Performance of a cryogenic system for the superconducting RF cavity at NSRRC

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A helium cryogenic system that is designed based on the modified Claude cycle provides cooling power to the superconducting RF cavity and the superconducting magnet in the synchrotron light source. This paper presents the performance and the features achieved by the cryogenic system. A maximum cooling capacity 469 W and a maximum liquefaction rate 139 L/h is obtained at the storage dewar. Commission with the magnet is successful and shows small impact on the cryogenic system as coil quenches. Finally, the failure events which interrupted the system operation is summarized.

INTRODUCTION

A helium cryogenic system that is designed based on the modified Claude cycle provides a maximum cooling power 450 W at 4.5 K or a maximum liquefaction rate 110 l/hr using liquid nitrogen for precooling. Construction of this system started from Feb. 2001 and the installation began in Oct. 2002. The commission phase started from Jan. and ended in Oct. 2003. This helium system is dedicated for the cooling of a 500 MHz superconducting radio frequency (SRF) cavity which is the key item of an upgrade project to enhance the beam current and stability of NSRRC electron storage ring. Besides, this helium system keeps a superconducting magnet at 4.3 K (1.085 bar), where the magnet is cooled at the liquefaction mode. The cryogenic system is a turnkey system and provided by the Air Liquide Company. The system includes one 315 kW compressor, one 45 kW recovery compressor, one 10 kW refrigerator, one 2000 liter dewar, and two 100 m^3 gas helium buffer tanks. Inside the cold box, two expansion turbines connected in series provide the major cooling power for helium gas stream. Two 80 K adsorbers and one 20 K adsorber are installed in the cold box. The switch and regeneration of the two 80 K adsorbers are fully automatic and performed without interrupting the cold box. There are two analyzers monitoring the impurity level of the helium flow. One analyzer monitors the oxygen and humidity level at the cold box side, the other one monitors the oil aerosol and nitrogen level at the compressor side. The designed thermal dynamic state and preliminary test result of this helium system can be found in references [1,2].

PERFORMANCE

During the commission phase the target of the cryogenic system focused on the maximum refrigeration power and the maximum liquefaction rate. Status of the system is archived and trends of the data are analyzed. Table 1 summarizes the commission result obtained at the 2000 l main dewar. The liquefaction rate is obtained by measuring the dewar rate-of-rise with built-in level sensor and under the condition cold gas returned to the cold box. The refrigeration capacity is measured by the dewar built-in DC heater. The system provides a maximum liquefaction rate 139 l/hr with liquid nitrogen for precooling and a liquefaction rate 59 l/hr without liquid nitrogen. For the refrigeration capacity we obtained a cooling power 258 W with 11 l/hr liquefaction rate without liquid nitrogen and a cooling power 452 W with 5 l/hr liquefaction rate using liquid nitrogen. By linear extrapolating the data we have a cooling power 327.2 W (469.5 W) at refrigeration mode without (with) liquid nitrogen for precooling. During measuring the liquefaction rate and refrigeration capacity without liquid nitrogen precooling, we observed the mass flow rates are 24 g/sec and 44 g/sec respectively; the values are 39 g/sec and 82 g/sec with liquid nitrogen precooling.

Table 1　Feature of the cryogenic system during capacity measurement at main dewar

Item	Units	Design value				Measurement value			
		Refrigeration		Liquefaction		Refrigeration		Liquefaction	
		w/o LN2	w/ LN2	w/o LN2	w/ LN2	w/o LN2	w/ LN2	w/o LN2	w/ LN2
Cooling capacity	W	255	450	-	-	327.2	469.5	-	-
Liquefaction rate	l/hr	-	-	51	115	-	-	52	134
Mass flow rate	g/s	51.2	73.9	42.3	59.6	44	82	23.5	39
Frequency driver	Hz	35	52	30	42	42	57.5	33.2	43.5
Discharge pressure	bar	12.2	15	15	15	15	15	15	15
Suction pressure	bar	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Suction-pressure fluctuation	mbar	＋/－3	＋/－3	＋/－3	＋/－3	＋/－2	＋/－1	＋/－2	＋1/－2
Main dewar pressure	bar	1.25	1.3	1.25	1.3	1.25	1.272	1.25	1.25
Pressure fluctuation in main dewar	mbar	＋/－3	＋/－3	＋/－3	＋/－3	＋/－1	+3/-2	＋/－1	＋/－1
Warm turbine speed	Hz	2724	2730	3340	2658	2912	2751	3200	2754
Cold turbine speed	Hz	-	2069	-	-	1837	1969	1846	1988

A further capacity verification after the 5 m long, nitrogen thermal shielding, multi-channel line was performed. The liquefaction and refrigeration capacity was measured in a 500 l test dewar, which was connected to the multi-channel line via an adopter and 1.6 m long flexible vacuum jacket lines. Table 2 summarizes the measured result obtained at the test dewar. The measurement for the liquefaction rate with liquid nitrogen precooling showed a rising rate 114 l/hr in the test dewar and a rate 25 l/hr in the main dewar. A liquefaction rate 59 l/hr in the test dewar was obtained without liquid nitrogen. Thus a maximum refrigeration capacity 327.1 W (447.9 W) without (with) liquid nitrogen precooling is obtained in the test dewar. For all the measurement in the test dewar, a higher flow rate into the cold box is required to achieve a comparable capacity as the case measured in the main dewar.

