SRF QUALITY ASSURANCE STUDIES AND THEIR APPLICATION TO CRYOMODULE REPAIRS AT SNS*

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Abstract

Many of the SRF activities involve interactions with cryomodules which presents risk for particulate contamination to RF surfaces. In order to understand and reduce contamination in cryomodules during maintenance activities such as vacuum pumping and purging, and in-situ cryomodule repairs, a Quality Assurance (QA) study was initiated to evaluate these activities and improve them where possible. This paper covers the results of these activities including procedure development for in-situ cryomodule repairs, investigations on particulate control during pumping and purging and the study of particulate generation during beam line valve actuation and discussion of further improvement in these areas.

INTRODUCTION

The Superconducting Linac (SCL) group at SNS has as its main responsibility to maintain the SCL performance and reliability from both an acceleration and cryogenic operational point of view. To date, the SCL group has not fully disassembled a single linac cryomodule for repairs and has relied on performing in situ repairs on cryomodules which reduces cost and downtime [1]. The repairs to these cryomodules are performed through existing access ports located at each cavity to cavity location as well as the ends of the cryomodule [2]. Repairs so far have been completely successful, with little or no performance degradation but are very difficult to perform and present a high risk of increasing field emission, a main performance limitation of the SCL [3]. Additionally, first time repairs present new challenges and one cannot rely on past experience so the risk is even higher. To reduce these risks, a quality assurance effort was started to measure the performance of the critical tasks required for typical cryomodule repair procedures and to make improvements based on experimental data.

THE MOCK CRYOMODULE

In order to perform these measurements a mock cryomodule was designed and fabricated which utilizes existing string tooling to save cost. This mock cryomodule, allows for development and testing of new and existing procedures as well as for training of staff on procedures prior to the actual cryomodule repair. The mock cryomodule will help build confidence that repair procedures will have minimal impact to cryomodule performance, it will allow for the further development of tooling and procedures and increased the reproducibility of performing the tasks. The mock cryomodule hardware is not fully representative of the real cryomodule but presents the same physical challenges and access limitations as the real thing. One key factor in the mock cryomodule design was to accurately represent the physical limitation repair personnel would be faced with, which is the most challenging part of these repair tasks. Some of the repairs require distortion of ones arms to achieve the task or are better performed facing away from the cryomodule. The first focus of the quality assurance effort was to use the mock cryomodule to test existing techniques for the removal of HOM can probes, a standard maintenance procedure for SNS cryomodules that have not had them removed already, and to develop improvements to the existing procedures where possible. The results of this effort were implemented on a repair (summer 2015) of a high beta cryomodule, CM12.

The mock cryomodule (see Fig. 1) consists of the assembly string rail with a dressed cavity mounted on modified cavity support posts which are used for string assembly.

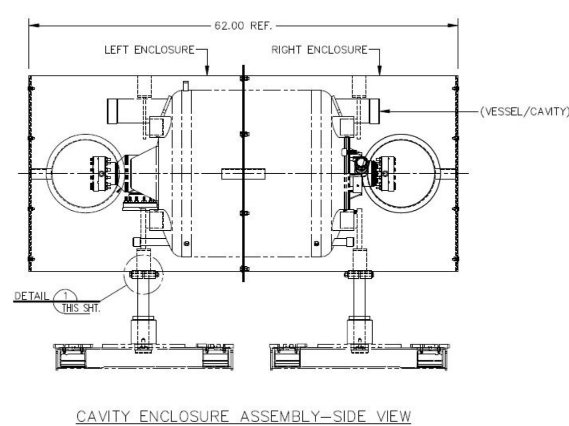

Figure 1: Schematic of the mock cryomodule side view.

A stainless steel shell made to the thermo-shield inner diameter was designed to be split in the center, allowing for insertion from the cavity ends and the two half's are then bolted together in the center. The weight of the structure is carried by rail support posts and the shell half's are aligned to the cavity by plugs which insert into the helium vessel nitronic rod support posts . Ends of the structure are sealed with Lexan covers which are see through and can be remov-

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able if needed. Access ports where placed on one side of the structure and were made to the dimensions representing the real cryomodule access ports. The full mock cryomodule assembly takes less then ten minute to complete.

