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Improvement of Cryogenic System for China Spallation Neutron Source

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Abstract. The commissioning of China Spallation Neutron Source(CSNS) cryogenic system was completed in July, 2017. It runs 258 days totally until July, 2018, and the longest continuous running period is 184 days. CSNS had passed the national acceptance in August 2018. Now it is running stable from September 19th 2018. There are no any faults in the process of running. However, cryogenic system needs to be improved in the near future. The flow of hydrogen cycle can't be controlled effectively. The flows through the cryogenic circulators working at the same frequency are different. The pressure drop of the ortho-para convertor is very high, and it maybe the root cause of this phenomenon. Therefore, the ortho-para convertor needs to be redesigned and re-manufactured, and the flow resistance must be measured. In future, the new ortho-para convertor will be installed in hydrogen cold-box.
Keywords: China spallation neutron source, cryogenic system, ortho-para convertor.

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.[1] CSNS cryogenic system mainly includes a helium refrigerator and hydrogen loop. The helium refrigerator is provided by Linde with cooling capacity of 2200W at 20K. Hydrogen loop system mainly consists of the hydrogen circulator cold-box and the 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. Helium refrigerator and hydrogen loop exchanges heat in helium-hydrogen heat-exchanger.[2]CSNS cryogenic system flow diagram is shown in Figure 1.

The installation of the CSNS cryogenic system has been finished on Jan 2017 and commissioned on July. Though it successfully is cooled down to 20 K, it met two problems.

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The one is that the cool-down process is not smooth. Pressure and flow changes rapidly. The other one is that the flow of hydrogen circulation flow didn't meet the design requirements. In 2017 ~ 2019, cryogenic system operates about 9 months each year, and it run stably without any failures. In order to solve the two problems, during the summer maintenance in 2018, The helium refrigerator control program was upgraded. After then, the temperature of expander outlet can be controlled, it is a big advantage for cooling automation process. In May 2019, in order to reduce the flow resistance, a new ortho-para convertor was manufactured, and the old one will be replaced during this summer maintenance.

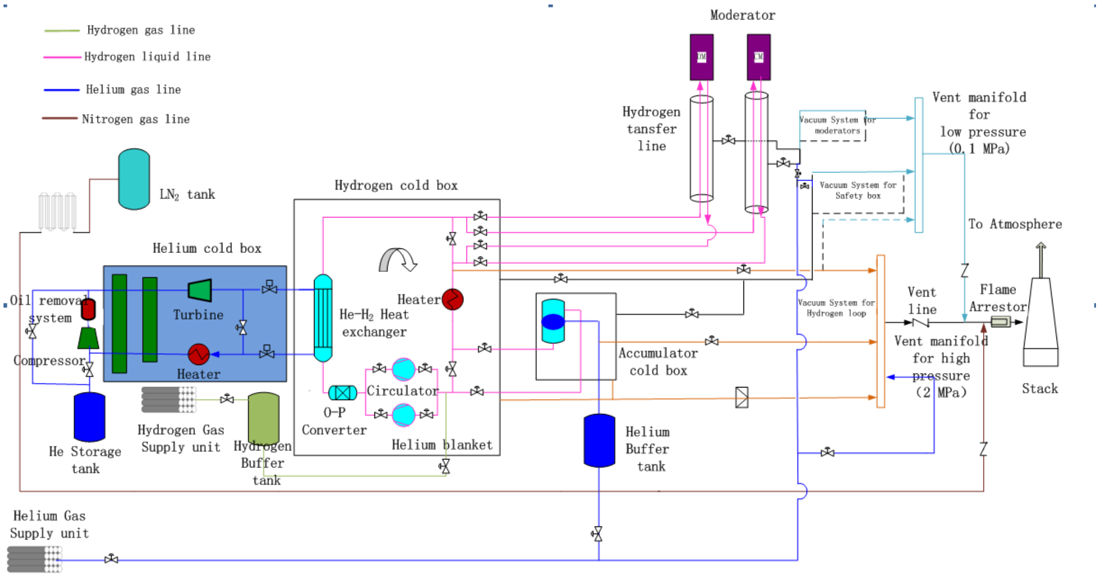

Figure 1.CSNS cryogenic system flow diagram.

