Commissioning of cryogenic system for China Spallation Neutron Source

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Abstract. China Spallation Neutron Source (CSNS) cryogenic system provides supercritical cryogenic hydrogen to neutron moderators, including a helium refrigerator, hydrogen loop and hydrogen safety equipment. The helium refrigerator is provided by Linde with cooling capacity of 2200 W at 20 K. Hydrogen loop system mainly includes cryogenic hydrogen pipes, hydrogen circulator cold-box and accumulator cold-box. Cryogenic hydrogen pump, ortho-para convertor, helium-hydrogen heat-exchanger, hydrogen heater and accumulator are integrated in hydrogen circulation cold-box, and accumulator cold-box. Hydrogen safety equipment includes safety valves, rupture disk, hydrogen sensor, flame detector and other equipment to ensure that cryogenic system in dangerous situations will go down, vents, or takes other measures. The cryogenic system commissioning work includes four steps. First, in order to test the refrigerating capacity of refrigerator, when acceptance testing, refrigerator internal heater was used as thermal load. Second, using simulation load as heat load of moderator, hydrogen loop use helium instead of hydrogen, and cooled down to 20 K, then re-warming and test the leak detection of hydrogen loop system. Third, base on the step 2, using hydrogen as working medium, and optimized the control logic. Forth, cryogenic system with the moderators joint commissioning. Now, cryogenic system is connected with the moderators, and the forth step will be carried out in the near future.

Keywords: China Spallation Neutron Source, cryogenic system, commissioning.

1. Introduction

China Spallation Neutron Source (CSNS) cryogenic system provides supercritical cryogenic hydrogen to neutron moderators, and the para hydrogen concentration is 99%, working at 15 bara, 18–22 K.\textsuperscript{[1]} CSNS cryogenic system mainly include a helium refrigerator, hydrogen loop and the hydrogen safety equipment. The helium refrigerator is provided by Linde with cooling capacity of 2200 W at 20 K. Hydrogen loop system mainly include cryogenic hydrogen pipes, hydrogen circulator cold-box and accumulator cold-box. Cryogenic hydrogen pump, ortho-para convertor, helium-hydrogen heat-exchanger, hydrogen heater and accumulator are integrated in hydrogen circulation cold-box and accumulator cold-box. Hydrogen safety equipments include safety valves, rupture disk, hydrogen sensor, flame detector and other equipments to ensure that cryogenic system in dangerous situations will go down, vents, or takes other measures.\textsuperscript{[2]} Cryogenic hydrogen pump provides flow to the hydrogen loop. Helium refrigerator and hydrogen loop exchange heat in helium-hydrogen heat-
exchanger. Ortho-para convertor can accelerate ortho-hydrogen converting to para-hydrogen. Hydrogen heater can adjust the cryogenic system heat load. Cryogenic hydrogen pipes connect hydrogen circulation cold-box with neutron moderators. Simulated load can simulate heat load of neutron moderator. Accumulator can change the hydrogen loop volume by bellows expansion, and it can reduce the pressure changes when the hydrogen loop temperature changes.

CSNS cryogenic system flow diagram is shown in Figure 1. CSNS cryogenic system completed the installation of the helium refrigerator in July 2016. Acceptance testing on the helium refrigerator was completed in August, using the refrigerator internal heater as thermal load, and verify whether the helium refrigerator refrigerating capacity meets the requirements of the contract. In early January 2017, The installation of all the cryogenic system equipment was completed, and the commissioning was started. To ensure safety, commissioning work was divided into two steps. First, using simulated load as heat load of moderator, hydrogen loop uses helium instead of hydrogen and cooled down to 20 K, then re-warming and we did leak detection on hydrogen loop system. Second, based on step 1, using hydrogen as working medium, and cooled to 20 K, optimize the control logic. At last, hydrogen loop cooled to 20 K succeeded, then the simulation loads were removed and the installation of two hydrogen pipes with neutron moderators was finished. The next step is the jointed commissioning of cryogenic system and moderators.

Figure 1. Cryogenic system flow diagram.

2. The acceptance test of the helium refrigerator
In July 2016, we completed the installation of the helium refrigerator, it mainly includes compressor, oil separator, helium cold-box, purifier, and purity analyzer. In order to ensure the purity of the helium in pipes, active carbon must be desorbed by high temperature, and we replaced the helium in the pipes three times. After helium compressor start, external purifier is used for further purification, until water, nitrogen, hydrocarbons and hydrogen content of helium refrigerator are under 5 ppm and the sum isn't more than 10 ppm, and helium purity conforms to the start up requirements of the turbine. The helium refrigerator has an internal heater, and this heater is the thermal load of neutron moderator in test mode. Helium refrigerator can be tested in different refrigerating capacity by changing heater power. Helium refrigerator was tested in 3 refrigerating capacities, respectively 700 W, 1400 W, and 2300 W and each working condition was running for 24 hours. Screenshot of helium refrigerator running at 2300 W refrigerating capacity is shown in Figure 2. State point of helium refrigerator at 700 W, 1400 W,
and 2300 W is shown in Table 1. Test results showed that the helium refrigerator can run stably, and refrigerating capacity meet the contract requirements while stably running.

| Refrigerating capacity /W | Discharge pressure /bara | Suction pressure /bara | Post-expansion temperature /K | Post-expansion temperature / bara | Flow /g/s |
|--------------------------|--------------------------|------------------------|-------------------------------|----------------------------------|-----------|
| 700                      | 8.64                     | 1.541                  | 14.5                          | 1.76                             | 83.8      |
| 1400                     | 10.11                    | 1.798                  | 14.9                          | 2.01                             | 96        |
| 2300                     | 11.86                    | 1.97                   | 15.8                          | 2.25                             | 104       |

Figure 2. Helium refrigerator running state at 2300 W refrigerating capacity.

