LOW-BETA SRF CAVITY PROCESSING AND TESTING FACILITY FOR THE FACILITY FOR RARE ISOTOPE BEAMS AT MICHIGAN STATE UNIVERSITY *

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Abstract

Major work centers of the new SRF Highbay are fully installed and in use for FRIB pre-production SRF quarter-wave and half-wave resonators, including inspection area, high temperature vacuum furnace for cavity degassing, chemical etching facility and processing and assembly cleanrooms. Pre-production activities focus on optimizing workflow by reducing process time, tracking part status and related data, and identifying bottlenecks. Topics discussed may include; buffered chemical polish (BCP) etching for cavity frequency control, degassing time reduction, automated high pressure rinse, particle control against field emission, pre-production cavity test results and implementation of workflow status program.

INTRODUCTION

The FRIB project is now in pre-production cryomodule fabrication and assembly phase. A new low beta cavity processing and testing facility has been installed to support building 48 coldmasses that contain a total of 332 cavities [1]. The first pre-production coldmass consists of eight β =0.085 quarter-wave resonators (QWR) and three 50 cm 8 Tesla solenoids. The second pre-production coldmass consists of eight β =0.53 half-wave resonators (HWR) and one 50 cm 8 Tesla solenoid. The baseline workflow has been established (Fig. 1) however, feedback from pre-production is valuable to optimize workflow and techniques for production.

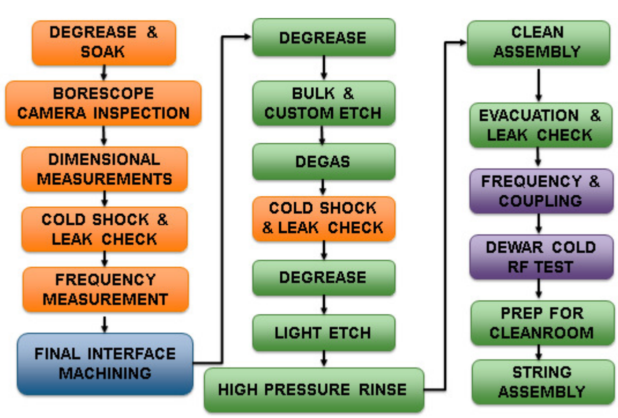

Figure 1: Production cavity workflow.

FACILITY GENERAL OPERATIONS

The SRF Production Floor is fully implemented and in use. The facility includes a receiving and tagging station, rack storage and kitting area to support production inventory control and assembly. Individual work center boards and a main electronic dashboard are installed and actively used to track cavity work flow through the facility work stations.

The SRF staff complete a comprehensive SRF Production Floor training which includes FRIB Leak Detector and Vacuum Equipment Standardization, SRF Coldmass Workflow, Coldmass Component Handling, SRF Department Quality Control Workflow, 5S Training, E-Traveler System, and General Cleanroom Training. Shoe covers are donned upon entering the SRF Production Floor to reduce contamination.

CAVITY ACCEPTANCE PROCESS

An SRF Cavity Vendor Risk Management and Quality Assurance Plan has been documented. The plan defines the strategic cavity workflow prioritization. The Acceptance Criteria Listing (ACL) is immediately performed upon cavity delivery (built-to-print procurement acceptance). The strategic priority rank on cold vertical tests is listed below:

1. Vendor qualification: first cavity of each type and first cavity delivered from each new vendor
2. Vendor mass production needs: cavities used for frequency validation
3. Critical path needs: cavity tests needed to meet FRIB master schedule near or on critical path
4. Quality monitoring: at least every 1 of 8 incoming cavities from each vendor

If a cavity fails a certification test a root cause must be identified, and prioritization made to continue sequential cavity tests from the same material lot and/or fabrication lot. All cavities (100%) are planned to be cold vertical tested before coldmass assembly, and 100% of cryomodules tested before tunnel installation.

As of September 1st 2015, a total of 43 FRIB cavities have been received [2]. The cavity status dashboard is updated each morning and allows personnel to easily see router status and cavity location. All β=0.041 cavities have

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been received for a total of 19, twelve β =0.085 cavities, three β=0.29 and nine β =0.53 cavities have been received.