Table 2　Feature of the cryogenic system during capacity measurement at test dewar

Item	Units	Measurement value			
		Refrigeration		Liquefaction	
		w/o LN2	w/ LN2	w/o LN2	w/ LN2
Cooling capacity	W	327.1	447.9	-	-
Liquefaction rate	l/hr	-	-	59	139
Mass flow rate	g/s	50.5	89	29.5	48.2
Frequency driver	Hz	56.1	59	47.9	50.7
Discharge pressure	bar	15	14.699	15	15
Suction pressure	bar	1.05	1.05	1.05	1.05
Main dewar pressure	bar	1.38	1.4	1.38	1.38
Test dewar pressure	bar	1.3	1.3	1.18	1.19
Warm turbine speed	Hz	2993	2770	3200	2750
Cold turbine speed	Hz	1950	2042	1931	2050

Stand-alone operation of the cryogenic system has the following features. The suction line pressure has a variation smaller than +/-2 mbar and the variation is smaller than +3/-3 mbar for the dewar pressure. A frequency driver that implements an energy-saving feature varies the frequency in the range 30 Hz to 60 Hz such that the mass flow of helium changes from 44 g/s to 89 g/s. In the refrigerator, two 80 K cryogenic adsorbers automatically switch at every 100 h and the off-duty one automatically proceeds to on-line regeneration for the next operation. It takes 4.5 hr to complete the regeneration process. The interlock logic keeps the cryogenic system safe from utility failure and a small-capacity compressor recovers the helium to the storage tanks and maintains a suction line pressure at 1.1 bar. The emergency power maintains continuous operation of the control system and the recovery compressor to minimize helium loss in case of an electricity failure. The time required to warm up the cold box to room temperature is 18 hr; it takes 38 days to naturally warm up the main dewar at zero level to room temperature. Initial cooling down of the cold box and the main dewar from room temperature to 4.5 K takes 36 hr, and it takes 10 hr to store the liquid helium to 80 % main dewar level with liquid nitrogen precooling. During the liquid helium accumulation period, value of the dewar level sometimes stagnates at 40% and 82%. As dewar level approaching the maximum setting value, the turbines will turn down their speeds and the heater will turn on to avoid over-level event.

COMMISSION WITH MAGNET

A superconducting magnet SW6 with helium vessel of volume 200 l was installed in the storage ring in Jan. 2004. The cold box did not provide liquid helium to the magnet until the severe damaged warm turbine was replaced with a new one. Figure 1 shows connection of the cold box, the main dewar, the test dewar, and the SW6 magnet. Location of the SRF cavity to be installed in Nov. 2004 is also indicated. A control valve box is connected to the downstream of the multi-channel transfer line. The SW6 and the test dewar are then connected to the valve box via flexible transfer lines. The cold gas from the test dewar returns to the cold box, while the gas from SW6 returns to the compressor suction line. Operation pressure for the SW6, the test dewar, and the main dewar is 1.08 bar, 1.24 bar, and 1.4 bar respectively. The SW6 is designed with small margin to its critical field and the cryostat is operated close to 4.3 K. Instead of high Tc material the current lead of the coil is made of copper and cooled by the cold helium gas. Thus the measured temperature of the return helium gas is around 60-70 K, which is lower than the estimated temperature 100 K. Because of the low operation pressure and the high return gas temperature, the returned gas from SW6 is warmed up and sent back to the compressor.

