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STUDY ON THE LN2 CONSUMPTION OF THE BEAMLINE LN2 TRANSFER SYSTEM FOR TPS PROJECT

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Abstract

One system to transfer liquid nitrogen (LN_2) will be installed at TPS in 2015 for beamline. This system includes two transfer lines (length 600 m), eight keep-full devices and 26 branch lines with 26 control valves for 24 straight sections of beam lines. The required consumption of LN_2 for each beam line is 30 L/h. An archive system was developed to monitor and to calculate the consumption of LN_2 for each beam line. This consumption was calculated based on the pressure difference and the flow coefficient (K_v) of the control valve. This paper presents the configuration of the LN_2 supply system at NSRRC and a test bench of the calculation of LN_2 consumption. A simple test result is presented and discussed.

INTRODUCTION

A helium-cryogenic system with refrigeration (450 W) began its operation from 2003. The liquid-nitrogen (LN_2) supply system entered service at the same time. Figure 1 is the current status of the LN_2 supply system at NSRRC. The LN_2 supply system was finished for Taiwan Light Source (TLS) in 2009. The LN_2 transfer system for the Taiwan Photo Source (TPS) project began its installation and commissioning in 2013.

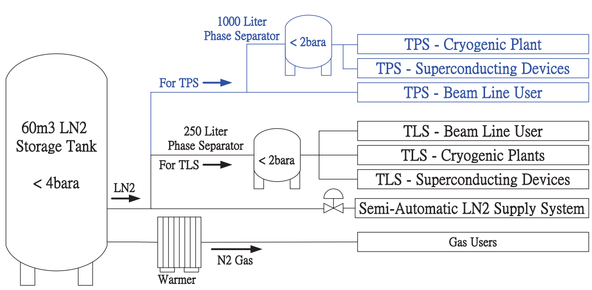

Figure 1: Configuration of the LN_2 supply system at NSRRC.

LN_2 Supply System at NSRRC

One LN_2 storage tank (60 m^3) replaced the original one (20 m^3) in 2009. In total, the LN_2 flows through a vacuum-shielded LN_2 transfer line (length > 300 m) and one phase separator (250 L) to users at TLS [1]. The TLS users comprised of two liquid-helium (LHe) refrigerators (450 W) [2], one superconducting RF cavity, five superconducting magnets, two beam-line laboratories, and one semi-automatic LN_2 supply system. A line (length > 300 m) for gaseous nitrogen (GN_2) used to purge or to clean the machine or experimental samples also existed inside the LN_2 system.

We installed a vacuum-shielded LN_2 transfer line (150 m), one phase separator (1000 L) and one helium refrigeration system (700 W) [3] in 2013. We finished the commissioning of a multi-channel line (LHe/GHe/LN_2 /GN_2) for four TPS superconducting RF cavities in 2015 April. The total length is more than 130 m. We began to install two vacuum-shielded LN_2 transfer lines (length 600 m) with 26 control valves used in TPS beam-line laboratories in 2015 April. Figure 3 shows the configuration of the LN_2 transfer system of NSRRC.

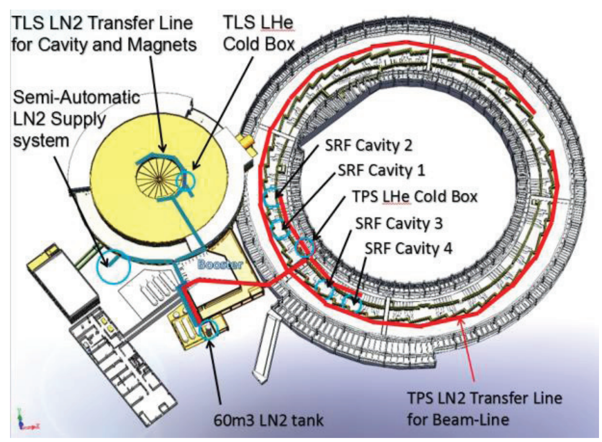

Figure 2: Configuration of LN_2 transfer line of NSRRC.

LN2 Consumption

Increasing numbers of users introduce a rapidly increasing consumption of LN2. Figure 3 shows the LN_2 consumption at NSRRC from 2005 to 2014. The average consumption is about 955 m^3 per year from 2005 to 2009, but the average consumption increased to 1777 m^3 per year from 2010 to 2014. The major increase was due to the TPS project. Many machines and systems were tested and commissioned during these five years. Figures 4 and 5 show the LN_2 ratio of users. It was easy to estimate the budget of TLS LN_2 consumption because of the stabilized operation in year 2009, but more than 51 % of the total amount LN_2 consumption was used to support the relevant testing of TPS in year 2013. It is difficult to estimate the LN_2 consumption under such conditions. To understand the LN_2 consumption of each user is an important issue for the stability of the LN_2 supply due to the budget control. A typical theory of valve sizing can help us to calculate the real-time consumption of LN_2

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based on the pressure difference and the flow coefficient (K_v) of the control valve.

