The Insulating Vacuum System of the SNS Cryomodules

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Abstract. The 81 superconducting RF cavities of the Spallation Neutron Source (SNS) accelerate the beam from 186 to 1000 MeV [1]. These cavities are fabricated of niobium and installed in 23 cryomodules each containing either 3 or 4 cavities. To achieve the required performance the cavities are operated in a superconducting state at ~2K achieved by submerging the cavities in individual cryostats of supercritical helium. The cryomodules provide a vacuum jacket around these cryostats to minimize heat leak due to gas convection and need to be maintained at a pressure <1e-5 torr. During initial operation helium leaks were experienced in some cryomodules requiring them to be actively pumped to maintain this pressure. This paper provides an overview of the design, installation and operation of the Insulating Vacuum System (IVS) installed for this purpose.

1. System Design and Configuration
The leak rate was measured on 4 leaking cryomodules to establish a reasonable basis for the design, the recorded values ranging from 1.9E-6 to 4.0E-5 torr-l/s. On one cryomodule the leak rate was also measured at 2K and 4K where the difference was found to be < 1%. A simplified thermal analysis of the multi-layer blanket system indicated that a pressure of < 1.0E-4 torr would be required to limit heat gain of the cryomodules due to gas conduction < 10% of that due to thermal radiation.

The insulating vacuum space of the cryomodule acts as a cryopump since it contains the cryo-cooled superconducting cavities which operate at a temperature of ~ 2K to 4K. At this temperature the saturated vapor pressure for helium > 10 torr. While the gas load to be pumped will be essentially helium for the analysis a mixture of 90% helium with 10% of other residual gases was assumed [2].

In addition to meeting the vacuum performance requirements noted above the IVS is also required to be reliable, compatible with the anticipated radiation environment and cost effective. To provide reliability and to allow the system to be serviced while operating a dual pumping system was selected. Radiation levels were also a consideration in the reliability equation; as a result the pumps were located as far from the cryomodules as possible within the physical constraints of the tunnel and the electronics located remotely. When viewed down the tunnel in the opposite direction to the beam, see figure 1, the cryomodules are located in the bottom left quadrant and the IVS pump sets in the upper right quadrant providing a physical separation of about 5’. The electronics and gauge controllers for the system are located in the klystron gallery; a cable run of about 120’ between the pumps and gauge heads and the control electronics. For design purposes a radiation exposure < 1.0E6 rads was specified in the vicinity where the pumps would be located.

Various mechanical configurations of the IVS were evaluated ranging from pumping each cryomodule individually to all cryomodules being pumped from a common manifold which would extended the over 700’ of the cold linac. Design trade-off studies were conducted to determine the
most effective configuration the outcome of which was a configuration that serviced 4 cryomodules from a centrally located pumping system. A compact design was desirable due to physical constraints and as a result advantage was taken of the ability to operate the system at a relatively high pressure of 1.0E-4 torr when pumping the design level leak of 1.0E-4 torr-l/s from each of the 4 modules. This allowed the diameters of the manifolds and the size of components to be minimized.

A further trade-off study was conducted to compare the use of a diffusion pumped (DP) system, which has been previously used in a number of other facilities to perform a similar function, with that of a turbomolecular (TMP) pumping system. This trade-off indicated that the overall capital costs would be about 30% lower and that the steady state power consumption would be reduced by over 50% by using the TMP based system. Being dry further reinforced the selection of a TMP based system over that of the DP system which has the attended problematic issues of using oil, especially in a radiation environment.

2. Mechanical Design and Equipment Layout
The pump support frame, which is suspended from the roof of the tunnel, supports two horizontally opposed TMP pumping stations (figure 2). Each station consists of an air cooled TMP rated at 50 l/sec helium backed by a diaphragm roughing pump rated 15 l/min. The TMP is mounted vertically and has a 4.50” CF inlet flange to which is mounted a pneumatically operated angle valve. These two angled valves are connected by a 2.50” diameter horizontally teed manifold which joins to the main 3.00” diameter manifold which interconnects the 4 cryomodules that extend about 35’ in each direction. This manifold is supported from the roof of the tunnel. The connection between the main manifold and the local manifold of each cryomodule is by a vertical line, 2.00” diameter line about 5’ in length, which uses viton sealed KF flanges to allow ready removal of this section for cryomodule removal in the event that this would be required. Pneumatically operated angled valves connect the vertical line from the main manifold to the local manifold of the cryomodule which is connected to the cryomodule via a manually operated gate valve (figure 3). Another manual valve is provided to allow connection of a temporary pump cart for pumping down the cryomodule insulating vacuum if ever required. The complete manifold is of modular design, fabricated of 304 stainless steel with sections limited to about 6’ in length for ease of installation. All permanent connections use metal sealed CF flanges, all valves are "spring to close" with bellows sealed stems and viton sealed poppets. Stainless steel bellows are strategically located to facilitate alignment of the manifolds during installation.

