The Design and Fabrication of Liquid Nitrogen Transfer System for Taiwan Photon Source Beamlines

At Taiwan Photon Source (TPS), the main liquid nitrogen (LN_2) transfer line of length 600 m for beamline endstations was installed in 2015. It previously supplied LN_2 to a maximum of 24 beamlines. **TPS 13A**, of which the aim is advanced and general studies of biological structures and structural kinetics in solution or condensed forms under environmental simulations, from atomic to micrometer scale and time resolution ranging from microsecond to minute, was installed during 2018 and 2019. We designed and self-manufactured one LN_2 transfer line according to the requirements of **TPS 13A**, to supply LN_2 into the double-crystal monochromator (DCM), to solve the problem of thermal deformation of the crystal. Otherwise, the keep-full device was intended to be used in place of the chiller's phase separator.

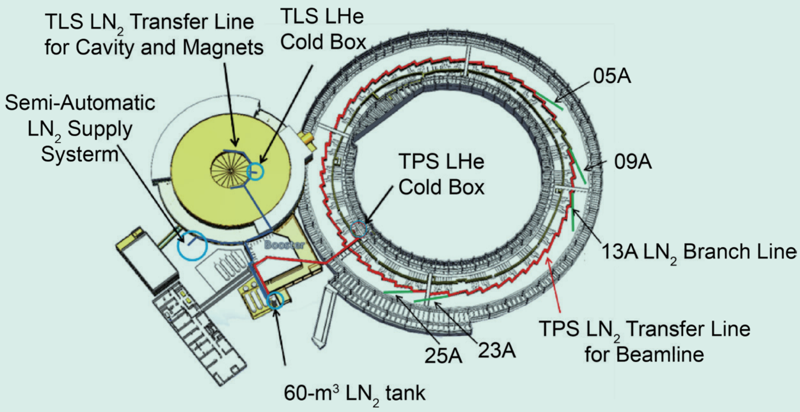

Fig. 1: Configuration of the LN_2 transfer system in TLS and TPS.

The installation and commissioning of one LN_2-transfer system for the TPS project were completed in 2015.[1] This system consisted of two transfer lines (length 600 m), eight keep-full devices, and 24 cryogenic control valves for 24 straight sections of beamlines. The consumption of LN_2 required for each beamline is 20 L/h. The LN_2 supply from a single storage tank (60 m^3) was refilled every day from an LN_2 truck. Another transfer line of length more than 300 m that supplied users of Taiwan Light Source (TLS) was installed in 2003. The configuration of the LN_2-transfer system in TLS and TPS is shown in **Fig. 1**. During the years 2015–2018, four LN_2 branch lines for TPS beamlines (**05A**, **09A**, **23A**, **25A**) were installed, enabled, and used LN_2 to cool the beamline equipment for the DCM. Some unexpected problems appeared on these four LN_2 branch lines, such as that the separator filling process being too noisy, ice or water formed due to cold nitrogen gas exhaust, the pressure downstream of the pressure-reducing valve that activates the safety valve was excessive, and heat loss caused by the non-vacuum design of the pressure-reducing device was excessive. In 2019, we designed, constructed, installed, and tested one vacuum-shielded LN_2 branch line for **TPS 13A**.

Based on long-term operation in an early beamline LN_2 branch, some problems should be considered and avoided in this self-manufactured LN_2 branch line, such as reducing the heat load, reducing the sound, decreasing the two-phase flow, improving pressure stabilization, and avoiding the ice and water phenomenon. For these purposes, we designed three devices construct in the branch line, a pressure regulator, a keep full, and a sound-suppression device with a heater.

Figure 2 shows the structure of a pressure-regulator device. One pressure-regulator valve connects with an LN_2 pipe located in a chamber for gaseous nitrogen. For maintenance, the top and bottom caps of the chamber can be opened. We can open the caps and adjust the pressure of the pressure-regulator valve during cold conditions while pure gaseous nitrogen flows into the chamber. We installed a check valve in the chamber to avoid the worst-case based on which the pressure-regulator valve leaks after thermal cycles. Two pressure transducers were installed at the downstream side and the GN_2 chamber. This device's

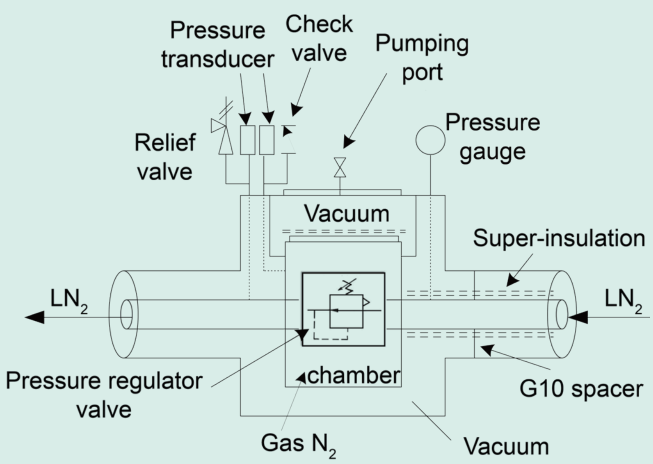

Fig. 2: Pressure-regulating device.

