

CAVITY PROCESSING RESEARCH LABORATORY AT FERMILAB: SRF CAVITY PROCESSING R&D

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Abstract:

A center for cavity processing R&D at Fermilab, called the Cavity Processing Research Laboratory, is currently in the final stages of installation and commissioning. This facility contains centrifugal barrel polishing, a horizontal electropolishing tool, a 1000°C vacuum furnace, a high pressure rinse tool utilizing ultrapure water, ISO class 4, 5 and 6 clean rooms for cavity assembly work and various other associated pieces of support equipment. All the operations are designed for single cell and nine cell 1.3 GHz Tesla type cavities except for the electropolishing tool which will initially be only for single cell use. Upgrades are currently being examined for single and five cell 650 MHz cavities. The current status of the facility and plans for future work are discussed.

INTRODUCTION

Performance specifications are becoming more stringent for next generation particle accelerators. As requirements on accelerating gradients and quality factors increase, it becomes essential to fully understand how each process affects the cavity's performance. This is especially important at Fermilab where the International Linear Collider (ILC) and Project X are both of interest. The ILC has a high accelerating gradient requirement while Project X has a high quality factor requirement [1,2]. These two different performance specifications likely mean the cavities will follow different processing paths.

The Cavity Processing Research Laboratory (CPL) is a facility dedicated to the R&D of the processes and materials needed to consistently produce cavities with sufficient performance characteristics of next generation particle accelerators. This paper will discuss the CPL and some of the work that will be done in it.

CPL LAYOUT

Fig.1 shows the general layout of the CPL. The CPL contains all the operations needed for cavity processing in a small area. The layout was designed based on a

processing concept thought to be beneficial for SCRF cavities called "tight loop" processing.

There are five general areas in the CPL that are labeled and each is represented by a different color in Fig. 1. The green is the centrifugal barrel polishing (CBP) area. The pink area is for chemistry operations including horizontal electropolishing (EP). The light blue area is a utilities area for equipment associated with the clean rooms and high pressure rinse (HPR) process. The orange area is a suite of clean rooms for high pressure rinsing and preparation of the cavities for cold testing. The red area contains a 1000°C vacuum furnace and loading fixture for the furnace.

- 1) The black lines represent the tight loop process flow path with letters being major unit operations and numbers being decision points. The path that a cavity might go through is as follows: Cavity enters process at (0)
- 2) Cavity goes for bulk material removal at (1) [either (a) CBP or (b) EP]
- 3) If cavity receives CBP it gets an additional rinse (c) and light EP (b) before proceeding
- 4) Cavity goes for ultrasonic rinse at (c)
- 5) Cavity goes for hydrogen degassing at (d)
- 6) Cavity goes for light EP at (b)
- 7) Cavity goes for ultrasonic rinse at (c), HPR at (e), assembly for cold test at (f)
- 8) Cavity goes for cold test at IB1—leaves tight loop processing area of IB4

This is a standard path that a cavity might follow, but deviations from baseline processing can occur. One specific example is shown. If a cavity were to have a high quality factor and gradient, but also show signs of field emission, simply doing another HPR and cold test is often appropriate. This is shown in Fig.1 by a second entry point (entry points are shown as (0)) into the cavity processing loop just upstream of the clean rooms and HPR (shown as (e)).

