rate on upper half cells, and un-uniform removal. In order to compensate this un-uniform removal, cavity had to be processed twice in two different orientations. As example, even if the target removal was 5 um, cavity will be processed with 2.5 um in each orientation.

Acid Agitation

Current oscillation is important during the EP process. Cornell applied acid agitation during the process to maintain current oscillations. From the systematic study on the half-cell coupon cavity [3], it had turned out that lower half cell had current oscillation, but upper half had no or very small oscillation. In addition, acid agitation enhanced the difference of current density between upper and lower half cells. To decrease the removal difference between upper and lower half cells, we decided to not applying the agitation during the EP voltage on. So far no significant cavity performance difference was seen between the process with and without agitation.

Cathode Bag

During the EP process, hydrogen gas was generated on cathode and seen as hydrogen bubbles. Its attacked niobium surface, sometimes bubble traces were seen on RF surface. Hydrogen bubbles could be absorbed into niobium bulk and induced hydrogen Q-disease. To avoid these negative impacts caused by hydrogen bubbles, cathode bag was installed along with cathode to guide the bubbles into outside of cavity. This cathode bag successfully worked with horizontal EP system. Vertical EP also had same issue, and impacts were much worse. The hydrogen bubbles went up to the top end sleeve and built up thick hydrogen foam layer. This foam could made more contaminants and more chance to hydrogen got into cavity surface. To eliminate this hydrogen foam layer, Teflon mesh net was lapped on stirring tube (Fig. 1). The mesh guides bubbles into the top end sleeve joint, and the bubbles were evacuated into air. Foam layer was successfully eliminated.

VT RESULTS OF VEP'ED 9-CELL CAVITIES AT CORNELL

VEP was applied on various 9-cell cavities which had different target accelerator field gradient (Eacc) and cavity qualification values (Qo). We will summarize recent 9-cell works at Cornell in two categories. The first one is VEP on high gradient cavities and second one is VEP on high-Q cavities.

High Gradient Cavities

Cornell's standard surface procedures on 9-cell cavities aiming high gradient (Eacc > 40 MV/m) consists of bulk VEP, high temperature bake, light VEP, and low temperature bake (120 deg. C*48 hrs). All chemistries were followed by USC and HPR. The highest gradient achieved by VEP at Cornell was 40MV/m with Qo of 8e9 in 2 K helium bath so far [3]. The cavity shape was 1.3 GHz TESLA shape. This cavity's result was also satisfied ILC base line specification values (Qo of 1.0e10 at 31.5 MV/m and Qo of 8.0e9 at 35 MV/m). Figure 4 shows the summary of recent high gradient cavity results.

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The average was 30±6MV/m with Qo of (1.7±0.2)e10 in 2 K with five 9-cell cavities. The lowest gradient was limited by defect on RF surface, not chemistry. So far VEP seems to be reliable up to 30MV/m for high voltage cavities. Further R&D to improve the yield is necessary.

High-Q cavities

Nitrogen doping is now very well known as high-Q cavity processing aiming LCLS-II project at SLAC [4,5]. The specification values for LCLS-II are Qo of 2.7e10 at 16 MV/m, 2 K. This high-Q cavity processing consists of bulk EP, high temperature bake followed by nitrogen doping, and light EP. Cornell also has been contribute on LCLS-II project and processed high-Q 9-cell cavities based on VEP [6]. Cornell's nitrogen doping procedures are: 1) degas cavity in 800 deg. C*3 hours; 2) induce nitrogen gas into furnace about 40 m Torr*20 minutes: 3) close nitrogen gas and keep evacuation 30 minutes in 800 deg. C. The final removal with VEP after doping was 14-27 um. Those conditions were determined by systematic study on nitrogen doped single cell cavities at Cornell [7]. Figure 5 shows the best results of nitrogen doped 9-cell cavities at Cornell. The average of Qo at 16MV/m was (3.1±0.3)e10. The average quench field was 17±2MV/m in 2K helium bath. These results satisfied LCLS-II specs.

