BCP SYSTEM FOR THE ANL-FNAL SCPF*

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Abstract

FNAL has undertaken an effort to design, develop, commission and operate a system that efficiently polishes the interior and exterior surfaces of superconducting radiofrequency (SRF) cavities using buffered chemical polish. This system was designed for the Joint Superconducting Cavity Processing Facility (SCPF) at ANL for use during the GDE S0/S1 ILC cavity testing programs. The demands of the S0/S1 programs required the development of a pre-industrial type polishing system that ensures operator safety as well as procedure reliability and repeatability. The BCP System design methodology and technical details are presented, including a discussion on the control system design and philosophy. The BCP System's safety features, ancillary hardware, and operational scope are also described.

INTRODUCTION

A collaboration between Fermi National Accelerator Laboratory (FNAL) and Argonne National Laboratory (ANL) was established to develop and operate a complete superconducting radio frequency (SCRF) cavity processing and clean assembly facility located at ANL (Figure 1) [1]. This collaboration utilizes ANL's existing management infrastructure for chemical facilities and divides resources equally between FNAL and ANL to facilitate construction, operation, and maintenance of common infrastructure. Each laboratory is responsible for its own portions of the facility but collaborates closely on shared elements.

Subsequent to the ANL/FNAL collaboration formation and the initial design of the SCPF, the International Linear Collider (ILC) Board Task Force on High Gradients (S0/S1) determined that a regional approach is required to address ongoing difficulties of achieving high yield in ILC cavity performance [2]. The Task Force determined that the SCPF at ANL will play a significant role as one of the processing outposts of the GDE Americas region for ILC cavities [3]. Therefore, the scope of the SCPF was redefined to meet the ILC surface processing requirements and to function as one of the critical Global Design Effort (GDE) Americas facilities for the S0/S1 ILC cavity processing and testing program.

To accommodate all surface processing requirements for ILC cavities, several integral components must be included in the SCPF at ANL. These instruments must perform the following tasks: buffered chemical polishing (BCP), electropolishing (EP), pre-cleaning, high pressure rinsing (HPR), and clean component assembly. Both groups share a pre-cleaning or ante-room area but maintain separate cleanrooms for HPR and particle-free assembly. ANL has developed an EP system and FNAL a separate BCP system in their respective chemical rooms.

This paper covers topics related to the design and commissioning of the FNAL BCP System. Design objectives, which include operator safety considerations, control system design philosophy, and system capacities are presented. Additional hardware required to process ILC cavities ancillary to the BCP system is also described.

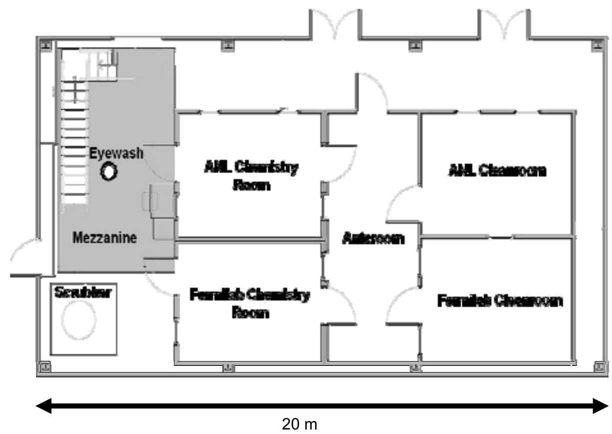

Figure 1: Layout of SCPF at ANL Bldg. 208

DESIGN OBJECTIVES

Background

To achieve high accelerating gradients in niobium SRF resonators, the damaged surface layers must be removed. In the S0/S1 program, there are two standard methods of damage layer removal: EP and BCP. The EP and BCP material removal processes have been extensively described in numerous publications [4,5,6,7,8]. EP and its role in the Joint SCPF at ANL will be presented at a later date.