Acceptance Criteria Listing Details

The acceptance criteria listing or ACL, shown in Table 1, is a list of quality checks to ensure the cavity meets mechanical and quality specifications.

Table 1: Acceptance Criteria Listing

Task
Ultra sonic clean degrease
Water soak
Borescope camera inspection
Dimensional Measurements
Frequency measurement
Cold shock
Leak check

Two unique inspection tasks for these particular cavities include internal inspection and drift tube alignment measurements. A borescope camera, is used to view inside the difficult to access geometry of the half-wave resonators. The 6.1 mm optical tip video camera is used to record video of the internal RF surfaces and all electron beam welds. A detailed video (20-40 minutes) of each cavity is recorded and documented with the inspection record. The beam line aperture alignment dimensions are achieved using a gantry coordinate measurement machine tool with a total probe length of 28.5 cm. The probe extends into the quarter wave and half wave resonators to indicate the beam ports and drift tube ports with an 18 mm ceramic sphere, allowing for high precision measurements.

DIFFERENTIAL ETCHING FOR FREQUENCY TUNING

The new chemistry facility has been operational since November 2014. State-of-the-art chemical process equipment was installed for safe and reliable performance with user friendly human machine interface (HMI), sophisticated controls, safety interlocks and alarms implemented to eliminate exposure to buffered chemical polish acid and toxic chemical vapors [1]. Each FRIB cavity type (Fig. 2) has been processed and production tooling commissioned. Over 70 cavity etches have been performed and 20 tuning plate etches since the new facility was installed. One important feature of the cavity etch cabinet is the rotational fixture with mounting plate to allow for full cavity rotation. Each FRIB cavity type has a custom set of acid input and acid exit quills for bulk/light etch and custom etching. The inlet quills are designed to optimize flow and velocity to improve removal uniformity.

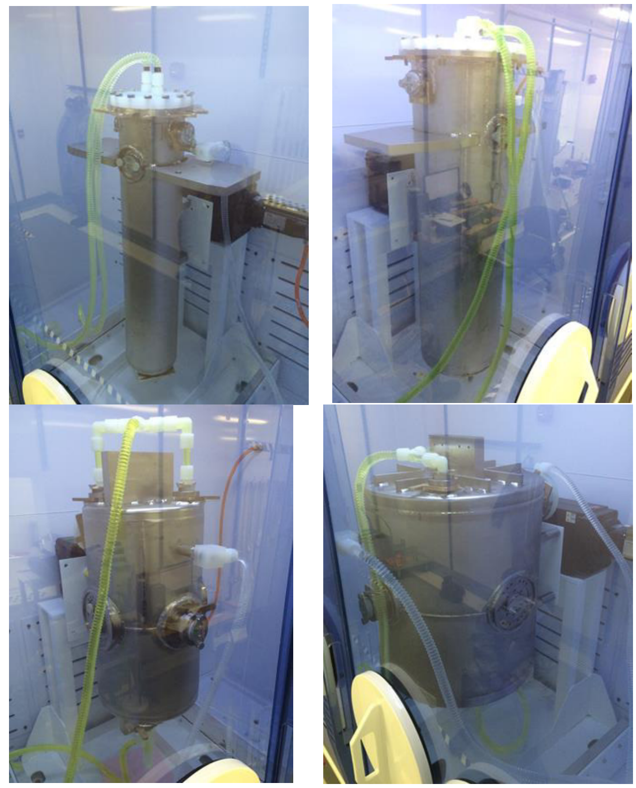

Figure 2: Etch configuration for each FRIB cavity type.

Custom or differential etching is chemical etching in a specific area of the cavity to shift the frequency up or down for tuning. Differential etching was successfully performed on β=0.085 cavities for the ReA3 project [3] and has been successfully performed on at least one of each FRIB cavity type in the new facility [4]. The etching variables have been determined and provide repeatable and reliable tuning. The frequency is measured before and after custom etching and a plot of microns removed versus shift in frequecy is developed for each cavity type (Fig. 3). The custom etching step is applied as needed for tuning but not necessarily required for all cavities.