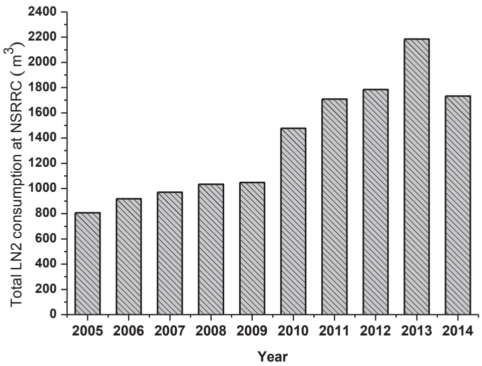

Figure 3: 10-year LN_2 consumption at NSRRC.

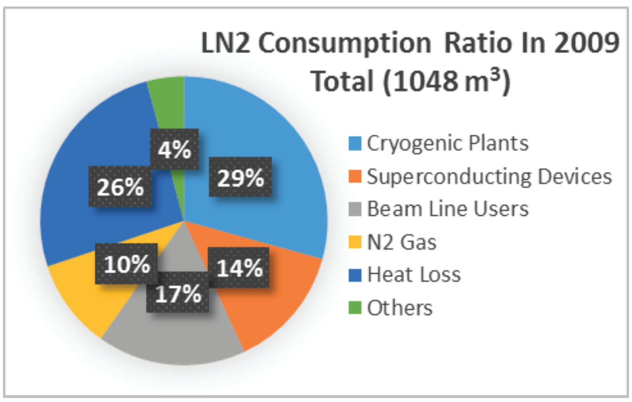

Figure 4: LN_2 consumption ratio in 2009.

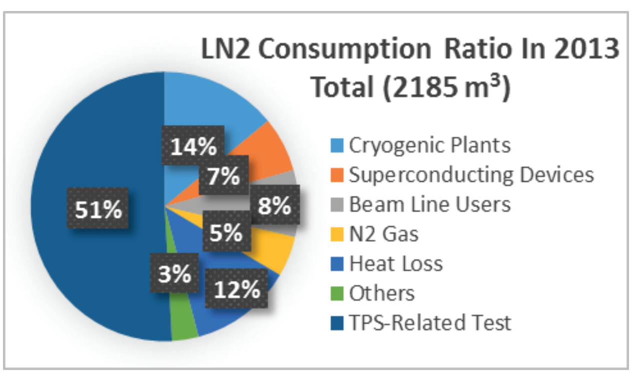

Figure 5: LN_2 consumption ratio in 2013.

LN_2 TRANSFER SYSTEM FOR THE TPS BEAM LINE

One system to transfer liquid nitrogen (LN_2) transfer system will be installed for the TPS beam line in 2015. This system includes two transfer lines (length 600 m), eight keep-full devices and 26 branch lines with 26 control valves for 24 straight sections of the beam line. The required consumption of LN_2 for each beam line is 30 L/h. One special design was implemented for a mass flow-rate calculation of LN_2. Two pressure transducers are located upstream and downstream of each control valve, respectively, shown in Figure 6.

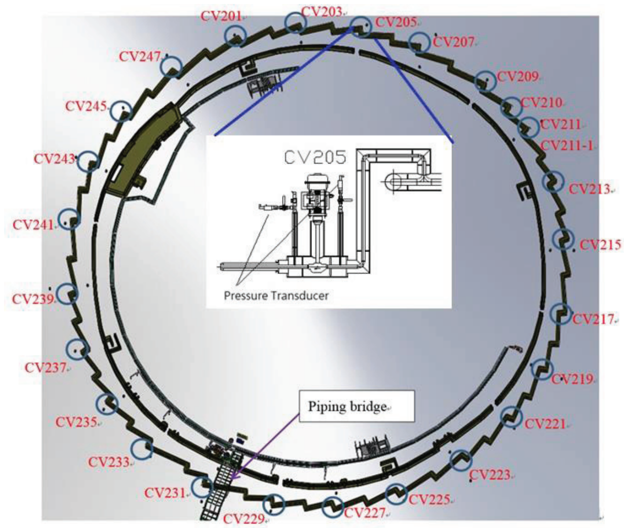

Figure 6: Overall transfer line for beam-line at TPS.