HOM PROBE REMOVAL ON CRYOMODULES

The HOM Probe removal and blanking is difficult on these cryomodules because the size of the access port and the location of the hardware requires one handed repairs with no direct vision of the repair area. This is due to the diameter of the access port and when the repair person's arm is in the access port, it blocks all vision of the repair area. Additionally, the location of the tuner end HOM is inside the tuner frame and is not in line of sight of the access hole.

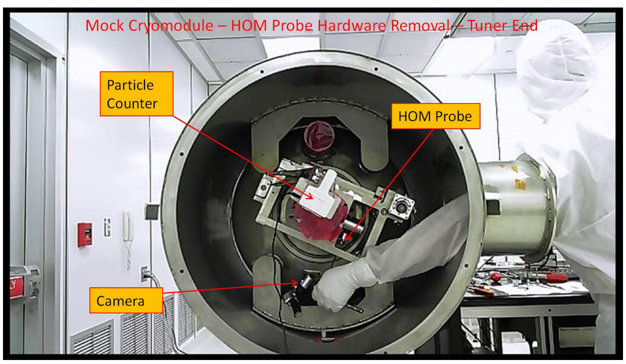

Figure 2: Mock cryomodule experimental setup.

Typically a camera is placed inside the cryomdule to aid the repair persons vision of the repair area, so they are typically facing away from the cryomodule. These complications can easily frustrate the person performing the repair and significantly add to the time of the repair and its variability. The first step to improving this procedure was to first practiced on a bare cavity not installed in the mock cryomodule, to gain understanding of the details of the hardware removal and subsequent blanking of the flange. Several areas where improvements could be made were identified such as: a reliable way to retain the nut plates in place, improving the aluminum seal fit which would not stay in place (especially on the probe flange on the tuner end that faces down) and improving the alignment of the blanking flange to the bolt pattern. These items represent the most difficult, time consuming and risky parts of the repair task. Next the mock cryomodule was assembled and experiments were performed removing the HOM probe and blanking the flange while collecting data on particulate generated inside the cavity and video taping the procedure. A portable particle counter was placed inside the end beam line flange as well as at the opposite end of the cavity (see Fig. 2).

Several solutions to each of the identified problems were developed and tried in the mock cryomodule while recording data. In two of the cases there was a clear winner, the aluminum seal diameter was increased to have a press fit into the blanking flange to keep it in place during the procedure and studs were used to thread into the nut plates to provide alignment of the blanking flange to the bolt pattern. The problem of retaining the nut plates in place was a more difficult problem and resulted in at least two options which were successful in trials. The first option was to apply kapton tape around the nut plates and sealing them to the cavity HOM flange which was used on the field probe (FP) end HOM. The second was to use Silicon -boron putty and to form it around the nut plates and the flange which was used for the tuner end HOM. Data showing particle counts generated inside the cavity from the time of breaking the seal (loosening the first bolt) to having a positive seal with the blanking flange as well as the time to complete the task is shown (see Fig. 3). This data was taken at the end of a extensive training period of two month repeating the tuner end HOM repairs and a few of the easier FP end repairs. Particle count data shows good result (low counts), improvement with experience as well as reduction in time. The labels FPE and TE stand for Field Probe End and Tuner End respectively. Results in applying the experience and modified procedures to the HOM repairs on CM12 showed good results in that there was no identifiable RF performance degradation in the cavities that under went repair determined from the test cave test of this module in September 2015. Future improvements to the Mock CM were identified to be adding of access ports opposite the existing ones to allow for a second repairs persons assistance during the repairs and the addition of multilayer insulation which is considered a significant source of contamination in side real cryomodules.

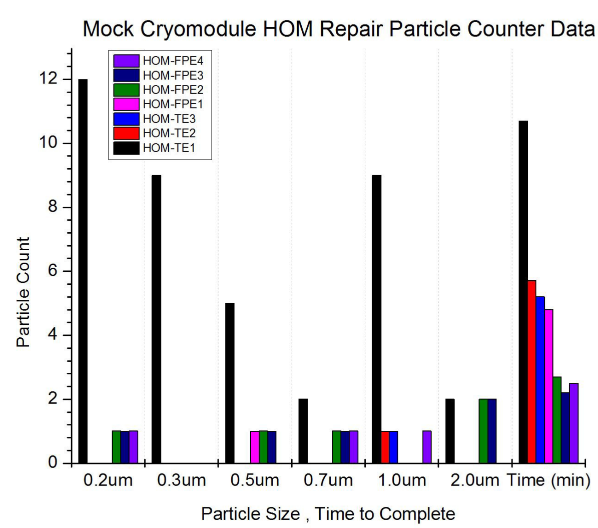

Figure 3: Mock cryomodule practice data.