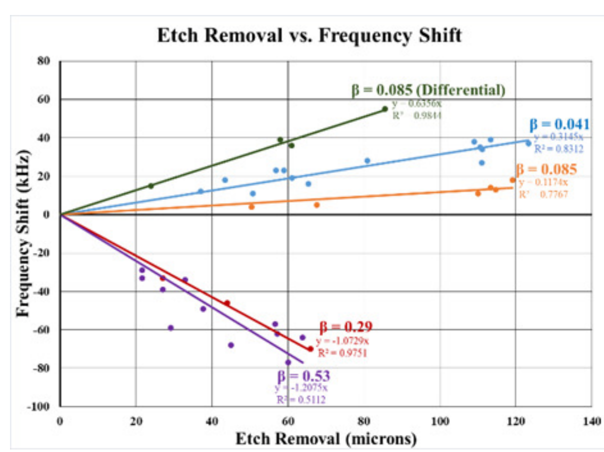

Figure 3: Etch removal versus frequency shift for each FRIB cavity type [4].

PRODUCTION HEAT TREATMENT

The risk of Q-disease is eliminated by implementing a hydrogen degassing step after bulk and differential chemistry. All FRIB cavities are fired in the high temperature vacuum furnace (Fig. 4) starting with a soak at 350ºC for 12 hours and then ramping to 600ºC for 10 hours. The vacuum pressure is kept around 1x 10^{-5} torr. The lower temperature is used to avoid annealing and subsequent movement of the quarter wave inner conductors. The cavities are degreased and completely dried before installation into the furnace which is located in a clean zone. Custom designed tooling will allow for two FRIB cavities, of any type, to be degassed in the same run. This allows for up to 6 cavities per week to be degassed. Since recommissioning the furnace in the new facility 16 cavities have been treated.

The total treatment time was reduced by beginning the nitrogen purge cycle at a higher temperature, which cut 10 hours off the total time. Reduction of soak time at 350 ºC is being investigated and could potentially save another 5 hours.

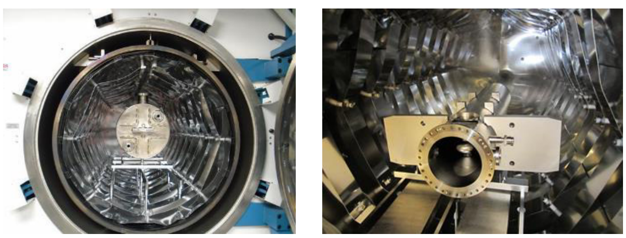

Figure 4: HWR and QWR installed into furnace.

AUTOMATED HIGH PRESSURE RINSE

Multiple cavity geometries are required for the FRIB project and require a versatile and flexible high pressure rinse (HPR) system. The half-wave resonators have been specifically designed with two ports on each end for cleaning and processing access. Quarter-wave resonators have one demountable bottom flange for access to the RF surfaces (Fig. 5).

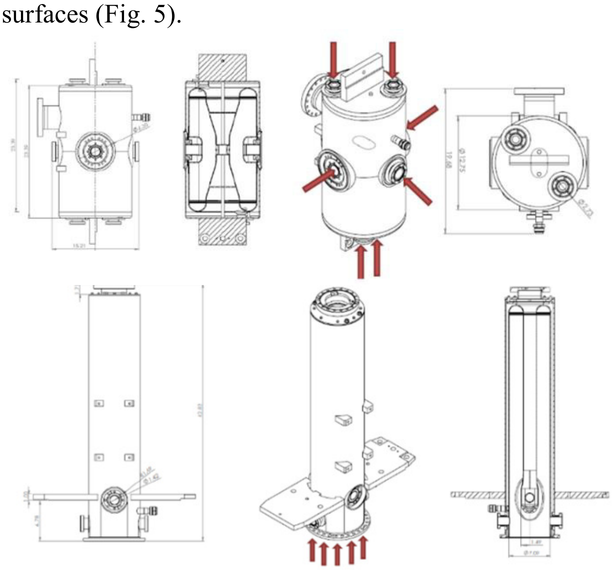

Figure 5: Cleaning access for HWR and QWR.