The chemistry, as it relates to the SCPF BCP system is described in [9]. To summarize, BCP is a mixture of 49% HF, 69.5% HNO_3, and 85% H_3PO_4 in a ratio of 1:1:2 by volume. When introduced to the ~1m^2 1.3 GHz 9-cell ILC niobium cavity surface at a temperature of 12C, approximately 1 kW of heat is released. This heat must be removed with cooling water by conductance through the cavity wall on the opposite side of the reaction. At a 12C reaction temperature, the BCP removes approximately 1 μm/min of niobium from the cavity surface. This target temperature provides a convenient metric to gauge total material removal for a given process. Though the process parameters are fairly straightforward, the control of all mechanics and the reaction temperature in a safe and repeatable way is best accomplished by a formally developed control system.

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A description of the original controls system for the BCP system is covered in [10]. The modifications and improvements to the original control system have been implemented and are presented in this paper.

The BCP System for the ILC S0/S1 processing program will be primarily used to remove the contaminants on the outside cavity surfaces to prevent fouling of the interior surfaces during the hydrogen degasification bake cycle. Until large grain and single-crystal cavity production matures, the relevancy of processing the inside surfaces of fine-grain ILC cavities for vertical performance testing at very high fields (>25MV/m) is limited due to the BCP quench field limit well below that of EP. However, BCP processing on large-grain and single crystal cavities has shown great promise as a replacement for EP [11]. The BCP System will play a significant role in proving whether multi-cell large-grain or single crystal cavity processing can eliminate EP from the processing sequence. For the near future, the role of the BCP System will be to provide external surface polishing of S0/S1 cavities and internal polishing on other 1.3 GHz cavities not in the S0/S1 program.

Industrialization

One of the BCP System's fundamental design precepts was to build a tool with features attractive to industry. High volume cavity surface processing will need tools that are safe and easy to use with robust design which allow quick change between operations. The BCP System design accomplished these goals by focusing on operator tooling and controls system. These features are easily duplicated in any BCP System constructed in the future.

The BCP System design is modular in that many shapes and sizes of cavities can be processed without making modifications to the BCP System itself as long as the processed surfaces are within the capacity of the system. Each cavity type requires its own tooling (jackets, holding fixtures, etc.), but the connections to the BCP System and the method in which the process takes place are the same.

Safety

Processes that use concentrated HF require extreme user caution and tight procedure control. At ANL, a formal safety program at the SCPF has been implemented that dictates proper HF handling techniques, appropriate personal protective equipment, and emergency response procedures. Any operation utilizing HF or other concentrated acids must obey the approved SCPF umbrella safety documents. In addition to the umbrella safety documents, setup, operation, and shutdown procedures are all controlled via checklist. This checklist ensures all proper precautions specific to the procedures are taken.

The BCP System was designed to limit the BCP (HF) handling and contact opportunity to an absolute minimum. At no time does an operator physically manipulate the BCP other than when rolling BCP supply drums enclosed in secondary overpack containers. During routine operation, the only opportunity for contact is during fitting disconnection after a procedure. All fluid (BCP, cooling water, dilute waste) manipulation is performed by safety and implementing uncomplicated flow mechanics,