2. Control program update of the helium refrigerator

From August 2017 to July 2018, there were 4 round running in total, and the longest round running was from December 11, 2017 to June 14, 2018, 258 days in total. The whole process was stable without any fault occurred, and the trends are shown in Figure 2. TI4101 is the outlet temperature of the heat exchanger. TI4105 is the inlet temperature of the heat exchanger. PI4141 is the outlet pressure of the heat exchanger. FI4121 is the flow of hydrogen cycle. P4104 is the frequency of the hydrogen circulation pump. The beam power increases up to 20 kW this year, and the flow of hydrogen circulation was enough to cover the heat load. However, pressure and temperature fluctuated violently in all four round cool-down processes. In addition, the flow of hydrogen circulation did not meet the design. The fluctuation was concentrated in the 35 K - 30 K, and as shown in Figure 3, since the density of the hydrogen in this temperature range will be increased dramatically. Therefore, if improper control, it will cause the dramatic changes of density and pressure.

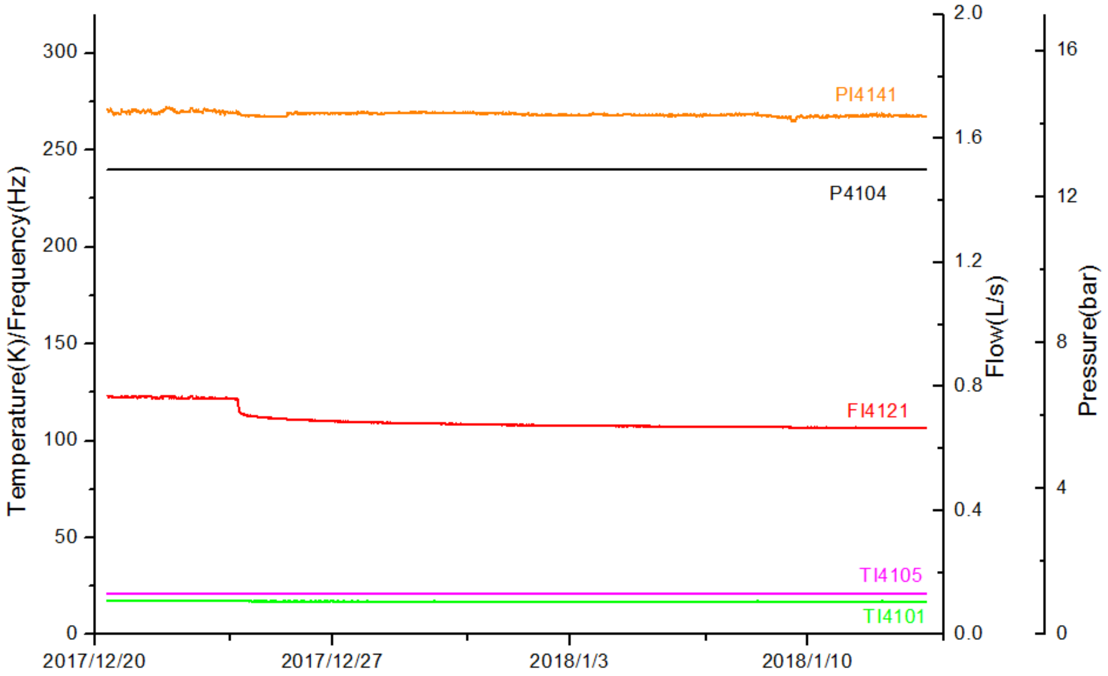

Figure 2.Running curve.