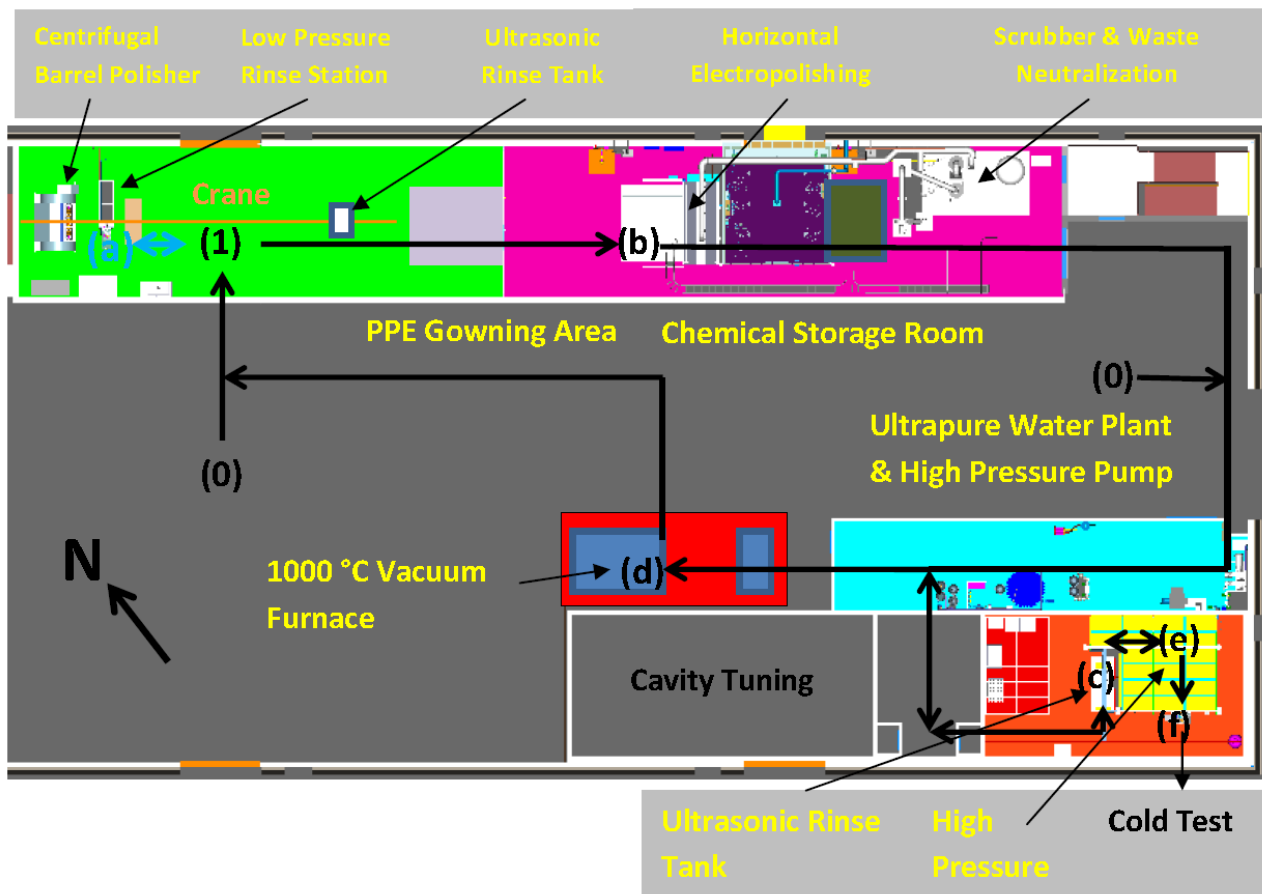


Figure 1: General layout of CPL with process flow path outlined.

CENTRIFUGAL BARREL POLISHING

CBP is an alternative processing technique that polishes the inside of superconducting rf cavities by rotating the cavities at high speeds while filled with an abrasive media. Centrifugal barrel polishing (CBP) has received great interest at Fermilab because of its ability to produce mirror like finishes, reduce amount of chemistry needed, and repair defects that could not be repaired with standard processing techniques. CBP has proven to be a very useful technique for repairing defects in 9-cell Tesla-type cavities that could not be repaired by further chemistry. Single cell results are very promising and demonstrate increased accelerating gradient and quality factor when compared to processing by electropolishing alone [3, 4].

CBP has been operational for over one year now at Fermilab. Many single and nine cell cavities have been processed via this technique at the CPL. The CBP processing technique will be further refined through the examination of new polishing media. Coupled with the CPL electropolishing tool, the CBP process can be developed to minimize the amount of post CBP chemistry. The effect of the mirror like finish obtainable using CBP on cavity performance will be studied. Since CBP can yield surfaces much smoother than EP alone, and EP produces cavities that are already close to the

gradient limit for Tesla-type cavities, other cavity geometries like the re-entrant shape will be studied [3].



Figure 2: Centrifugal barrel polisher and rinse station.

HORIZONTAL ELECTROPOLISHING

Electropolishing is the current baseline cavity processing technique because of its ability to produce relatively smooth surfaces on niobium SRF cavities [5]. Although extensive work has been done on the electropolishing process, there are still problems associated with it. Problems with the process include, pitting, sulfur precipitation, and hydrogen contamination of the niobium.

The Fermilab CPL electropolishing tool has design elements from the Jefferson Lab EP tool [6], the Argonne National Lab EP tool [7], and an EP tool designed and built at Fermilab but operated in industry [8]. A picture of the Fermilab EP tool can be seen in Fig.3 and a schematic is seen in Figure 4.

Most of the wetted flow path of the CPL electropolishing tool is made of fluoropolymers which are resistant to the sulfuric & hydrofluoric acid mixture. The only exceptions to this are the heat exchanger and cathode, which are made out of high purity aluminum that has good resistance to the acid mixture.



Figure 3: Horizontal electropolishing tool shown with a single cell Tesla-type cavity.

