ADVANCED VERTICAL ELECTRO-POLISHING STUDIES AT CORNELL WITH FARADAY*

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Abstract

Cornell's SRF group and Faraday Technology, Inc. have started collaborations on two phase-II SBIR projects. Both projects are aiming for the development of advanced Vertical Electro-Polishing (VEP) for Nb SRF cavities, such as HF free or acid free VEP protocols. These could be eco-friendlier alternatives for the standard, HF-based EP electrolyte used, and could bring new breakthrough performance for Nb SRF cavities. Here we give a status update and report first results from these two projects.

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]. Both, Horizontal and Vertical EP are currently done with hydrofluoric (HF) acid based electrolyte, which is the mixed acid of sulphuric acid and hydrofluoric acid in 9~10:1 ratio in weight. As the SRF projects become bigger, the impact of large usage of hazardous HF based acid on niobium cavities for the environment becomes not negligible. Therefore, R&Ds on a less hazardous or more eco-friendly niobium surface process has been performed and has made good progress [2, 3]. As part of recent progress on this eco-friendlier advanced EP work, Faraday Technology, Inc. and Fermi National Laboratory (FNAL) demonstrated a high gradient of 44MV/m with 1.3GHz TESLA single cell cavity, which was processed by Pulse forward/pulse reverse EP (Bipolar-EP) with HF free electrolyte at Faraday Technology, Inc. [4]. RF test was performed by FNAL [5]. The collaboration of Faraday Technology, Inc. and FNAL was supported by funds from the American Recovery and Reinvestment Act (ARRA). For further R&D on advanced EP, now Cornell's SRF group and Faraday Technology, Inc. have started collaborations on Bipolar-EP with HF free/acid free electrolyte. Thise collaboration is supported by the Department of Energy's (DOE) phase-II Small Business Innovation Research (SBIR) program. In this paper, we report an status update and present the plans for these projects in details.

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VEP SYSTEM AT CORNELL

Overview

Figure 1 shows a 1.3GHz TESLA shape single cell cavity (left) and a 9-cell cavity (right) installed in Cornell VEP system. The Cornell VEP system can process 1.3GHz single-/multi-cell cavities with up to 9-cells. During the VEP process, the cavity has temperature controlled water cooling on the cavity outside wall and EP acid agitation (0~1Hz) by a paddle on a stirring tube, which is shown in the middle of Fig. 1. A HF based EP electrolyte is used, but no circulation is applied on the electrolyte during the process. Figure 2 shows a typical EP current profile during a single cell cavity VEP at Cornell. EP voltage is fixed at 12V. The temperature of the cavity outside wall is kept below 20degC.

Figure 1: Cornell's VEP system.

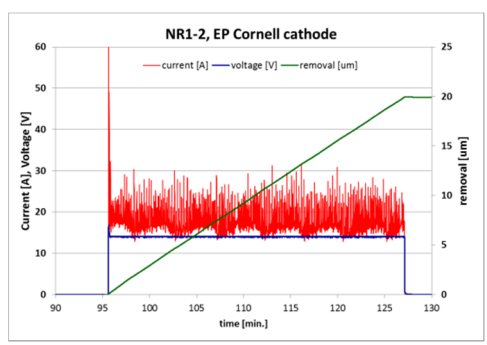

Figure 2: Typical EP current profile for a single cell VEP.

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Cornell VEP Achievements

Cornell had successfully demonstrated the capability of VEP on the high gradient cavities for the ILC project, which requires cavity specification for the accelerating field (Eacc) >35MV/m with cavity quality factor (Q_0) >$0.8x10^{10}$ at 2K [6]. 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 [7]. Figure 3 shows that Cornell's VEP has achieved a high gradient of 40MV/m with Q_0 of $0.8x10^{10}$ with a TESLA shape 9cell cavity reaching an important milestone for VEP. Further R&D goals for Cornell's VEP program are high gradient with high yield and removal uniformity. 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 much larger removal than that of the other end cell located on bottom. To compensate the removal un-uniformity, the cavity needs to be flipped and additionally processed after finishing half of the target removal. Cornell has collaborated with KEK and Marui Galvanizing Co. Ltd to improve the removal uniformity [8].

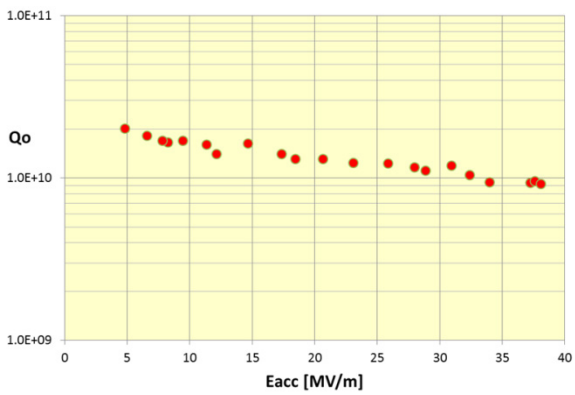

Figure 3: High gradient achievement of Cornell's VEP with 1.3GHz TESLA shape 9-cell.

BIPOLAR EP SYSTEM AT FARADY TECHNOLOGY, INC.

Overview

Figure 4 shows the Bipolar EP system for a 1.3GHz single cell cavity at Faraday. Detail descriptions of the bipolar EP techniques are published and can be found elsewhere [4, 9]. Figure 5 shows a general representation of the Bipolar EP anodic/cathodic pulse waveform. The waveform consists of 1) an anodic forward pulse to grow an oxide layer on the niobium surface, 2) voltage time off to dissipate the heat, remove reaction products, and replenishes reacting species, and 3) a cathodic pulse with reversed voltage remove the oxide layer on the niobium surface, thus eliminating the need for HF.