3. Cool down commissioning with helium

In early January 2017, cryogenic system installation had been finished. Simulated load was used instead of neutron moderator, simulating the heat load of neutron moderator. Heat load of two neutron moderators corresponding to 200 kW proton beams which is CSNS design objective of 320 W and 240 W, respectively.

At the end of January until the end of April we have completed the five rounds of cool down commissioning with helium, failure twice and success three times. In the beginning, it was difficult to control hydrogen loop pressure by the valve opening of hydrogen loop inlet and outlet. After the two times failure, suitable valve opening was found and get success. On April 12, the fifth round of the helium cool down commissioning was started, and the cooling process is divided into 4 steps, pressure-up mode, cool-down mode, stand-by mode, and re-warm mode. In order to ensure the bellow is not destroyed, the differential pressure on both sides of the bellow must be less than 1.5 bar. If the differential pressure is higher than 1.5 bar, cryogenic system will initiate the interlock procedure. Helium side of accumulator is fixed at 14.5 bara, so hydrogen loop side of accumulator must be strictly controlled pressure in the process of commissioning. The first step, pressure-up mode, pressure of helium side and hydrogen side rise alternately until 14.5 bara, and it must be confirmed that differential pressure is within a reasonable value. The second step, cool-down mode, start the helium refrigerator and set the refrigerator temperature at 16 K, two hydrogen circulation pumps start and run to 240 Hz. Hydrogen circulation pressure decreases with temperature decrease, and the system fills gas...
to maintain pressure automatically. After 18 hours cooling-down, hydrogen circulation cooled down to 20 K. The third step, stand-by mode, using simulated loads which set 320 W and 240 W respectively to simulate the heat load of neutron moderators, cryogenic system run 24 hours stably. The fourth step, re-warm mode, helium refrigerator closed cool-down mode. Hydrogen circulation pressure increased with temperature rise, and it vented to stable pressure if the pressure exceeds the set value. When the temperature increases to 300 K, the cool down commissioning of helium is complete.

Cooling curve is shown in Figure 3. In Figure 3, TI4101 is the outlet temperature of the heat exchanger. TI4105 is the inlet temperature of the heat exchanger. PI4145 is the inlet pressure of the heat exchanger. FI4121 is the flow of hydrogen cycle. P4104 is the frequency of the hydrogen circulation pump.

![Cooling curve of helium commissioning.](image)

**Figure 3.** Cooling curve of helium commissioning.

4. **Cool down commissioning with hydrogen**

After cool down commissioning which used helium in hydrogen loop, in April and May we did cool down commissioning which used hydrogen in hydrogen loop three times, also use the simulated load to simulate the heat load of neutron moderator. The first time and second time cool down commissioning failed, because the density of hydrogen changes greatly at 33 K, and it cause the pressure change greatly. When hydrogen loop temperature has a little change, the pressure change greatly. After the two times failure, the process of cool-down mode is divided into two steps. First step, all the point of hydrogen loop cooled to about 50 K. Second step, the speed of cool-down must be slow by changing settings of refrigerator. At last, the third time succeeded. The cooling process is divided into 4 steps, pressure-up mode, cool-down mode, stand-by mode, and re-warm mode.

The first step, pressure-up mode, pressure of helium side was 14.0 bara while hydrogen side was 15.0 bara. The second step, cool-down mode, start the two hydrogen circulation pumps and set to 283 Hz, then open the helium refrigerator and set the refrigerator temperature at 50 K. When the whole hydrogen cycle cool-down to 50 K, we reduce the outlet temperature setting value. After 30 hours, the whole hydrogen cycle reached 18 K. The third step, stand-by mode, we open hydrogen heater to 700 W. Simulated loads were set 320 W and 240 W quickly, then turn off quickly, simulating the change of heat load, and cryogenic system run stably without venting or filling gas. At stable state, hydrogen pumps run at 240 Hz, the flow of hydrogen cycle is 0.36 L/s which can meet the work requirement of neutron moderators. After 48 hours running, we began to re-warm. Hydrogen pumps run still, and
helium refrigerator switched cool-down mode to re-warm mode. When the temperature of hydrogen cycle increase 300K, the commissioning of hydrogen was completed.

Cooling curve is shown in Figure 4. In Figure 4, TI4101 is the outlet temperature of the heat exchanger. TI4105 is the inlet temperature of the heat exchanger. PI4145 is the inlet pressure of the heat exchanger. FI4121 is the flow of hydrogen cycle. P4104 is the frequency of the hydrogen circulation pump.

![Cooling curve of hydrogen commissioning.](image)

**Figure 4. Cooling curve of hydrogen commissioning.**

5. Conclusion
CSNS cryogenic system uses hydrogen as the medium to cool down to 20 K successfully, and can satisfy the refrigerating design demand under the working condition of 200 kW proton beams. Now the cryogenic system has dismantled the simulation load, and finished the butt welding with the moderators. The next step is the joint cool down commission of cryogenic system and moderators. The cryogenic system control logic will be further optimized. The emergency discharge, fault recovery mode will be tested. In addition, we need a long-time running to verify the reliability of the cryogenic system.

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