INSTALLATION AND COMMISSIONING OF THE 200-M FLEXIBLE CRYOGENIC TRANSFER SYSTEM

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Abstract

NSRRC is constructing the Taiwan Photon Source. SRF modules have been selected to serve as accelerating cavities in the electron storage ring. A test area for the SRF modules is established in the RF laboratory, including the cryogenic environment. Liquid helium is transferred from cryogenic plants of the TLS, which is not only remote from the RF laboratory but also involves a complicated route of 205 m total length. The main concerns about cryogenic transfer are the difficulty of installation, heat load, two-phase flow and pressure loss. Flexible cryogenic transfer lines of type concentric tube were chosen for both the supply of liquid helium and the return of cold helium gas. With these two long transfer lines, the installation period was greatly decreased to one week. With a 500-L dewar in the RF laboratory and valve boxes at both ends of the transfer lines, a cryogenic transfer system was completed over a large distance and proved to function satisfactorily.

INTRODUCTION

The National Synchrotron Radiation Research Center (NSRRC) is constructing a 3-GeV synchrotron facility, the Taiwan Photon Source (TPS) [1]. To build the radio frequency (RF) system for this TPS project, an RF test area is established in the RF laboratory, which includes a high-power RF transmitter, a low-level RF control system and radiation-shielded space. The last major work to be done in this test area was the cryogenic environment for the high-power RF test of the superconducting radio frequency (SRF) modules. Two liquid helium plants exist in the experimental area of the Taiwan Light Source (TLS) [2], with sufficient cooling capacity much beyond the operating requirements of the SRF module and superconducting magnets in the TLS. An optimum strategy is thus to transfer the available liquid helium from these cryogenic plants to the SRF test area.

It was first reckoned that the valve box for the SRF module of the TLS has one complete set of spare ports for cryogenic fluids that can serve as source ports for the cryogenic transfer system. This TLS SRF valve box is located in the experimental area, just above the shielding tunnel of the TLS electron storage ring. A spare valve box, a 500-L liquid-helium dewar, and a phase separator for liquid nitrogen (LN2) were moved to the RF test area in the RF laboratory, located in another building. Shown in Fig. 1 are these end components of this cryogenic transfer system. A route from the TLS SRF valve box to the valve box in the RF laboratory for the cryogenic transfer lines was also devised with an integrated length of 205 m. To cope with the complicated piping route and limited working period in radiation-restricted areas, flexible cryogenic transfer lines shielded with liquid nitrogen were selected to deliver the liquid helium (LHe) and cold helium gas (GHe).

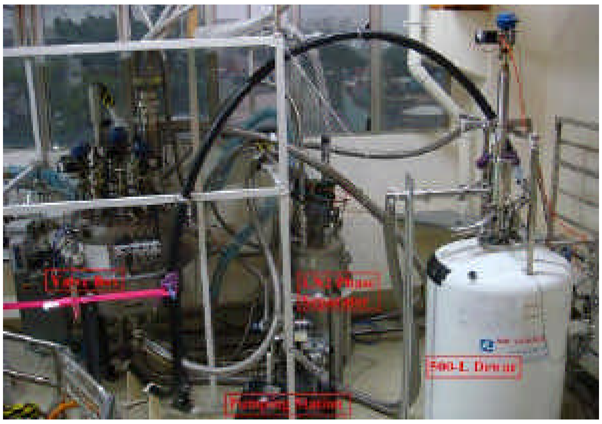

Figure 1: Main components of the cryogenic transfer system installed at the RF laboratory.

This cryogenic transfer system has been established. The test results show that the cooling capacity of liquid helium delivered to the RF test area can attain 100 W, with all cold helium gas recovered to the cold box of the liquid helium plant. The configuration, considerations, installation and test results are described in this report.

CHALLENGES AND CONSIDERATIONS

The challenges of building the cryogenic transfer line are due mostly to the large distance and complicated route. The distance of 205 m is certainly a major concern for the heat load, pressure drop and cold mass. The heat load on the LHe line vaporizes the liquid helium, not only to decrease the transfer efficiency but also to cause two-phase flow in the LHe line. This extra cold gas has to be returned through the GHe line. A greater heat load on the LHe line thus increases the pressure drops on both the LHe line and GHe line. A phase separator in the middle of the LHe line is a possible solution, but such a component would increase the engineering complication, so it was excluded from this cryogenic transfer system.

