STATUS OF SPALLATION NEUTRON SOURCE CRYOGENIC TEST FACILITY (CTF)*

M. Howell#, A. Coleman, B. DeGraff, S-H. Kim, T. Neustadt, J. Proulx, J. Saunders, W. Strong, D. Vandygriff, ORNL, Oak Ridge, TN 377831, USA
T. Xu, FRIB, East Lansing, MI 48824, USA

Abstract

The Spallation Neutron Source (SNS) is building Superconducting Radio Frequency (SRF) processing and testing facilities to support the reliability and sustainability goals of the enterprise. In addition, these facilities position the SNS superconducting linac (SCL) for improvement programs and future upgrades. Some of the testing facilities require cryogenic helium at both 4 K and 2 K. Currently, the Central Helium Liquefier (CHL) supplies 4 K helium to the linear accelerator and excess capacity is utilized to supply the test cave. As more facilities become available and testing is more frequent, it is essential to separate testing in the SRF facility from the operation of the accelerator. This paper describes the cryogenic system and the commissioning of that system at SNS to facilitate SRF testing needs. The initial phase of the project was to supply 4 K helium to a Vertical Test Area (VTA) and the test cave which is capable of housing either the Horizontal Test Apparatus (HTA) or a cryomodule. The scope of the initial phase of this project has been expanded. The system will be outfitted with warm pumping capability to produce 2 K helium in the testing systems. In addition, a liquid helium fill station will be incorporated to fill portable Dewars.

INTRODUCTION

The Spallation Neutron Source contains a superconducting linear accelerator which consists of eleven medium beta and twelve high beta cryomodules. The availability and reliability of the cryomodules has been high. However, the superconducting section of the linear accelerator has not met the energy specification of 1 GeV [1]. To increase the energy of the beam and meet future upgrade requirements, the performance of multiple cryomodules must be improved. To improve these cavities, there are two options. These cavities can be replaced which will involve removing, disassembling, and rebuilding cryomodules. This approach is cost prohibitive. A second option is to implement additional processing or conditioning of the superconducting cavities. SNS is currently installing and developing superconducting radiofrequency processing and test facilities to develop methodology in increasing beam energy and facilitating necessary repairs. The CTF refrigeration system will provide helium at both 4 K and 2 K to the SRF test facilities.

Multiple repairs of cryomodules have been performed at SNS by in house staff. These include tuner repairs, removal of HOM antennas, and repair of helium circuit, beam line vacuum and insulating vacuum leaks. In one case, a mild plasma processing was applied to a cryomodule to improve its performance [2]. After repair, the cryomodules have been qualified in the test cave using the CHL to supply helium. This couples the testing and qualification process to the actual operation of the linear accelerator. The implementation of the CTF decouples these two differing objectives.

DESIGN OVERVIEW

The original scope of the CTF refrigeration system was to provide 4 K helium to the test cave and the VTA [3]. This scope has been expanded to include adding 2 K capability through the use of a warm pumping system. Because the availability of liquid helium has been scarce, a liquid helium fill station to supply portable Dewars to the neutron instrument and sample environment areas has also been added to the scope. By having this subsystem, the liquid supply chain issues can be mitigated with the helium gas storage that is normally available in the CHL. A block flow diagram of the CTF system is included below in Fig. 1.

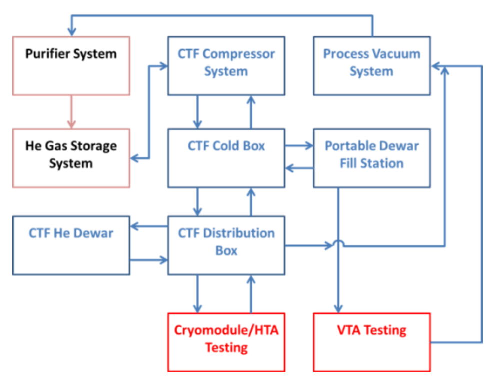

Figure 1: CTF Block Flow Diagram.

As system design has progressed and operational experience has increased, the cryogenic loads in the various testing modes have been further defined. Table 1 summarizes the estimated cryogenic loads of the various test modes. These loads are based on actual test results observed during operation of cryomodules in the test cave.

Table 1: Cryogenic Load Design Criteria

Test System	Nominal T_{bath}(K)	Primary Load (W)	Shield Load @4K (W)	Coupler Flow (g/s)
Cryomodule Test	4	400	200	< 0.5
	2	80	200	< 0.5
HTA Test (single cavity)	4	100	120	< 0.5
	2	20	120	< 0.5
VTA Test (CW)	4	600	None	NA
	2	150	None	NA

The Linde LR280 was specified with a refrigeration capacity of 650 W at 4.4 K and liquefaction capacity of 240 L/hr. This system can operate in multiple operational configurations. The system cold box supplies helium through the distribution box and helium Dewar when servicing the test cave. However, the VTA and fill station are supplied from a second set of bayonets on the cold box.