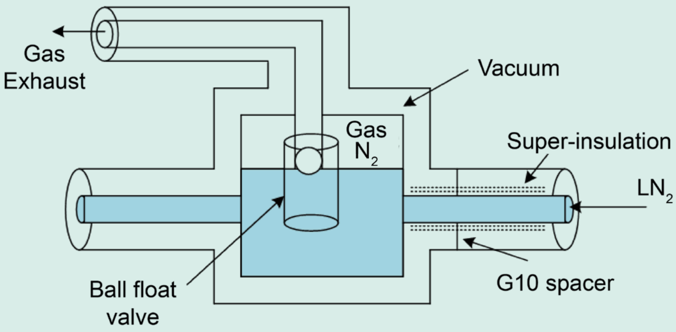

Fig. 3: Keep-full device (+ buffer + exhaust port).

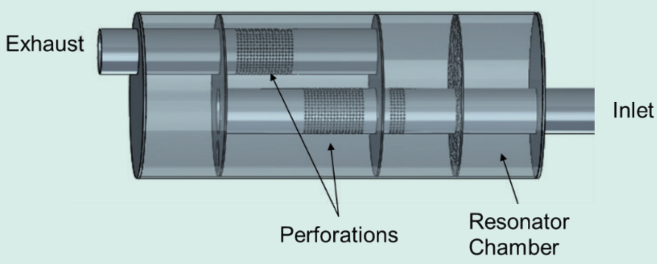

Fig. 4: Sound-suppressor device.

heat load was reduced by using vacuum-shielded and super-insulation-shielded types. The G10 material is used to provide support inside the pipe.

Figure 3 depicts the structure of a keep-full device. This vacuum-protected keep-full device is also vacuum-protected. A buffer contains a single mechanical ball-float valve. The ball-float valve exhausts the GN_2 away at the start of the two-phase flow of nitrogen flowing through the buffer's entrance. The ball blocks the exhaust port within the ball-float valve until the LN_2 fills the buffer. The two-phase flow of fluids occurs as a result of heat ingress, and liquid nitrogen vaporizes to nitrogen gas in the branch line. This condition can cause an accumulation of gaseous nitrogen in the pipeline, especially if there is little or no flow. The gas that has emerged is exhausted *via* the keep-full device. The branch line is completely mechanically and automatically filled with liquid nitrogen.

A sound-suppression device was hence designed to diminish the noise by altering the flow velocity and the audio structure. The structure of this sound-suppression device, shown in **Fig. 4**, which uses the porous characteristics to reduce the air vibration to decrease the noise, mainly refers to a common exhaust muffler for motor vehicles. This muffler is classified as a resistance muffler, also known as an acoustic filter. The most basic type of expansion chamber is a thick tube with a large cross-section connected to the airflow channel tube, but the end is a thin tube. Adjusting the length of the cross-section buckle of the expansion chamber (large tube) affects the reflection and interference performance of the sound wave. There was no sound-absorbing material installed. This sound-suppression device is located at the exhaust port of the keep-full device. The condensation or icing occurs because of gaseous nitrogen at a low temperature. We wrapped an electrical heating wire around the surface to bring the exhaust up to room temperature.

Figure 5 depicts the LN_2 branch line for **TPS 13A**. The vacuum-shielded branch pipe is about 6 m long, and the sound-suppression device is about 1 m long. Several tests were carried out before the installation on-site. A cold shock test was performed on the branch lines, which were filled with liquid nitrogen. The goal was to investigate the effects of thermal stress on fittings and welds. Each fitting and weld was tested at 80 K and after being warmed to room temperature. This procedure was repeated three times. The measured rate of helium leakage was less than 1.0×10^{-9} mbar L s^{-1} in the evacuation mode with vacuum level 1.0×10^{-3} mbar. The pipeline was filled with helium at 5 barg for leak testing. The standard rate of leakage of the sniffing mode is less than 1.0×10^{-5} mbar L s^{-1}.

