HISTORY OF CRYOMODULE REPAIRS AT SNS

M. Howell#, R. Afanador, B. DeGraff, M. Doleans, D. Douglas, B. S. Hannah, S-H. Kim, C. McMahan, T. Neustadt, S. Ottaway, J. Saunders, P.V. Tyagi, D. Vandygriff
ORNL, Oak Ridge, TN 377831, USA

Abstract

The operation of the Superconducting linear accelerator (SCL) has matured and now averages less than one trip per day. The availability of the SCL including radio-frequency systems, high voltage converter modulators, controls, vacuum and other support systems over the last three years is approximately 98%. The SNS has been in operation for ten years including the commissioning period. In support of achieving the stability of operation, multiple cryomodule repairs have been performed. Repairs to cryomodules have included instruments, helium leaks, valve actuators, cavity tuners, insulating vacuum repairs and upgrades, power supplies, higher order mode (HOM) feedthroughs, coupler windows, and coupler cooling components. Performance degradation has been experienced in multiple cavities. This has been corrected by thermal cycling the cryomodules with the affected cavities. Only two cavities have displayed slight permanent degradation that could not be corrected by thermal cycling. Repairs made to the SNS cryomodule will be detailed in this paper.

INTRODUCTION

The Spallation Neutron Source contains a superconducting linear accelerator which consists of eleven medium beta and twelve high beta cryomodules. The strategy to maintain high availability while operating at high power has multiple elements. The first and foremost step was to gain understanding of the machine during commissioning and initial operations such that the machine could be set up in a reliable manner while delivering beam. Due to the limited final linac output energy, each cavity is set at a maximum stable gradient based on the collective limiting gradients achieved through a series of SRF cavity/cryomodule performance tests at SNS, rather than setting uniform gradients as designed [1]. The second step in the strategy is to make systems as simple as possible while developing adequate diagnostic and protection schemes. This enables the operations staff to quickly diagnose issues and prevents permanent damage to the machine. Because simplicity is emphasized in the system design, the turnover from the system experts to the operations staff was facilitated. Good communication between the system experts and the operations staff is a critical component to the long term successful operation of the machine. Another key element of the strategy to maintain high availability at high power is to keep some energy margin. This allows operating flexibility during operation and serves to minimize down time during neutron production. One cavity is operated at zero energy gain so that it can be utilized in the event that another cavity has to be reduced in gradient. The final step to this strategy is to perform proactive and preventative maintenance. When the performance of a cryomodule is impacted, a repair plan is developed for that cryomodule. It is determined whether that repair can be completed within the tunnel (such as thermal cycling) or if the cryomodule needs to be transported to the cryomodule repair facility (such as coupler replacement). After determining the location for conducting the necessary repair, the cryomodule is evaluated for ancillary repairs and maintenance activities that correct deficiencies and enhance the cryomodule operation.

* This work was supported by SNS through UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. DOE
# howellm@ornl.gov

REPAIR HISTORY

Statistics for cryomodule repair at SNS have been maintained and recorded since 2007. A variety of repairs on cryomodules have been performed. These repairs can be broken into two categories; repairs that require thermal cycling of the cryomodule and repairs that do not require thermal cycling. Issues that require thermal cycling include helium leaks, cavity performance degradation, inoperable or unstable tuner, cable problems, excessive power coupling to the HOM, and coupler window leaks. Issues that do not require thermal cycling include instrumentation damage, faulty valve actuator, power supply failures, and coupler cooling system adjustments. A pie chart depicting the repairs performed at SNS since 2007 is included in Fig. 1.

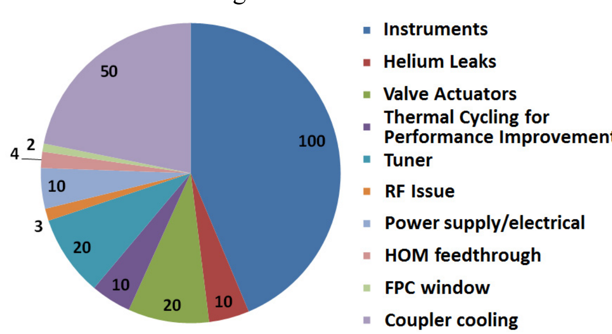

Figure 1: Number of SNS Cryomodule Repairs.

