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PROGRESS OF PIP-II ACTIVITIES AT IJCLab

P. Duchesne†, N. Gandolfo, D. Le Dréan, D. Longuevergne, R. Martret, T. Pépin-Donat,
F. Rabehasy, S. Roset, L. M. Vogt, Université Paris-Saclay, CNRS/IN2P3, IJCLab , Paris, France
P. Berrutti, M. Parise, D. Passarelli, Fermilab, Batavia, USA

Abstract

Since 2018, IJCLab is involved in PIP-II project on the design and development of accelerator components for the SSR2 (Single Spoke Resonator type 2) section of the superconducting linac. First pre-production components have been fabricated, surface processing and cavity qualification in vertical cryostat are on-going. IJCLab has upgraded its facilities by developing a new set-up to perform rotational BCP. The progress of all processing and testing activities for PIP-II project will be reported and, in particular, a dedicated study to qualify removal uniformity compared to static BCP will be presented.

INTRODUCTION

The Proton Improvement Plan-II (PIP-II) encompasses a set of upgrades and improvements to the Fermilab accelerator complex aimed at supporting a world-leading neutrino program over the next several decades and more specifically at providing an intense neutrino beam to the future DUNE project (Deep Underground Neutrino Experiment). PIP-II benefits from a strong commitment as in-kind contributions of international partners among which France is involved through CEA and CNRS/IN2P3 agencies. Since 2018, IJCLab, unique actor for CNRS/IN2P3 contribution, is strongly involved in the pre-production and production phases of PIP-II project and more specifically on the design and development of accelerator components for a section of the superconducting linac named SSR2 [1]. CNRS/IN2P3 contribution consists of:

- Supporting design of SRF components as tuners, power couplers and cavities.
- Procuring several pre-production components as tuners and power couplers.
- Supporting fabrication, validating in vertical cryostat and re-processing cavity surfaces if required of pre-production SSR2 cavities.
- Supporting fabrication, validating in vertical cryostat of 33 production cavities and re-processing a maximum of 25% of cavities if required.

The manufacturing and the surface processing of the first prototype cavities procured by Fermilab* are ongoing [2]. The first step of surface preparation consists in a bulk BCP (Buffered chemical polishing) performed on the bare cavity, followed by a light BCP and heat treatment after the helium tank integration. The required average material removal will be in the range of 150-200µm to eliminate the damaged layer created during the manufacturing.

In this context, IJCLab has upgraded its facilities by developing a new setup to perform rotational BCP (Figure 1) starting from the existing one used to perform static BCP of Spoke resonators equipped with their helium vessel [3]. The heat generated during the chemical reaction is dissipated through both the chilled acid bath and the cooling water flowing through the helium vessel. In the case of static BCP setup, as the cavity remained fixed during the process, it has to be emptied, rinsed, disassembled, flipped and re-assembled after half the time to etch as homogeneously as possible the overall surface. The implementation of rotational BCP will now avoid this intermediate disassembly and thus reduces drastically the operators' intervention and risk occurrence.

Moreover, previous studies proved that the implementation of a rotation during chemical etching improves significantly the homogeneity [4,5] and surface quality by avoiding patterns as grooves, stripes or bubble marks.

Figure 1: Rotational BCP setup at IJCLab

The new setup developed at IJCLab was experimented on a SSR2 prototype bare cavity equipped with a removable dummy tank. Static and rotational treatments were performed in order to measure wall thicknesses and induced frequency shift. Surface quality and homogeneity of the niobium removal have thus been addressed.

This paper aims at summarizing all preliminary results obtained on the first SSR2 prototype.

EXPERIMENTAL SETUP

The new rotational BCP setup was developed by taking into account our experience matured on ESS and MYRRHA projects. To efficiently keep the cavity walls cold during the treatment, a chilled water flow is maintained around the cavity. To achieve this, a removable dummy tank was designed for the SSR2 bare cavity. Its geometry is very similar to the helium vessel to have identical interfaces.

Dummy Tank

The dummy tank is composed of two half shells in stainless steel and closing parts in PVC (Figure 2). EPDM seals

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†patricia.duchesne@ijclab.in2p3.fr

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mainly ensure the water tightness. Once the two wheels are attached to the dummy tank, it is installed on the rollers of the chemistry cart. By means of a motorized gear mechanism, the cavity can be rotated along its beam axis.