CAVITY PUMPING AND PURGING

Another repair procedure which presents risk of contaminating cavities is during pumping and purging of vacuum spaces. To further understand this process a vacuum laser particle counter was connected in between the cavity flange and the isolation valve on a HB cavity in the clean room.

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Next the clean room pump cart was connected to the cavity valve. This pump cart is used for venting and pumping cavities and cryomodules during repairs and is located just outside the clean room and the pump line enters the clean room through an access port in the wall. The pump cart has pneumatic valves which allows the operators to pump out vacuum spaces with a roots style mechanical and turbo pump for ultra high vacuum and a filtered gas bleed up line for venting operations which bypasses the high vacuum portion of the system (see Fig. 4. The goal here was to determine if

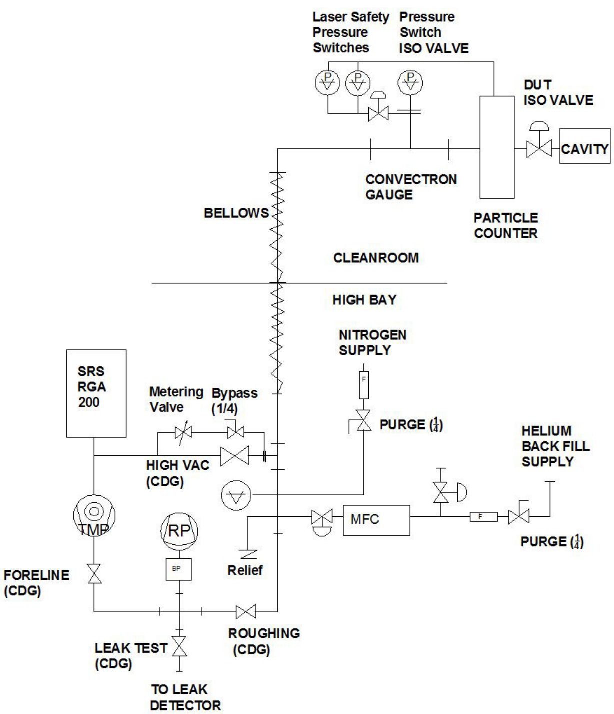

Figure 4: Clean room vacuum pump cart schematic.

particulates were entering the cavity during any of the vacuum operations and if so try to reduce them by changing the hardware or procedure. First the cavity was pumped down to establish a baseline pressure, remove excess moisture and to leak check the system. Following the pump down the cavity and pump cart was vented with clean nitrogen from a liquid nitrogen dewar supply through the cart vent line and filter by opening the purge valve fully (1/4 turn valve). During repeated vent cycles the particle counter showed no particle counts. Next the system was fully vented the pump cart was turned off and the turbo spun down to rest. Then the system was turned on and the roughing and turbo started and pumping through the high vacuum line was established. The cavity was then pumped down by opening the " Foreline" valve and the "High Vac" valve to the mechanical roots pump. During the pump down cycles particle counts were observed during the initial stages of pumping in the range of 300 to 9 Torr (see Fig. 5. The pump downs were repeated with just the roughing pump only but the results were similar with particle counts. Particle data suggests some movement of

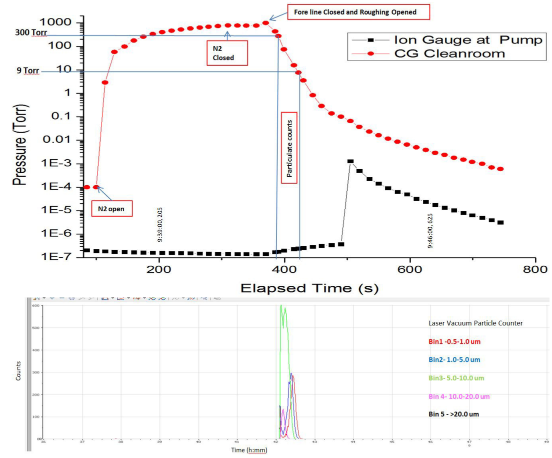

Figure 5: Purge and pump down particle data.