An automated robotic high pressure rinsing tool has been designed and procured. The robotic system is an improvement over present techniques and has great potential to reduce processing time and labor requirements. The novel approach utilizes real data from dimensional inspection for each serialized cavity to perform a custom automated process. The new system will be installed in the HPR work center in the SRF cleanroom (Fig 6).

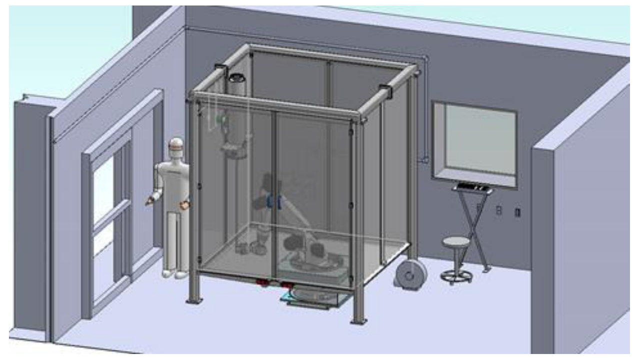

Figure 6: Layout of HPR cell in cleanroom.

In order to accommodate manufacturing variances in SRF cavities, some of which have ports with deviations in the true position of more than 0.5 in (1.27 cm), an offset to the robotic high-pressure rinse will be implemented. The FRIB controls group and inspection team were consulted to verify that the cavity port data obtained from the coordinate measuring machine (CMM) is capable of outputting a file format compatible with the robot control system.

In order to ensure the robotic high-pressure rinse system operation, it was verified that the robot could be programmed to run its rinse cycle with very minimal operator intervention. Full robotic computer simulations have been performed for each cavity type (Fig 7). During initial cavity inspection the dimensional measurements are recorded on the CMM gantry and a data file exported in a '.txt' or '.xls' file format to an internal directory.

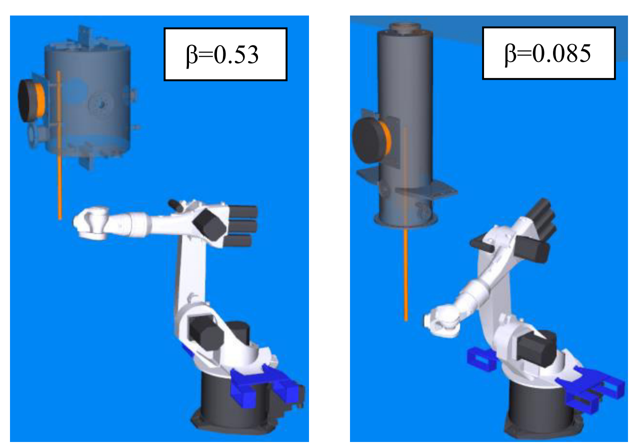

Figure 7: Simulation of robotic HPR system.

During final processing, once an etched cavity has been loaded into the rinse cell, the appropriate dimensional file

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will be uploaded to the high-pressure rinse HMI. The offsets from the file will be incorporated with the operational recipe. The robot will perform a preliminary alignment verification step. The arm will go to each port in succession, and will project a laser crosshair on the port opening. The operator will verify that each port is aligned properly, and will confirm one-at-a-time that the offsets are correct on the HMI by pressing a checkbox. Once all port orientations have been verified, the automated high-pressure rinse program will begin to run. The cavity can be left alone for the remainder of the rinse cycle, and can be removed from the cabinet to be dried once the cycle is complete.

The wand nozzle assembly penetrates in and out of the cavity port based on a predefined program and the nozzle assembly oscillates 45-90 degrees. This delivers the 1200 psi (83 bar) high pressure ultra pure water to interior RF surfaces. The cavity remains stationary while all movement is provided by the robotic arm therefore reducing contamination and handling risks involved with moving the large low beta cavities.

