DEVELOPING FACILITIES FOR SNS CRYOMODULE PERFORMANCE IMPROVEMENTS*

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Abstract

Superconducting RF cavity facilities are currently being developed at SNS, aimed at addressing the limitations and availability of installed cavities and the direct support of the future power upgrade plans. Current efforts are directed towards development of in-situ repairs and developing processing techniques to increase available linac gradients. Procedures have been developed and implemented and the results will be presented for the repair of four cryomodules in the last year. Cryomodule testing facilities are being developed to further understand the collective limitations of installed cavities and spare cryomodule production is underway to develop and fabricate two high beta and one medium beta cryomodules. The direction and status of SRF facilities will be presented.

SUPERCONDUCTING CRYOMODULE FACILITIES AT SNS

During the construction of the SNS accelerator, 11 medium beta (0.61) and 12 high beta (0.81) cryomodules were fabricated at Thomas Jefferson National Accelerator Facility, shipped to SNS and installed in the linac section of the accelerator. At this time there was no urgent need for SRF facilities with the exception of some clean work areas, portable cleanrooms, and limited utilities which were used for the installation effort. During this time the RF Test facility was installed but was not functional and the main focus was on commissioning and developing cryomodule operational experience as quickly as possible. Once the Superconducting Linac (SCL) was commissioned and operating, several limitations to cavity operating performance became known and further understanding of the operational limits was needed. The main concern was unusual higher order mode (HOM) signals, excessive fundamental power coupling out HOM couplers and breakdowns in cavities due to field emission and multipacting. Individual cavities operate to high gradients but must be turned down due to collective effects from electron heating [1]. Significant effort was spent understanding these problems and this knowledge was critical to setting optimal operating parameters. Today the SCL is one of the most stable operating systems in the accelerator [2].

Table 1: SRF Facilities at SNS

SRF Facility	Classification	Details
Cleanroom		
Small part cleaning/degreasing	ISO 7 (M 5.5)	58m^2
Cleanroom- String assembly	ISO 5 (M 3.5)	58m^2
Cleanroom – Cavity assembly	ISO 4 (M 2.5)	2.5m^2
Cryomodule Test Facility		
Horizontal Test Facility		
	Space	11m x 4m
	Cryogenic Connections	Supply transfer line Shield transfer line **Return transfer line
	**Test Facility Refrigerator	200W 2K 200W Shield
***Vertical Test Facility**		Standard dewar/pit design
	Dewar	Depth -3.35m
		Diameter – 71.1cm
	Cryogenic source	Separate helium refrigerator
***DI water Plant**	E-1	2268 liter storage, 38 liter makeup
***High Pressure Rinse Station**		Cavity remains stationary
	Wand	Rotates and translates
	Nozzles	Water Fanjets
		2 opposed
		Nitrogen gas Fanjets 2 opposed
	Pump	LEWA Teflon diaphragm -15 lpm

Today there is the need to expand the SCL facilities to support linac maintenance on cryomodules, qualify subcomponents for repairs and for the development of spare cryomodules. Spare cryomodules will allow for the

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recovery and upgrading of problematic cryomodules in a recycling program.

The SRF facilities are located in the RF Test Facility building [3], where an installed cleanroom complex, horizontal test cave and the supporting utility infrastructure such as DI water plant and an RF test-stand are already located. The RF teststand consists of a 5MW, 805MHz RF klystron with full low level RF controls [4]. Although the existing facilities have adequately provided for limited servicing and repair of installed cryomodules, the plans are to extend and improve these facilities for compatibility with development and fabrication of in-house spares and to develop additional in-situ cryomodule performance improvements. In Table 1, SRF Facilities at SNS, are listed and brief details about them are provided. New facilities currently in design or construction are also listed and identified by the single asterisk *. Facilities that will be added as part of the power upgrade plan (PUP) are identified by double asterisk **. Currently there are several limitations to the existing facilities which prevent routine RF testing of cavities or components. The test facility support infrastructure has not yet been completed and is planned for installation when the PUP begins. Currently cryomodules can be tested in the test cave but only during operation's accelerator physics study periods or maintenance downs due to the lack of a separate helium gas return transfer line and an additional dedicated refrigerator supporting the test facility. These missing facilities will be completed during the power upgrade.

CRYOMODULE REPAIR STRATEGY

With the requirements for high beam availability and high beam power at SNS, in-situ methods of repair and performance improvements are becoming more important. The cost and amount of time spent to rework a cryomodules is significant to operations. For SNS there is an additional burden in that there are currently no spare cryomodules and this makes developing new in-situ methods of repair a must to keep the installed components healthy while the spares are being designed and produced.

