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NSLS-II RF CRYOGENIC SYSTEM*

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Abstract

The National Synchrotron Light Source II is a 3 GeV X-ray user facility commissioned in 2014. A new helium refrigerator system has been installed and commissioned to support the superconducting RF cavities in the storage ring. Special care was taken to provide very stable helium and LN2 pressures and flow rates to minimize microphonics and thermal effects at the cavities. Details of the system design along with commissioning and early operations data will be presented.

INTRODUCTION

The NSLS-II RF cryogenic system, shown in Fig. 1, consists of a dedicated 4.5 K helium plant, LN2 system and RF system. The cryogenic system was designed for the complete build-out of the RF system, however only half of the RF is installed in the project scope. The cold box, compressors and dewar are all standard units, however boxes for helium and LN2 distribution are designed specifically with the application of superconducting RF in mind and have special features. Likewise the controls are split into two parts: one for the cryoplant operation, the second for the valve boxes that control the flow to and from the SRF cavities.

RF 4.5K COOLING REQUIREMENTS

The liquid helium cooling requirements for the NSLS-II RF cryogenic system was calculated for the full build out of two RF straights, each with two 500 MHz cavities and one 1500 MHz third harmonic cavity. The RF straights some 40 meters from the cold box and dewar, requiring some 45m each of vacuum jacketed transfer lines. In addition an RF test cave is located 20 m away. Each location requires valve boxes with 4 valves per cavity: LHe supply, cold GHe return, warm GHe return and LN2 supply. In addition the valve box for the RF test cave has valves for the transfer lines to the valve boxes (A and B) feeding the RF straights. Heat leaks were assigned to the rigid transfer lines (0.2 W/m), flexible VJ lines (1.6W/m), valve box and dewar losses. Dynamic heat loads from RF losses in the RF cavities were calculated as a function of cavity voltage. Since these losses are proportional to the square of the cavity voltage, and the required voltage of 3.3 MV per two cavities (1.5 MV each) and 4.8 MV per four cavities (1.2 MV each) the dynamic losses do not rise dramatically with the addition of the second RF straight. The 4.5K cooling requirements are summarized in Table 1.

Table 1: RF Cryogenic Requirements

Cryo=Plant Heat Load	Initial Project	Final Build
Total 500 MHz RF voltage (MV)	3.3	4.8
Number of 500-MHz cavities	2	4
R/Q (44.5 * # cavities)	89	178
Number of harmonic-cavities	1	2
R/Q (45 * # cavities)	90	180
Dynamic RF losses	(W)	(W)
500-MHz cavity Nb Q=7.5E8	69	71
500-MHz cavity Cu (W)	5	5
1500 MHz Nb (W) Q=3E8 (V= 1/3 V@500MHz)	20	31
1500 MHz Cu (W)	13	15
Dynamic Load Total	107	123
Static Heat Load	202	393
RF-ON, Total Load, W	309	516
150% Total Load	463	774

The total cryogenic load of 774 Watts is met by the largest of the Linde L280 series refrigerator/liquefier. Final specification was for a guaranteed 741 watts at 4.5 K as measured in the manifold box which is the central distribution point of the system.

CRYOGENIC PLANT

The cryogenic plant consists of the screw compressors, cold box with three (3) gas bearing turbo-expanders, 3500 L Dewar, gas management system, pure He gas storage tanks and helium purity analyser. The cold box includes integrated dual full flow 80 K adsorbers for manual regeneration, integrated single full flow 20 K adsorber for the removal of Neon and hydrogen, option of LN2 pre-cooling. The operation of the plant can be summarized as providing a full dewar of liquid Helium. The remainder of the cryogenic plant consists of the multichannel vacuum jacketed transfer lines, "manifold" valve box and two distribution valve boxes. The operation of the cavity side of the cryogenic system can be summarized as keeping the superconducting cavities helium vessel full of liquid with minimum of pressure and level variations which