The automated system will eliminate almost all alignment fixtures, reduce risk of contamination and human touch labor.

PRODUCTION TEST STANDS

Vertical test stands are used to mount, evacuate and perform cold RF testing of each cavity, for certification, prior to coldmass installation. Five inserts are planned to meet the production cavity-testing schedule in the SRF Highbay. The FRIB cavities are fully fabricated at the testing phase including full helium jacket. The testing configurations (Fig. 8) utilizes the cavity helium vessel as would be done in the cryomodule the helium fill connected to the helium vessel and the cavity vessel is filled with liquid helium which then overfills into the header space. The configuration is more efficient and faster than the common method of dunk testing, mostly performed on undressed cavities. The Dewar space around the cavity is evacuated to about 1 x 10^{-5} torr to provide insulating space around cavity vessel.

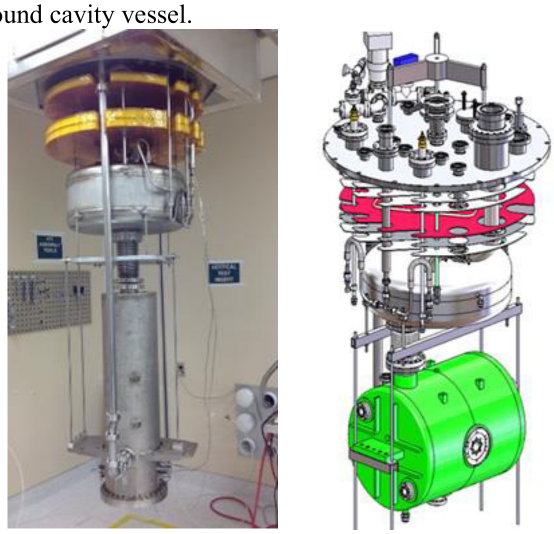

Figure 8: FRIB production insert design.

The inserts are versatile to interface with the four FRIB cavity geometries. Two existing inserts have minor alterations to interface with the new facility infrastructure, which includes a lower profile total lid height to enable fit under the Dewar shield blocks. Two insert designs will be used during testing; insert number two is a legacy design that has full capabilities for certification testing and insert four style has the capability to include integrated coupler testing. Small changes were made to the insert four design for future inserts to include a larger header. The insert four design will simplify the cavity mounting process to use the same vacuum components for each cavity type.

The insert has a 56 liter liquid helium header made from stainless steel which is hung from three G10 rods for the 44” (111.8 cm) diameter lid. The female bayonets are interchangeable at the underside connection. The pressure relief of the helium system is adequately sized for one cavity of any FRIB type. Between the top lid and helium header are a series of shielding discs including mu metal magnetic shielding, copper liquid nitrogen shield and copper coated G-10 disc insulation. The cavity is mounted directly below the helium header with adapter bars. The clean vacuum manifold mounted to each lid has full range vacuum measurement provided by a thermocouple gauge and a cold cathode gauge, an 81 l/s turbo molecular pump and over pressure event burst disc. The clean vacuum manifold is designed to work with the Dewar shielding blocks and the slow clean pump and purge cart. To simplify the clean vacuum manifold on the lid only the minimum components are included on the lid, most of the diagnostics are part of the stand-alone clean pump cart. This strategy reduces cost and assembly time. All materials under the lid are non-magnetic and checked for residual field before installation.

CLEANROOM ASSEMBLY

Cleanroom assembly techniques have been established for FRIB coldmass assembly. Verification of clean particle free surfaces is performed prior to final closure assembly. Surface particle counts are done with a tool that displaces particles on the surface using pressurized air and then vacuums them into a laser particle counter. The method is automated and repeatable. A similar function is achieved with the use of pressurized filtered nitrogen gas and a hand held particle counter, however it is not automated. The probe does not touch the RF surfaces but hovers closely to the surface, referred to as the helicopter method (Fig. 9). The counts are performed on all accessible cavity surfaces and vacuum flanges. Surface counts of less than one particle per in^2 at 0.3 micron in size are deemed clean. The documented specification 1246D defines Cleanliness Level 1 as one particle per 0.1 m^2 at 1 micron in size. If higher counts are found then the part is recleaned or processed. Individual cavity tests and horizontal module test results [5] produce no field emission indicating that particle measurement quality control and clean assembly techniques are effective.

