DESIGN OF A LIQUID-HELIUM TRANSFER SYSTEM FOR THE TPS PROJECT

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Abstract

The construction of the Taiwan Photon Source (TPS) storage ring is in progress, to be completed in mid 2012. A new helium cryogenic system, to be provided by Linde Company, will be installed after the TPS storage ring is completed. Superconducting radio-frequency (SRF) modules are required to maintain the electron energy of the storage ring and are operated in a refrigeration mode such that cold gaseous helium from the cavity cryostat is returned to the refrigerator. A distribution valve box and individual segments of multichannel transfer lines are required to supply liquids helium and nitrogen to the SRF cavities and to recover the gaseous helium and nitrogen to the cryogenic system. Here we discuss the configuration and design features of the LHe transfer system, and present also calculations of the heat load and pressure drop of the transfer system.

INTRODUCTION

The Taiwan Photon Source (TPS) project proposes an electron accelerator with beam current 400 mA at 3 GeV and small emittance 2 nm rad, in progress at NSRRC. The circumferences of the storage ring and booster ring are 518.4 m and 496.8 m, respectively. Superconductive RF (SRF) modules will be installed in short straight sections to maintain the level of energy of the electrons. One new 700-W cryogenic system is required to produce sufficient LHe for the SRF modules. The LHe transfer system is required to feed LHe and LN_2 individually to the SRF modules and to recover gaseous He to the cryogenic system.

The cryogenic system has maximum cooling capacity 725 W, with associated compressors, oil-removal system (ORS), four helium buffer tanks, one 7000-L Dewar, piping for gaseous helium at room temperature, helium distribution transfer lines, and a liquid-nitrogen transfer system. The helium cryogenic system was contracted to Linde company in 2009, for installation in 2012 [1].

The design features of the TPS helium-transfer system are similar to the current system [2]. The advantages of the new system are simplicity, programmable control for fluid flow, small heat load and pressure drop, and recovery of gaseous N_2 from SRF modules and process line. The helium-transfer system was contracted at the end of 2010, for installation in 2012. Here we present the configuration and design features of the helium-transfer system. The pressure drop of the helium-transfer line is constrained by the operating pressure of SRF modules, the pressure drop of heat exchangers of the cold box, and the suction pressure of the main compressor. Thus, the estimated heat load and the corresponding pressure drop of the helium-transfer system are also discussed.

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BUDGET OF CRYOGENIC HEAT LOAD AND CONSIDERATION OF THE PRESSURE DROP

Budget of the Cryogenic Heat Load

The SRF modules are operated in a refrigeration mode such that cold helium gas from SRF modules is returned to the cold box. Table 2 shows that the refrigeration heat load during normal operation of eventually four SRF modules is less than 360 W at 4.5 K (static heat loss 120 W and dynamic heat load 240 W). In addition to this heat load, warm helium gas flowing at 0.72 g s^{-1} (equivalent to 80 W at 4.5 K) introduces a liquefaction load (21 L h^{-1}) for the main cryogenic plant. Each SRF module will also require a maximum flow 250 L h^{-1} of liquid helium during cooling and a static loss 350 W at 4.5 K during RF processing. The designed budget of head load of the LHe and GHe transfer lines is 0.1 W m^{-1}, and the total heat load about 25 W corresponds to its total length 125 m. The heat loads of the DVB, branch transfer lines, cryogenic connection between the rigid liquid-helium lines and the cryogenic adapter, the vacuum-insulated cryogenic coaxial line and its associated connections are about 171 W. The four SRF modules will not undergo cooling and processing at the same time. The total heat load of refrigeration is considered to be 636 W at 4.5 K during normal operation. The design of the dimensions of the process line and cryogenic control valves must thus supply sufficient LHe to the SRF modules and recovered GHe to the cold box.

Table 1: Budget of Heat Load for the Helium-Transfer System

Items	Four SRF modules
Static heat loss	120 W
Dynamic heat load	240 W
RF waveguide	21 L h^{-1}
Valve boxes	75 W (4*15+15)
transfer lines	25 W
Branch helium transfer line	96 W
Total sum	556 W+21 L h^{-1} (~ 636 W)

The consumption of liquid nitrogen is summarized in table 2. Transfer lines, valve boxes and SRF modules all require LN_2 as thermal shield; their consumptions are 13, 30 and 60 L h^{-1}, respectively. The total rate of LN_2 consumption is about 103 L h^{-1}.

