MULTI-CELL VEP RESULTS: HIGH VOLTAGE, HIGH Q, AND LOCALIZED TEMPERATURE ANALYSIS

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Abstract

Cornell's SRF group has been developed Vertical Electro-Polishing (VEP) for many years. So far VEP'ed cavity performance was limited by too much Q-slope above 25 MV/m. For ILC 9-cel cavity "ACCEL9", we minimized VEP removal based on previous VEP studies with single- and multi-cell cavities at Cornell. ACCEL9 achieved 38MV/m with Qo of 9.0e9 at 2.0K in the pi-mode. This is the first 9-cell cavity that achieved ILC base-line specifications (Qo=1.0e10 at 31.5MV/m, Qo=8.0e9 at 35MV/m) by VEP in the world.

INTRODUCTION

We have been developing VEP for high gradiet reserach at Cornell and ILC's alternateive concept design (ACD). VEP has been successfully applied on single- and multi-cell niobium superconducting RF cavities. In this paper, we will describe the recent results of VEP R&D on ILC base-line 9-cell cavity and localized temperature analysis during VEP at Cornell.

CORNELL VERTICAL ELECTRO-POLISHING

ILC base-line cavity processing consists of bulk horizontal EP (~120um), 800C hydrogen degassing, light horizontal EP (~20um), ultra-sonic cleaning with detergent, high pressure ultra-pure water rinsing (HPR), and bake out (120C, 48hrs). VEP is expected as ACD of horizontal EP. Compared with horizontal EP, VEP could eliminate rotary acid seals, sliding electrical contact, cavity vertical/horizontal position control fixtures, and acid circulation. The acid plumbing/containment also could be simplified. So, the cost reduction of capital equipment is expectable.

Cornell VEP procedures

Cornell VEP is processed as follows, (1) fill up acid in the cavity, no acid circulation during the process, (2) start and keep acid agitation by stir tube with puddles, aluminium cathode is fixed, (3) start cavity outside cooling (4) turn on voltage and start current integration to calculate VEP removal (5) turn off voltage after finishing the target removal, (6) continue acid agitation about 30min. (7) stop agitation, damp acid, and start initial rinsing with DI water. Table 1 shows typical parameters of Cornell VEP. Figure 1 shows the image of cavity cell and stir tube with puddle.

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Table 1: Typical Cornell VEP Parameters

Cathode	Aluminium >99.5%
Stir tube	PVDF
Paddles	PVDF
Seals	FEP encapsulated O-ring
End group	PTFE, HDPE
Electrolyte	24 litters/9-cell
Electrolyte composition	10:1 (H2SO4:HF)
Maximum use	9 g/L dissolved Nb
Current	150 Amperes
Voltage	14 volts
Temperature	15 to 19 C
Stir-tube transparency	>50%
Stir frequency	1Hz
Removal rate(ave.)	~0.3um/min.

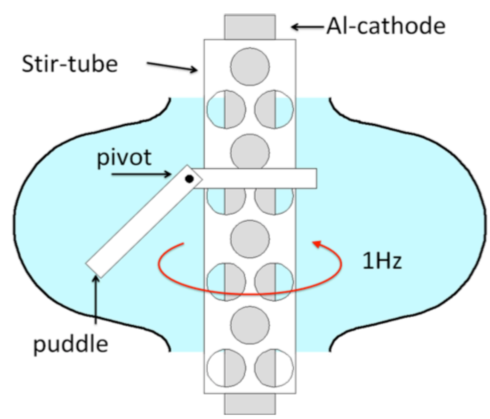

Figure 1: Image of cell and VEP stir tube with paddle.

