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The Redundant Compressor System for the Helium Cryogenic Plant at TPS

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Abstract. Recommissioning the 700-W helium cryogenic system was completed in 2014 and it entered service in 2015. The main target of this system is a stable supply of liquid helium to the superconducting RF cavities at Taiwan Photo Source. The annual maintenance of the compressor of the plant causes operation of the system to be suspended at least two weeks. To avoid such a long suspension for the cryogenic plant, we installed a redundant compressor system for the cryogenic plant in 2015. We can switch to this redundant compressor system and restart the cryogenic system in a few minutes. In this paper we present the configuration, local testing and long-term operation of this redundant compressor system.

1. Introduction
At NSRRC, the Taiwan Photon Source (TPS) project proposes to operate an electron accelerator with beam current 500 mA at 3 GeV. Two superconductive RF (SRF) cavities have been installed in the storage ring to maintain the eventual energy level of the electrons. One TPS helium cryogenic system provides the required cooling power for these SRF cavities. The compressor system, gaseous helium buffer tanks and cold box are located in three different areas as shown in figure 1. The helium cryogenic system was contracted to Linde Company in 2009, and arrived in July 2011. The four helium buffer tanks (each 100 m$^3$) were installed in 2010. The TPS helium cryogenic system was installed and commissioned by the supplier in the test area with a non-vacuum jacked LN$_2$ pipeline in November 2012. The TPS storage ring structure allowed for the installation in the second quarter of 2013. The system was then disassembled, brought to the TPS storage ring, reassembled and commissioned by NSRRC staff in May 2014 [1]. The compressor system annual maintenance requires the cryogenic plant operation to be suspended for at least two weeks. We installed one redundant compressor system for the cryogenic plant in 2015 to avoid such a long suspension for the cryogenic plant. The aim of this paper is to describe the installation and the result of commissioning of the redundant compressor system for the TPS cryogenic plant.
2. A redundant compressor for the cryogenic system

The TPS cryogenic plant consists of four buffer tanks (each 100 m$^3$), one main compressor, one oil-removal system (ORS), one gas-management panel (GMP), one recovery compressor, one recovery ORS or GMP, one cold box with two turbines and one dewar (7000 L). The configuration of the cryogenic system is shown in figure 2. The TPS cryogenic plant supplied liquid helium continually to two superconducting RF cavities in 2015. The redundant compressor system was scheduled to be commissioned at the end of year 2015. This redundant compressor, which was installed in the vicinity of the main compressor system, was similar to the main compressor system. The redundant compressor system completed its performance test with a cold box in January 2016.
2.1. Commissioning of the redundant compressor system
The piping work of the redundant compressor was completed in June 2015. The high pressure piping was pressurized to 18 barg and the low pressure piping to 3 barg to leak test at all connections, valves and welds. No leak greater than 1.0×10^{-5} mbar-l/s. Pure and dry gaseous nitrogen was used to purge all pipelines to decrease the particle number below the class-100 standard and the humidity below 6.6 ppm (dew point -60 °C). This took a long time. The active carbon (200 kg) inside the oil-removal system (ORS) that served to trap the oil and moisture from the compressor. Although the carbon will trap residual moisture from the compressor system (oil), this will greatly reduce the carbon’s ability to trap oil vapor; proper processing of the compressor oil, before charging the compressor with it, is very important to remove the moisture. We pumped the entire redundant compressor system with a dry scroll pump to less than 0.05 mbar and filled with gaseous helium (purity 99.9995 %) to 0.5 barg. This process of evacuating and back-filling was performed three times.

2.2. Local control system for the redundant compressor system
The purpose of the redundant compressor system is to serve as a back-up compressor system for the TPS cryogenic plant. In 2015, the superconducting cavities for TPS were being commissioned. The cryogenic plant must provide a continuous and stable liquid helium supply to the SRF cryo-modules. So, the staff at NSRRC developed one local control system for the redundant compressor system as shown in figure 3. We used the same PLC CPU (Siemens CPU317-2 DP) which was used for the TPS cryogenic plant. One HMI interface serves to start or to stop the compressor, to monitor the analogue signals (pressure, temperature, valves opening and speed of the compressor) and for manual control of the control valves of the gas-management panel. The system values can be archived and recorded with a data-acquisition program through the internet. Because the redundant compressor system is the same as the main compressor system, this local control system can stand alone to operate the main compressor system as well during annual maintenance.

![Diagram of Local Control System](image_url)

**Figure 3.** Local control system
2.3. Stand-alone operation for 72 h

The bypass valve is the only valve that is controlled automatically by the PLC program. The control function is proportional-integral (PI) control. If the low pressure is less than its set-point value (1.05 bara), the bypass valve opens more to accept more gaseous helium from the high-pressure pipe. If the low pressure is greater than the set-point value, the bypass valve closes more to decrease the gaseous flow from the high-pressure pipe. Figure 4 shows the 72-h stand-alone test of the redundant compressor. After 8 hours, we slowly opened the discharge valve to 40% for 3 min; the pressure of the suction line increased, and the bypass valve closed from 73.5% to 72% automatically. The high pressure also increased from 9.1 to 10.1 bara because of the greater flow of gaseous helium into the closed system. The speed of the compressor remained the minimum, 25 Hz. The continuous operation for 72 h showed that the redundant compressor and the local control system both run stably.

