

THE CURRENT STATUS OF THE CRYOGENIC SYSTEM DESIGN AND CONSTRUCTION FOR TPS

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Abstract

The TPS is 3 GeV photon source under construction in Taiwan. The electron eventually needs four superconducting RF cavities to maintain the energy. The construction of a new refrigeration/liquefaction helium plant is under way to supply the liquid helium for superconducting RF cavities. This is the third year of the seven years project and part of the design features and parameters is different from the preliminary design. This paper presents the design of the cryogenic system, which is including the features of the new cryogenic plant, the pressure drop of warm helium pipeline, the distribution valve box and the multichannel line. The design of liquid nitrogen supply line and the phase separator will be also included.

INTRODUCTION

At NSRRC, the Taiwan Photon Source (TPS) project proposes an electron accelerator with a beam current of 400 mA at 3 GeV and a low emittance of 2 nm-rad. The circumference of storage ring and booster ring is 518.4-m and the 496.8-m, respectively. The superconductive RF (SRF) cavities will be installed in short straight sections and maintain the energy level of the electron. The main target of the new cryogenic system is to provide the sufficient cooling power and the stable pressure of liquid helium supply to the SRF cavities [1].

In the preliminary design of the first year, the heat load budget, the configuration of the cryogenic system, and the layout has been clearly define. However, due to the variant of lattice design, civil work design and total budget constrain, the layout and the part of parameters of cryogenic system may have difference.

The cryogenic system has maximum 725-W cooling capacity with associated compressors, oil removal system (ORS), four helium buffer tank, one 7000-L Dewar, room temperature gas helium piping, helium distribution transfer lines, and liquid nitrogen transfer system.

The helium cryogenic has been contract out to Linde company in 2009 and to be installed in the year 2012. The four helium tanks have installed with 100-m³ capacity and two of them stored 9.5 barg helium gas. The design of liquid nitrogen (LN₂) transfer system, the distribution valve box, and multichannel line (MCL) is under way.

This paper is to present the current status of the new cryogenic system (725-W cooling power) which was included the modified heat load budget, the configuration, room temperature gas helium piping, LN₂ transfer system, the distribution valve box, and MCL transfer system.

CRYOGENIC HEAT LOAD BUDGET AND LN₂ REQUIREMENT

In TPS operation, the refrigeration heat load during nominal operation of eventually four SRF modules is less than 360-W at 4.5K (the 120-W static heat loss and 240-W dynamic heat load). In additional to this heat load, a warm helium gas flow of 0.72 g/s (Equivalent to 80-W at 4.5K) presents a liquefaction load to the main cryogenic plant. Moreover, the heat load of distribution valve, multichannel line, branch transfer lines, the cryogenic connection between the rigid liquid helium lines and the cryogenic adapter, the vacuum insulated cryogenic coaxial line and its associated connections are about 230-W. The total refrigeration heat load is equivalent to 670-W at 4.5K. The cryogenic system must thus supply a refrigeration power of 590-W and support a liquefaction rate of 21 L/h. The equivalent refrigeration capability is 670-W during the operation of the SRF cavities. The minimum design refrigeration power of the Main Cryogenic Plant is 725-W at 4.5-K, which equal to 108% of the operation heat load.

Table 1 : The heat load budget for the SRF cavities

Items	Four cavities
Static heat loss	120 W
Dynamic heat load	240 W
RF waveguide	21 L/h
Valve boxes	83 W (4*12+35)
Main multichannel transfer line	51 W
Branch helium transfer line	96 W
Total sum	590 W+21 L/h (~ 670 W)

Table 2 : Estimate LN₂ consumption

Cryogenic plant	97 L/hr
Four SRF cavities	60 L/hr
Distribution Valve boxes	30 L/hr (4*6+6)
Multichannel Line	13 L/hr
Total sum	200 L/hr

The summarized liquid nitrogen consumption is listed in table 2. The LN₂ provide the precooling power for the

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cryogenic plant to reach the maximum cooling power and the required LN₂ consumption is 97 L/hr. The MCL, distribution valve, and SRF cavities required the LN₂ as thermal shield and the consumption is 13 L/hr, 30 L/hr, and 60 L/hr, respectively. The total LN₂ consumption rate devices is about 200 L/hr.

CONFIGURATION AND DESIGN FEATURES

Figure 1 presents the layout over view of the cryogenic system, the piping, and the SRF cavities in the TPS project. Six gas tanks remain in their originally installed position, which is the tank area I; another four new 100-m³ gas tanks will be installed in the tank area II. The new compressors and oil removal system installed in the TPS compressor room. The refrigerator/liquefier, main Dewar, and distribution valve box will be installed in the TPS storage and eventually four SRF cavities is occupied on adjacent four short straight sections.