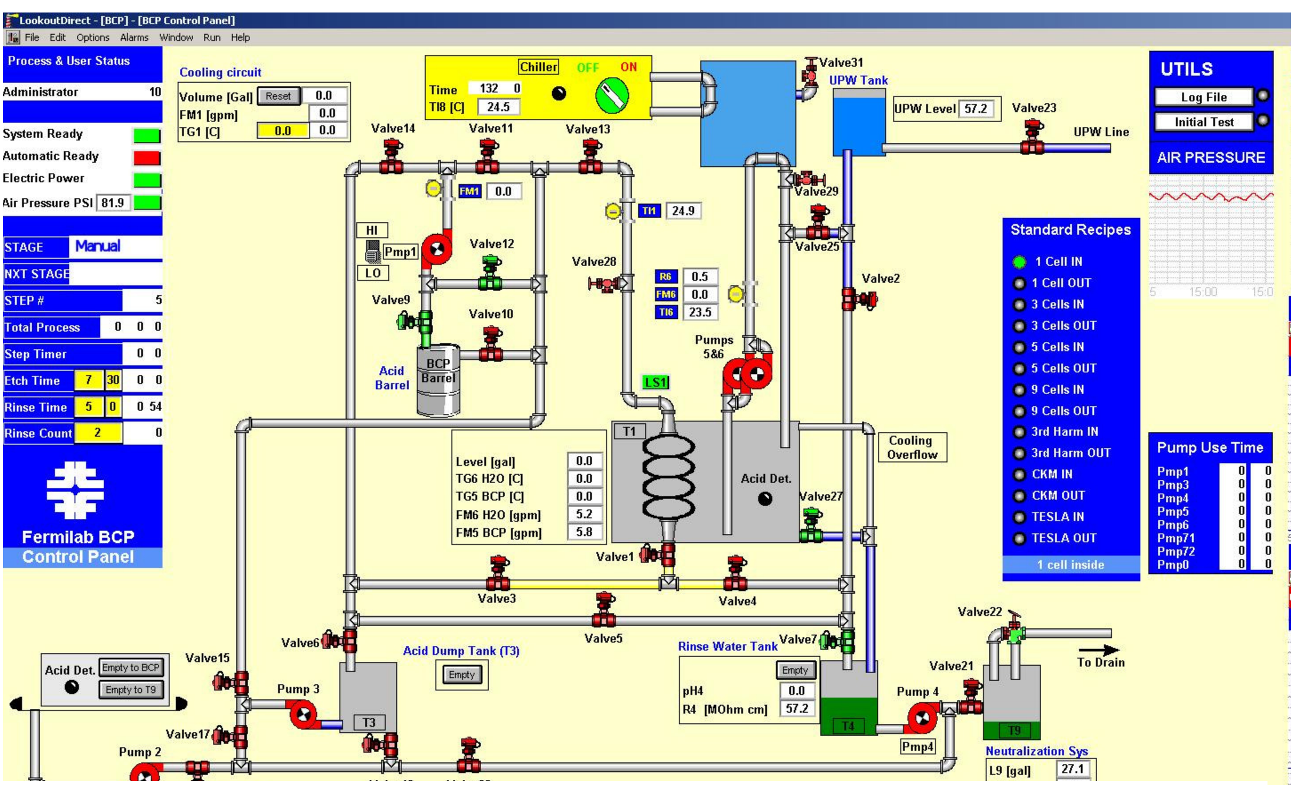

Figure 2: BCP System flow schematic. Operator GUI screen capture.

programmable logic controller (PLC) controlled flow mechanics. Should leaks in the plumbing occur, all likely areas reside within secondary containment.

Operator exposure to dilute waste is also extremely limited. All dilute waste generated during a procedure is neutralized and pumped to a drain by an automated neutralization system. Operator involvement in a procedure is limited to connecting the cavity to the BCP System, stinging BCP drums, and running the procedure remotely from a control center located outside the chemistry room.

Process Control

The fluid flow mechanics are required to handle BCP, ultra pure water for rinsing and cooling, and dilute waste simultaneously. Expecting an operator to manipulate these fluids with numerous valve openings and closings and pump activation and deactivation while monitoring several sensors is unreasonable in a process that is sensitive to so many variables. Therefore, a PLC and software interface with a PC was chosen to perform these operations. An operator is expected to key into the interface the procedure to be performed, move the processes from one step to the next, and verify that the control system is responding to all sensors as needed.

DESIGN DETAILS

BCP and Neutralization Systems

The fluid mechanics are divided into separate subsystems for BCP and cooling water flow. The BCP System flow schematic is shown in Figure 2 with the cooling water loop shown on the right and the BCP loop on the left. The separate loops do not share like plumbing which prevents inadvertent mixing of acid and water. The subsystems meet at the cavity/jacket but are separated by the resonator wall. The cavity is enclosed in an etching jacket and connected to five separate lines: BCP supply and return, cooling water supply and return, and cooling water overflow.