![Figure 4](image-url)

**Figure 4.** Stand-alone operation for 72 h (A) Discharge valve opening, (B) compressor speed, (C) high pressure, (D) low pressure, (E) bypass valve

2.4. DC-bank supply test

In 2010, we built two sets of 400-kW DC UPS (also called a DC-Bank system) to keep two 315-kW compressors in fully loaded operation for at least 3 min when the power sagged or the power was cut off. Figure 5 shows the basic configuration of the DC-Bank. The DC-Bank was connected in parallel to the inverter, thus not affecting the inverter operation when the DC-Bank requires maintenance or experiences a failure. This section presents the configuration of the DC-Bank and the testing of the system. The results show that, when the inverter is operated at 130 kW with the main power cut off, the redundant compressor retains stable operation for 240 s with the DC-Bank support. The basic configuration of the DC-Bank system is shown in figure 6. In the standby mode the charger module charges the battery and maintains full power; one booster module boosts the battery voltage to the working voltage (about 90% of the VFD DC-bus voltage), which is in our case about 480 V dc. The DC-Bank supplies no power to the VFD. When the city electrical power supply is interrupted or
experiences a voltage drop causing the DC-bus voltage to drop more than 10%, the DC-Bank supplies the dc power immediately to the DC-Bus of the VFD to keep the VFD output power system operating (active mode). When the city electrical power supply returns to normal conditions, the DC-bus of VFD returns to normal (in our case about 510 V dc) and the DC-Bank automatically stops supplying power to the VFD and stays in the standby mode. The DC-Bank system is connected in parallel with the VFD system; any failure, maintenance or disconnection of the DC-bank for any reason does not affect the normal operation of the cryogenic system.

![Diagram](image)

**Figure 5.** Configuration of the DC-Bank

![Graph](image)

**Figure 6.** Test of the DC-Bank supply (A) compressor running speed, (B) city electrical power supply, (C) charger voltage

Table 1 presents the voltage values of the DC-Bank and the compressor inverter during a power-cut test. According to this table we readily understand how the DC-Bank works when the main power is off.
### Table 1

|                      | Before power off [V] | At time of power off [V] | 4 min after power off [V] | Power on [V] |
|----------------------|----------------------|--------------------------|---------------------------|--------------|
| DC-Bank Output voltage (V1) | 503                  | 477                      | 477                       | 503          |
| DC Bus voltage (V2)    | 510                  | 477                      | 477                       | 510          |
| Battery voltage (V3)   | 503                  | 503                      | 430                       | 510          |
| Charger voltage (V4)   | 400                  | 220                      | 220                       | 480          |

### 3. Modification of the control system for redundant function

In the beginning of the commissioning phase of the TPS cryogenic plant, we decided to have a redundant compressor system for the continued operation during a maintenance period. One option for the control system was to have the redundant compressor system is permanently connected to the TPS cryogenic plant, which requires the hardware and software of the control system to be modified. This would require all modification and testing to be done by the cryogenic plant vendor; this solution did not meet cost and schedule requirements. The option selected by NSRRC staff is shown in figure 7. Two RS485 repeaters are used with no change to the software program, in the following manner. First, we reconnect the profibus cable; the two profibus connections of the main compressor and the main ORS/GMP move to the end of the PLC stations after RS485 repeater 1. Second, the two profibus connections of the redundant compressor and the redundant ORS or GMP are after RS485 repeater 2. Third, these two RS485 repeaters are connected to other PLC stations of the TPS cryogenic plant. Fourth, the common signals are changed to relays. In the normal case, repeater 1 is in "On mode" and repeater 2 is in "Off mode", so that the main compressor system is serviced. If repeater 1 is in "Off mode" and repeater 2 is in "On mode", the redundant compressor system is serviced. The switching time is less than 10 s.

![Figure 7. Signal and profibus configuration](image-url)
4. Performance results using the redundant compressor
In January 2016, we successfully switched over to the redundant compressor from original compressor system and restart the liquefaction of cryogenic plant in 10 s. The cold box continuously performed liquefaction or refrigeration for more than 100 h. Figure 8 shows the results of an imposed test. The heater power in the liquid-helium dewar (7000 L) was turned on at 610 W for more than 10 h, then was turned off (heater power 0 W) for 20 min then turned on at 600 W again. The pressure in the dewar and suction line had a significant fluctuation. The level of the liquid helium increased rapidly. About 6 h later, we increased the heater power from 600 W to 820 W. The impact was smaller. This test indicates that the redundant compressor system operates as well as the main compressor system. In the performance test we obtained the rate of liquefaction without LN\textsubscript{2} precooling at 86.6 L/h; the refrigeration rate was 612 W without LN\textsubscript{2} precooling. For comparison, the original performance values with the main compressor system are roughly the same.

![Figure 8](image_url)

Figure 8. (A) LHe dewar pressure, (B) LHe dewar heater, (C)LHe dewar level, (D) low pressure

5. Conclusion
We installed one redundant compressor system for the cryogenic plant in 2015. We can switch to this redundant compressor system and restart the cryogenic system in 10 s. In this paper the configuration, switch over method, results of commissioning and a performance test of the redundant compressor system has been discussed in detail.

References

[1] H H Tsai, F Z Hsiao, H C Li, S H Chang, T F Lin, W S Chiou, C P Liu. 2015 The Commissioning of Helium Cryogenic System and LN2 Transfer System in the TPS Ring Physics Procedia, Vol 67 pp 183-188.