MULTI CELL VEP AT CORNELL

Many VEP processes and RF tests on TESLA shape full 9-cell cavities (ACCEL5, 9, 10, AES5), and many efforts for the optimaization of VEP parameters have been continued at Cornell. These works have contributed as a part of US's ILC cavity R&D programs. In this paper, we pick up ACCEL9 (A9) and describe the recent results of A9. Table 2 shows the RF test summary of A9. At the early stage, gradient was always limited around 25MV/m. We found the defect on SRF surface of cell#1. We tumbled and removed it. After tumbling, A9 was processed again by bulk VEP, 800C bake, oxypolishing, and 120C bake out. Cavity gradient was improved up to 36MV/m, but limited by Q-slope (5th VT). We tried additional light VEP (30um) and 120C bake to cure Q-

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Table 2: VT Results Summary of ACCEL9 at Cornell

No	date	Preparation	Eacc max, Qo	Limitation
1st	15-Aug-07	VEP(160um)+ degas + VEP(30+40um) +USC+HPR+120C Bake	26.6MV/m, 7.6e9	Quench/FE
2nd	15-Sep-07	VEP(30um) +USC+HPR+120C Bake	26.3MV/m, 8.8e9	Quench
3rd	4-Feb-09	VEP (??) +USC+HPR+120C Bake	25.3MV/m, 3.5e9	Quench
4th	13-Mar-09	re-HPR	25.7MV/m, 6.5e9	Quench
5th	8-Mar-11	Tumbling (cell#1) + VEP(120um) + 800C degas + Oxypolish +USC+HPR+120C Bake	36.2MV/m, 4.3e9	Q-slope
6th	14-Mar-11	VEP(30um) +USC+HPR+120C Bake	25.6MV/m, 1.1e10	Quench
7th	5-Apr-12	VEP(5um)+USC+HPR+120C Bake	39.5MV/m, 6.7e9	RF power/FE
8th	10-May-12	re-HPR	38.0MV/m, 9.0e9	Quench

slope, but performance was degraded to 25MV/m and limited by quench (6^{th} VT).

Analysis of Previous VEP Studies at Cornell

Before reprocessing A9, we analyzed previous VEP results of single- and muti-cell cavities at Cornell. We focused on the dependence of final VEP removal on the cavity performances. Figure 2 shows the analysis on final VEP removal vs. maximum field gradient. This plot includes both of single- and multi-cell cavities results. The results of cavity which was found to have defects on SRF surface by inspection were not included. Figure 2 suggests that the smaller removal, less than 10um, is promising for high gradient >35MV/m. We consider the limitation of VEP'ed cavity mostoly relates to RF surface contaminants caused by hydrogen and sulpher which produced during VEP process. Minimizing of VEP removal could result in suppressing these contaminants. We decided to process A9 with 5um VEP.

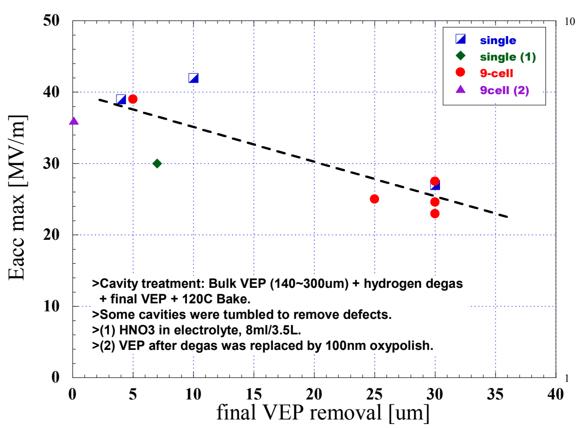

Figure 2: Analysis on field vs. final VEP removal.

5um VEP on ACCEL9

A9 was disassembled and exposed to air about a year after 6^{th} vertical test. We did ultra-sonic cleaning (USC) with detergent prior to VEP. We did minimized VEP of 5um on A9. We also applied methanol rinsing to reduce sulphur contaminants; filled up cavity with methanol and stirred about 30min. on VEP stand. After methanol rinsing, A9 was processed by USC, HPR, and 120C x 48hrs bake out.

