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EXTRA-COLD EP PROCESS AT FERMILAB*

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Abstract

FNAL has established a Cold Electro-Polishing (EP) method which maintains the outer surface temperature of cavity cell around 12~15 degC during EP process. Cold EP has been applied on the various SRF cavities as the final removal of 10 μm or less and contributed to achieve high RF performances with them. To investigate more feasibility and capability of EP at lower temperature, the FNAL EP temperature control system was recently upgraded. Extra-cold EP process below zero-degC at cavity cell region was successfully performed on 1.3GHz 1-cell cavity. A compatible RF performance with cold EP method was also demonstrated during the cavity vertical testing. Here we report details of extra-cold EP process and the cavity test results in this paper.

INTRODUCTION

Electro-Polishing (EP) is one of key techniques for niobium SRF cavity treatment to remove materials from its surface. FNAL EP processes have two different temperature conditions depends on removal range. Precise temperature control over the cavity is established by applying cooling shower on cavity outer surface and controlling EP acid temperature. “Hot EP” is applied on the removal more than 10 μm. During this process, the cavity outer cell surface is maintained around 32 degC, and the cavity beam tubes are maintained around 5 degC. “Cold EP” is applied on the removal below 10 μm, which maintains the cavity outer cell surface around 12~15 degC and the cavity beam tubes around 0 degC. An example, when we do bulk removal of 120 μm, 110 μm is removed with hot conditions, then last 10 μm was removed with cold conditions. For the removal 10 μm or below, whole process is done with cold conditions. Cold EP was established at FNAL with the motivation of precise temperature control to achieve continues large current oscillations during the EP process which would provide better surface finish [1]. Cold EP method has been successfully applied on single-/multi-cell niobium SRF cavities with elliptical shape at FNAL EP facility and ANL EP facility and contributed to the cavities achieved high-Q and/or high gradient performances. As one of new challenges in EP R&D at FNAL is investigating impacts of EP process with much lower temperature conditions. The first challenge is seeking the lowest temperature FNAL EP tool can run and control the process. The second challenge is applying that “Extra-Cold” EP conditions to the cavity and perform cryogenic testing.

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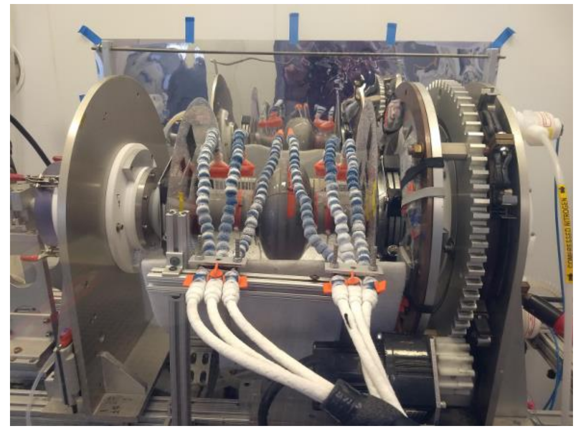

Figure 1: 1.3GHz 1-cell on FNAL EP tool.

EP TOOL AT FERMILAB

Figure 1 shows 1.3 GHz TESLA shape single cell cavity on FNAL EP tool at CPL (Cavity Processing Laboratory). Six cooling shower line for cavity outer surface also can be seen. This EP tool is capable for single cell cavities with frequency of 1.3~3.9 GHz.

Electrolyte

EP electrolyte is the mixtures of sulfuric acid (H_2SO_4) and hydrofluoric acid (HF). Fermilab uses EP electrolyte with the ratio of H_2SO_4 : HF = 13.5 : 1 by volume. Concentration of each acid Fermilab uses are H_2SO_4 > 96 % and HF ~70 % by weight. The electrolyte was pre-mixed by the company and delivered to Fermilab (~110 L/drum). A fresh electrolyte of 10 L was transferred from the EP electrolyte drum to the acid tank of EP tool. This 10 L of electrolyte was circulated during EP process and dumped to the waste drum after the process, no electrolyte was reused even if the removal was small. The administrative removal limit with 10 L of electrolyte is 80 μm on 1.3 GHz single cell cavity; this corresponds to the niobium concentration of about 11 g/L.

