

QUALITY CONTROL OF CLEANROOM PROCESSING PROCEDURES OF SRF CAVITIES FOR MASS PRODUCTION*

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Abstract

Quality control is a key factor in the SRF cavity mass production. This paper summarizes ongoing research at the facility of Rare Isotope Beams (FRIB) to validate the quality assurance of SRF cavities while optimizing processing procedures for mass production. Experiments are conducted to correlate surface cleanliness for niobium surfaces with high pressure rinse time using $\beta=0.085$ quarter-wave resonators (QWR) cavities. Diagnostic devices, a liquid particle counter, a surface particle detector and a total organic carbon (TOC) analyzer are used to monitor key parameters for quality control. Rinse water samples are collected during high pressure rinsing to measure liquid particle counts. The SLS 1200 Sampler is used to detect the presence of liquid particles of $0.2\mu\text{m}$ and up to $1\mu\text{m}$ to set standards for acceptable cleaning thresholds and optimize high pressure rinse time. The QIII+ surface particle detector is used to scan the high electric field region of the $\beta=0.085$ QWR to ensure high pressure rinsing efficiency. The $\beta=0.085$ QWR RF testing data are analyzed and results are presented to investigate the correlation between attained acceleration gradients and surface cleanliness.

INTRODUCTION

A quality control (QC) system is in place for cleanroom processing of SRF cavities at FRIB. The FRIB QC system embeds diagnostic tools and stringent cavity processing procedures to control particle contamination, increase field emission onset level and attain high acceleration gradients. The e-traveler system is launched to document procedures and to provide a reporting tool for data mining and decision-making. This paper presents the findings of the commissioning and use of the liquid particle counter during the high pressure rinsing process. The paper also focuses on the QC steps for the clean assembly of $\beta=0.085$ QWR, and investigates the potential of predicting the cavity attained gradient (E_{acc}) at field emission onset based on its QC data collected during processing.

QUALITY CONTROL FOR CLEANROOM PROCEDURES

High Pressure Rinsing (HPR)

HPR is a key step that precedes the final SRF cavity assembly for RF vertical testing. HPR is proven the most

effective tool as a final surface treatment to remove particles and to reduce field emission [1]. The FRIB HPR tool for production is still under development. The current HPR tool resides in an ISO5 cleanroom. Cavities are high pressure rinsed by rotating the cavity on a rotary aluminum cylinder flange as illustrated in Figure 1. A stainless steel spray nozzle wand with 8 jets moves in and out from below the rotating cavity. The HPR system utilizes a 3HP CAT pump and a final $0.1\mu\text{m}$ filter; both of which are located outside the cleanroom. The CAT pump pressurizes the ultra-pure water to ~ 8300 kPa.



Figure 1: $\beta=0.085$ QWR on high pressure rinse in ISO5 cleanroom

Ultra-pure Water (UPW) Quality Control

A reliable ultra-pure water system is essential to the successful operation and process quality of the HPR system. The current ultrapure water system is fed by a 7.6 l/m reverse osmosis system (RO). The resistivity of the ultrapure water system ranges between $17.2\text{--}17.6$ $\text{M}\Omega\text{-cm}$. The resistivity is monitored by an inline resistivity meter. The TOC is measured routinely for all points of use on the UPW distribution line using a TOC analyzer. The UPW TOC levels are consistently below 50 ppb. The microbiological quality of the system is analyzed every year to detect any bacterial buildup and assess the need for the system sterilization. Ultimately, a well-defined maintenance schedule is followed to replace critical system components. [2]

Another integral component for monitoring the UPW and the HPR process is the liquid particle counter. The Liquid particle counter (SLS-1200) is a device that pressurizes the water sample using a built in pump and a syringe. The device is capable of detecting $0.2\mu\text{m}$ size particles and up to $1\mu\text{m}$. A $\frac{1}{4}$ " stainless steel national pipe tapered thread (NPT) fitting was installed on HPR system tray to collect drain water samples during cavity HPR.

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Liquid Particle Counter Commissioning Experiments

An experiment was set up to HPR one $\beta=0.085$ QWR (SC246X) and commission the liquid particle counter. The cavity was high pressure rinsed for 140 minutes per standard operating procedure. Rinse water samples were collected off the NPT fitting with tygon tubing that fed directly into a glass beaker. Another set of samples was collected directly off the NPT fitting without the tygon tubing. Samples were analyzed for liquid particle counts to display a descending trend with time as the cavity gets cleaner (see Figure 2). Although the tygon tubing was ultrasonic cleaned, the cumulative liquid particle counts in rinse water samples collected with the tubing attached were extremely higher than those collected without the tubing. It was concluded that liquid particle counts samples should be collected directly off the NPT fitting.