Both the diaphragm roughing pump and fan for cooling the TMP are relay controlled and the TMP is powered and controlled from the electron drive unit located remotely in electronic racks in the klystron gallery (figure 4). Vacuum gauging is strategically located to monitor and allow the control of
the IVS. Thermal couple gauges (TC) and cold cathode gauges (CCG) are located at the inlet of each pump and in the main manifold connecting the individual cryomodules. A CCG is located on each of the 4 cryomodules to monitor insulating vacuum pressure. As previously noted the gauge controllers are located remotely in electronic racks located in the klystron gallery. All valves are controlled via 24V solenoids and valve position is monitored by open and close limit-switches powered from the PLC located in the electronic racks located in the klystron gallery.

3. Control Hardware Design
The IVS requires four electronics racks to service all 23 cryomodules [3]. Each rack uses an Allen-Bradley ControlLogix 5000 Programmable Logic Controller (PLC) which controls two pumping stations pumping 4 cryomodules. The PLC provides all interlocks and controls the pump stations and associated vacuum valves. The PLC uses EtherNet/IP to communicate to the EPICS Input/Output Controller IOC and Linux workstation [4] which provides the operator interface. To reduce the number of PLC I/O connections, a Digi PortServer is used to interface with the MKS Series 937A controller’s serial communication card and provides a RS-232 serial to Ethernet connectivity to allow full read and write capability for the vacuum gauges. Commands to turn CCG’s high voltage on/off, change set points and to monitor pressures are accomplished through the Digi PortServer.
4. System Control Logic
The IVS is designed to operate without operator intervention following initial start-up using either or both TMP pumping stations. A PLC interfaces provide flexibility in the overall control scheme with system operation implemented from the EPICS screen shown in Figure 5. The health/serviceability of the TMP pumping station is monitored by the electron drive unit which will automatically shut the pump system down on detection of a problem and which will also be indicated on the EPICS screen. Limit switches are used on all valves to provide a positive indication of valve position and the location of the CCG’s has been selected to protect the integrity of the insulating vacuum of each cryomodule.

At start-up the pump inlet pressure is compared to that of the main manifold and provided the pump inlet pressure is lower the pump inlet valve will open. The pressure in the main manifold is then compared with the insulating vacuum pressure of each cryomodule and provided the main manifold pressure is lower the cryomodule insulating vacuum inlet valve will open. If during operation the main manifold pressure exceeds 1.0E-4 torr this would indicate an insulating vacuum leak in one of the cryomodules has exceeded the design leak rate. At this point the operator would sequentially close each cryomodule insulating vacuum inlet valve in turn monitoring the rate of rise to identify the suspect cryomodule so that it can be taken off-line and corrective action taken. The system has been designed with the capability to conduct this rate of rise test automatically allowing the vacuum integrity of all cryomodule to be monitored on a routine basis allowing early intervention. This feature has not yet been implemented.

5. System Status
Currently seven cryomodules have been identified as having helium leaks of sufficient magnitude that active pumping is required. Fortunately these cryomodules are located in 3 groups and in positions that have allowed the 4 cryomodules configuration to be implemented in a logical manner. Two leakers located in cryomodule positions, 6 and 8, two in positions 9 and 11 and three in positions 13, 14 and 15 which correspond respectively to three cryomodule insulating pumping groups; 5 to 8, 9 to 12 and 13 to 16. At this time the mechanical installation has been completed for these three cryomodule insulating pumping groups and the electrical and controls installation completed on pumping group 5 to 8. This section of the IVS is currently being commissioned. Completion of the installation and commissioning of pumping groups 9 to 12 and 13 to 16 is planned for the next shutdown scheduled for the later part of 2007. The design of the remaining 3 groups of 4 cryomodules is complete but procurement and the subsequent installation and commissioning will be delayed until the need for active pumping in these sections has been identified.

6. System Operating Experience
Due to the criticality of this system the system has been operated for a period of about 3 months but the final connection to the cryomodule insulating vacuum remains to be made. This is allowing the reliability of the equipment to be checked and the control system operated to ensure that the hardware and software provided is robust and reliable. Following this initial shake down the system will be connected to the cryomodule insulating vacuum.

References
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