CLEANROOM TECHNIQUES TO IMPROVE SURFACE CLEANLINESS AND REPEATABILITY FOR SRF COLDMASS PRODUCTION*

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Abstract

The Facility for Rare Isotope Beams (FRIB) and ReA linear accelerator projects at Michigan State University (MSU) utilize Superconducting Radio-Frequency (SRF) cavities for their accelerating structures. The structures are cleaned and assembled in a cleanroom to reduce particle contamination. The project requires more than 350 SRF cavities. In preparation for production we want to maximize repeatable processes and reduce work time. The cleanroom assembly group at MSU investigates process techniques performed in the cleanroom. Diagnostic tools, such as a surface particle counter, liquid particle counter, and airborne particle counter are used to quantify environments and optimize processes. Defined procedure specifications are necessary for cleaner, more repeatable processes. Storage options and cleaning processes are evaluated. The experiments are independent of cavity results and focus on creating the cleanest surface and environment in the most efficient manner. The experimental methods and results are summarized.

INTRODUCTION

The low-β cavities used for the ReA3 and FRIB Linacs have design characteristics that are a challenge for cleaning and final surface processing. FRIB cavities will have a low profile beamline conflat with blind tapped holes. The cleanliness of the cavity components and RF surfaces are critical to successful cavity operation [1]. A variety of cleaning techniques have been developed to control particulate contamination over many years. Among other techniques, ultrasonic cleaning, high pressure rinsing, and clean gas purging have been widely used by SRF laboratories. Quantitative particle counting was used to evaluate cleaning and storage procedures. A surface particle counter [2] was used to count particles with diameters ranging from 0.3 microns to 10 microns.

Experiments were performed to determine effective techniques for cleaning and storage of components used in the assembly of FRIB cavities including removable tuning plates, standard vacuum flanges, and custom made flanges with tapped holes. Methods were developed to reduce processing time of subassemblies and vacuum components while ensuring particle free surfaces.

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Figure 1: QIII+ surface particle counter and 2” probe scanning titanium blind tapped holes flange.

PROCESSING VACUUM COMPONENTS

Surface Cleaning and Storage Experiments

Commercial 304 stainless steel conflats are used as accelerator vacuum components and are therefore critical subjects for the experiments. Both 2.75” and 3.375” diameter conflats were included in these experiments. To study and identify the best cleaning technique for blind tapped holes, similar experiments were performed on 7” titanium flanges (Figure 1) with 5/16”-24 threads. The SRF community has found blind tapped holes to be very challenging to clean which poses a significant contamination threat. All experiments were repeated at least twice and yielded reproducible results. Average results for each component type will be presented and discussed.

All components were prepared for the cleanroom using the following standard operating procedure: degrease with acetone, scrub using Micro-90® (1% solution), rinse with DI water, wipe with methanol. The components were transported to the ISO7 [3] cleanroom for ultrasonic cleaning, drying and storage. Ultrasonic cleaning was performed for 30 minutes in a 1% solution of Micro-90® in UPW at 100°F. A final ultrasonic rinse in UPW was performed at 140°F for 40 minutes.

Components were stored in an ISO7 cleanroom to present the highest contamination risk scenario and will be contrasted later with storage in an ISO5 cleanroom. Over a two month period surface particle counts were periodically taken on the seal surfaces and over the holes of the flanges.

The effectiveness a medium pressure rinse (20-40 psi) with UPW to rinse off particles that accumulated over time was evaluated. Post-drying surface particle counts were performed in an ISO7 cleanroom the following day.