Currently, plans have been made to develop and apply in-situ RF processing to the installed superconducting cavities in parallel with redesign and fabrication of the first spare cryomodules. The processing techniques to be applied are helium and plasma processing. The helium processing method has been applied to installed cryomodules at various laboratories with some success. This helium processing method is easy to apply but has statistically provided only about 1 MV/m improvement to installed cavities limited by field emission. This method will be performed on the next cryomodule tested in the RF test facility and then will be applied to the linac. Additionally, we are pursuing the development of plasma cleaning, an industrially accepted method for cleaning of semiconductor wafers. A plasma cleaning setup has been assembled and commissioned in the RF test facility. This system has the same components necessary for helium processing and hardware will be used for both. The plasma setup consists of a high beta cavity with standard flange hardware and couplers, a gas mixing and metering manifold and a solid state 500 watt RF source. Niobium witness samples are mounted inside the cavity beam-line and will allow for surface analysis and the ability to understand how contaminants are being modified. To date, the system has been commissioned and plasma established in the cavity with two different gas mixtures. Figure 1, shows the plasma processing setup located in the RF test facility building.

Figure 1: Plasma processing setup with HB Cavity.

PRODUCING SPARE CRYOMODULES

With the urgent need for producing a few spare cryomodules and the requirements by Department of Energy to comply with 10CFR851 it was decided to build these spares in-house. What the 10CFR851 document requires is that the new spare cryomodules will be designed and fabricated to be compliant with pressure vessel codes. The process of designing to pressure vessel code is straight forward but will take additional time to complete the module redesign and drawings before spares can be produced. The Oak Ridge National Laboratory (ORNL) is well suited for producing the few spare cryomodules in-house and handling pressure vessel fabrication already. ORNL has a code compliant machine shop, qualified welders and an X-ray weld analysis shop. All pressure vessel work in this shop is performed to ASTM standards. Along with these facilities at ORNL, there is significant material testing and surface science laboratories and expertise available for aiding progress and addressing problems. By choosing this path of building in-house, this will allow time for developing the new design into a production model and to train staff. The goal is to have the future nine upgrade cryomodules fabricated in industry and in-house expertise will be necessary to support the procurement contracts. This will also allow time for building staff expertise in-house to properly maintain these new cryomodules once received.

A decision was made on the new cryomodule design to establish the pressure boundary for all new cryomodules at the vacuum vessel and endcan envelop and not on the internal cavity and helium vessel envelop. This decision stems from the lack of code based materials within the cavity helium circuit design. Some of the materials used are recognized by the code board but are not listed materials and therefore would require code cases for each material to become a code listed material. Another difficulty is the ability to test materials at the operating temperatures. SNS has started the testing of materials for mechanical properties for all of the materials used in cavity helium vessel fabrication and have fully analyzed all electron beam welds on two of the spare six cell HB cavities.

The one facility that is missing at SNS is the chemical processing facilities for the niobium cavities. These facilities are necessary for removal of damaged niobium surface layers due to fabrication procedures. This removal is by acid etching of the cavity interior by one of two methods, buffered chemical polish or by electropolish. Both processes require chemical handling, processing equipment and first response hydrofluoric acid training for staff. Currently Thomas Jefferson National Accelerator (Jlab) is performing all the cavity processing, assembly and cryogenic testing of the cavities for the three spare cryomodules. The first four cavities have just completed qualification at JLab and will be used in the first HB spare cryomodule. The chemical facilities at ORNL, will be eventually needed for rework of cryomodules installed in the linac which are activated. Planning has begun to establish a limited cavity chemistry facility in the Nuclear Science and Technology Division at ORNL, to gain experience with these processes and to support future cavity processing needs for activated cavities.

CRYOMODULE REPAIR SUMMARY

Although cryomodules are operating stably at SNS, currently there is one cavity not being operated in the linac due to HOM coupler damage and one cryomodule is removed from the SCL for repairs. To date several different SCL operating problems have been identified and over the last few years, repairs were attempted to recover performance to cavities in 4 of the 23 installed cryomodules. Cryomodule in linac position 19 (CM19) was removed due to excessive fundamental power coupling out a HOM coupler. This cryomodule was moved to the cleanroom and procedures were developed to vent and repair the cavity without extensive disassembling of the cryomodule. Repairs were performed through a 15.2cm access port with special tooling to remove both HOM coupling probes from the problem cavity. Cameras placed inside the cryomodule were extensively used during the repairs due to the small access hole and the location of the couplers. Repairs were completed on the cryomodule just as the test cave facilities were completing. CM19 was commissioned along with the new test cave facility and both were a big success. The procedures and tooling used in the repairs led to the first successful in-situ repair of a beam-line component through an access port, and no degradation to performance was experienced in commissioning of CM19. The cryomodule was then installed into the accelerator. Currently CM19 is the highest performing high beta cryomodule in the linac. At this time a decision was made to remove CM12 from the linac due to its suspected beam-line leak and because this cryomodule was limited by field emission and would be a good tool for further development of in-situ processing techniques. The testing of CM19 was important feedback on developed techniques and would allow us to proceeding with more aggressive repairs on installed cryomodules in the linac.