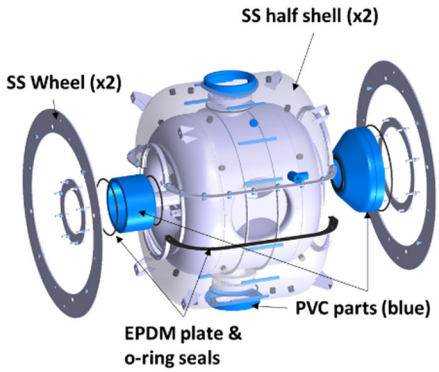

Figure 2: Dummy tank for SSR2 bare cavity

Acid and Water Circuits

A standard mixture of the three following acids is used: hydrofluoric HF, nitric HNO3 and ortho-phosphoric H3PO4, with 1:1:2.4 volume proportions to comply with local regulations. The acid, maintained at 8°C, enters through two ports: a left beam port and the bottom side port and exits through the other two ports (Figure 3). The cavity is filled with acid in static and rotation is initiated only when cavity is completely full. The acid inlet is separated in 2 circuits through a 3-way ball valve and the 2 outlets are gathered in one circuit also thanks to a 3-way ball valve. These valves are required to ensure complete filling and draining by forcing the acid flow only toward side ports. At each extremity, are installed two rotary unions allowing full rotation of the acid circuit.

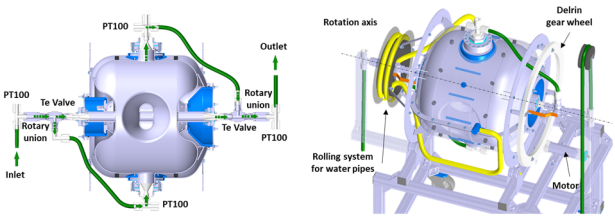

Figure 3: Acid and water circuits.

The cold water, maintained at 10°C, enters through one port of the dummy tank and exits through another port on the opposite side. A winding system of the water pipes has been implemented at one extremity restricting the rotation to a back-and-forth motion with an amplitude of ± 350°.

Experimental Protocol

To qualify the BCP, three chemical treatments were planned, one static BCP (BCP1) and two rotational BCP (BCP2 & BCP3). The targeted average material removal was limited to 50 µm for each treatment in order to achieve a total removal around 150µm and to correctly measure the thickness at each intermediate step. A campaign of thickness measurement was repeated before and after each operation using an ultrasonic sensor (model Echo7 – Sofranel – translator DLK-20125). To improve the precision of the thickness measurements at the same location, some masks have been used to locate precisely one hundred measuring points on the cavity surface (Figure 4). We can notice that some areas are not accessible because of stiffeners welded on the cavity (end walls) and space clearance (center part of spoke bar).

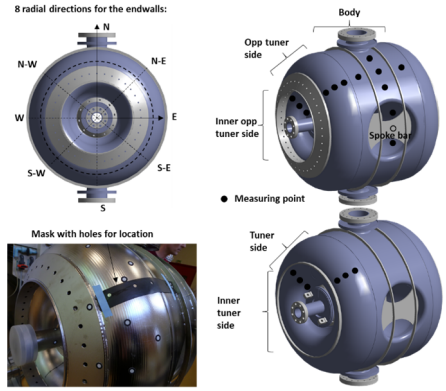

Figure 4: Thickness measurements.

EXPERIMENTAL RESULTS

BCP Parameters

Table 1 summarizes the main parameters for the three BCP runs performed on the SSR2 bare cavity. Beside rotation speed and niobium concentration in the acid at the start of the operation, all parameters are identical. Temperature set points were identical but measured temperatures were actually different as ambient temperature had a non negligeable impact on final temperatures of acid and cooling water.

Table 1: Main Parameters of the Chemical Treatments

Parameter	Unity	BCP1	BCP2	BCP3
Duration	min	75+75	150	150
Rotation speed	rpm	-	0.5	0.5
Niobium concentration	g/l	11.5	2.37	6.48
Acid flow rate	l/min	14.4	14.4	14.4
Cavity filling	%	100	100	100
T° acid set point	°C	12	12	8
T° water set point	°C	9	9	9

BCP Results

Table 2 gives the main results on the weight and the frequency shifts of the cavity. The rotational BCP2 and BCP3 have an higher etching rate than BCP1. However, it is difficult to draw a conclusion as the etching rate is significantly impacted by both Niobium concentration and temperature. Nevertheless, for both rotational BCP runs, the final acid temperature was maintained below 15°C whereas for static BCP, the temperature raised above 20°C. In that sense, the rotation improves clearly acid mixing and thus avoids acid overheating. This observation is in good agreement with simulations [5]. Another interesting observation

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is that the frequency shift induced by the static BCP is almost negligible and one order of magnitude lower than the measured values for rotational BCP. This behaviour is very difficult to anticipate by simulation but this trend is in favour of a more homogeneous removal as it will be discussed later.