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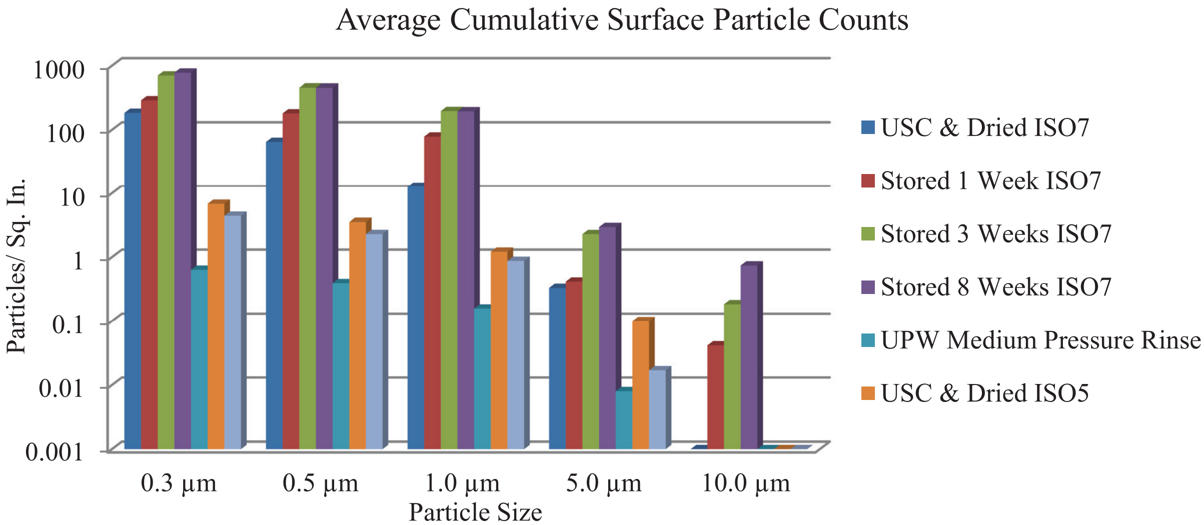

Figure 2: Cleaning and storage techniques comparison for 2.75" conflat flanges.

All flanges were ultrasonic cleaned, dried, and stored in an ISO5 cleanroom using the 3 different techniques: stored directly under a HEPA filter, bagged in ISO7 air and stored (ISO7), or bagged using ionized N_2 and stored (ISO7). Figure 2 is a comprehensive representation for the 2.75"conflat experimental results.

Surface Cleaning Results

The preparation procedures for the cleanroom, ultrasonic cleaning, UPW medium pressure rinsing, drying in different cleanroom environments (ISO7 vs. ISO5), and storage techniques were evaluated.

Standard procedure is to dry ultrasonic cleaned components in an ISO5 cleanroom. An adjustable nozzle was used to create a medium pressure spray of UPW on tapped flanges and was confirmed effective. Medium pressure rinsing with UPW is a cost effective cleaning technique to remove accumulated particles, however, dwell time waiting for the part to dry must be considered.

Particles that accumulate on stored components over time are highly dependent on the activity level and type in the cleanroom. Only light (ultrasonic cleaning) activity took place in the ISO7 cleanroom during weeks 3-8 (Figure 2). Long term storage of components in an ISO5 cleanroom under HEPA filters does not guarantee or preserve cleanliness (Figure 2).

Bagging clean components using ionized N_2 is the most effective storage technique. This method should be used to store and ship clean components.

To save time, the use of pressurized air to spray off components will be investigated for effectiveness and compared to the UPW medium pressure rinse.

The FRIB cavity designs include niobium-titanium flanges with blind tapped holes. Titanium prototypes of these flanges (Figure 1) were subjected to an additional series of experimental steps to simulate cavity process steps. A final surface count was performed and results are shown in Figure 3. Results of the cumulative surface counts indicate that titanium flanges with blind tapped holes can meet specification. Higher surface counts were encountered on the bellows of Flange D, not the blind tapped holes. Counts on the tapped holes averaged 3 particles/sq. in., this is lower than the acceptable semi-conductor industry threshold of 20 particles/sq. in.[2]. The final FRIB flange design does not include a bellows.

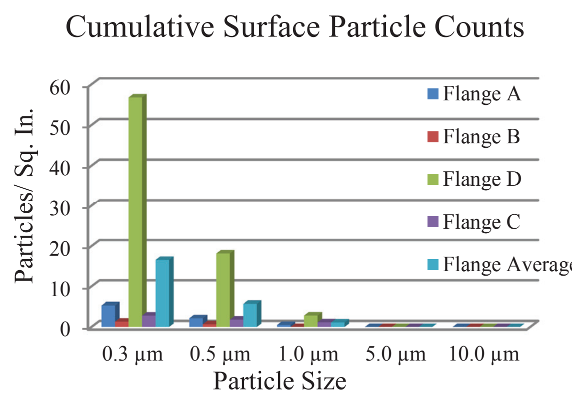

Figure 3: Counts of tapped holes on titanium flanges.