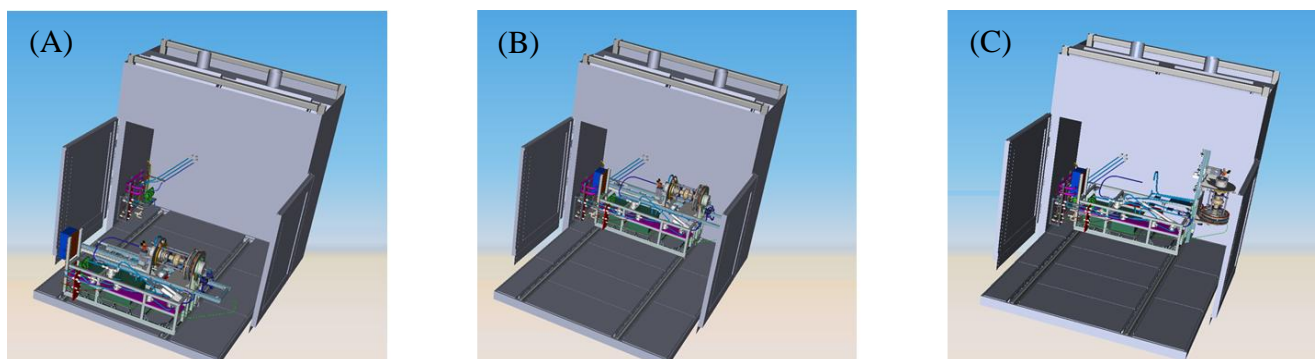


Figure 4: The CPL electropolishing tool. (A) The EP tool withdrawn from the cabinet for cavity removal/installation. (B) The tool in the horizontal position ready for operation. (C) The tool in the vertical position used for cathode extraction/insertion and rinsing.

Fig 4A shows the electropolishing tool with the sled extracted. To do an EP process, the sled must first be extracted and the cavity installed in the EP tool. The cavity is installed on the EP tool by two quick disconnect chain clamps [7]. After the cavity is installed in the EP tool, the sled is installed in the cabinet (Fig 4B). There are 5 electrical connections, 4 liquid connections and 2 gas connections, which are all quick-disconnect connections that must be made once the sled is in place. Then the doors of the cabinet are closed and the cathode is inserted while the cavity is in the vertical position as seen in (Fig 4C). The electropolishing process is run in the horizontal position (Fig 4B). The cavity only goes vertical for cathode insertion/removal and rinsing.

Much design effort has gone into insuring the safe handling of the concentrated acids used in the EP process. This is partially shown in Fig5. Chemicals are stored in a

dedicated chemical storage room which has acid vapor monitors and spill detectors. The EP process is done in a ventilated cabinet that also has spill and vapor monitors. A 1500 CFM scrubber is used to process fumes from the EP cabinet. All processes are done on spill containment floors that drain to a dedicated containment system. There are typically 2 to 3 levels of containment between the operator and the acid. A safety shower resides directly next to the EP tool that delivers 20 gpm of tepid water. The shower is interlocked with the EP tool and directly notifies emergency dispatch if activated.

The EP tool is currently operational with water only. After the tool is approved for chemical use, several things will be studied, including decoupling cooling from acid flow, reducing hydrogen contamination, reducing sulfur contamination and optimizing CBP.