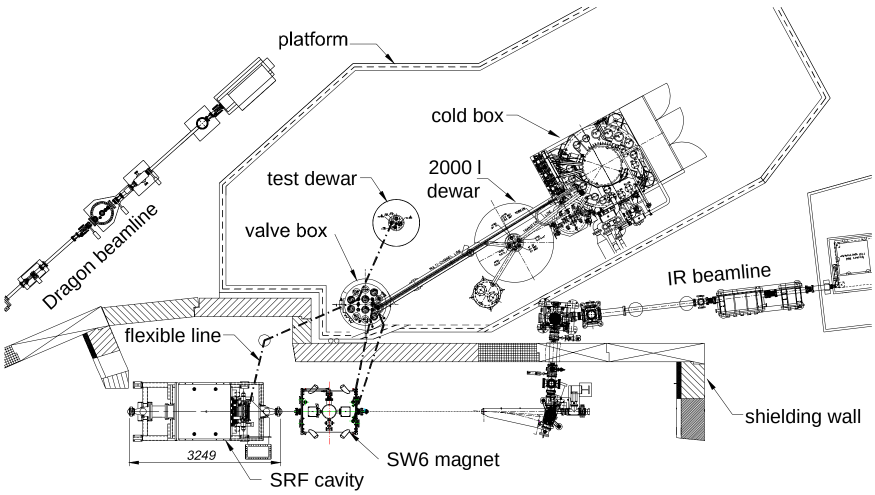

Figure 1 Layout of the cold box, main dewar, valve box, test dewar and SW6

Commission of the SW6 is quite successful. Figure 2 shows the training records of the SW6 coil. After ten times of training, the coil was charged to the design current 285 A and a magnet field 3.2 T was maintained. Three hours after the successful training of SW6, the beam current of the storage ring was stored at 200 mA without difficulty. Each coil training caused a quench and then vaporized a maximum 10 liter liquid helium. The stored energy of the coil is 50 kJ and part of the stored energy is dumped to the flywheel diode. The diode is cooled partly by liquid helium and partly by cold helium gas. During the training period the cold box and the test dewar was isolated from SW6 and the compressor kept running to recover the large amount of helium gas from SW6 cryostat. Consumption more than 60 l/hr was required to continuous fill liquid helium to the SW6 cryostat and kept a constant level. Another measurement indicates that the heat load of SW6 cryostat consumes liquid helium up to 3 l/hr as the coil current is 285 A. We concluded most of the helium is vaporized to accommodate the heat loss during the helium transfer phase. A total heat loss 30 W is estimated for the control valve box, the multi-channel line, the flexible transfer line, and the connectors.

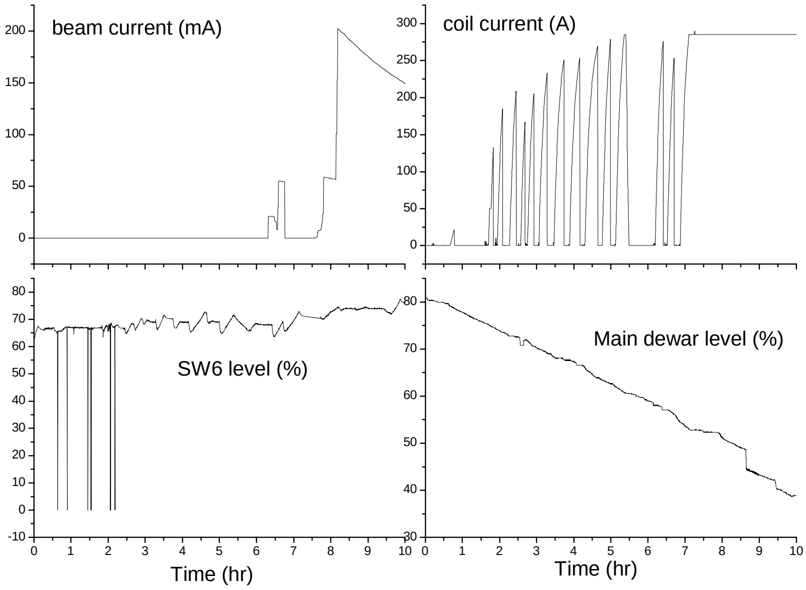

Figure 2 Training records of SW6

Without liquid nitrogen precooling the cold box can not maintain the main dewar level if no cold gas returns to the cold box. Two strategies are used to solve this problem. We open the by-pass valve in between the helium supply line and cold return line in the valve box and let the cold gas come back to the cold box. In the meanwhile the helium level for SW6 cryostat is regulated at On-Off control filling mode with inlet valve opened at 5% and triggered from +/-1 % cryostat level fluctuation. Small impacts on the cryogenic system are observed as the SW6 quenches: a pressure fluctuation +/-2 mbar in the suction line, a pressure fluctuation +/-3 mbar in main dewar; a temperature increase 0.3 K in cold return gas from the valve box; and a speed fluctuation +/-10 Hz at cold turbine. The On-Off filling mode for SW6 causes a pressure fluctuation +/-2 mbar at the test dewar.

TRIP RECORDS

Several events interrupted the operation of the cryogenic system. Table 3 summarizes the number of trips caused from different parts. The oxygen sensor failed due to some unknown reason. Failure of the compressor motor is believed caused from the poor lubrication of motor bearing. Failure of the output control card of the frequency driver may be owing to the overheating of its cabinet inside temperature. Damage of the warm turbine may cause from impurity or dust. A poor controlled cooling water temperature for the compressor leaded to an oscillating helium temperature in the discharge line. This unstable temperature disturbed the whole system and finally the compressor was tripped due to too big temperature oscillation as compressor speed was high. Cooling water with well-controlled temperature will avoid this kind of event.

Table 3 Trip records

Event	Count	Cause
Warm turbine failure	3	Damaged by impurity or dust
Oxygen sensor abnormal reading	3	Sensor cell damage
Compressor motor damage	1	Motor overheated due to poor bearing lubrication
Frequency driver failure	1	Output control card failure
Electricity shortage	3	Electricity trips
Cooling water failure	2	Small flow rate; unstable water temperature

REFERENCES

1. Hsiao, F. Z., et al., The Liquid Helium Cryogenic System for the Superconducting Cavity in SRRC, Proceedings of the 2001 Particle Accelerator Conference (2001), 1604-1606
2. Hsiao, F. Z., et al., The Pilot-Runs of the Helium Crygoneic System for the TLS Superconducting Cavity, Proceedings of the 2003 Particle Accelerator Conference, Oregon, Portland (2003).