The heat load on the GHe line must also be minimized to increase the operating efficiency of the liquid-helium plant. The standard design to decrease the heat load is to provide shielding with both vacuum and liquid nitrogen, as well as installation of super-insulating material in multiple layers inside the vacuum-shielding channels. A

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decreased diameter of the transfer line decreases both the radiated heat load and the mass to be cooled, but increases the pressure drop. Optimization of the selection of pipe sizes is based mainly on the calculations of heat load and pressure drop. The cold mass is a concern to the cooling process. Based on our calculations, the chosen flexible lines can be cooled without difficulty as long as the liquid-nitrogen channels are cooled for some days to decrease the temperature of the central lines below 200 K.

The piping route of this cryogenic transfer line is complicated, not only across buildings and through vertical wells, but also with many bends. Briefly, the route begins from the bottom of the TLS SRF valve box and proceeds 16 m along the curved tunnel roof of the TLS electron-storage ring, through a 23 m bridge, upward to the ceiling and penetrating the building wall with a length of 16 m, then downward along a 3 m well to reach the roof of the TLS booster. After a 34 m passage on this booster roof, a 6 m vertical well and a 47 m horizontal trench lead it to the building entrance of the RF laboratory. Here the transfer line route proceeds along mostly straight sections and six bends, in total 60 m and including a 4.5 m rise to the ceiling of the RF laboratory. The total length is measured as 205 m.

The TLS ring is regularly operated in a constant-current mode to serve synchrotron light users [3]; the booster ring is thus always in operation. Both the shielding roof of the electron-storage ring and the booster roof are radiation-restricted areas; work on these areas is limited to periods of machine shutdown. Together with the complication of the piping route, multi-channel transfer lines of various designs were then abandoned. CRYOFLEX$^{?}$ flexible transfer lines of concentric multi-tube design (NEXANS product), already functioning satisfactorily in BESSY with a length of 150 m [4], were chosen for this purpose. To fulfil the demands of small pressure drop and small heat load, flexible lines of four-tube type were selected.

Each tube of the flexible lines is made of stainless steel, helically corrugated and longitudinally welded. A continuous flexible line of hundreds of meters is practicable. The concentric tubes resemble bellows; the diameter of each tube is thus specified with two numbers as shown in Fig. 2. The central tube delivers LHe and cold GHe, respectively. Next to a vacuum channel, the third channel delivers liquid nitrogen and follows with another vacuum channel. The vacuum channels are filled with multi-layer super-insulating materials and low-loss spacers to decrease the heat load on the cryogenic fluids. The outer surface of the flexible line is protected with a PE jacket. The piping route is so complicated that installation of a 200 m line from one end to another is too difficult. A break was then decided on the TLS booster roof that separates each line into sections of lengths 67 and 138 m, respectively. This large roof provides ample space for turnaround and length absorption. The flexible lines are thus installed as beginning from the TLS booster roof to both ends. The main lines are connected with bayonet fittings, whereas the nitrogen channels are linked with extra short, highly flexible lines with bayonets so as to become independent of orientation.

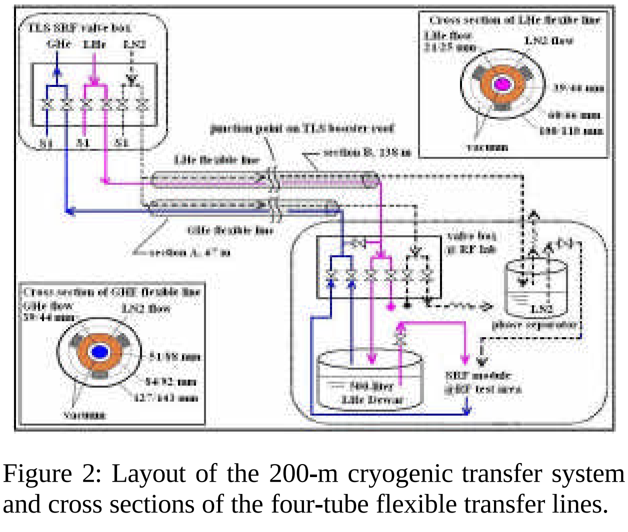

Figure 2: Layout of the 200-m cryogenic transfer system and cross sections of the four-tube flexible transfer lines.

Figure 3: Flexible transfer lines delivered to NSRRC and the supporting frame to unroll these lines.

INSTALLATION

The long flexible lines were delivered to NSRRC as four rolls of diameter about 4 m, as shown in Fig. 3. Special frames were manufactured to hold the wooden drums and to unroll the transfer lines. The lines are not entirely flexible and require a minimum radius 1.5 m for each bend. Some assisting tools and ropes to make and to fix the bends, and to keep the line on location, were prepared. To avoid difficulty along the piping route and to speed the installation, most preparations were done some weeks before the actual installation. First, a soft plastic pipe was placed along the piping route to test every condition. Supporting frames were then installed all along the route. Scaffolds with slides, as illustrated in Fig. 4 to reach the TLS booster roof from the ground, were also built in advance.