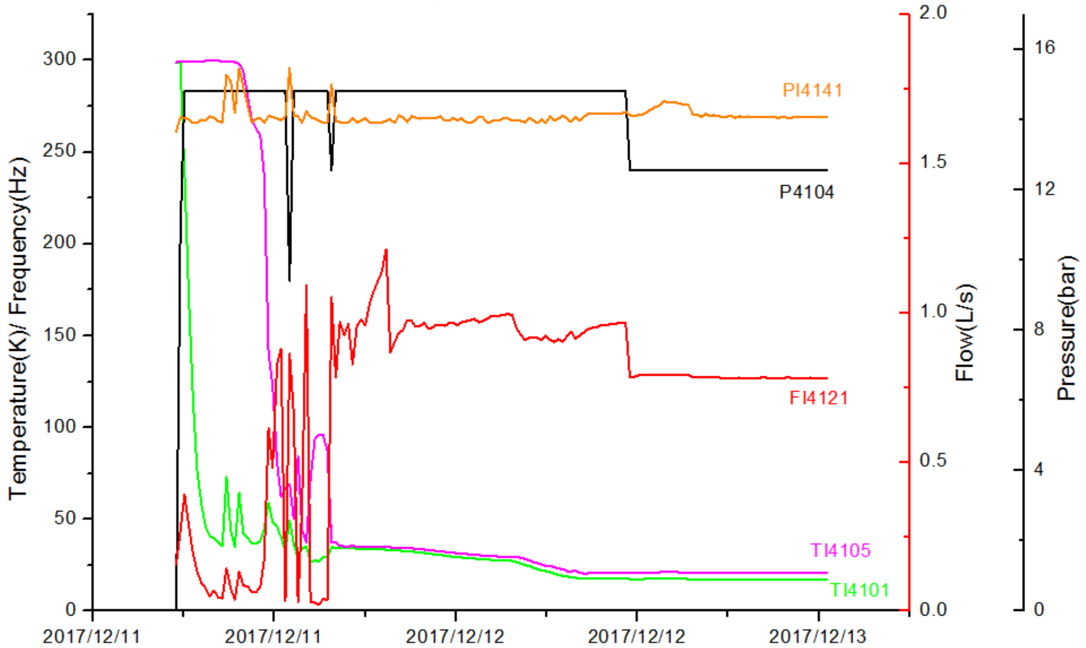

Figure 3. Cool-down curve before control program update.

During 2018 summer maintenance, helium refrigerator control program was upgraded, since the minimum capacity of helium refrigerator was more than the heat load in cool-down process, and it can't maintain set temperature. The new control program makes the temperature of expander outlet stable by the heater in the refrigerator. It turns out helpful for cool-down process.

In September 2018, after control program upgraded, cryogenic system was cooled down to 20 K. The cooling curve as shown in the figure 6, and pressure and temperature fluctuation are still occurred in 35 K- 30 K, and the graph is shown in Figure 4, because the operation of new control program was unfamiliar for us. TI4101 is the outlet temperature of the heat exchanger.

TI4105 is the inlet temperature of the heat exchanger. PI4141 is the outlet pressure of the heat exchanger. FI4121 is the flow of hydrogen cycle. P4104 is the frequency of the hydrogen circulation pump. Some inappropriate operation may cause the fluctuation. In the 2019 summer maintenance, several rounds of cooling-down will be performed to optimize the operation.