Table 2: Estimated Consumption of $LN_2$for the Helium-Transfer System

Four SRF modules	60 L h^{-1}
Valve boxes	30 L h^{-1} (4*6+6)
Transfer lines	13 L h^{-1}
Total	103 L h^{-1}

Consideration of the Pressure Drop

Heat exchangers in five stages inside the cold box provide the amount of flow capacity for the required liquefaction or refrigeration power. The heat exchangers are of plate type that introduces a large pressure drop because of a small gap between these plates. The designed pressure drop of the plate heat exchangers is 110 mbar when the system operates at maximum refrigeration power with LN_2 precooling. The suction pressure of the main compressor and the designed outlet pressure of the cold box are 1.05 and 1.15 mbar, respectively. The operating pressure of the SRF module is 1.3 bara or less. The designed pressure drop of the GHe process line must thus be less than 40 mbar (1.3 mbara-1.15mbara-0.11 mbar).

CONFIGURATION AND DESIGN FEATURES

Fig. 1 shows an overview of the layout of the distribution valve box (DVB), control valve box (CVB),

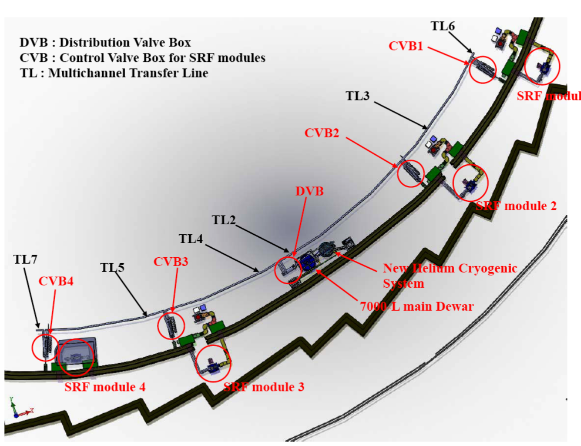

Figure 1: Overview of the layout of the new helium cryogenic system and the location of SRF modules.

the new helium cryogenic system, transfer lines (TL), and SRF modules in the TPS project. The DVB is located adjacent to the new helium cryogenic system to distribute LHe and LN_2 to the CVB of the SRF modules, and to recover GHe and GN_2 also via TL2, TL3, TL4 and TL5, respectively. The CVB are located outside the tunnel and feed LHe and LN_2 to the SRF modules and recover the GHe and GN_2 via individual transfer lines. The entrance of the transfer lines is then blocked by concrete to prevent the radiation penetrating from the accelerator. The SRF modules are located upstream and downstream of the DVB, respectively. The total lengths of TL2, TL3, TL4, TL5, TL6 and TL7 are 30.3, 27.1, 26, 27, 7.6 and 7 m, respectively.

Process Flow Diagram of the Transfer System

Figure 2 shows a schematic diagram of the transfer system. TL1 connects the DVB and the new helium cryogenic system. TL2 and TL3 connect DVB, CVB2 and CVB2, CVB1, respectively. TL4 connects DVB and CVB3 to the SRF3 and TL5 connects CVB3 and CVB4, respectively. TL6 and TL7 connect CVB1 and CVB4, respectively, with a blank at the end for possible future extension. Upstream of TL6 and TL7 is isolated by cryogenic control valves to prevent thermal acoustic oscillation (TAO) because of a large temperature difference and aspect ratio of the length and diameter of the process line. The Dewar is operated in the pressure range 1.2 to 1.4 bara. The diameter of the outer vacuum jacket of the transfer line is greater than 21 cm, and four

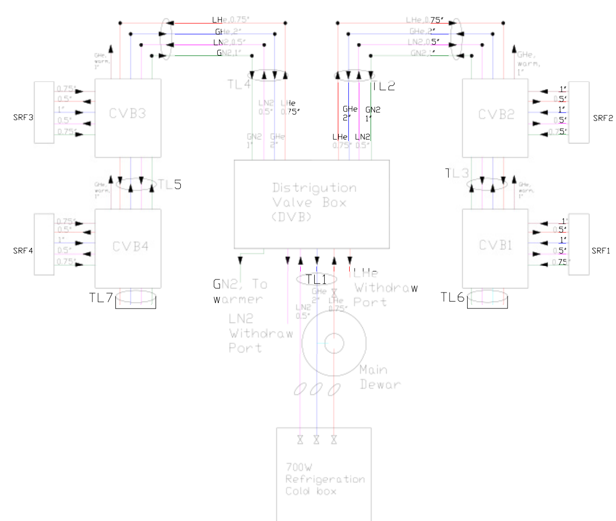

Figure 2: PFD of the transfer system.

process lines will be included -- LHe supply line, GHe return line, LN_2 supply line and GN_2 return line. The diameters of the LHe, GHe, LN_2, and GN_2 lines are DN20, DN50, DN15 and DN25, respectively. The design of the GN_2 return line leaves a possibility to recover the latent heat of gaseous N_2 and return it to the LN_2 to decrease the consumption from the LN_2 storage tank. The withdrawal port serves to provide LHe and LN_2 from a mobile Dewar to keep cold the transfer line and SRF cavities when the 7000-L LHe Dewar or 60000-L LN_2 tank is not functioning.