Table 2: Main Results of the Chemical Treatments

Parameter	Unity	BCP1	BCP2	BCP3
Max acid T° at outlet	°C	22	14	15
Weight difference	Kg	0.6	0.78	0.815
Average removal	µm	48.4	62.9	65.7
Etching rate	µm/min	0.32	0.42	0.43
Frequency shift	kHz	-1.75	-17.1	-13.5
Etching sensitivity	kHz/µm	-0.04	-0.275	-0.208

In term of surface quality based on visual inspection, no differences have been noticed as depicted on Figure 5. No obvious trace of groove, stripe or bubble mark are visible on the walls after static BCP as it was observed on previous experience on SSR1 cavities at Fermilab [6].

Figure 5: Surface finishing of SSR2 cavity after static BCP (Left), after rotational BCP (Center) – SSR1 cavity after static BCP (Right).

Finally, from the thickness measurement campaign, the average and standard deviation values obtained from more than one hundred data points are summarized in Table 3.

Table 3: Average Thickness Removal Estimated by Weight and Thickness Measurements

Parameter	Unity	BCP1	BCP2	BCP3
Average removal evaluated by weight	µm	48.4	62.9	65.7
Average removal estimated by thickness	µm	45.5	63	58.3
Standard deviation	µm	13.5	14	15.5

An overview of all measurements and the statistical distribution are as reported in the Figure 6. From these data, no obvious improvement of the homogeneity of thickness removal can be concluded. Standard deviation is similar for all BCP runs. This could be partially explained by the low reproducibility of thickness measurements with ultrasonic probe on non-flat surfaces. Although the repeatability of the measurement is very good on flat surfaces, better than 10 um, it appears that the reproducibility of the measurement (before/after BCP run) is poor as a tiny positioning error of the probe leads to an error of several tens of um because of the curvature. In a more detailed visualization, the Figure 7 presents the removed thickness by region. Only in region with low radius of curvature as the cavity body, it appears that the reproducibility of the measurement is good enough to unveil a better homogeneity during rotational BCP.

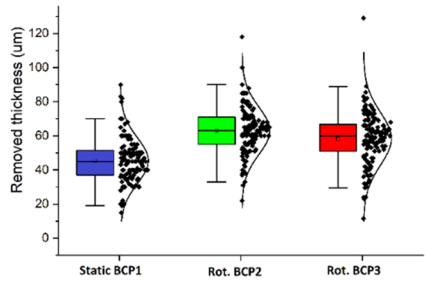

Figure 6: Distributions of thickness data points after BCP.

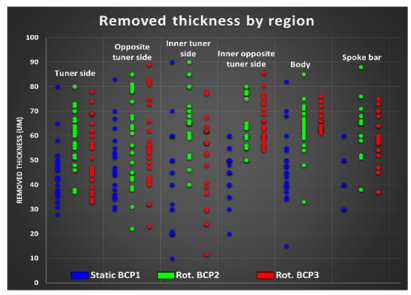

Figure 7: Removed thickness by region and by BCP.

Frequency Sensitivity Analysis

The impact of a uniform removal on the RF frequency was estimated by numerical simulation with COMSOL [7]. For an uniform removal, the etching sensitivity is -0.52 kHz/µm. Thus etching sensitivity could be a good indicator to evaluate the homogeneity of the thickness removal. The closer the measured etching sensitivity is from the simulated value, the better is the homogeneity. In that sense, we can effectively conclude qualitatively from Table 2 that a rotational BCP leads to a more uniform material removal.

CONCLUSION

The new setup to perform rotational BCP at IJCLab is now operational. Compared to the previous static BCP, the chemical treatment is more convenient for the operators, more efficient and less risky (no intervention is required at half the time). Project-wise, the implementation of rotational BCP is a real improvement in term of cost, human resources, time and risk. However, even though some indicators like the frequency shift tend to confirm a better homogeneity with rotational BCP, we were unable to prove by direct measurement of material thickness a more uniform removal. The limited accessibility and low reproducibility of the measurement on curved surfaces lead to non-negligible errors. Finally, quality-wise, rotational BCP allows a better mixing of the acid significantly limiting the acid temperature increase over time, thus guaranteeing optimal SRF performances.

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