7^{th} VT Results; 5um VEP

Figure 3 shows the VT results of A9 processed by 5um VEP. A9 achieved high gradient of 39.5MV/m with Qo of 6.7e9 at 2.0K in the pi-mode. Radiation at highest field was 32Rad/hrs. Limitation was RF power and radiation, but not quench. We also measured at 1.8K, A9 achieved 35.8MV/m with Qo of 1.5e10 in the pi-mode. Limitation was run out of liquid helium, but not quench. We surveyed cavity after warming-up, no activation was found. To reduce the radiation we did additional HPR on A9 and tested again. No chemical etching was done for the next test.

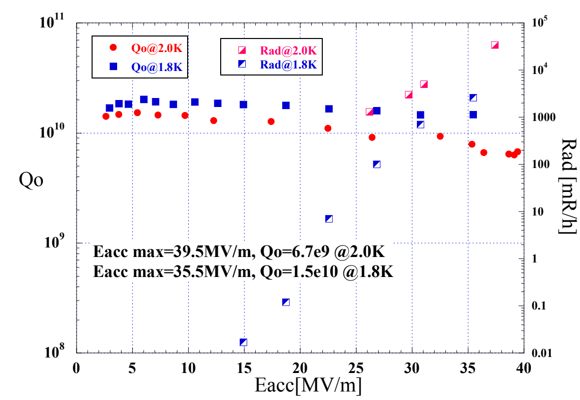

Figure 3: 7^{th} VT results of ACCEL9.

8^{th} VT Results; re-HPR

Figure 4 shows the VT results of A9 processed by additional HPR. A9 achieved high gradient of 38.0MV/m with Qo of 9.0e9 at 2.0K in the pi-mode. Cavity was limited by quench. Radiation was significantly reduced to 1mRad/hrs at highest field. Radiation onset was also improved from 15MV/m to 30MV/m. This result satisfied ILC base-line specifications; Qo of 1.0e10 at 31.5MV/m and Qo of 8.0e9 at 35MV/m, which are indicated by two X-dots in Figure 4. This is the first achievement of ILC base-line specifications by VEP in the world. Figure 5 is the analysis result of pass-band measurements. It shows the highest field of each cell. It is consistent with the pi-mode result. Figure 5 suggests that cell#2 or #8 seems to have responsibility of quench limit in the pi-mode.

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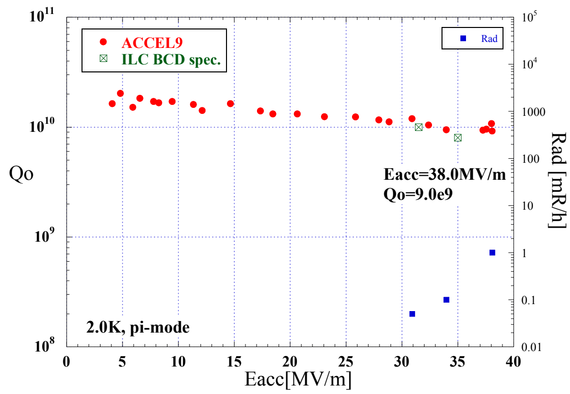

Figure 4: 8th VT result of ACCEL9.

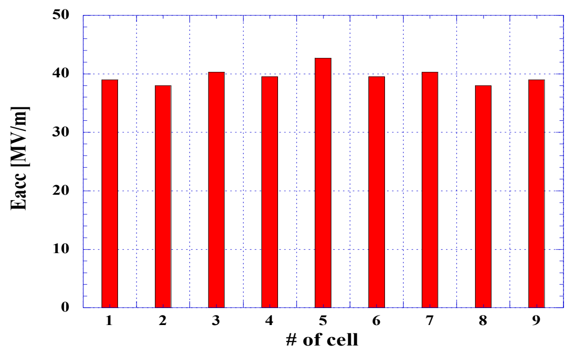

Figure 5: Pass-band measurements analysis.