The installation was done during a scheduled two-week machine shutdown of TLS in 2008 October. One day before that shutdown, three long flexible lines were unrolled at the grass yard near the TLS booster. In the following four days, all flexible lines were installed to the correct position under the cooperation of two experienced engineers from NEXANS and about fifty workers from NSRRC. Some short flexible lines and adaptors to link

Figure 4: Scaffold to raise the flexible transfer lines from the grass yard to the TLS booster roof.

the long flexible lines and the valve boxes were also installed and mostly connected in this period. Only the connectors to the TLS SRF valve box were not attached. Because of all preparations, effective organization and group efforts, the installation of the long transfer lines required only five days, as scheduled.

LEAK TEST AND OFF-LINE COLD TEST

To ensure that all lines were not damaged during the installation, an immediate leak test was essential. The liquid-helium line was connected to the gaseous helium line at the TLS RF valve-box side with a vacuum-jacketed adaptor. Gaseous helium was then filled to 5 barg into both the helium and nitrogen channels, respectively, from the RF laboratory side. The rates of leakage measured on all insulating vacuum volumes of the transfer lines were all less than 2?10^{-9} mbar-l/s, conforming to specification.

In the RF laboratory, an electronic system for the main end components shown in Fig. 1 was established with functions signal monitoring, valve control, safety interlock and data acquisition. The design, assembly, wiring and functional test of this electronic system were all undertaken by NSRRC members. Spare spaces were reserved for possible signal extension and modification.

Both helium and nitrogen channels were filled with liquid nitrogen for several days as a first cold test in 2009 January. After warming near 295 K, a test of helium leakage was performed again; no leakage was found. Before connecting to the TLS SRF valve box, several cold tests with liquid nitrogen were performed and followed with leakage tests. These precautions ensure that the lines and connectors are all leak-tight after thermal cycles. Liquid helium was first transferred from the RF laboratory, sequentially through the GHe and LHe lines, and finally accumulated in the 500-L LHe dewar in 2009 March. All these off-line cold tests not only ensure the performance but also assist handling the integrated characteristics of this cryogenic transfer system.

COMMISSIONING

The cryogenic transfer system was linked to the TLS SRF valve box in 2009 June, during a long shutdown of TLS. All related helium lines and vessels were then purged and pumped with pure helium gas three times, to ensure no damage to the cryogenic plants. In the pre-cooling process of this cryogenic transfer system, liquid nitrogen was supplied from the TLS SRF valve box into the LN2 channel of each long transfer line. The vaporized nitrogen flow was gradually increased to 120 slpm for the LHe line and 160 slpm for the GHe line over three days until the liquid nitrogen reached the RF test area from both the LHe and GHe lines. The pre-cooling procedure continued a further three days until the temperature of the LHe line inside the valve box at the RF test area attained 150 K. Liquid helium was then supplied from the cryogenic plant to cool the entire system including the 500-L dewar. Liquid helium accumulated in the 500-L dewar six hours later. The 200-m LHe line was totally cooled to liquid helium temperature in three hours, and the extra three hours served to cool the 500-L dewar, because it was not pre-cooled with liquid nitrogen.

The tests and measurements in the following weeks showed that the delivered liquid helium suffices to maintain the 500-L dewar at a constant level with the internal heater being powered to 100 W. The measured heat load along the total path of liquid-helium transfer supply is about 97 W when the 500-L dewar is the only consumption of the cryogenic plant, and about 62 W when the SRF module S1 of TLS is also operational. It is thus concluded that the heat load on the liquid-helium transfer path of this cryogenic-transfer system is about 44 W, with contributions from not only the 205 m LHe line but also from two valve boxes, three bayonet junctions and two short transfer lines without LN2 shielding.

Some minor modifications were introduced in this system to improve its operating performance such as to achieve cooling capacity of 150 W and to reduce the pressure drop. Detailed measurements of the heat load on both the LHe and GHe lines after modification and related operating conditions to increase the capability to transfer liquid helium will be reported elsewhere.

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REFERENCES

[1] C.C. Kuo, *et al.*, “Design Status of Taiwan Photon Source,” EPAC08, Genoa, Italy, p. 1986 (2008).

[2] F.Z. Hsiao, et al., “Continuous Operation of Cryogenic System for Synchrotron Light Source,” EPAC08, Genoa, Italy, p. 2503 (2008).

[3] G.H. Luo, et al., “Overview of Top-up Injection at Taiwan Light Source,” SRI2007, AIP conference Proceedings, Vol. 879, p. 13 (2007).

[4] J. Knobloch, et al., “Status of the HoBiCaT Superconducting Cavity Test Facility at BESSY,” EPAC04, Lucerne, Switzerland, p. 970 (2004).