The water cooling loop receives water from a gravity feed tank which is automatically pre-filled before a procedure begins. The cooling loop includes plumbing and pumps between a heat exchanger and the etching jacket. The water flows on the opposite side of the etch process thereby removing the reaction heat. The reaction heat carried away by the water is removed from the cooling loop in a plate and frame heat exchanger. An external chiller supplies the heat exchanger with 6C to 10C chilled water. This double heat exchange arrangement prevents acid from escaping the chemistry room to the primary chiller in the event of a leak between the etching jacket and cavity.

BCP is supplied to the process via direct pumping from a pre-cooled drum. The BCP flows from the supply drum through the cavity and back to the drum. At the conclusion of the etching process, the BCP in the cavity and system plumbing flows into an acid dump tank which resides below the process. The acid is immediately pumped into the process supply drum. Once the cavity is free of BCP, ultrapure water (UPW) from the gravity feed tank flushes through the system thereby rinsing the cavity and all lines that carry acid. The dilute waste generated dumps into a dilute waste tank next to the acid dump tank. The rinse cycles continue until the dilute waste reaches a pH of 4 or higher as measured by a pH sensor located in the dilute waste tank. All of the dilute waste is pumped from the tank to the automated neutralization system.

The neutralization system contains a 95 gallon storage tank, 10 gpm recirculation pump, and metering pump that doses liquid NaOH into the tank. Redundant pH sensors in line with the recirculation pump communicate with the PLC which 'tells' the metering pump to dose caustic into the tank until the pH of the dilute waste is above 5 – a level safe to dump into the ANL sewage system. No concentrated acid is neutralized.

All materials used to construct the BCP and neutralization systems are approved for HF handling. PVDF, Teflon, fluorinated Viton, and PFA are common materials suitable for HF. Where possible, bead and crevice free PVDF tube welding was employed to minimize the number of fittings. All valves and pumps are certified for HF as well as other acids.

The BCP System is shown in three photos in Figure 3 as installed. The left photo is the neutralization system and its secondary containment. The center photo shows the BCP system and PVC test vessel. The right photo shows local ventilation hoods installed to capture process fumes released at the BCP supply drum that resides beneath the hood openings.

Figure 3: Neutralization system, BCP System, and ventilation ductwork.

Ventilation System

Removing process fumes (NO_x, HF vapor) is critical to safe operation. The ventilation system was designed to capture fumes at the source, or potential source in the case of leaks. All plumbing and vessels are located in a large frame covered by a Lexan skin. The Lexan skin forms a fume hood with the draft created by a large suction manifold located at the top surface of the frame. The BCP System plumbing was enclosed in a fume hood not to capture process fumes but to gather fumes from possible leaks. Should a leak occur, an operator can safely neutralize it without the risk of fume exposure.

The process fumes are released at the supply drum. Since the acid loop is sealed except at the drum stinger ports, all fumes will escape from the ports rather than at the reaction location. Localized hoods at the surface of the supply drums remove the process fumes and give the operator a safe location to open overpacks and sting BCP drums.

The last direct fume removal locations are at the acid and dilute waste tanks. Direct venting of these tanks keeps the chemistry room fume concentration well below what is allowed for safe entry even if a leak occurs.

All fumes removed by the ventilation system are treated in a 3000cfm scrubber that services both SCPF chemistry rooms. When necessary, 90% of the scrubber capacity can be locally channeled to any of the duct locations in the chemistry room.

Control System

The control system operates and monitors 26 valves, 6 pumps, 6 pH sensors, 5 flow meters, 5 temperature gauges, 2 resistivity sensors, and 4 level indicators. A PLC with a PC graphical user interface (GUI) monitors all sensors and manipulates the pneumatic valves and pumps during a procedure. Though the BCP procedure is uncomplicated, the amount of hardware required to perform the mixing, etching, and rinsing operations is substantial. A PLC provides the most reliable means to perform all systematic monitoring operations.

An etching procedure is divided into several main steps. These steps are BCP mixing, filling, polishing, and rinsing. A semi-automated controls approach cues the operator to move to the next process step upon completion of the prior operation. This approach allows the operator to monitor the progress of each step without having to worry about the pump and valve actuation sequence. The PLC 'watches' all sensors and informs the operator of system status via the GUI. All sensor data is logged and time stamped to include in cavity travelers and for future reference.