The next cryomodule identified for repair was CM10 which had a cavity with a noisy field probe signal, and CM09 cavity which had a tuner that was running excessively. CM10 was fully vented and access to the field probe identified the problem to be a loose cable. CM09 had the tuner motor, harmonic drive replaced and the piezo tuner removed. With CM10 the procedure used for venting 19 was utilized and this cryomodule is now fully recovered and being operated at its original gradient. CM09 was not successful however, after cooling down the cryomodule the tuner is still running excessively and therefore being operated at a lower gradient then its operational limit to reduce the tuner movements. Next work on CM12 began and it was moved to the cleanroom. During this repair three large beam-line to insulating vacuum leaks were discovered, all coming from failed HOM ceramic feed through. Suspicion is that during commissioning of cryomodules multipacting occurs in the HOM coupler detuning the notch filter and high fundamental power propagates through the feed through. These type or RF events can thermally shock the ceramic. Clear evidence of multipacting in the HOM coupler was identified during the commissioning of CM19 after the repairs. CM12 was then moved to the test-cave for commissioning and was cooled down. During the cool down it was identified that an additional cold leak on the helium circuit was appearing around when the piping reached 100 Kelvin. After much testing, suspicion is that the leak is located in the return end-can piping. Efforts are now focused on opening up the end-can to clearly identify the location of the leak and repair it.

RADIATION LEVELS IN THE SCL

With increasing beam power, the activation levels of installed linac components are increasing. Activation is mainly due to beam loss, although the beam loss is small at <1 watt per meter [5]. The ability to perform quick repairs in the linac will increasingly be reduced to control personnel radiation exposures as the machine beam power increases and reaches its design goal of 1.4MW. Currently the beam power is between 500-600KW and is scheduled to be increased each run period until the

1.4MW level is reached. To better understand the radiation levels in the tunnel, several measurements have been made to quantify source terms, integrated doses to installed equipment and to measure decay rates to better predict personnel exposure rates and reduce them. First the isotopes from source terms were measured in the linac area of the machine between CM4-5. Table 2, shows the top ten source terms from the SCL, measured by the radiation control group. This spectrum differed significantly from the spectrum taken in the ring injection region in that the source terms were smaller and Nb-90 was not present. Next the radiation decay in the linac was measured as a function of time by increasing the sensitivity of neutron detectors to be sensitive to gamma emission. This provided a better understanding of the decay rates in the linac. Typically when the production run ends, The radiological control technicians (RCT's) perform a detailed radiation survey and the access into the SCL is delayed for one day to reduce exposure rates. This data is presented on Figure 2, Radiation Decay Measurement in The SCL [6]. Additionally High dose TLD's were placed on most of the cryomodules exiting gate valves. Here the total integrated radiation dose for the run period for an integrated beam power was determined for the linac components. This data is presented in Figure 3, SCL Radiation Exposure. Through these series of measurements we are better able to plan and perform our maintenance duties.

Table 2: SCL Radiation Source Terms

Radiation Source Terms			
SCL		Range	
uCi	Isotope	(keV)	
1.31	Mn-52	1329.23	1338.73
1.26	Mn-52	1429.77	1439.27
1.01	Cr-51	317.3	324.43
0.88	Ni-57	1914.11	1924.39
0.82	Na-24	2745.68	2758.32
0.78	Sc-44m	269.35	276.48
0.77	Co-56	2590.73	2602.59
0.75	Mn-52	931.32	940.03
0.67	Nb-90	2311.6	2323.46
0.64	Nb-90	2179.91	2190.98

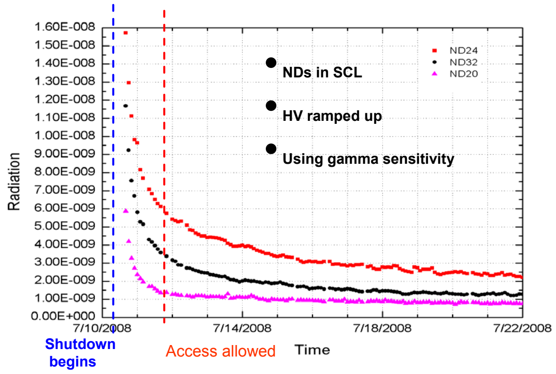

Figure 2: Radiation decay measurement in the SCL.

