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SURFACE POLISHING FACILITY FOR SUPERCONDUCTING RF CAVITIES AT CERN

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Abstract

A new SRF cavity polishing facility which covers the needs for present projects like the HL-LHC and its CRAB cavities as well as ongoing and future activities in the frame of the FCC study was commissioned at CERN in 2019. This facility can handle chemical and electrochemical polishing baths, can process both niobium and copper-based cavities on a wide range of geometries, starting at 400 MHz up to 1.3 GHz for elliptical type of cavities and more complex shapes as defined by the DQW and RFD CRAB design. The main subassemblies of this facility are presented. Some important design details and materials choices of the facility will be briefly discussed together with the range of operational parameters. First results on different substrates and geometries are discussed in terms of surface finishing and polishing rate uniformity.

INTRODUCTION

CERN new facility for polishing SRF cavities was assembled and commissioned in 2019 with the purpose of covering the treatment of a wide range of accelerating structures. To fulfil this objective, the facility is composed of three main assemblies: two independent chemical plants and one cavity handling equipment. Altogether, the facility can process all foreseen accelerating cavities, independently of the nature of the substrate, for HL-LHC, like DQW and RFD CRAB cavities, with and without their helium tank; as well as the cavities defined within the FCC study, including the 400 MHz monocell elliptical structures. In Fig.1 are the 3D representation of the listed cavities and their overall dimensions. The main requirement is that the cavity holding frame is equipped with compatible supports and interfaces.

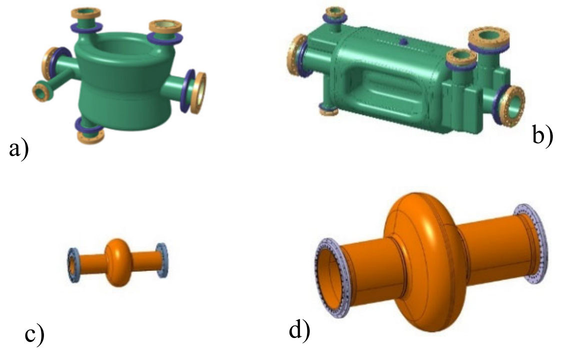

Figure 1: a) DQW, 497 mm diameter by 660 mm in length; b) RFD, 412 mm diameter by 919 mm in length; c) 1.3 GHz, 216 mm diameter by 414 mm in length; d) 400 MHz, 693 mm diameter by 1095 mm in length.

The facility concept was entirely designed internally, and the main assembly fabrications, as listed previously, were outsourced.

FACILITY DESCRIPTION

The new facility was installed in an existing building, which had already all necessary services to house chemicals handling equipment, namely wastewater and fumes extraction as well as the supply of demineralised water (up to 60 l/minute at >10 MOhm.cm). The footprint of the installation, 45 m^2, was optimised to cope with space constraints inside the building such as the existing hydrofluoric acid compatible basin and fumes extraction ducts.

The facility is composed by three main subassemblies. A first chemical plant to handle copper electropolishing bath (H_3PO_4 (85% w/w) 55% v/v + n-butanol (99% w/w) 45% v/v), a second chemical plant to handle niobium Buffered Chemical Polishing (BCP): H_3PO_4 (85% w/w) 50% v/v + HNO_3 (65% w/w) 25 % v/v + HF (40% w/w) 25% v/v) or electrochemical (H_2SO_4 (95% w/w) 90% v/v + HF (40% w/w) 10% v/v) polishing baths, and a cavity handling device, which has a useful working volume of 1000 mm in diameter by 1500 mm in length and can handle charges up to 300 kg. The following subsections present a detailed description of the subassemblies shown in Fig. 2.

Figure 2: a) copper chemical plant; b) niobium chemical plant; c) cavity handling device.

Chemical Plants

Each plant was assembled as an enclosed independent unit including its own retention and extraction to create a first confinement and reduce the impact of any chemical incident. This separation provides more flexibility for future modifications and improves the safety of the installation as it hinders any accidental mixes of different baths in case of a leak or mishandling. As example, Fig. 3 presents a 3D drawing of the copper chemical plant module.

All pipes, valves and instrumentation were from off-the-shelf PVDF (Polyvinylidene fluoride) parts and, where

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necessary, FPM (fluor elastomer) or PTFE (Polytetrafluoroethylene) were chosen as seal material. All other parts in contact with the processing baths, such as chemicals storage, were custom-made out of PVDF raw material. The lines are equipped with temperature- pressure-sensors and flowmeters and the storage tanks with temperature and level sensors.