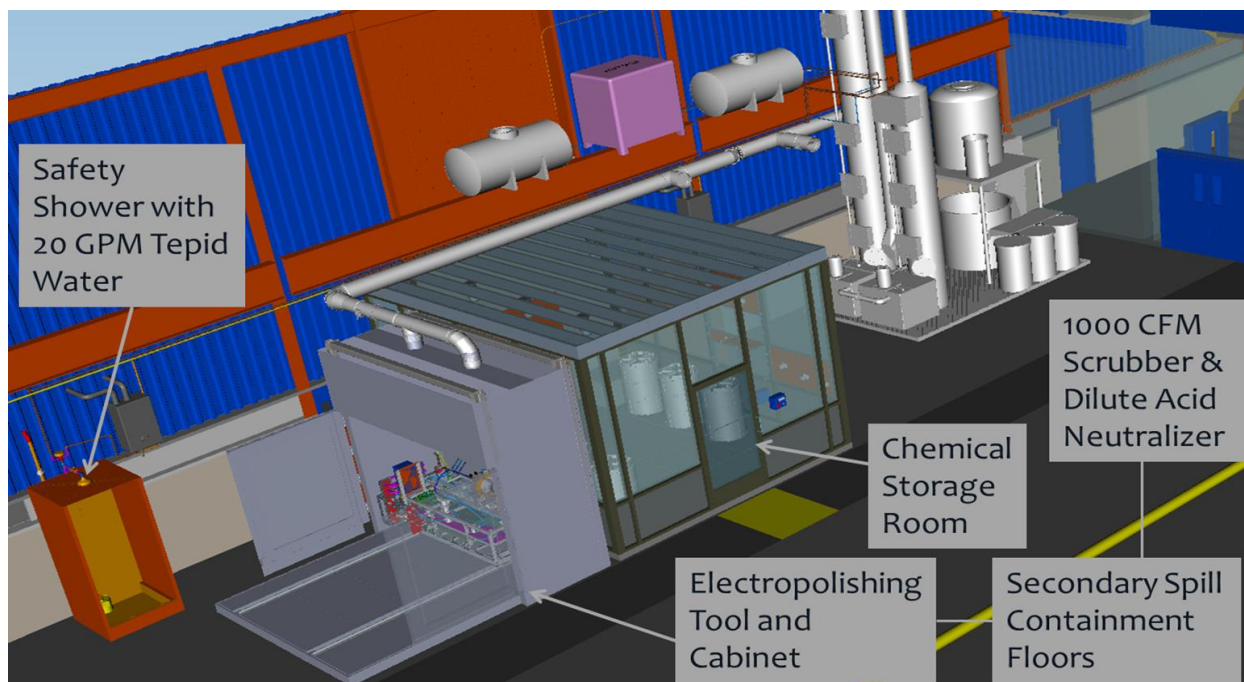


Figure 5: General layout of chemistry area highlighting safety features.

1000 °C VACCUM FURNACE

A recent addition to the CPL is the 1.3 GHz cavity vacuum furnace seen in Fig 6. The furnace is used to degas hydrogen from cavities during an 800°C bake cycle. Since the furnace was installed at the end of 2010, 11 single cell cavities and 5 nine-cell cavities have been baked. The 2-3 hour 800C plateau heat treatment typically reduces the partial pressure of hydrogen inside the oven by at least two orders of magnitude. No cavities that have received heat treatment in the furnace have shown Q disease thereby proving the effectiveness of the oven at hydrogen removal.

A typical recipe consists of pumping the chamber to a vacuum pressure of less than 5×10^{-5} Torr within two hours at room temperature. Then a vacuum pressure rate of rise measurement is taken to determine if the chamber has a leak. The heat is then switched on raising the chamber temperature 10°C per minute. Once the chamber and cavity reach a temperature of 800°C, the cycle holds the temperature at $800^\circ\text{C} \pm 5^\circ\text{C}$. The soak lasts up to 3 hours depending on the prior cavity processing. During the 800°C soak, the chamber pressure typically begins at 1×10^{-5} Torr and is reduced by an order of magnitude by the end. At the end of the soak, the heaters turn off and the furnace is left to cool under vacuum. The end of the cycle is reached once the chamber and cavity reach 50°C. Argon gas is used to backfill the chamber to bring it up to atmospheric pressure.

At any time during the cycle, if the total pressure rises above 1×10^{-4} torr, the recipe goes into hold until

the total pressure is pumped down to less than the 5×10^{-5} Torr. Hydrogen outgassing peaks when the chamber reaches approximately 600°C and drops approximately two orders of magnitude by the end of the 800°C plateau.



Figure 6: 1000 C vacuum furnace.

The chamber can accommodate two single cell cavities or one nine-cell cavity. Two cryopumps are attached to the chamber that gives a net pumping speed of 4800 L/sec air. A dry roots pump provides rough pumping capability. During the furnace operation, RGA measurements of the partial pressures are recorded. A full spectrum of 1-100 amu is recorded every minute. Cold cathode gauges provide pressure readings. The maximum allowed operating temperature of the furnace is 1000°C. The heating elements are 2-inch wide molybdenum strips which surround the hot zone. Six layers of molybdenum make up the thermal shields. Chilled water kept at 70°F keeps the outer surface of the dual-walled chamber cool to the touch during operation.

CLEANROOM & HPR OPERATION

The CPL cleanroom infrastructure occupies a 9 meter by 14.5 meter footprint in southeast corner of Industrial Building 4 in Fermilab's Industrial Building Complex (Orange area in the bottom right corner of Fig 1.). All major components necessary to effectively clean and prepare 1.3 GHz elliptical SRF cavities for performance testing reside within this small footprint.

Originally designed to accommodate one-cell 1.3 GHz R&D cavities, the facility has been adapted to accommodate nine-cell 1.3 GHz cavities as well as 650 MHz one-cell cavities. In the near future, additional tooling will be developed to accommodate 650 MHz five-cell cavities of both 0.6 and 0.9 Beta designed for Project X.