LN_2 Consumption Calculate

Three flow characteristics of a control valve are equal percentage, modified equal percentage and linear. The K_v (flow coefficient) value increases by the same increment for each fraction of travel of a control valve with ideal linear flow characteristics. In our LN_2 supply for the TPS beam line, we use a linear control valve to calculate easily the K_v value. A calculation of the K_v-value is standardized in IEC534 [4], but in our case the K_v-value was constant, as the control valve was chosen. We can then modify the formulae. Figure 7 shows a typical installation of a control valve in a control loop.

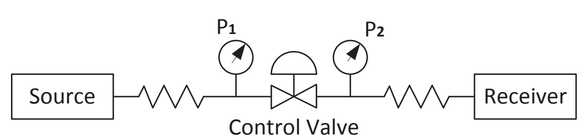

Figure 7: Typical installation of a control valve.

Of five equations to calculate the flow consumption with varied working fluids and flow conditions, equation (1) is used to calculate the liquid flow, equations (2) and (3) are used to calculate the gas flow, and equations (4) and (5) are used to calculate the vapour or steam.

$$W = Kv * \sqrt{1000 * \rho * \Delta p} \tag{1}$$

$$W = Kv * 519 * \sqrt{\frac{\rho_G * \Delta p * p_2}{T_1}} \tag{2}$$

When $p_2 > p_1/2$ and $\Delta p < p_1/2$

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$$W = Kv * 259.5 * P_1 * \sqrt{\frac{\rho_G}{T_1}} \qquad (3)$$

When $p_2 < p_1/2$ and $\Delta p > p_1/2$

$$W = Kv * \sqrt{1000} * \sqrt{\frac{\Delta p}{\upsilon_2}} \qquad (4)$$

When $p_2 > p_1/2$ and $\Delta p < p_1/2$

$$W = Kv * \sqrt{1000} * \sqrt{\frac{p_1}{2 * \upsilon^*}} \qquad (5)$$

When $p_2 < p_1/2$ and $\Delta p > p_1/2$

The K_v value is here provided by a determined control valve. W (kg/h), p_1 (bar absolute) and p_2 (bar absolute) represent the fluid flow, the upstream pressure and the downstream pressure, respectively. Δp (bar) represents the pressure drop. ρ and ρ_G (kg/m^3) represent the specific densities of gases at 273 K and 1.013 bar, T_1 (K) represents the upstream temperature. υ_1 represents the specific volume of steam or vapour at p_1 and T_1. υ^* represents the specific volume of steam or vapour at $p_1/2$ and T_1.

Test Bench and Test Result

On April 2015 we set up one simple test bench for the LN_2 consumption with varied K_v values of the control valve. The test bench comprised one control valve, two pressure transducers (PT), one LN_2 dewar, one scale and one gaseous-nitrogen mass-flow meter. Figure 9 shows the test bench for LN_2 consumption and measurement. A 20 % static opening was set for the control valve to perform the test. The calculated rate of mass flow was 2.41 kg/min based on equation (2), as the flow condition was closed two-phase flow. From the accessible data from the scale and the mass-flow meter we obtained a real number about 1.8 kg/min. There is a 25 % difference between the calculation and the measurement results.

The LN_2 transfer line is always a two-phase (LN_2 and GN_2) flow condition under normal operation. There is no standard formula for two-phase flow. The described methods include much uncertainty. It is recommended that each separate calculation of the K_v-value of a liquid should add a factor. We shall try to find an appropriate factor for our system in the future.

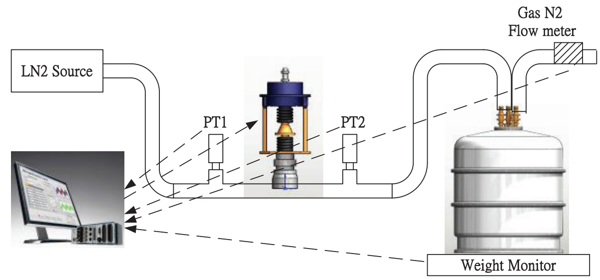

Figure 8: Test bench.

SUMMARY

The consumption of LN_2 at NSRRC increases annually because of the TPS project. In this work we tried to obtain the flow of LN_2 calculated based on the pressure difference and the flow coefficient (K_v) value of the control valve. We built a test bench to test the method and obtained an acceptable result. A preliminary test was performed, but we must implement one factor for every single branch line to have a precise formula to calculate the flow consumption that is near the real situation.

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