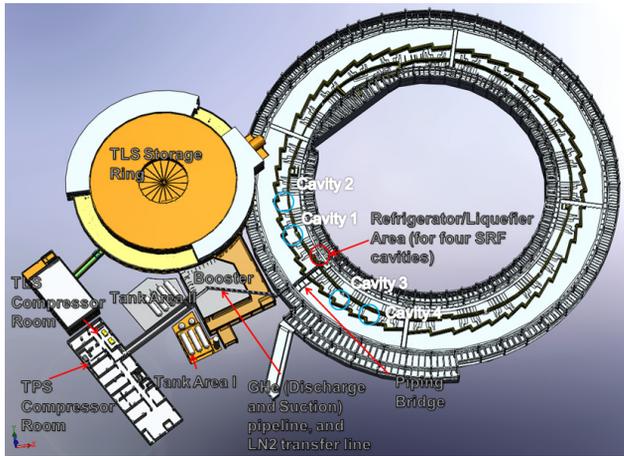


Figure 1 : Layout over view of helium cryogenic system and location of SRF cavities

LN₂ Transfer System

Liquid nitrogen is stored in a 60000-L nitrogen Dewar, which is installed adjacent to the tank area I. The total length of the nitrogen-transfer lines, from the storage to

the manifold of the refrigerator/liquefier is 146-m. The transfer line comprises vacuum-insulated piping with a 1.5-inch diameter liquid-nitrogen line and a 3-inch diameter vacuum pipe. The connection of the LN₂ transfer is to be the field joint and to reduce the number of heat bridge of the process line to minimize the heat loss. One gas vent will be installed in the highest position to reduce the nitrogen vapour during the LN₂ transfer. An additional phase separator is installed in front of the 725-W refrigerator to keep the supply pressure within a variation +/-50 mbar as illustrate in Figure 2.

Room Temperature Gas Helium Pipeline

The 8-inch diameter suction line and 3-inch discharge line with operating pressure 1.05 bara and 13 bara, are installed between the compressor and refrigerator/liquefier. The pipe length for 8-inch and 3-inch are 176-m and 175-m, respectively. The make-up line between the compressor of the 725-W cryogenic plant and the new gas tanks is a pipe of diameter 4-inch and an operating pressure in the range 1.5 – 10 barg; the length of the piping is 82-m. The pressure drop of the discharge line is relevant to the performance of the cooling capacity. Based on the process calculation, the criteria of the total pressure drop is 200 mbar. The pressure drop of the suction line is constrained by the inlet pressure of the compressor, that is 1.05 bara. Based on the outlet pressure of the refrigerator/liquefier, the criteria is about 80 mbar. The pressure drop is calculated based on the following formula [2]:

$$f = \frac{\Delta P \times D}{\frac{1}{2} \rho u^2 \times L} \quad (1)$$

$$f = \begin{cases} \frac{64}{Re_d}, & Re_d \leq 2300 - \text{lar min ar flows,} \\ 0.316 Re_d^{-0.25}, & 4000 < Re_d < 10^5 - \text{turbulent flows} \\ \left(1.8 \log \frac{Re_d}{6.9}\right)^{-2}, & Re_d \geq 10^5 - \text{turbulent flows} \end{cases}$$

f : friction factor

ΔP : pressure drop

ρ : fluid density

u : inlet velocity

D : inner diameter of the pipeline

L : piping length

Re_d : Renolds number

The required minimum cooling capacity is 725-W, which is equal to 90 g/s of helium process flow for the discharge line and suction line. The outlet pressure of the compressor and refrigerator/liquefier is 13 bara and 1.15 bara, respectively. The elbows and gravity effect were considered. Based on the given flow parameters and piping diameter, the Reynolds number of the discharge

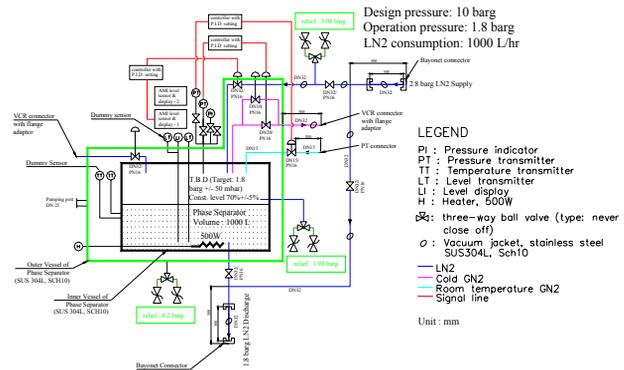


Figure 2 : Process flow diagram of the LN₂ phase separator

line and suction line is 74118 and 27794, respectively, that is turbulent flows.