PROCESSING TUNING PLATES

The quarter wave resonator design for FRIB includes a semi-rigid plate that adjusts the effective length of the outer conductor for the purpose of tuning. The tuning plates in the β=0.041 ReA3 cryomodule were ultrasonic cleaned before cleanroom assembly. A high pressure rinse (HPR) step was introduced for tuning plates in the β=0.085 prototype cavities due to field emission from the plate. In the FRIB production β=0.085 cavities the plate is an additional 70 mm away from the inner conductor nose, reducing the field from 23 MV/m to 5.86 MV/m [4][5].

A study was done to streamline the processing steps of tuning plates for FRIB. Table 1 shows the steps in the current procedure and the steps for the proposed procedure for processing tuning plates.

Table 1: Procedures used for processing tuning plates. Steps eliminated in proposed process are italicized.

Current Procedure (Group A)	Proposed FRIB Baseline Procedure (Group B)
Ultrasonic Clean for 30 minutes in 1% Micro-90® in UPW	Ultrasonic Clean for 30 minutes in 1% Micro-90® in UPW
Ultrasonic Clean for 40 minutes in UPW	Rinse with DI water faucet nozzle (medium pressure rinse)
Rinse in low pressure UPW faucet in ISO5	BCP etch 5 microns (5 minutes)
Buffered Chemical Polish (BCP) etch 5 microns (5 minutes)	Rinse 5 minutes in UPW with medium pressure nozzle in ISO7
UPW HPR in tool 30 minutes @ 1500 psi in ISO5	
Dry in ISO5 cleanroom	Dry in ISO5 cleanroom

Experimental Design

To move the rinsing steps from an ISO5 cleanroom to an ISO7 cleanroom, the water quality at the proposed point-of-use needed to be quantified. The points-of-use tested were the ISO7 sink and ISO5 sink and ISO5 HPR tool. These points-of-use are fed by an UPW distribution line. Resistivity at all points-of-use is consistently above 17.4 MegaOhms-cm. Total organic carbon (TOC) at all points-of-use is below 200 ppb. Liquid particle counts [6] of samples from all points-of-use are comparable within a standard deviation. Installation of the medium pressure nozzle on the ISO7 faucet did not affect resistivity, TOC, or liquid particle count measurements.

A surface particle counter was used immediately before removing the tuning plates from the cleanroom for BCP etching (Stage 1) and after drying in the ISO5 cleanroom (Stage 2).

Results

Particle counts after both processing paths were comparable to drying overnight in an ISO5 cleanroom as shown by the scale in Figure 4. The tuning plates in Group A and Group B at both stages of data collection were adequately particle free.

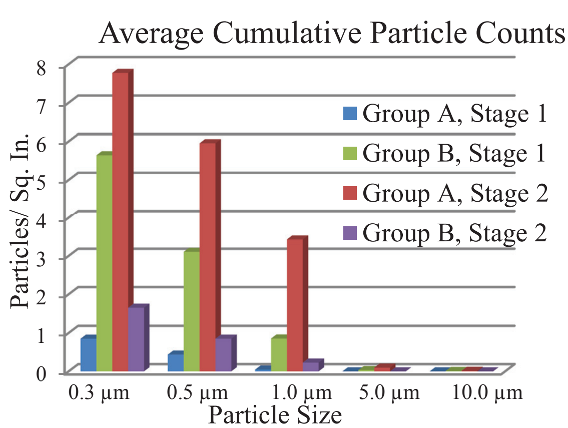

Figure 4: Surface particle count data of two stages of different procedures on tuning plates.

Production Impact

Surface particle data does not show lower counts for additional ultrasonic cleaning or use of the high pressure rinse tool. Eliminating non-value added steps reduces touch labor by 30 minutes per plate and cycle time by 90 minutes. An estimated 143 tuning plate processes are required for FRIB production. This study reduces FRIB effort by 6.5 weeks of people hours.

Moving the rinse step from the ISO5 room to the ISO7 room reduces risk of cross contamination by eliminating a walking path through the cavity assembly area.

The high pressure rinse tool is prone to mechanical failure and has been identified as the least reliable cleanroom equipment. The FRIB production cleanroom will have two high pressure rinse tools. Eliminating high pressure rinsing of the tuning plate increases infrastructure redundancy which reduces schedule risk in the instance that one tool requires troubleshooting. This also presents the opportunity to parallel process different cavities types without the need to re-tool.

This study has been one of the many efforts to apply LEAN manufacturing principles to the production of SRF cavities for FRIB. Reducing motion, cross-contamination risk, and extraneous process steps will allow operators to put more focus on value-added tasks.

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