LOCALIZED TEMPERATURE ANALYSIS

Temperature of cavity outside surface is one of the important VEP parameters. To understand more details of VEP process, we did localized temperature analysis using single-cell cavity. We put thermometers on top and bottom half cup of single cell cavity; 4 for each half cell. Figure 6 shows image of thermometers on cavity. Figure 7 shows the total current (blue line) and the temperature oscillations of top and bottom half cell during VEP process, respectively. It shows temperature behaviours were different between top and bottom half cell. Current oscillation shows 2 types of spikes; sharp and wide one. Temperature oscillation of top half cell seems to just follow current spikes. But that of bottom half cell seems to follow only sharp spike of current oscillations. We have no clear understanding and explanation for these behaviours yet. We need more data taking of this phenomena and more data analysis to get understanding and control of VEP.

SUMMARY

Cornell's SRF group made the 1st breakthrough of VEP R&D. The first trial of minimized VEP on ACCEL9 was already successful and achieved the ILC specifications. Other ILC full 9-cell cavities, ACCEL10 and AES5, are waiting for processing and test. Figure 8 shows current status of 9-cell cavities which we have. To demonstrate reproducibility and a high yield, Cornell VEP R&D will be continued.

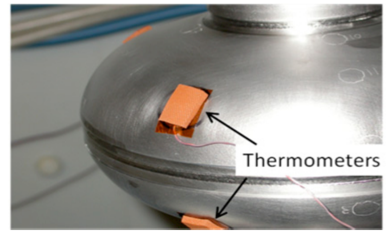

Figure 6: Image of localized temperature monitoring.

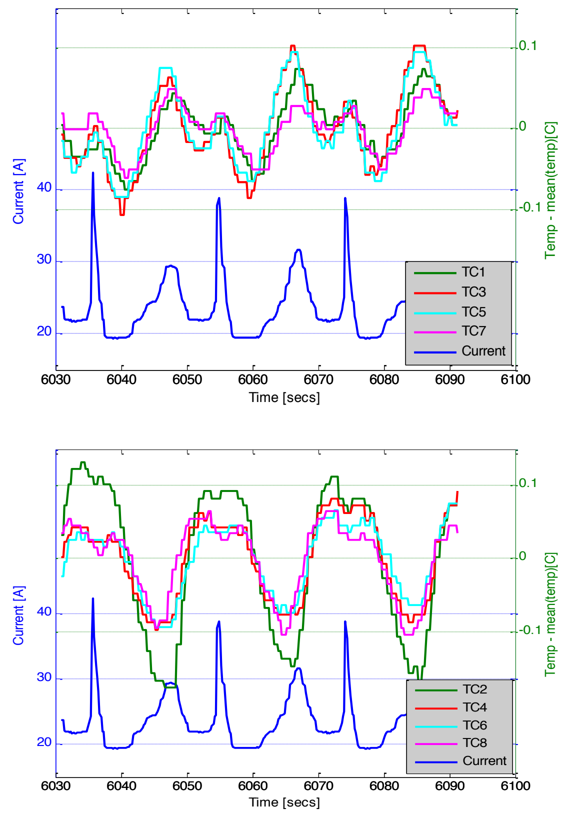

Figure 7: Localized temp. monitoring; Top: temp. at top half cell, Bottom: temp. at bottom half cell.

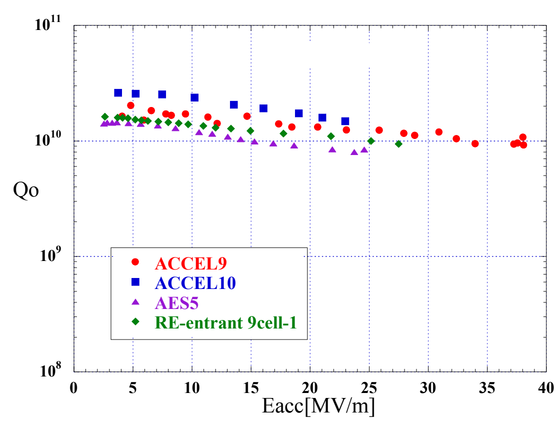

Figure 8: Current status of 9-cell cavities at Cornell.