Process Flow Diagram of the DVB

Figure 3 shows a process flow diagram of the DVB. The DVB provides the distribution function for the new cryogenic system. The main purpose of the DVB is to provide the separate helium stream and nitrogen streams to SRF modules 1, 2 and 3, 4. Three multichannel ports connect to the new cryogenic system, TL2 and TL4, respectively. The DVB is shielded with LN_2 to decrease the heat load and one LN_2 keep cold device is installed to vent the vaporized nitrogen. One transfer line is designed to connect to a passive warmer, and then to the suction line to provide a bypass function for the SRF modules and TL during the cooling phase or a trip event of the cryogenic system. The pressure indicators and pressure transmitters are located at the outlet of multichannel ports to monitor the stability of the pressure for both helium and nitrogen streams of the transfer system. The temperature transmitters are installed to monitor the temperature variation during normal operation and the cooling phase. Two Venturi flow meters (FM5 and FM6) are installed at the GHe process line of TL4 and TL5, respectively, with a calibrating function to monitor the flow rate of the cold return gas. The data are transferred into the corresponding heat load to diagnose the status of the SRF modules and transfer lines in real time. All cryogenic valves inside the DVB are in automatic operation with position feedback. One human-machine interface (HMI) is developed for remote control of these valves and automatically preceding the cooling process.

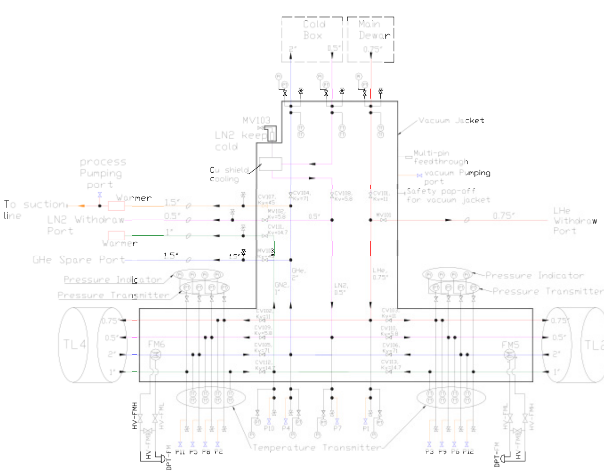

Figure 3: Process flow diagram of the DVB.

SIZING OF THE CRYOGENIC CONTROL VALVES AND PRESSURE DROP OF THE GHE PROCESS LINE

Sizing of the Cryogenic Control Valves for the LHe and LN_2 Process Line

The sizing of the cryogenic control valves of supply line is based on the required rate of volumetric flow, the flow coefficient (Kv), the fluid density and pressure difference between upstream and downstream of the cryogenic control valve. The required rates of volumetric flow of LHe and LN_2 for two SRF modules are 477.5 and 61 L h^{-1}, respectively. The selected Kv of the LHe and LN_2 cryogenic valve are 11 and 5.8, respectively, at fully open based on the available commercial product. For the given rate of volumetric flow and Kv value, the calculated pressure differences at the LHe and LN_2 cryogenic valves are 0.22 and 0.24 mbar, respectively. The operating pressure differences of the LHe and LN_2 cryogenic valves are at least 100 mbar and 1.8 bar, which are sufficient to provide the required flow rate of the SRF modules.

Pressure Drop of the GHe Process Line

The dimensions of GHe process line and cryogenic control valves were designed as large as possible to decrease the pressure drop. Based on the calculation, the maximum pressure drop is 8.97 mbar corresponding to the piping length (77.4 m, including a transfer line 12 m long from CVB1 to SRF1) to the SRF1. The GHe cryogenic valves contribute 1.83 mbar pressure drop at fully open. The total pressure drop is 10.8 mbar, which is less than the required 40 mbar.

SUMMARY

The design of the LHe transfer system was completed and contracted at the end of 2010; its installation and commissioning will be done in early 2013. The new transfer system is simple and programmable for process control, and has a small heat load and pressure drop. The complete monitoring sensors were also considered and implemented. The transfer system was considered to recover the vaporized GN_2 for recycling as LN_2 in the future.

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