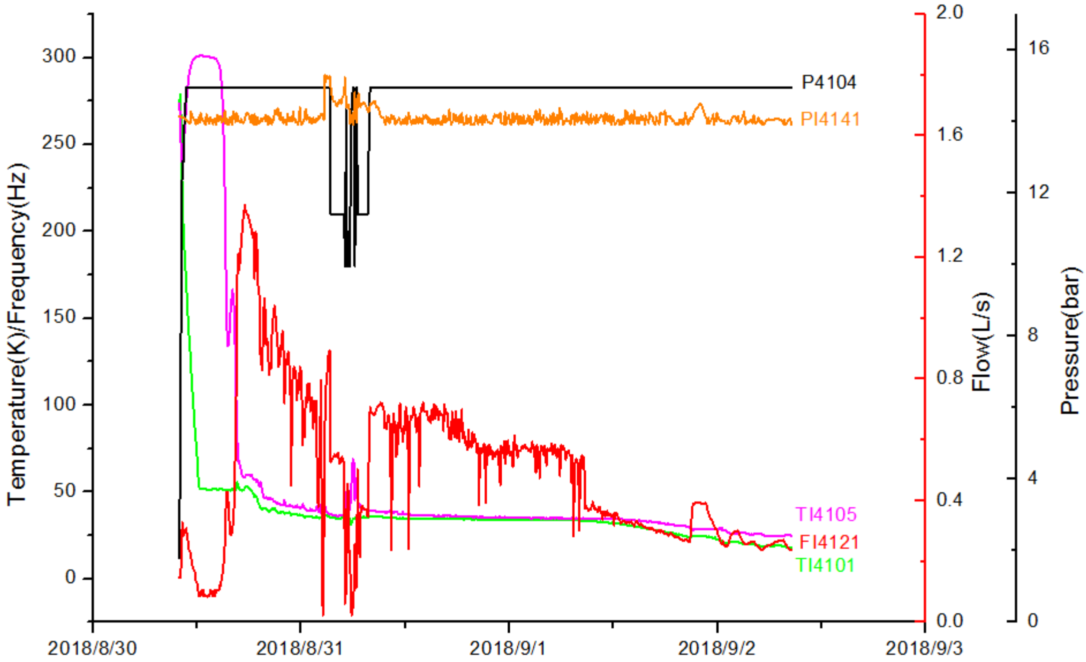

Figure 4. Cool-down curve after control program update.

3. Control program upgrade of helium refrigerator

The flow of hydrogen circulation was lower than design requirements in past two years. The flow is 0.4 L/s in the continuous running from September 2018 to June 2019. The flow can meet the heat load of 50 kW proton beams this year. In the running of 2019-2020, proton beams may increase to 100 kW. Therefore, higher flow is compulsory.

The cryogenic system running partial data is shown in Table 1. Pressure drop of ortho-para convertor is 0.103 MPa, and pressure head of pump is 0.107 MPa. The pressure head of pump meets the design requirement. Therefore, in order to increase the hydrogen circulation flow, it is necessary to reduce the flow resistance of ortho-para convertor.

Table 1. cryogenic system running partial data.

	Pressure/MPa		Pressure/MPa
Pump inlet pressure	1.453	Convertorinlet pressure	1.560
Pump outlet pressure	1.560	Convertoroutlet pressure	1.457
Pressure head	0.107	Pressure drop	0.103

Ortho-para convertor is filled with 22 kg catalyst. Filters are installed above and below catalyst, respectively. The reason of the huge flow resistance may be too much catalyst or filters with too small mesh. In order to investigate that, we built a testing platform.Due to the risk of liquid hydrogen, The helium at 80 K is used for the test. First test, used the current Ortho-para converter with 22 kg catalyst, pressure dropand system flow were measured. Second test, in order to measure whether the filters are the main flow resistance, removed 22 kg catalyst, preserved filters, pressure dropand system flow were measured to compare the first test data. Third test, used a new shorter cylinder with the same filters, filled with 6 kg catalyst, pressure drop and system flow were measured to compare again. The test data is shown in Table 2. By the test data we can see that the pressure drop is almost zero after removing the catalyst, so it can be proved that filters mesh is appropriate, and filters isn't the root cause of high flow resistance. Pressure drop reduced to about 1/5 of the first test after replacement for 6 kg catalyst, and flow is about 2 times to the first test, so it proved that too much catalyst is the main reason of high flow resistance.

Table 2.test data.

	flow resistance of convertor /MPa	**Flow**/L/s	**Catalyst**/kg
1	0.15	0.9	22
2	Almost 0	2.0	0
3	0.03	1.7	6

4. Future work

This summer maintenance,the new ortho-para convertorwith 6 kg catalyst will be installed to the hydrogen cold-box. The system will be cooled down to verify the performance in September this year. Furthermore, method of cool-down operation needs to be grasped. Smooth cool-down process and high flow are anticipated this year.

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