With all of the repairs that have been completed, it was necessary to perform thermal cycles of the cryomodules. Since 2007, there have been 34 instances of cryomodules being thermally cycled.

The number of repairs does not necessarily indicate the severity associated with the repair. The most significant repairs conducted that affected cryomodule performance are thermal cycling due to performance degradation, tuner repairs, HOM feedthrough removal, coupler replacement, and the repair of helium leaks due to failures in the cold

ISBN 978-3-95450-142-7

feedthroughs. These specific repairs are detailed in the remainder of this paper

THERMAL CYCLING DUE TO GASEOUS CONTAMINATION

During operation of the superconducting linac, vacuum bursts have occurred and drastically changed cavity performance. The change of performance can be attributed to particulate contamination, gaseous contamination, or a combination of both. Theoretically if it is only gaseous redistribution, it is possible to reverse the change of condition by thermally cycling the affected cavity. To date, there have been 10 instances in which cryomodules were thermally cycled for performance recovery. All but two cavities have recovered fully. Because thermal cycling a cryomodule presents the risk of creating a leak or making one worse, only selected cryomodules exhibiting the most severe degradation have been thermally cycled.

TUNER REPAIRS

Tuner repairs have been conducted to address three basic issues; Piezo stack failures, stepper motor and harmonic drive unit failures, and irregular or excessive cavity vibration. Most tuner repairs occur within the linac tunnel. The piezo tuner was included in the original design of the SNS cryomodule to compensate for Lorentz force detuning of the cavities. If an unexpected mechanical resonance was experienced in the cavity, the fast piezo could be utilized. However, there has been no such unexpected resonance. Therefore, the low level RF control system can compensate for these detuning forces [2]. Due to pressure changes in the cryomodules either during the 2K to 4K transition or during upset conditions, several failures with piezo stacks have been experienced. The piezo tuners were replaced with the standard stand offs that are utilized on the other two legs of the tuner. The piezo tuners have never been actuated in operation at SNS. Because of this history, it was decided to remove them from any cryomodule that requires maintenance.

Repairs to the cryomodules have been required to correct failures of the stepper motor and harmonic drives and also to correct abnormal or excessive vibration of a cavity. The failures of the drives and motors can usually be attributed to normal operating wear. Fig. 2 shows a harmonic drive with excessive wear. Irregular or excessive vibration has been witnessed during cavity operation in a few cavities. This vibration is due to a worn harmonic drive or a loosened mechanical connection between the tuner and the cavity. This vibration was corrected by either replacing the harmonic drive or by tightening the tuner mount to the cavity.

HOM FEEDTHROUGH REMOVAL

During the SNS project it was decided to have HOM couplers as insurance due to unknown parameters during the design period such as HOM frequency spread and HOM frequency centroid difference between calculated values and real ones [3, 4].

Figure 2: Harmonic Drive Assembly.

About 15 % of installed cavities in the SNS SCL are showing abnormal signals through HOM feedthroughs while running with RF only. All attenuators for the HOM signals were damaged in 1 year of operation. Observations and physical conditions near the HOM couplers imply that HOM coupler failures and/or degradations seem to be a result of electron activities originated by combinations of multiple causes such as electromagnetic field at the HOM coupler, multipacting, field emission, and even a gas discharge with fundamental accelerating mode. A few cavities were inoperable due to large coupling with the fundamental accelerating mode [5]. In 2007, the SNS re-evaluated the HOM characteristics including dangerous HOM modes measurement for all installed cavities. It was concluded that HOM couplers are not needed for the SNS and it was decided to remove HOM couplers when cryomodules are taken out of the tunnel for repairs. Four cryomodules were taken out of the tunnel so far for various repairs and leaks were detected from half of the HOM feedthroughs. Fig. 3 shows a blanked off HOM feedthrough port after the repair was conducted.

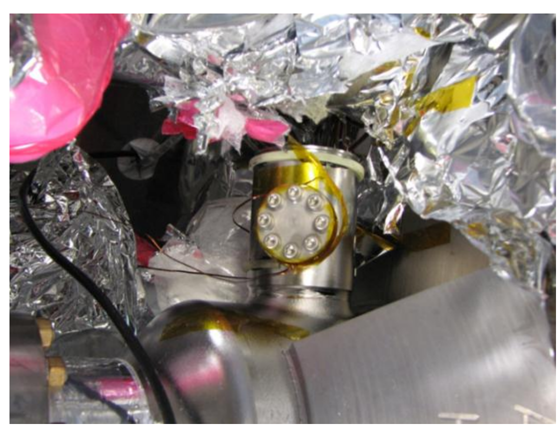

Figure 3: Blanked HOM Feedthrough Port.