either particulates or water droplets during the pump downs and further investigations is needed to determine the source, even though all precautions to keep the system dry were taken. Next the pump cart was modified for a slow pump down through a metering valve labeled "Metering bypass" on Figure 4. The process of venting the cart and spinning down the turbo was repeated and this time the particle data showed only noise level of the instrument, few counts of one, a big improvement. The metering valve was set to around a cv-0.019 extending the pump down time by nine minutes for the experiments and a comparison of data is presented (see Fig. 6.

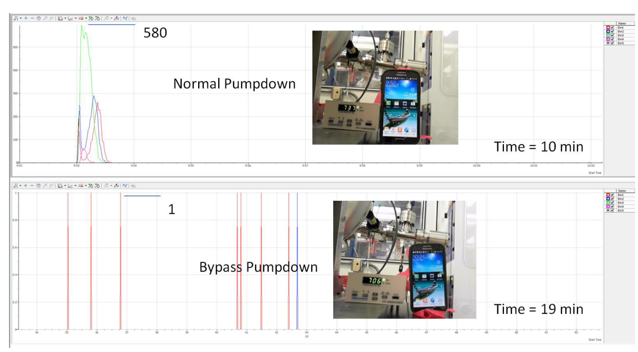

Figure 6: Comparison of pump down particle data, normal top and slow bottom.

BEAM LINE VALVE TESTING

Another area where particulates can enter RF surfaces is through the actuation of beam line valves. Typically segmented linac designs have two sets of beam line valves on each end of the cryomodule. The inner set is used during the assembly stages of the string for isolation and build out of the cryomodule, they are typically located inside the cryomodule vacuum shell. These valves get very few cycles over their lifetime. The outer set of valves are typically used for cryomodule protection in case of a vacuum event and are part of the machine protection scheme, they are accessible

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in the tunnel on the very ends of the cryomodule. These valves typically get many cycles throughout their lifetime, such as during vacuum and machine trips as well as during maintenance and vacuum repair activities (see Fig. 7.

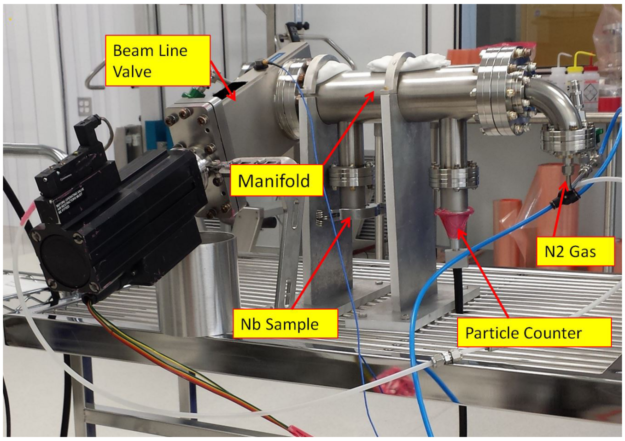

Figure 7: Beam line valve test setup.

The SNS cryomodules use a pneumatically operated fail safe valve for this location. A study of the particulate generation from these valves was performed as well as comparing them to two additional manufacturers valves as possible replacements. Valve A and B were new from the vendor and valve C was a spare valve removed from a CM repair. The setup for the experiment was to mount one of the the valves on a manifold of the same diameter as the beam line and the length of the warm to cold transition in the SNS cryomodule, about twelve inches in length. Two additional ports were added to the manifold one for a air particle counter and the second a filtered purge line. The paddle sealing side of the valve was mounted to face the manifold opening and the other side of the valve was blanked with a conflat flange. The experiment was performed at atmospheric pressure with a 1 cfm nitrogen gas flow throughout the cycling. Each assembly of the system subcomponents including the valve were cleaned with ionized nitrogen gas and carefully assembled in the clean room. Each of the three valves were cycled repeatedly over 60 minutes with a cycle time of 1 minute. The particle counter was setup to bin data every 6 seconds for the best resolution. Additionally a vibration sensor was placed on the short side body of the valve to measure vibration during the cycles. (see Fig. 8. Particulates were collected from Valve B and C by inserting a niobium witness sample (10mm dia.) on a post that was mounted on the KF40 flange. This made the witness sample at the height of the interior manifold surface. The niobium sample was ultrasonically cleaned in DI water with a 1 percent liquid detergent, followed by DI water rinsing and ionized nitrogen gas cleaning prior to the insertion. After the cycling was complete the post was removed and the sample was transfered by tweezers to a glass vile and was sealed with a plastic cap.