Should a problem in the procedure occur, the PLC is programmed to not only respond to the problem, but also inform the operator of the error. The operator always has the option of hitting a hard-wired manual override stop button that automatically dumps the acid into the acid dump tank. The control system is insensitive to power outages or loss in air pressure. Redundant power supplies and backup compressed air tanks were implemented to prevent lengthy procedure stoppages during failures of either of these systems.

A recipe format was adopted to facilitate processing a variety of cavity types and sizes with the BCP System. Each cavity type and procedure length as well as other parameters are defined in the recipes. At the beginning of a procedure, the operator chooses or modifies a recipe and the PLC will run the step routines accordingly.

Ancillary Hardware

Bare cavities cannot be processed with BCP without special hardware. The hardware designed and fabricated for use in the SCPF includes two etching jackets (outside and inside) for 1.3 GHz 9-cell ILC cavities, a chemically resistant transport cart, and handling tooling that grabs the etching jackets.

The etching jackets are an interface between the BCP System and the cavity. The jacket acts as a container that protects the cavity as well as provides a means to cool the process during a polishing procedure. The jackets are constructed primarily of PVDF and sealed with Viton o-rings. The jacket is installed vertically and held together with De-Sta-Co style clamps. Sanitary quick-type clamps are used to make all fluid connections. A 3-D image of the outside surface etching jacket is shown in Figure 4.

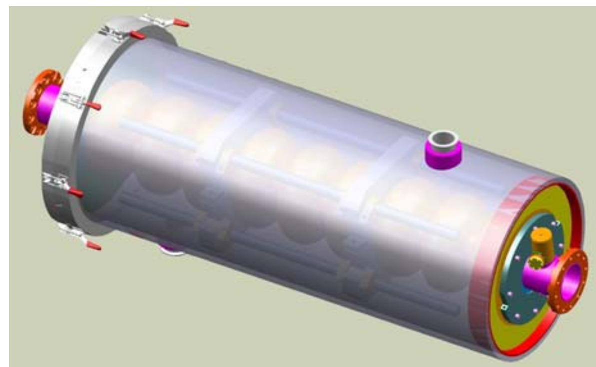

Figure 4: 1.3 GHz 9-cell cavity outside etching jacket.

A chemically resistant transport cart with 500lb capacity was specified and purchased. This cart is capable of hoisting a 9-cell ILC cavity installed in an etching jacket filled with water and BCP. Tooling that allows the cart to grab the cavity and jacket was designed and is currently in production. The cavity transport cart and tooling are shown in Figure 5.

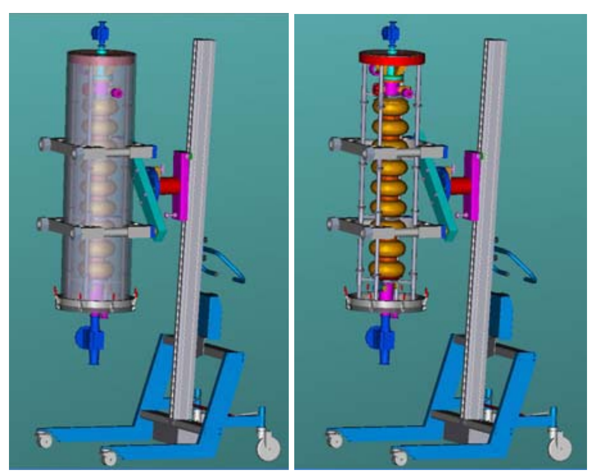

Figure 5: Transport cart holding cavity with and without etching jacket.

CONCLUSION

BCP processing at the SCPF at ANL is nearly a reality. The BCP System is designed and assembled and being commissioned. The control system and recipe programming for 9-cell ILC cavities is nearly complete. The last remaining hardware is in procurement and will be arriving shortly. With all developmental elements converging simultaneously, the only remaining hurdle is the ANL safety review that will cover the operation of the BCP System. A successful safety review will give the Joint SCPF a full cadre of chemistry capability.

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