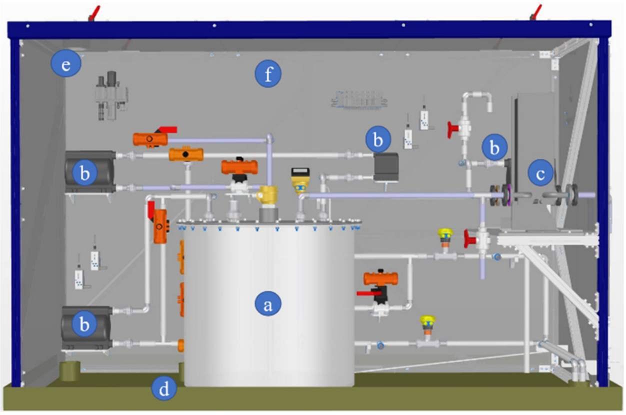

Figure 3: a) polishing bath storage tank; b) pumps; c) heat exchanger; d) retention; e) extraction duct connection; f) module enclosure frame.

All pumps are air operated double diaphragm type and parts in contact with the baths are made from fluorinated polymers and depending on the pump, they can provide from 4 up to 60 l/min.

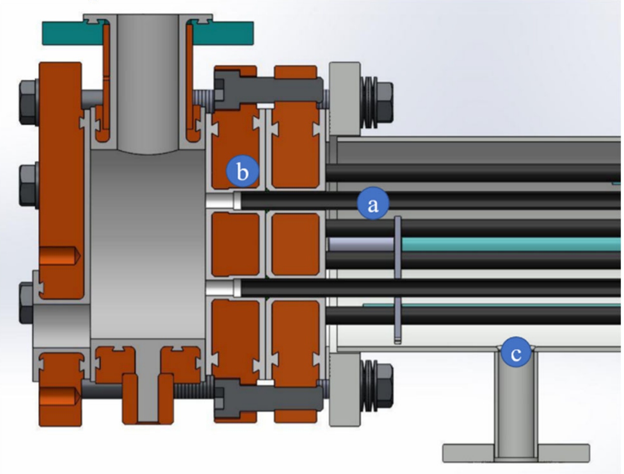

Figure 4: a) SiC pipes; b) PFA coated steel; c) 304L stainless steel.

The heat exchangers are adapted to each chemical plant to cope with bath chemical compatibility issues and cost. Thus, the one for the copper processing plant has 3.3 m^2 of exchange surface, is made entirely of 316L stainless steel and it is off-the-shelf, while the one for the niobium processing plant has 1 m^2 working surface, is custom-made from SiC pipes assembled on off-the shelf carbon steel parts coated with high purity PFA and the outer shell is in 304L stainless steel, as shown in Fig. 4. The process bath rich in HF (hydrofluoric acid) circulates inside the SiC pipes and through the PFA coated steel and the cooling fluid outside the SiC pipes and within the 304L shell.

Cavity Handling Device

A 3 D view of the cavity handling device is shown in Fig. 5 without the safety frame. The device main frame is in 316L stainless steel and the parts in contact with the chemical baths are made of PVDF, PTFE or PFA. This device respects European machine safety standards and is CE marked. As such, the device is partially enclosed as shown in Fig. 1, and it is only accessible when it is stopped. It is equipped with its own retention and fumes extraction; it has its own control unit, which is autonomous in terms of machine safety parameters allowing to stop the process whenever they are breached.

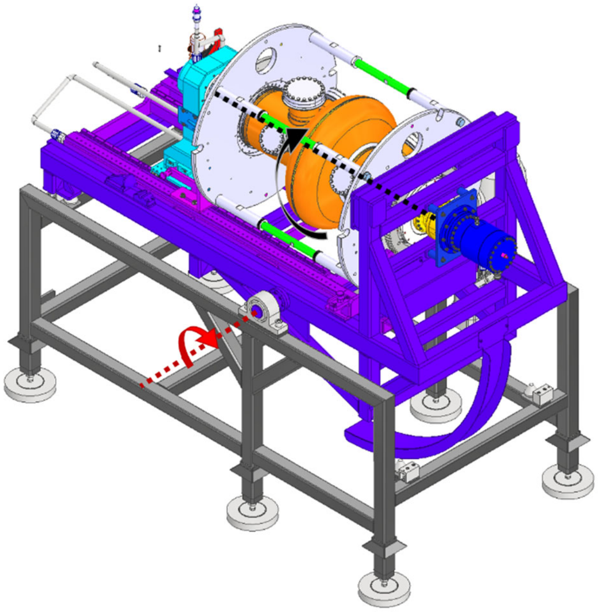

Figure 5: cavity handling device. In red the axis to move the cavity from horizontal to vertical, supported by the dark blue frame and equipped with the fixed interface. In black the rotation axis. In magenta the main sliding table. In light blue the secondary sliding table with the movable interface.