Results from the testing showed that valve B and valve C were the best performers with regards to particulate generation however valve B's closing force measured 16g of vibration on the sensor. Valve B has an adjustment to the pneumatic exhaust to damp this vibration but the test was conducted as received from the vendor. Valve A particle data had strong correlations to the valve movements and Valve B and C did not show this correlation. Valve C is currently installed on the production cryomodules. Analysis of the particulates collected on Niobium witness samples by SEM showed that carbon and silicon were present on both B and C's valves. Particle sizes ranged from sub-micron to 10's of microns. Valve B particulates, mainly consisted of carbon and water based elements, where as valve C's particles contained more metals and hardware elements. Additionally all three valves showed reduction in particle counts with increasing valve cycles which seems to be a good way to cleanup the valves prior to installation. Results of the valve studies indicated several important features such that each valve particulate and vibration performance were different enough to warrant inspection as a qualification. Further studies of valves will be needed to draw strong conclusions from the testing.

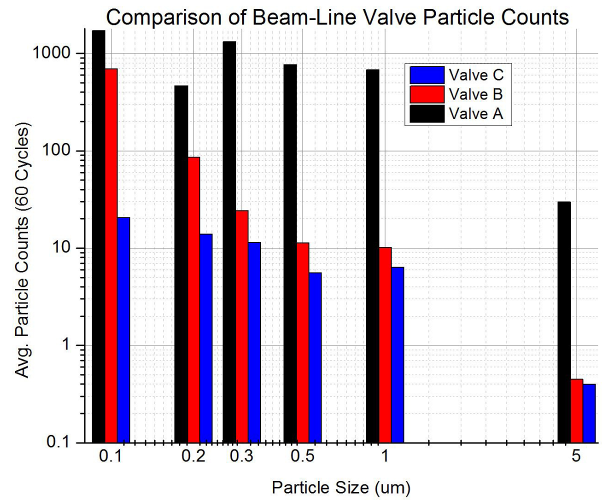

Figure 8: Beam line valve comparison.

Table 1. summarizes the particles collected and analyzed (SEM) from valve C cycling .

Table 1: Particulates Collected During Valve C Cycles

Size (um)	Element Data
6x10	Cu,O,C
1x1.5	Ag,O,C
2x12	Fe,Cr,Ni,Mn,O,C,Ti
1x2	Ni,O,C
0.6x0.4	Cu,O
3x5	AL,O,Si,B,C,Cu
1.2x3	Cr,Fe,O,C,Ni

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Table 2. summarizes the the particles collected and analyzed (SEM) from Valve B cycling.

Table 2: Particulates Collected During Valve B Cycles

Size(um)	Element Data
20x24	C,O
10x25	C,O,Si,Mg
1x2	C,O,Ca
1x1	O,C
2x10	C,O
1.5x6	Si,C,O
4x3	P,C,V,Ca,Al,Ti
4x3	C,O,Cu
1.5x1.5	O,C,Si,P,Cu,K
0.4x0.8	O,C,B
1x0.5	O,C,P,Ca,K

CONCLUSION

At SNS the SCL group has started additional quality assurance steps to improve the understanding and procedure development for in-situ cryomodule repairs and to continue its success rate in this activity. A mock CM was fabricated and used to further develop the HOM repair procedures and was practiced and implemented on CM12 with no RF performance degradation. Additionally pumping and purging experiments were carried out to further understand particulate movement during these activities which lead to the modification of the pump down procedure and hardware to allow for slow pump downs which was also used on CM12. Beam line valve testing is underway and has increased our understanding of particulate generation with these critical devices. Plans are to continue these quality assurance studies as needed to base cryomodule repair decisions on experimental data and ensure success rate for future repairs of the installed cryomodules as they age and need additional repairs.

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