The primary processing capabilities of the cleanroom area include SRF cavity high pressure rinsing (HPR), ISO Class 4 (class 10) cleanroom assembly, ultrasonic cleaning, hardware preparation and slow cavity evacuation and venting.

Cleanrooms

The cleanroom arrangement consists of three nested cleanrooms with the largest being a 14.5 meter by 5.5 meter ISO Class 6 cleanroom containing a 3.7 meter by 2.4 meter ISO Class 5 and a 3.8 meter by 3.8 meter ISO Class 4 cleanroom. Fig 1 shows the arrangement of these three cleanrooms with the ISO Class 6 cleanroom shown in orange, the ISO Class 5 cleanroom shown in red and the ISO Class 4 cleanroom shown in yellow.

The ISO class 6 cleanroom contains general cleaning infrastructure including large heated ultrasonic degreasing and rinsing tanks sized to accommodate 5-cell dressed 650 MHz cavities. The ISO Class 5 cleanroom is used to pre-clean all cavity hardware and tooling prior to entry into the ISO class 4 cleanroom. Personnel gowning also takes place in the ISO class 5 cleanroom for work performed in the ISO class 4 cleanroom.

The ISO class 4 cleanroom contains the High Pressure Rinse (HPR) tool, clean cavity assembly and handling hardware, and the connection to the UHV and venting system. Fig 7 shows a view into the ISO Class 4 cleanroom.



Fig 7: ISO Class 4 cleanroom with HPR tool.

HPR System

The HPR System, seen in Fig 8, is an adaptation of the ANL/FNAL SCPSF HPR tool that was originally designed based on an HPR tool used at Cornell University [7,9].



Figure 8: High pressure rinse tool.

This style HPR tool has a rotating wand and a vertically translating cavity. The wand is mounted to a rotating turntable that spins at approximately 2 RPM. The cavity and support frame are mounted to a Bosch-Rexroth linear actuator that moves at a pre-programmed translation rate. The standard vertical translation rate used in the CPL and at the ANL/FNAL SCSPF is approximately 6 mm/min. A three-pass rinse is considered a complete rinse cycle. All HPR System operations are PLC controlled and operated via remote control.

Two opposing fan-style spray nozzles are mounted to the end of the rotating wand pointed orthogonal to the cavity translation direction. The nozzles used for 1.3 GHz cavities are Spraying Systems Inc. part number 1/8MEG-4002 which has a 40 degree spraying angle and a flow capacity of approximately 4.5 l/min/nozzle.

The CPL high pressure rinse system employs a LEWA double-diaphragm high-purity pump capable of 1500 psi continuous delivery of UPW water at up to 19 liters/minute. This style pump is used in multiple SRF cavity processing facilities including the ANL/FNAL SCSPF.

UPW System

Ultrapure water (UPW) is supplied to the facility via reverse osmosis-based purification plant that utilizes multi-staged de-ionization mixed beds, ultra-filtration and UV sterilization. The UPW system has 2300 liter storage capacity with a continuous water make-up rate of 17 l/minute. UPW circulates at 2.8 bar gauge pressure throughout the cleanroom footprint. The water typically has a resistivity of better than 18 Mohms.

UHV Dry Pumping Station

Maintaining a particle-free cavity following the HPR cycle is critical to mitigating field emission (FE) in high-gradient cavities. In addition to particle-free flange assembly techniques, evacuating and venting cavities in a slow and clean manner is required to achieve FE-free cavities. Slow evacuation is controlled via a Brooks Instrument mass flow controller that allows controllable pressure drop of 1-50 mBar/minute from atmospheric pressure to 1 mbar absolute. Figure 9 shows a photo of the CPL vacuum and venting system.



Figure 9: UHV Dry Pumping and Venting System

SUMMARY

A center for cavity processing R&D at Fermilab, called the Cavity Processing Research Laboratory, is currently in the final stages of installation and commissioning. This facility contains centrifugal barrel polishing, a horizontal electropolishing tool, a 1000°C vacuum furnace, a high pressure rinse tool utilizing ultrapure water, ISO class 4, 5 and 6 clean rooms for cavity assembly work and various other associated pieces of support equipment. All the operations are designed for single cell and nine cell 1.3 GHz Tesla type cavities except for the electropolishing tool which will initially be only for single cell use. Upgrades are currently being examined for single and five cell 650 MHz cavities. Interesting results have already been obtained from the CBP process and it is hoped that additional meaningful results can be obtained as the other processes begin to become fully operational.

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