Figure 4: Faraday technology, Inc.'s Bipolar EP system [4].

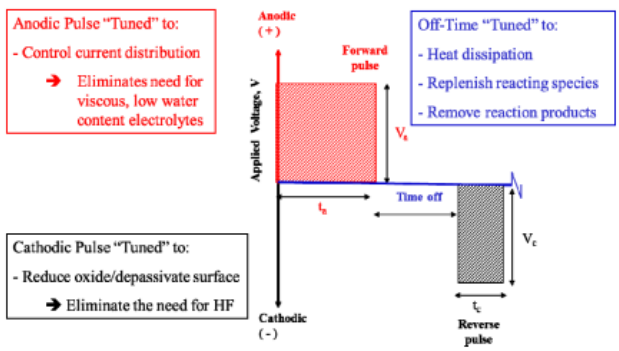

Figure 5: General bipolar EP representation [4].

Bipolar EP Achievements

Faraday technology, Inc. processed a single cell cavity with Bipolar-EP, and FNAL tested that cavity. A high gradient of 44MV/m with Q_0 of $1.0x10^{10}$at 2K was achieved (Figure 6). The cavity test details can be found in reference [5].

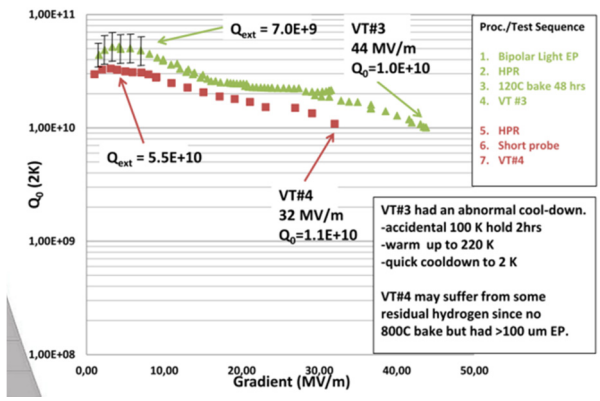

Figure 6: RF test results of a Bipolar EP'ed 1.3 GHz TESLA shape single cell cavity [5].

Figure 7 shows optical inspection images of the electron beam welding (EBW) seam on the RF surface. The top image is from the equator weld of a VEP'ed single cell cavity, the bottom image is from the equator weld of a Bipolar-EP'ed single cell cavity. Similar defects or features were seen on both surfaces.

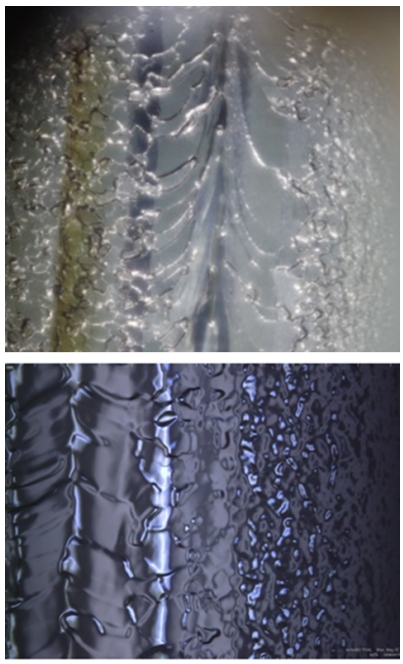

Figure 7: Optical inspection images of the equator weld seam on the RF surface. Top: post VEP 120μm, bottom: post Bipolar-EP 120μm [5].

PHASE-II SBIR WORK AT CORNELL AND FARADAY TECHNOLOGY, INC.

Cornell and Faraday technology, Inc. are currently collaborating on two projects, which are supported by DOE's phase-II SBIR program. Both projects are based on Bipolar EP techniques.

Eco-Friendly Bipolar Electrochemical Bulk Processing of SRF Cavities

The project goals are the scaling up of the Bipolar EP system from single cell scale to 9-cell cavity scale. For the first commissioning of the upgraded system, Cornell has fabricated three 1.3GHz TESLA shape single cell cavities. Three single cells will be connected via Teflon spacer rings and treated together as a 9-cell scale cavity equivalent string. The length of this string is about 1200mm, which is close to the length of TESLA shape 9-cell cavity of 1250mm. The cavity string will be processed with a new Bipolar-EP system at Faraday technology, Inc. RF test will be performed on three single cells one-by-one at Cornell. Cavity fabrication was completed recently at Cornell (Fig. 8) Baseline RF test based on traditional VEP followed by 9-cell scale Bipolar EP will be carried out this year. RF test on three single cells after the 9-cell scale Bipolar EP is planned for early 2017.

Figure 8: Three 1.3GHz Tesla shape single cell cavities.

Acid-Free Electro-Polishing

This program will conduct a feasibility study of Bipolar EP with near-neutral, aqueous, and acid-free salt based electrolytes. R&D on Nb coupons is in good progress at Faraday. A half-cell coupon cavity fabricated at Cornell is also available for an actual cavity scale process investigations. Initial Bipolar EP trial on a single cell cavity with salt-based electrolyte will be done at Faraday this year, and RF test is planned at Cornell for early 2017.

SUMMARY

The frontier of Electro-Polishing (EP) development is now moving into Vertical EP and Bipolar-EP techniques. Especially, eco-friendlier Bipolar-EP shows good initial results with a single cell cavity. Cornell and Faraday technology, Inc. are collaborating now to establish this advanced EP technique on the 9-cell scale. This feasibility study on acid-free Bipolar EP will bring future cost reduction in cavity surface processing for future SRF projects. Detailed cavity performance results from these projects will be presented in the future.

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