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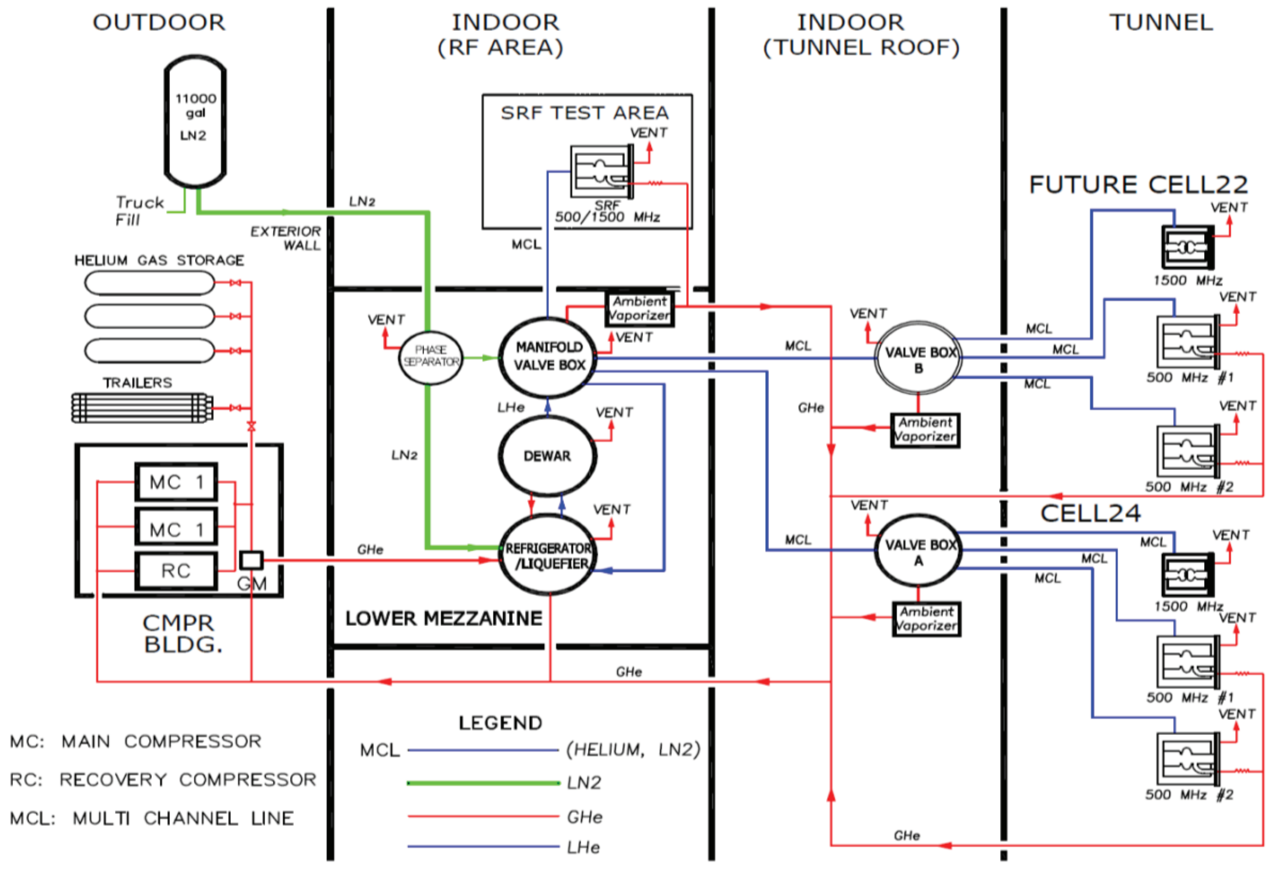

Figure 1: RF cryogenic plant diagram.

could lead to microphonics and degradation of RF cavity performance. It is guaranteed to 814 Watts of refrigeration at 4.5 K and has achieved in excess of this during acceptance tests.

VALVE BOXES AND CAVITY

The 3500 liter dewar serves as the interface between the plant and the distribution to the superconducting cavity loads. The dewar feeds a “manifold” valve box that in turn distributes LHe and LN2 to the test cave and to the remote valve boxes that feed the cavities in the two RF straights. The GHe returns back to the compressor after warming up in the ambient vaporizers. There is also a test vessel in the manifold box on the cold gas return line with helium level sensor and heater that was used for acceptance tests. The remote valve boxes each feed an RF straight with 3 cavities each. Each cavity in turn requires control valves for LHe, cold GHe return, LN2 supply and warm gas return. The design of the cryogenic system outside the plant was optimized to provide high quality liquid helium and nitrogen to the cavities. By high quality it is meant that it should be as high a percentage of liquid as possible, with minimum gas content to avoid turbulent flow and noise that may drive microphonics in the superconducting cavities. To achieve this phase separators are installed in the final valve boxes to separate and vent gas as close to the final delivery point as possible.

PLC CONTROLS

The control architecture was influenced by two factors. The cryogenic system is to be built in two stages, the first being the plant and the first valve box feeding the cell 24 RF straight which has been completed, and the second RF straight with its associated valve box and transfer lines added later. The RF group also wished to be able to program the cryogenic valve controls associated with the superconducting cavity in order to optimize the loops for minimal excitation of microphonics. In discussions with the vendor it was decided to split the controls PLC into two parts. The first (PLC1) is the standard LINDE controls PLC that controls the cold box, communicates to the compressor PLCs and provides overall control of the plant. A second (PLC2) was added which controls the valves that control flow to and from the superconducting cavities. This architecture allows us to program the valve control without the possibility of corrupting the critical PLC1 control of the cold box. It also will allow us to add the second RF straight and associated valve controls at a later date without affecting the plant. Close cooperation with the Linde controls engineer and BNL led to a very successful implementation of this two PLC architecture. This has enabled the cryogenic valve control for the cavities to be optimized over the first year’s operation.