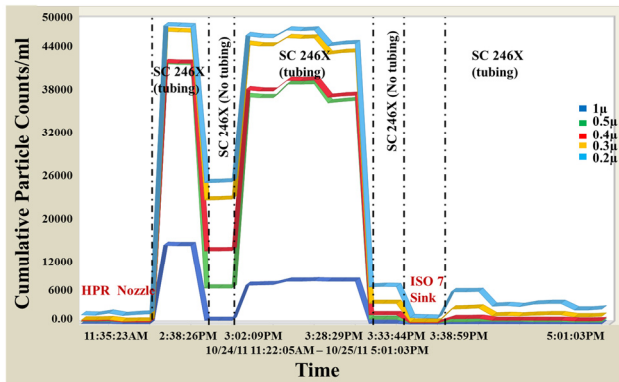


Figure 2: $\beta=0.085$ QWR (SC246X) HPR liquid particle counts time chart 10/24/2011

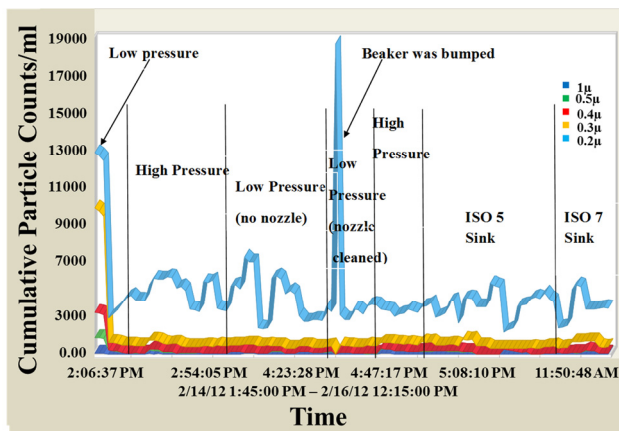


Figure 3: Liquid particle counts time chart for the UPW baseline experiment 02/14/12 - 02/15/12

Figure 3 displays the results for the baseline water quality experiment. This experiment was performed to investigate the water quality of the UPW system and to determine the HPR system baseline particle counts.

High and low pressure water samples were collected from the HPR wand with and without the spray nozzle. Samples were also collected from the ISO7 and ISO5 cleanroom sinks. Then the nozzle was disassembled from the wand, inspected, ultrasonic cleaned and re-installed to collect low and high pressure samples. UPW samples

were also collected from ISO5 and ISO7 cleanroom sinks. Results were plotted for comparison (see Figure 3). TOC and resistivity were recorded for each sample with values of 58 ppb and 17.2 M Ω -cm respectively. It was concluded that UPW from HPR spray nozzle has the same quality as the cleanroom sinks. The 0.3 μ m cumulative liquid particle counts ranged between 400-500 particles/ml.

It was noted that on one of the samples the beaker was accidentally bumped, creating a lot of bubbles. A sharp peak was recorded on the 0.2 μ m size counts (Figure 3), probably counting air bubbles as particles. Thus we will only report the 0.3 μ m cumulative liquid counts for all subsequent cavity processing and experimental work.

Components Preparation, Cleaning & Assembly QC Steps

Components used on cavity assembly undergo QC checks for residual magnetic field using a magnetometer. A demagnetizer is used to demagnetize components with residual field levels greater than 50 mG for ReA3 and greater than 15 mG for FRIB. The residual magnetic field is re-checked to ensure the acceptable threshold was attained. Components are prepared for the cleanroom using the following standard operating procedure: degrease with acetone, scrub using 1% solution of Micro-90®, rinse in deionized water, and wipe with ethanol. Components ultrasonic cleaning takes place in the ISO7 cleanroom for 30 minutes in a 1% solution of Micro-90® in UPW at 37.8°C, followed by a final ultrasonic rinse in UPW at 60°C for 40 minutes [3]. In the ISO5 cleanroom components are set to dry for assembly on the next day.

QC checks are performed on cleaned, dried components prior to their assembly to the cavity. The QIII+ surface particle counter is used to scan the seal surface on blanks, flanges, tuning plates, input and output couplers. The device is capable of detecting the presence of 0.3 μ m particles and up to 10 μ m. The surface particle detector uses a destructive sampling technique; as particles are removed from the surface, therefore the component gets cleaner. Surface particle counts are performed inside the cavity beam ports and RF ports. The inner surface of the outer conductor is also scanned for surface particle counts in the region below the beam and RF ports. These counts are illustrated as Q1, Q2, Q3 and Q4 in Figure 5. The surface particle count threshold for qualifying assembly components is set at 0.05 particles/cm² for the 0.3 μ m cumulative counts.

Air particle counts are performed at the cavity beam line before assembly to detect the 0.5 μ m particle size counts. The QC threshold of less than 1333 particles/m³ must be attained for the clean assembly to take place.