COUPLER REPLACEMENT

Two cavities have had leaks at the fundamental power coupler (FPC) window. These leaks are thought to have originated during an errant beam event in 2009. This did not result in catastrophic failure but rather resulted in a leak of approximately 10^{-6} torr l/s. As a result of forming

ISBN 978-3-95450-142-7

these leaks, the cryomodules were removed from the tunnel for repair. Replacing the inner conductor of the coupler which contains the coupler window was conducted inside the class 100 area of the clean room. Fig. 4 shows a picture of the coupler replacement in progress. The cryomodules have been returned to service and the performance of the cavities was restored to the original condition.

Figure 4: FPC Inner Conductor Replacement.

HELIUM LEAKS

The original cryomodule design for SNS included many in process diodes for accurate temperature measurement. During installation, the ceramic portion of the cold feedthroughs was damaged during welding. As a result, repairs were conducted by cutting through the insulating vacuum boundary and thermal shield to access the diodes. The cold feedthroughs were removed and replaced by surface mounted diodes. These surface mounted diodes have given reliable temperature feedback and operations utilizing these readings have been successful. While conducting these repairs, extra care had to be taken while cutting and grinding on activated cryomodule components. These repairs were conducted in a tent with the personnel wearing protective clothing and full face respirators. A radioactive work permit (RWP) was developed and radiation protection personnel were constantly monitoring the work to ensure safety of the workers and environment (Fig. 5).

Figure 5: Cryomodule Repair under RWP.

ADDITIONAL REPAIRS

A checklist has been generated to ensure that any suspect components are replaced or repaired when a cryomodule is removed from the tunnel. In addition to repairing the main issue that drove the decision to remove the cryomodule from the tunnel, components are inspected on the tuners, insulating vacuum system, beamline vacuum system, couplers, and helium circuits. Repairs are made to any failed components, instruments or leaks that are discovered during this inspection. Several components are proactively replaced such as cold cathode gauges, relief valves, the rupture disk, and the ion pump. Additionally, piezo stacks are proactively removed and replaced with the standard stand offs.

FUTURE CRYOMODULE IMPROVEMENT

The SNS cold linac has never operated at its original specification of delivering a 1 GeV beam at 60 Hz. To increase the energy of the beam, the cavity operating gradient of the high beta cryomodules needs to be increased by approximately 15%. [6] To reprocess these cavities out of the tunnel would not be cost effective. Therefore, a method of processing the cavities in-situ is under development. Preliminary results from plasma processing tests look promising to provide a way to increase gradient through in-situ processing.

ACKNOWLEDGMENT

We would like to thank all of the people at SNS that have made the repair of cryomodules possible.

REFERENCES

[1] Kim, S-H., “SNS Superconducting Linac Operating Experience and Upgrade Path”, LINAC’08, Victoria, Canada, September 2008.
[2] Ma, H. et al, “Low-level rf control of Spallation Neutron Source: System and characterization,” Phys. Rev. ST Accel. Beams, 9, 032001, March 2006.
[3] Sundelin, R. et al., “SNS HOM Damping Requirements via Bunch Tracking,” Proceedings of Particle Accelerator Conference 2001 (PAC2001) , pp.1984-1986, Chicago, Illinois, 18-22, June, 2001.
[4] Kim, S-H., el al., “Higher-order-mode (HOM) power in elliptical superconducting cavities for intense pulsed proton accelerators,” Nuclear Instruments and Methods in Physics Research, A 492/1, pp.1-10, Oct. 2002.
[5] Kim, S-H. el at., “Study on fault scenarios of coaxial type HOM couplers in SRF cavities,” Proceedings of Linear Accelerator Conference 2006, pp. 770-772, Knoxville, TN, 21-25, August, 2006.
[6] Doleans, M. et al., “Plasma Processing R&D for the SNS Superconducting LINAC RF Cavities”, SRF2013, Paris, France, September 2013.