Figure 6 (see next page) shows the pressure fluctuations of a tank, as well as the upstream and the downstream pressures of the pressure-regulating device. The pressure of the tank fluctuated from 2.6 to 2.7 bar gauge (barg) when the 60-m^3 LN_2 tank was refilled from the LN_2 truck; the pressure rose briefly to 2.9 barg, but the pressure upstream

Fig. 5: LN_2 branch line for **TPS 13A**.

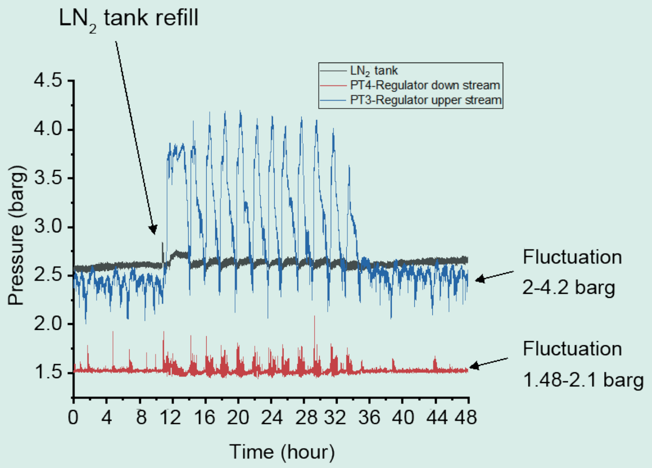

Fig. 6: Pressure fluctuations of the tank, pressures upstream, and downstream of the pressure-regulating device.

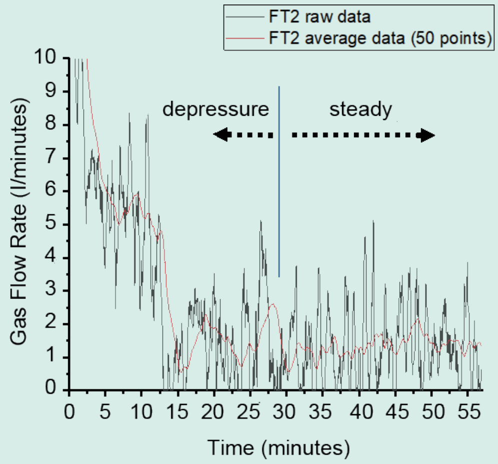

Fig. 7: The exhaust gas of the keep-full device.

of the pressure-regulating device was greatly shaken for a period of about 24 hours; the pressure fluctuation range was 2–4.2 barg, which was a large fluctuation when compared to the normal operation situation 2–2.6 barg. Because of the long-distance transfer and the random use of LN_2, pressure fluctuations were unavoidable. The mechanical pressure-regulating device stabilized the downstream pressure fluctuations and reduced their impact on the cryogenic equipment of the beamline. The downstream pressure of the pressure-regulating device is about 1.48 to 2.1 barg.

The static heat loss is an important quality indicator for the vacuum-shielded pipeline. This section describes the measurement of the heat load of this branch line. Pure saturated liquid nitrogen flowed through the LN_2 branch line. The static heat load along the entire path q_T vaporized the liquid, thus delivering the gas to the keep-full device. The total rate of mass flow, m_T, was measured after warming the cold gas with a passive heater. m_T is the vaporized LN_2 from the static heat load as the supply of the LN_2 was interrupted during the measurement. The calculation of the heat load was based on the following equation,

$$m_T \times h_{fg} = q_T$$

in which h_{fg} is the enthalpy of LN_2.

Figure 7 shows the mass flow measurement result. The average flow rate was about 1.5 L/min. Using the equation, we obtained the total heat load to be 5.68 W.

Two-phase flow, pressure fluctuations, condensation of water or ice, and noise in exhaust devices are all common problems in liquid nitrogen pipelines. The cryogenic team considered and eliminated these issues when designing and commissioning the branch line. The pressure-regulating device eliminated the pressure-fluctuation issue. The keep-full device improved the purity of the liquid fluid in the branch line, which replaced the separator that had been installed before the beamline cryogenic equipment. Sound suppression and the temperature controller reduce noise and avoid condensation. The overall heat load of the branch line (length 6 m) is about 5.6 W at 77 K. The commissioning with the beamline DCM device also had excellent test results. The design, fabrication, and assembly by the cryogenic team in NSRRC decreased not only the budget but also time. The design of more complex cryogenic piping for TPS is currently in the works. (Reported by Huang-Hsiu Tsai)

Reference

1. H. H. Tsai, F. Z. Hsiao, H. C. Li, S. H. Chang, T. F. Lin, W. S. Chiou, C. P. Liu, Phys. Procedia **67**, 183 (2015).