Figure 3 indicates the relationship of pressure drop and piping length. It is seen that the total pressure drop of the 3-inch pipeline and 8-inch pipeline line is 116 mbar and 6 mbar, respectively. The pressure drop is dominated by the pipe diameter with the same inlet pressure. Based on the calculation results, the 3-inch discharge pipeline and the 8-inch suction pipeline is sufficient to provide the low pressure drop of the room temperature helium flow.

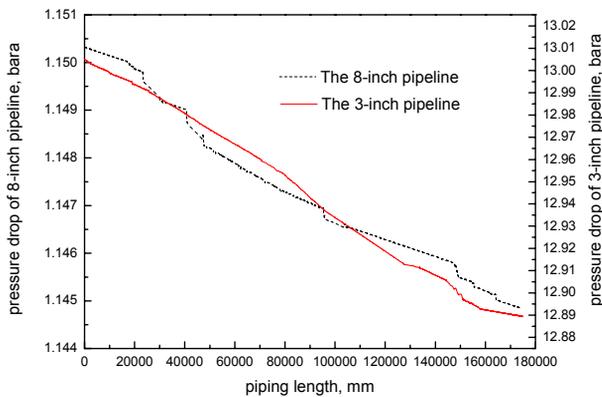


Figure 3 : The variation of pressure drop versus piping length

MCL Transfer System

Figure 4 shows the schematic diagram of the MCL transfer system. The liquid helium is transferred from the 7000-L Dewar to the switch-valve box via a 9-m multichannel transfer line, and then to the control-valve boxes. The diameter of outer vacuum jacket of the MCL is 10-inch and there will be four process line included, which were liquid helium (GHe) supply line, gas helium

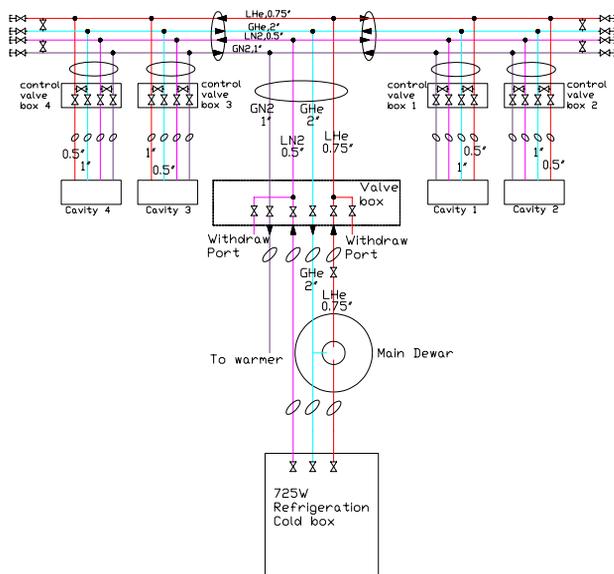


Figure 4 : Schematic diagram of distribution valve box and MCL to the SRF cavities

(GHe) return line, liquid nitrogen (LN₂) supply line, and gas nitrogen (GN₂) return line, respectively. The diameter of the LHe, GHe, LN₂, and GN₂ is 0.75-inch, 2-inch, 0.5-inch, and 1-inch, respectively. The design of the GN₂ return line is to remain the possibility to recover the latent heat of GN₂ and reproduced to the LN₂ to reduce the consumption of the LN₂ storage tank. The end of the MCL was isolated by the control valves, which intended to remain the possibility to extend the MCL to others helium cryogenic plants or superconducting devices in the future without containment the process line. The bypass valves of the LHe and LN₂ process line can be used to regulate the flow rate and pressure stability of the transfer line. The withdraw port is used to provide the LHe and LN₂ from the mobile Dewar to keep the transfer line and SRF cavities cold when the 7000-L LHe Dewar or the 60000-L LN₂ tank unfunctional.

SUMMARY

The new 725-W helium cryogenic plant is under construction and plan to installed in the year 2012. The four 100-m³ gas helium tanks and 60000-L LN₂ storage tanks have constructed and installed. The pressure drop of the gas helium pipeline was calculated. Results show that the pressure drop of the discharge pipeline and suction pipeline was 116 mbar and 6 mbar, respectively, based on the mass flow rate (90 g/s) of the 725-W cooling capacity. The design of LN₂ transfer system, MCL transfer line, and distribution valve box is under way and plan to contract out in the year 2010.

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