To operate the test cave, the system will experience a combination of refrigeration and liquefaction loads. The cold box will supply sub-cooled supercritical helium through the distribution box to both the shield and primary circuits. The primary flow will return through the distribution box to the cold box and serve as a refrigeration load. However, the shield flow will return to the warm compressor system through an ambient heat exchanger. This will act as a liquefaction load on the machine along with the coupler flow.

For operation of the VTA or fill station, the CTF will be operated in liquefaction mode. The CTF will supply liquid helium to a 2000 L fixed Dewar within the fill station. This Dewar will be used as a reservoir to either fill the VTA Dewar or a portable Dewar. The detailed design of this subsystem is complete and fabrication is nearing completion. A model of the fill station system is included below in Fig. 2. The fill station is scheduled to be operational in the first half of FY 14.

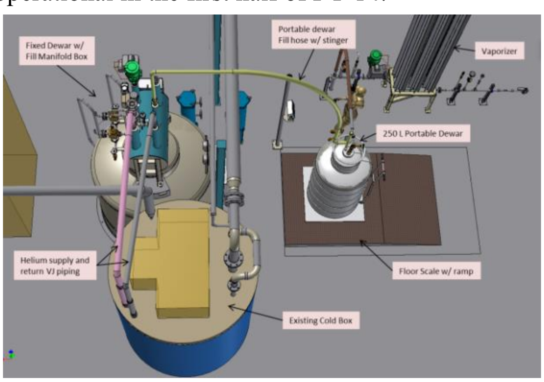

Figure 2: The model of fill station. [4]

The addition of a Kinney pumping skid will enable the system to operate at 2 K. SNS made use of the vast experience of personnel at Fermi National Laboratory in refurbishing this skid. This was a machine originally slated for operation at the SSC. It is a 10 g/s machine equipped with a blower, liquid ring vacuum pump, and oil pump. This portion of the system is scheduled to come on line in FY 14.

COMMISSIONING

The commissioning philosophy was to first start the warm part of the system including the compressor, gas management, and oil removal. This allowed any bugs to be worked out in the warm part of the system while being isolated from the cold box and turbines. The philosophy of this portion of the system was to make it as similar to the existing plant as possible to minimize operator training time, make use of existing control templates, and incorporate the Ganni Cycle [5] to use a floating discharge pressure system to match the load.

The primary goals of this portion of the commissioning were to test the operability, speed control, control functions and interlocks of the compressor, gas management, and oil removal system. Secondary goals were to gain valuable operator seat time and develop internal operating procedures. This test was completed at the end of January with a Linde representative present. The compressor screen shot is depicted below in Fig. 3.

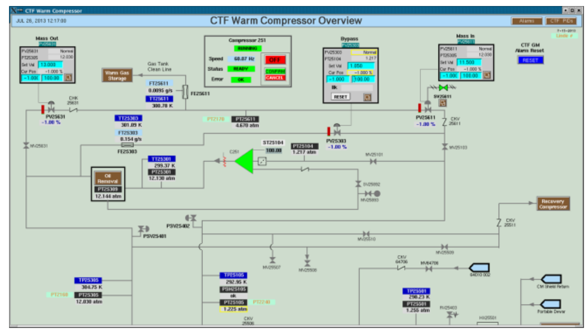

Figure 3: Warm compressor control screen.

After commissioning the warm system, a control logic review was conducted as a collaborative effort between SNS controls personnel and a Linde representative. During this review, the readiness of the controls was verified. The team verified that instrument loop checks, interlocks, operator controls, control algorithms, and initial loop tuning were properly implemented. The cold box PLC logic was reviewed thoroughly and a short action item list was generated and completed within a couple of weeks.

This positioned the team well to move to cold box commissioning. The cold box was operated integrated with the warm system and the helium Dewar. A simplified block flow diagram is included in Fig. 4. An example of the controls screens used during commissioning for this system is shown in Fig. 5. The goals of the cold box commissioning were:

1. Cool down cold box within specified time (< 6 hours)
2. Achieve specified capacities for refrigeration and liquefaction
3. Develop procedures and receive training
4. Demonstrate helium Dewar integrity and achieve specified boil off rate
5. Tune loops and refine control variables
6. Test interlocks and ensures system fails safe.

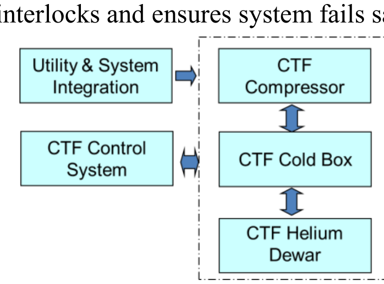

Figure 4: Cold box commissioning block flow diagram.