Temperature Control

Two chiller units and flow adjust valves in acid line and cooling lines control the EP process temperature (Fig.2 top). The 30 % propylene glycol is used to achieve below 0 degC without freezing. Temperature monitoring during EP process is done with six thermocouples. One is on cavity equator, two are on cavity beam tubes, another two are on the acid drain lines. The last one is in the acid tank of EP tool. Thermocouples, except the one in acid tank, are covered with insulator to avoid the impact from cooling shower or room temperature. Wireless thermocouple system is applied on the rotating cavity and the drain lines.

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Zone separators, flexible plastic disks seen on iris in Fig. 2 bottom, divide a single cell cavity in three zones (the cavity cell and the beam tubes). The separators prevent outside cooling water moves from one zone to another and allows to control temperatures in each zone independently. With these schemes, we could maintain the cavity cell and the beam tubes in different temperature conditions.

To improve temperature control and lower the process temperature conditions, the cooling system was upgraded as follows. (1) Re-arrange two chiller units' configurations in the system. Chiller #1 is modified to be used both for acid cooling and pre-cooling of returning shower coolant into chiller #2. (2) Enlarge shower line diameter for better flow. (3) Increase propylene glycol concentration from 30 % to 40 %. (4) install independent line per shower head and install flow adjust valves with monitor on each line (Fig. 2). (5) install thermal insulation sheet underneath of shower pan and thermal insulation tube on shower lines to avoid heat penetrations.

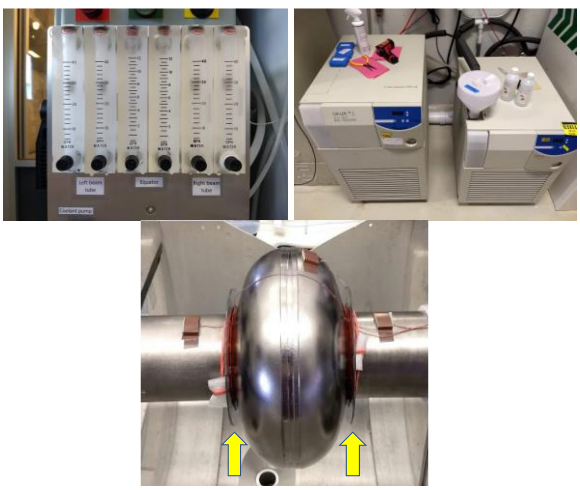

Figure 2: Chiller units (top right), flow monitor with adjustable valve (top left), and zoon separators (bottom, indicated with yellow arrows.).

These upgrades make EP acid and cavity outer surface temperature control much easier, faster, and very stable. The lowest EP temperature conditions (Extra-Cold EP) we established with this upgraded system is -4 degC at cavity equator and -8 degC at beam tubes during the process. EP acid temperature in the acid tank is maintained about 4 degC in this condition.

EXTRA COLD EP ON 1-CELL

Extra-Cold EP trial was performed on 1.3GHz TESLA shape single cell cavity. To focus on temperature control first, same EP voltage with other conditions was applied (18 volts). By optimizing chiller temperature set point, acid circulation speed, and cooling shower frow, the lowest temperature condition was established and stabilized around -4 degC at cavity equator outside. Extra-Cold EP was stably performed a whole day (~8 hours). Average EP current about 8 amps (5 mA/cm^2) and no current oscillation was seen with this condition (Fig. 3). The acid temperature in the tank was kept around 4 degC. After turning off the EP voltage, the cavity and acid were warmed up above 20 degC by adjusting chiller temperature to make acid viscosity lower. This is standard procedure when we finished low temp EP process to make acid dump quick and easy, also it help the cavity rinse process in the EP tool with DI water. Removal measurement by ultra-sound thickness gauge was performed before and after this process. The average removal of 25+-4 µm over the cell was obtained. The estimated average removal during this process is about 2~3 µm/hour over the cavity. The table 1 summarizes the parameters of FNAL EP tool for 1.3GHz single cell cavity. The numbers are average values.