It allows handling cavities either in vertical or in horizontal position. In the horizontal position, it provides the possibility of rotating a cavity, around its longitudinal axis, up to 10 rpm within steps of 0.1 rpm. The transition from vertical to horizontal or horizontal to vertical is predefined in a process step. To adapt to different lengths and to ease the assembly of cavities holding frame, the device is equipped with two independents manually operated sliding tables. One allows to adapt to the cavity length and enables the closing of the chemical bath line on the fixed interface, while the second allows to ease the electrical connection and to close the process bath line with the moving interface.

Besides the frame and the motorisation that enables the different movements as described previously, this device has three other subcomponents that are of interest and that are presented in Figs. 6, 7 and 8. First, the PTFE bellows that allow compensating small longitudinal and radial misalignment between the two interfaces, as well as of the cavities. Second, the two interfaces on each side between fixed and rotating parts. This subassembly performance is essential to ensure leak tightness and allowing the rotation movement. The main functional component is the radial bearing seal on which a sufficient constraint is applied to ensure the leak tightness and at the same time must be compatible with the different chemicals that are foreseen to be handled in this facility. Also, the roughness of the surface that is contact with the bearing seal lip was defined with an Ra of 0.8 µm to reduce mechanical wear and thus improve lifetime and reliability.

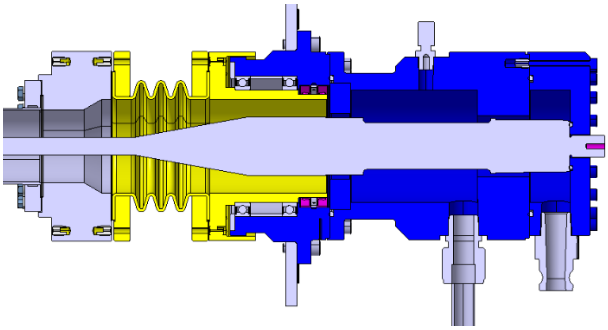

Figure 6: Detail of the fixed interface. In blue, the non-rotating part of the interface. In yellow, the rotating part with the PTFE bellow. In magenta, the FKM radial bearing seals. In light grey, at the centre, the cathode and its assembly for leak tightness.

Third, the electrical contacts needed for the electropolishing processing. The cathode side interface must be made leak tight as it crosses the boundary that defines the internal processing domain and thus is in contact with chemicals. The leak tightness is achieved with an O-ring that is compressed when the cathode is fixed with the help of a nut on the external side. The anode connection does not have the leak tightness issue but must cope with the eventual rotation of the cavity and to achieve this, the contact is done through a slip ring and square rods that are put in contact with the slip ring with the help of springs. The slip ring is in bronze and the tips are made of bronze plus graphite.

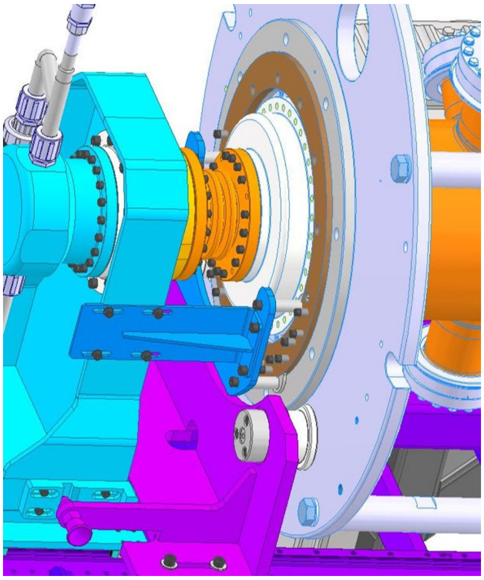

Figure 7: Movable interface with the slip ring, in brown.

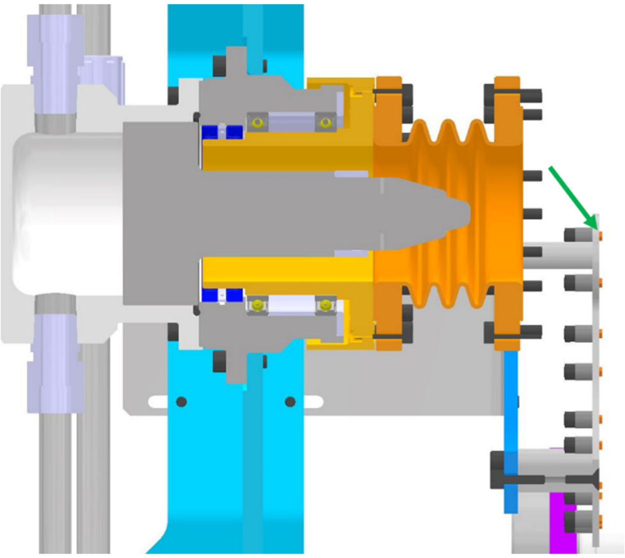

Figure 8: Movable interface with contact tips assembled on support plate (green arrow).