Figure 9: Surface particle counts on tuning plates.

In an isolated case, after a purge incident, surface particle counts were performed on a partially assembled cavity to better quantify the amount of particle contamination during such an event. The surface counts were four orders of magnitude larger, in the high electric field region, reaching over 100 particles per in^2 at 0.3 micron. As expected, the test produced x-rays and the cavity is being reprocessed.

The vertical beamline connections are challenging to perform. The clearance space between cavities is 3.6 in (9.14 cm) and the interconnecting bellows is 4.5 in (11.43 cm) at the relaxed length. The flange is at the surface of the helium vessel and incorporates blind tapped holes for connection. The bellows is installed by using an adjustable compression tool to squeeze the bellows to fit into position and then extend to make the flange connection. The copper gaskets are held in place with small pieces of Kapton® tape (Fig. 10).

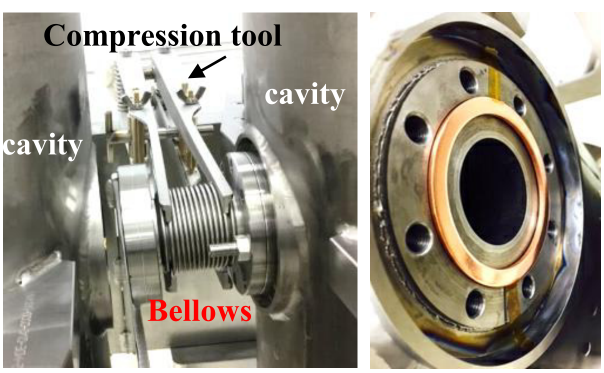

Figure 10: Bellows compression tool (left) and low profile flange with secured copper gasket (right).

Air particle counts are made prior to clean assembly and must be less than 10 particles/ft^3 at 0.5 microns. If counts are higher the source is identified and removed. The major contamination source in the FRIB coldmass assembly are sliding flange connections, particle shed from blind tapped holes and human contamination. The use of Kapton® tape limits the gasket from falling and more easily seats the flange during connection. Moving slowly and downstream of clean parts in the cleanroom limits the effect of human contamination. Personnel are cognizant of body movement during assembly, by avoiding placing extremities near open ports, swift movements or bending down. Clean part placement in custom baskets (fig. 9) is defined so not to reach over clean parts and for repeatable production set-up.

CONCLUSION

Low beta cavity baseline processing and assembly techniques have been applied to FRIB production cavities and all four cavity types have been certified for use in cryomodules. The standard processing procedures in the new facility have been verified and the results shown (Fig. 11) indicate specifications are met with margin.

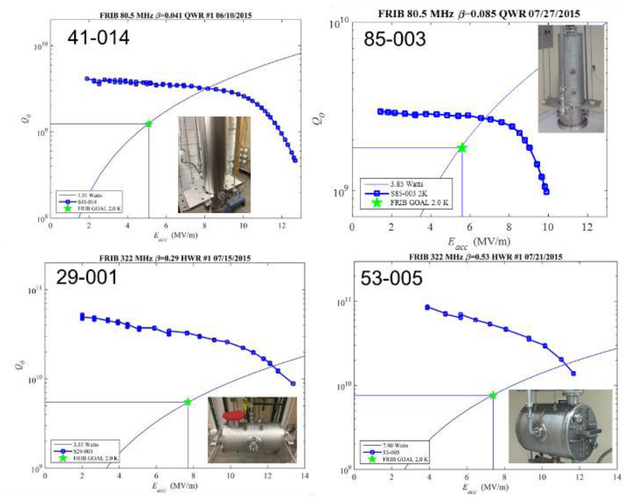

Figure 11: Q_0 vs. E_a for each FRIB cavity type.

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