CAVITY PROCESSING QC DATA & TEST RESULTS

Three $\beta=0.085$ QWR production cavities have passed the vertical Dewar testing at 4.3K and have been certified and assembled to ReA3 coldmass string. During the tests, the amount of X-rays emitted from the cavity is measured

with an ion chamber approximately 1 meter from the cavity. Figure 4 shows that the acceleration gradient for SC251, 256 and 252 production QWRs had a large margin above the ReA3 goal of 3.4 MV/m. The figure also shows test results for two prototype cavities (SC246 & SC247).

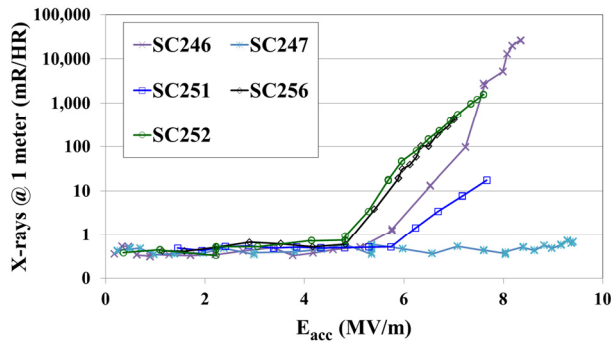


Figure 4: Field emission vs. E_{acc} for $\beta=0.085$ QWRs

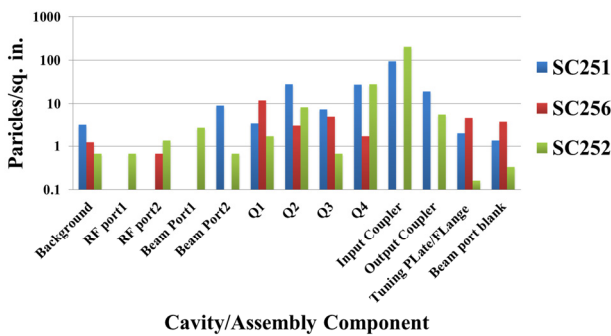


Figure 5: $0.3\mu\text{m}$ cumulative surface counts for $\beta=0.085$ QWR production cavities

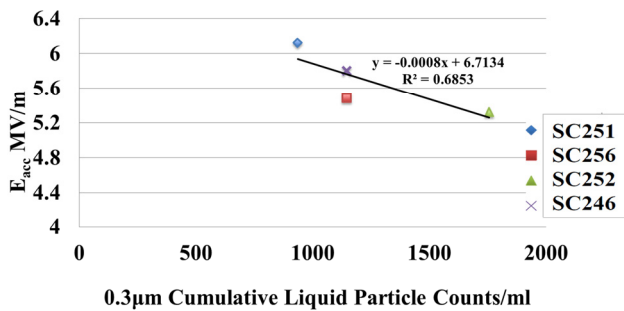


Figure 6: E_{acc} vs. $0.3\mu\text{m}$ cumulative final HPR liquid particle counts for $\beta=0.085$ QWR cavities

All cavities were processed per standard operating procedures; liquid particle counts were sampled every 20 minutes during HPR. QC checks and surface particle counts were performed on the cavities and assembly components to quantify cleanliness as in Figure 5.

Figure 6 is a plot for the $0.3\mu\text{m}$ cumulative liquid particle counts at the end of the $\beta=0.085$ QWR HPR vs. the cavity accelerating gradient at initial field emission onset. The figure illustrates a trend for an acceleration gradient at initial field emission onset of less than

5.9 MV/m if the cumulative liquid particle counts at the end of HPR is greater than 1000 particles/ml. We reported SC247 test results with no field emission and with the implementation of the QC system we recorded its final HPR cumulative liquid particle counts to be equal to the baseline particle counts of the UPW at HPR point of use.

CONCLUSION

FRIB cleanroom procedures have improved with the contribution of the QC system to ensure reproducibility of processing & clean assembly for mass production. The liquid and surface particle counters have been successfully commissioned and used. Acceptable cleaning thresholds have been identified. The overall surface cleanliness of cavities and assembly components has improved. The performance of $\beta=0.085$ QWR cavities that have been tested over the past year has improved; all production cavities were certified for ReA3. The processes are being optimized as this work paves the way for FRIB mass production through systematic procedures involving liquid, surface particle counts, field emission onset and acceleration gradient measurements. We reported findings on cavity liquid particle counts data during the HPR process that correlated to RF test results. Preliminary results show a trend for the acceleration gradient at FE onset that decreases as the $0.3\mu\text{m}$ cumulative liquid particle counts in cavity rinse water increases at the end of HPR. However many more cavity processes and tests are necessary to build a reliable statistical database and to define the right processing scheme for each cavity type.

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