Control System

A standard PLC/SCADA based Industrial Control System (ICS) has been developed in-house to provide all required functionality. The software was implemented using UNICOS-CPC, a CERN-made framework to develop industrial control applications, which is the organisation's de facto standard for ICS implementation [1]. CPC, the dedicated UNICOS package for Continuous Process Control, provides a solid baseline to standardize and accelerate the implementation of applications for process control [2]. Traditionally, and taking a rather simplistic approach to the matter, an ICS can be considered as having three layers: Field, Control, and Supervision. Also, for this chapter, we split the description of the facility into two distinct assemblies: the chemical plants and the cavity handling device.

All field devices in the chemical plants (valves and pumps) are pneumatically actuated. The supply of compressed air to 2-way and 3-way valves is controlled with multivalve solenoid blocks. Precise control of the pumps and analogue valves is achieved using proportional pressure regulators. Both are interfaced with the Master PLC through Profibus. All flowmeters and environmental sensors (temperature, pressure and level) are integrated in the PLC using 4-20mA current loops. All effect sensors are used to evaluate valve positions. On the control layer, a PLC, coupled with the required types of Analogue and Digital IO modules, commands all equipment in the facility (including the cavity handling device, as described below). A small local uninterruptible power supply (UPS) allows graceful shutdown of the machine in case of a power cut. To avoid the need of setting up a full WinCC-OA SCADA server and to manage yearly updates and license renewals, supervision is handled with a high-end industrial touch panel.

The cavity handling device has been equipped with high-performance synchronous servomotors and motor drives for motion, not because this application requires precise control of position, velocity or torque but because they

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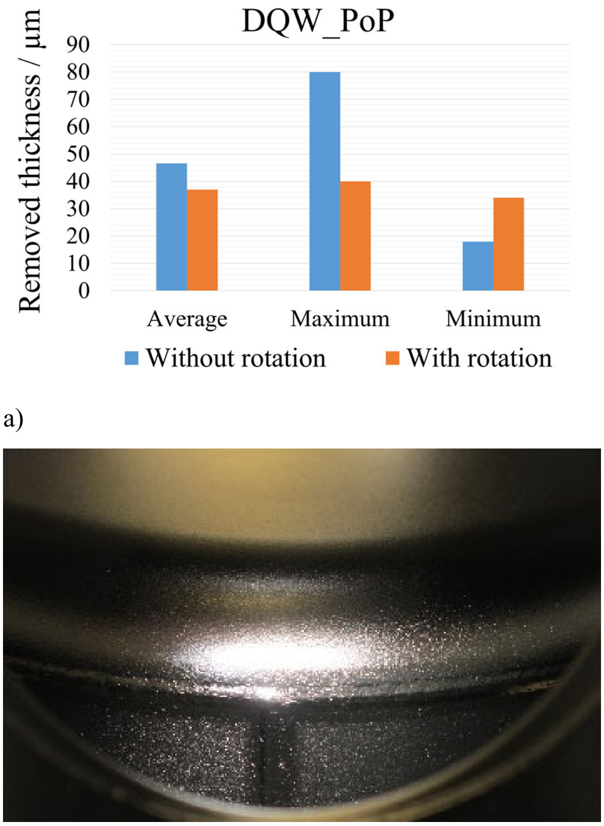
were recovered from a previous facility. An integrated PLC controls the motor drives and implements global safety features (e.g. stopping all movement in case the handling device doors are open). This PLC is controlled by the Master PLC of the installation, which can start or stop the rotation of the cavity, parametrise speed and direction of motion, and set the working position of the cavity. The data exchange format between the two PLCs was pre-agreed between CERN and the manufacturing company, and upon delivery the component was easily integrated in the main control system as a Profinet I-Device.

Others

The facility is completed with a chiller that is shared by both chemical plants, but sits outside them, and which has a cooling power of 5 kW at 0 °C; a DC power supply capable of providing 200 A up to 25 V and nitrogen gas supply to flush process gases and ensure a non ATEX atmosphere.