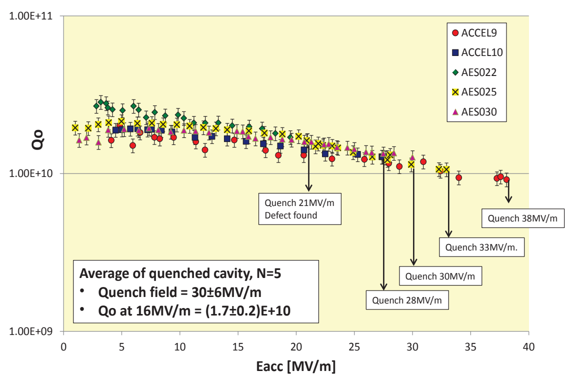

Figure 4: VT results of high gradient cavities processed with VEP.

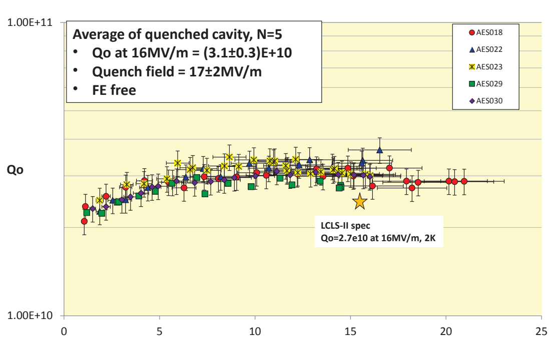

Figure 5: VT results of high-Q cavities processed with VEP.

FUTURE COLLABORATIONS

Cornell has demonstrated VEP capabilities on high gradient and high-Q cavities and also has achieved good performances which were comparable with the achievements of horizontal EP. For the further application of VEP on future projects and also for the new breakthrough on VEP, Cornell has stated various collaborations with other laboratory and companies.

Bipolar EP with Faraday Technology, Inc.

Faraday technology Inc. has continued the development of bipolar EP [8]. Faraday and FNAL had demonstrated the capability of bipolar EP on 1.3 GHz Nb SRF single cell cavities as the phase-I SBIR project [9]. As the advanced project of that, two phase-II SBIR proposals on bipolar EP had been submitted by Faraday and Cornell, and both were approved. One of them is aiming the demonstration of 9-cell scale bipolar EP process and RF testing. Cornell will provide three single cell cavities and Faraday will process those three cavities at once in upgraded 9-cell scale bipolar EP system. Cornell will perform RF testing on three single cells one by one. In parallel with this, Faraday will perform: 1) the parameter optimization of bipolar EP; and 2) fundamental study on acid free bipolar EP using the coupon cavity provided by Cornell.

Ninja-cathode VEP with KEK and Marui Galvanizing

KEK and Marui Galvanizing have started collaboration on VEP R&D [10]. A special EP cathode with retractable fin, called *Ninja-cathode,* has been developed by Marui. The motivation of this Ninja-cathode was to eliminate non-uniform removal during the VEP process. Cornell has joined this new VEP cathode collaboration with KEK and Marui. Cornell already contributed on KEK 9-cell cavity processes (bulk BCP and degas). The collaboration plans of this year are: 1) install Ninja-cathode and other related stuff provided form Marui into Cornell VEP system; 2) process KEK 9-cell cavity with Ninja-cathode at Cornell. This collaboration is supported by US-Japan Cooperative Program in High Energy Physics.

SUMMARY

Cornell has continued the development and upgrading of VEP system. With many efforts on parameter optimization, now VEP is used routinely on Nb SRF cavities at Cornell and works very reliably. VEP on High voltage cavities had achieved 40MV/m with TESLA 9-cell, VEP on High Q cavities based on N-dope had successfully achieved the requirements on LCLS-II, 2.7e10 at 16 MV/m, 2 K, with high yield. In addition, VEP results on high-Q cavities are comparable with horizontal EP. VEP collaborations toward further improvement and new breakthrough on EP have started between Cornell and Faraday, and also Cornell and KEK, Marui Galvanizing.

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