ISBN 978-3-95450-138-0

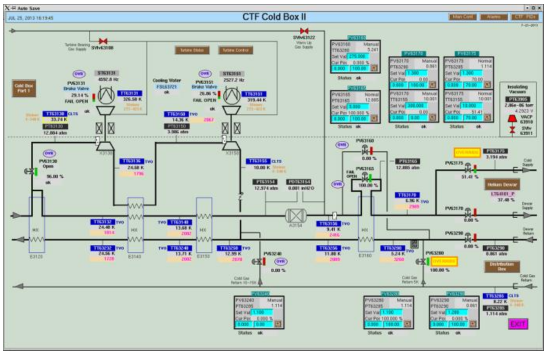

Figure 5: Cold box control screen II.

To commission the cold box in liquefaction mode, the cold box supplied helium to the helium Dewar and a small amount of vapour returned to the cold box. For commissioning, the distribution box was bypassed with three custom made u-tubes. The liquefaction rate was measured in two ways. The first was to observe how much the level increased in the helium Dewar over a specified amount of time. The second was to observe how quickly the helium gas storage pressure dropped in a specified amount of time and convert that to liquefaction rate. These two methods of calculation yielded results of 260 L/hr and 240 L/hr, respectively. Both met or exceeded the specified liquefaction rate. However, it is believed that the calculation method using helium gas storage tank pressure is more accurate than the method of using liquid level due to error introduced by level probe and helium Dewar geometry.

The cold box was commissioned in refrigeration mode by supplying helium to the Dewar and boiling it off with an electric heater. The maximum refrigeration capacity of the system was observed to be 750 W which is greater than the specified capacity. A screen shot of the helium Dewar with the input heater power of 759 W is included in Fig. 6. After the helium Dewar was filled, the system was shut down over night and the boil off rate was measured. It was found to be <0.75% per day as specified.

In addition to achieving the refrigeration and liquefaction capacities, interlocks were tested, internal operating procedures were developed, and loops were tuned. The commissioning gave opportunity to multiple operators to gain hands on experience with the system.

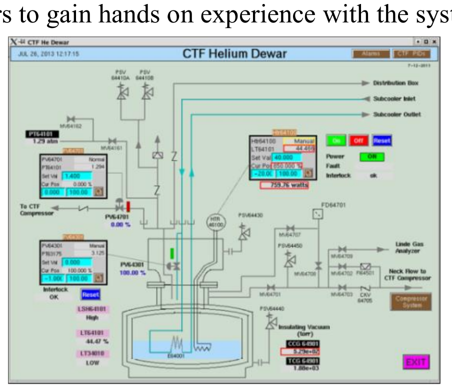

Figure 6: Helium Dewar control screen depicting refrigeration capacity.

LESSONS LEARNED

A few valuable lessons were learned during the design and commissioning of this system. One design change that was incorporated was to take the compressor bypass from after the second stage coalescer to minimize oil carry over. In the CHL system, oil accumulation is witnessed in the low and medium pressure headers. This change has eliminated this concern from the CTF system.

As controls personnel were performing check out of the gas management valves, it was discovered the Weka control valves required 5 atm instrument air pressure to operate [6]. The control valves in the CHL gas management system operate at 3atm air pressure. This required a change out of an air pressure regulator to accommodate operation of the CTF gas management control valves.

Another lesson learned involved bonding the cold box to ground. This was overlooked in the original installation of the system. The temperature sensors gave erroneous readings on both the TVO resistors and cryogenic linear temperature sensors (CLTS) [6]. This was corrected by connecting the box to ground.

This system was specified as a machine with frequent starts and stops that give ample opportunity to regenerate the 80 K and 20 K adsorbers. However in future systems, it may be advantageous to install isolation valves and a bypass. This can be used during warm up iterations and ensure that contamination does not enter other areas of the system.

ACKNOWLEDGMENT

We would like to thank all of the people that have made the fabrication, installation and commissioning of the CTF system possible. We recognize the dedication and hard work put forth by the SNS and Linde teams.

REFERENCES

[1] Kim, S-H., "SNS Superconducting Linac Operating Experience and Upgrade Path", LINAC'08, Victoria, Canada, September 2008.
[2] Kim, S-H., "R&D Status for In-Situ Plasma Surface Cleaning of SRF Cavities at Spallation Neutron Source", PAC2011, New York, New York, March 2011.
[3] Xu, T., "Status of Cryogenic System for Spallation Neutron Source's Superconducting Radiofrequency Test Facility at Oak Ridge National Lab", *Advances in Cryogenic Engineering 57*, edited by J.G. Weisend et al., Melville, New York, 2011, pp. 1085-1091.
[4] Willming, S., "Liquid Helium Filling Station", Presented at CTF Liquid Fill Station Preliminary Design Review, April 2013.
[5] Ganni, V., Design of Optimal Helium refrigeration and Liquefaction Systems, CEC-ICMC Short Course Symposium, 2007, Chapter 5.
[6] Strong, H. "CTF Readiness Review: Control System Overview", September 2013.