RESULTS

Since late 2019, the new facility has been able to process a set of different cavities and the main results are described hereafter. The very first cavity type to be handled was the DQW_PoP (Proof of Principle) CRAB niobium bulk cavity. This cavity was previously BCP polished in a different set-up, and it was the perfect candidate to assess the performance of this new installation.



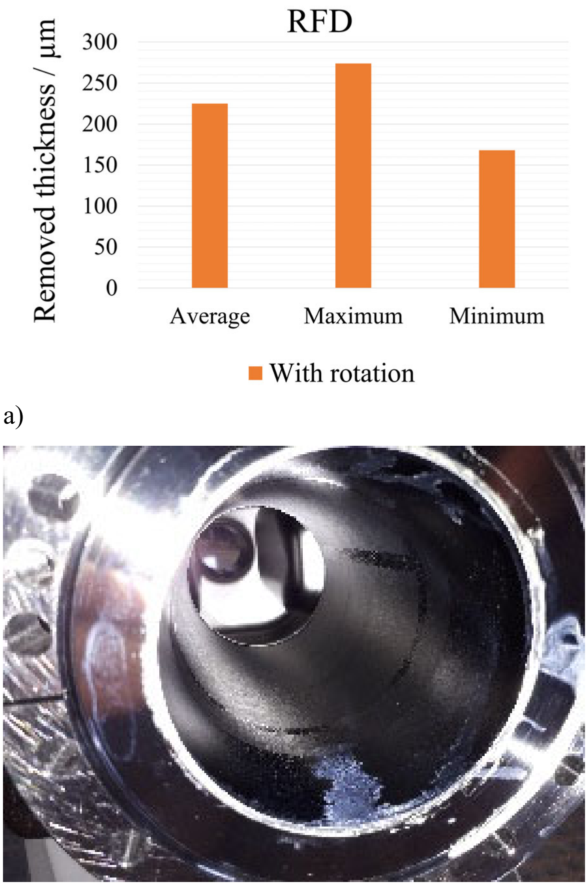
a)

b)

Figure 9: Data from DQW_PoP processing.

In Fig. 9a, the data from wall thickness removal distribution in the former facility, without rotation, are compared to those of the new facility, with rotation. For similar average material removal thickness, in the setup without rotation, the material removal along the cavity was quite uneven and extra handling was necessary to bring the extreme values closer to the average. With the new facility and the possibility of applying a rotation along the axis defined by the cavity beam ports, the maximum and minimum values of removed material became much closer, allowing a faster and reproducible processing. Furthermore, the resulting surface was homogeneous in morphology, stain free and in line with what is expected from BCP processing, see Fig. 9b.

The second cavity type to be processed were two RFD CRAB niobium bulk cavities. In this case, there are no equivalent data from other processing set-ups and an assessment of improvement in terms of material removal distribution cannot be made. However, also considering the even more complex geometry of the RFD, the obtained values are quite satisfactory, see Fig. 10a.



a)

b)

Figure 10: Data from RFD cavities. In a) it concerns RFD2 and in b) it concerns RFD1.

Not all was perfect, and the processing was modified after the first RFD to avoid the formation of stains near some ports as shown in Fig. 10b. Mainly, the removal of the polishing bath remaining in the process lines and trapped inside the cavity is now ensured by a rinsing step. The second RFD cavity was processed with this new sequence allowing to retrieve a homogeneous morphology and stain free surface. The RF performance achieved on this cavity was extremely good (up to 6.9 MV, $Q_0 = 6\times10^9$) and provided the proof that this facility can deliver high performing surfaces on SRF structures [3].

Lately, 1.3 GHz elliptical copper cavities were handled to define the best working parameters for electropolishing process, assess the cathode geometry and enable to transpose them to the 400 MHz FCC type cavities. The first results are very encouraging with very smooth and shiny surfaces across the 1.3 GHz copper cavities, both in horizontal and in vertical position, see Fig. 11.

Figure 11: 1.3 GHz copper cavity after electropolishing.

The only setback so far was that the present cathode is not fully compatible with vertical processing, namely for long runs as it does not hinder the polishing bath to create patterns on the surface. However, this problem is now well identified and can be easily solved with an adapted cathode and process approach.

CONCLUSIONS

The new facility has proved that it is capable of handling and processing successfully a variety of geometries and substrates as by design. Namely, RFD CRAB and 1.3 GHz elliptical niobium mono cell cavities were BCP processed, and 1.3 GHz elliptical copper mono cell cavities were electropolished.

High flexibility has been demonstrated allowing a rapid swap from one geometry to another, as well as from niobium to copper processing and vice-versa. As experience is building up, the time and effort needed for assembling and disassembling are becoming remarkably low, which allows a high availability of the new facility.

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