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LIQUID NITROGEN SYSTEM

Other synchrotron facilities have seen pressure variations on the LN2 distribution system cause disturbances on the cavities which have shown up on the synchrotron radiation. The LN2 system provided by PHPK was designed to avoid this. It uses a dedicated LN2 bulk supply tank of 11,000 gallons and a 200 m transfer line to deliver LN2 to a phase separator / distribution valve box. From this, the LN2 is supplied to the Cold Box for the helium plant precooling and also to the multi-channel transfer lines, the valve boxes and the cavities themselves to cool the thermal radiation shields. The use of multiple phase separators to vent nitrogen vapour and the dedicated LN2 bulk tank have provided a stable supply and there is no measurable disturbance on the cavities.

COMMISSIONING

In order to determine the net refrigeration capacity including heat losses in transfer lines and valve boxes 2-phase helium was sent from the LHe dewar via manifold to Valve Box A, then returned via bypass valves between the cavities supply and return valves still as 2-phase flow to the manifold and collected in the test vessel located in the manifold box. Besides a phase separation the incoming liquid is evaporated by a test heater. The return flow is measured as a function of heater power to calibrate and perform acceptance tests.

The cavities were commissioned in a similar manner with the helium flow measured in Valve Box A cold GHe return line. In order to measure the dynamic RF losses flow was measured with RF on and DC heaters in the cavity helium vessel off, and then RF turned off and the DC heaters turned slowly up until the same flow rate was achieved, all while maintaining constant level and pressure. As shown in Fig. 2 the DC heater power is then equal to the RF losses.

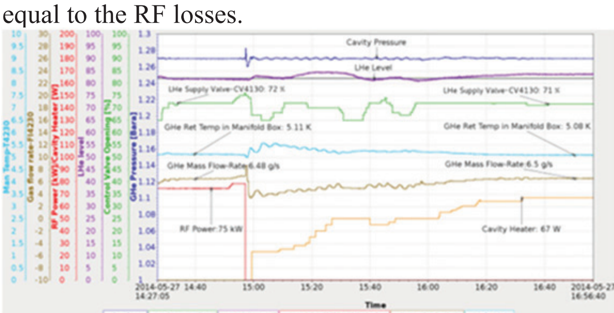

Figure 2: Calorimetric measurement of RF losses in the cavity.

OPERATING EXPERIENCE

The plant has been operated for over a year now and has had only one unscheduled downtime during operations. The ability to program the cryogenic system PLC2 in operations has proven critical. The warm GHe return valve for the cavity was programmed to open in the event of the GHe pressure reaching 1.35 bar in order to prevent helium loss as shown in Fig. 3.

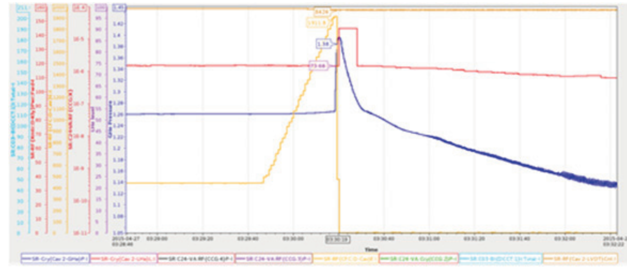

Figure 3: Pressure spike during cavity quench is clipped by automatically opening the warm GHe return valve.

We have had several small issues which have been resolved while maintaining plant operation. Most of the effort has been on the valve box and cavity distribution side where BNL was responsible for the programming of the LHe pressure and level loops in the cavity as well as the LN2 thermal transition temperature which affects cavity frequency. An example of such an improvement is given below. First is the stabilization of the helium level loop in the cavity shown in Fig. 4. The level was oscillating for several days after a system disturbance. Around midpoint in time in the plot the level was measured as a function of time for a step function in the LHe supply control valve setting. New P-I gain settings were calculated and set into the level control loop and the system was stabilized.

Figure 4: Helium level (red) pressure (blue) and helium flow (brown) to the superconducting cavities helium vessel before and after loop optimization.

In addition to the above example the temperature control loop for the LN2 cooling to the cavity thermal transitions was extensively studied and optimized as well as a problem with the AMI LHe level sensors locking up at certain levels solved by changing their operation from “update” mode to “sample” mode with 0.1 time constant.

ACKNOWLEDGMENT

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