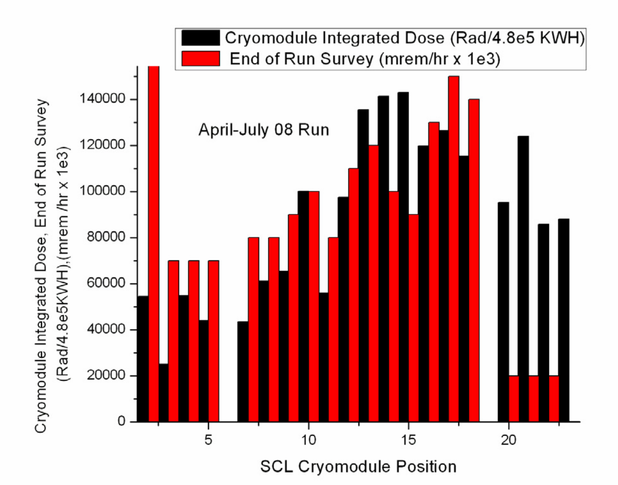

Figure 3: SCL radiation exposure.

CRYOMODULE ACTIVATION

One of the complications of repairing cryomodules at SNS is that they are now all activated. Although the activation levels are still low, controls must be put in place, planning and procedures used to reduce exposures and all must be thought of well before the repairs can start. For cryomodules recently repaired in the RF test facility or the production cleanroom, control boundaries were established and the cryomodule was allowed to set for several weeks before work was started. RCT's, surveyed and tested for removable contamination throughout the repair process. So far no contamination has been detected in or on any cryomodule. As an example of how much activation, CM19 after setting for two months was measured around 30urem/hr on contact externally and around 3mrem/hr internally on the beam-line components. Clearly the stainless steel bellows between the cavities was the most activated component inside of the vacuum vessel. As the beam power increases in the linac, so will the levels of activation on the cryomodules making it even more important for planning and development of in-situ repair procedures and optimized tooling and shielding. The radiation exposure predicted for personnel for the removal of a cryomodule is higher then the in-situ repairs would incur.

For the repairs performed in the tunnel, the activation levels are much higher at around 40-100mrem/hr on contact of beam-line components. Therefore radiation shielding was designed and used on CM09 and CM10 repairs, recently repaired in July-August maintenance period. For the repairs to these two cryomodules, two different types of shielding was designed and used. The first type shielding was a roll around cart for shielding the vacuum work. This provided personnel protection from beam-line components directly in front as well as from the longitudinal sources down the linac from both directions. This was achieved by providing movable shielding doors. The shielding provided a reduction of a factor of two standing directly behind the cart and about one third for personnel standing in the tunnel walk way. The beam-line vacuum work can take hours to setup and perform and therefore must be shielded to reduce exposures. Further improvements have been identified for this cart to include better shielding for personnel standing adjacent to the cryomodule.

The second type of shielding developed was for the internal beam-line components inside the cryomodule. In this case the cryomodule insulating vacuum boundary was vented and the access ports removed. RCT's then surveyed and tested for contamination inside the cryomodule before shielding was wrapped around the beam-line components. This shielding reduced the exposure about a factor of two as well. Improvements were also identified for this shielding and the main one was to reduce the spacing around the components to reduce longitudinal sources. In both cases the shielding was successful but the first use discovered that the task that needed to be performed became more difficult because of the shielding barrier and it will take time for staff to become accustomed to working behind barriers. In total over the five week repair period the maximum integrated radiation exposure for a single person working on cryomodules was around 18mrem, whole body dose.

ADDITIONAL CRYOMODULE REPAIRS IDENTIFIED

Plans are now being made to repair CM11 cavity b (the last remaining cavity not being operated in the SCL) failed HOM coupler during the February maintenance period 2009. The same methods and shielding will be used to gain more experience with this type in-situ repair.

Additionally during this maintenance period, an investigation into identifying and fixing cryomodule insulating vacuum leaks will begin in January. Currently there are seven cryomodules with known insulating vacuum leaks and have additional turbo pumps installed on them in the tunnel. Data suggests that four of the seven have outside to insulating circuit leaks, two are helium circuit to insulating circuit and one is unclear. Most leaks can be repaired in the tunnel but the helium circuit leaks will require an available spare cryomodule before they can be removed from the tunnel and repaired in the RF Test Facility.

SUMMARY

The SRF facilities at SNS have been constantly evolving and improving over time and now plans are to expand the capabilities to support the building and testing of spare cryomodules and in-situ processing of installed SCL components. New facilities will be aimed at increasing the capability of processing and testing of cryomodule subcomponents and adding the additional refrigerator to support both the horizontal and vertical testing facilities. Along with these new facilities, upgrades to the cleanroom and DI water plant will complete the necessary facilities for supporting the cleaning of subcomponents for ultrahigh vacuum and particulate controlled work.

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