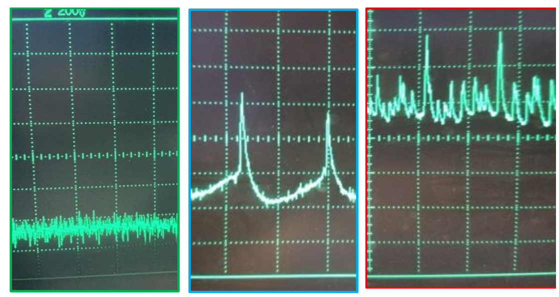

Figure 3: EP current profile. X axis shows time in 5 sec/div. Y axis corresponds to EP current in 8 A/div, the bottom X axis line corresponds to 0 amp.

Table.1 EP Parameters at FNAL

Parameters	[Unit]	Hot EP	Cold EP	Extra Cold EP
Target removal	[µm]	>10	10 or less	~30
EP voltage	[V]	18	18	18
EP current	[A]	40	15	8
Equator temp.	[degC]	32	15	-4
Beam tube temp.	[degC]	5	0	-8
Acid temp.	[degC]	20	12	4
Removal rate	[µm/hour]	13	5	3
Acid circulation	[L/min.]	1.5~2.3	1.5~2.3	1.5~2.3
Cavity rotation	[RPM]	1	1	1
Nitrogen gas flow	[L/min.]	1	1	[

VTS POST EXTRA-COLD EP

VTS Results

The cavity processed with Extra-Cold EP had std. 120 C x 48 hours baking and tested in VTS. The red dots in Fig. 4 shows 2 K result as Q vs. Eacc plot. Q of 1e10 at 43 MV/m was achieved in 2 K. The cavity was field emission (FE) free and limited by quench. Baseline performance of this cavity before Extra-Cold EP process was also shown in Fig. 4 as comparison (blue dots). The baseline result was 42 MV/m with Q of 1.2e10 at 2K, FE free, the limitation was quench. The baseline surface was finished with 5 µm Cold EP plus std. 120 C baking.

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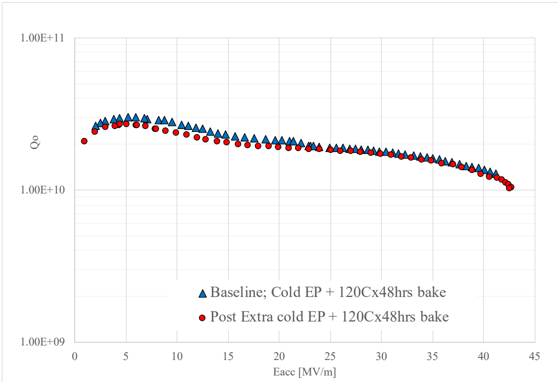

Figure 4: VTS results in 2K.

Discussion

Our expectations on lowering EP process temperature are that the lower temperature condition would make chemical reactions slower and more uniform, also make the removal more uniform over the surface. Those might also make the surface finish smoother and uniform. On the other hand, lowering the process temperature would decrease EP current density and might induce a degradation of surface roughness depend on how much surface was removed with that condition. So, there could be a potential risk to degrade the cavity performance if we lower EP process temperature too much. But the results of first trial was very successful. As the comparison in Fig 4 shows, the removal of 25 µm with Extra-Cold EP condition made the performance slightly better at highest point but did not degrade the high gradient performances. The result suggested that Extra-Cold EP would have no negative impact on surface roughness finish up to 25 µm at least. This is very encouraging since next challenge is applying this Extra-Cold EP condition on nitrogen doped cavity. The final EP removal necessary after doping would be about 10 µm or less. If Extra-Cold EP condition has no negative impact but have a positive impact on the doped surface finish as well, improvement on performances should be expected. The coupon study is also in progress at FNAL with various EP conditions. It would provide more findings via detail surface analysis.

SUMMARY

Feasibility and capability of Extra-Cold EP method against high gradient 1-cell cavity was successfully demonstrated. Achieved VTS result suggested that very low temp EP (-4 degC) or very low EP current density (~5 mA/cm^2) conditions did not cause damage to cavity RF surface up to 25 µm removal at least. Nitorogen-doped 1-cell cavity plans to have Extra-Cold EP as final EP to investigate its impact on cavity RF performances. More study on low temperature EP being performed by using 1-cell cavity and coupons at FNAL.

REFERENCES

[1] A. C. Crawford, “Extreme diffusion limited electropolishing of niobium radiofrequency cavities *Nuclear Instruments and Methods in Physics Research A*, vol. 849, pp. 5–10, 2017. doi:10.1016/j.nima.2017.01.006