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Commissioning of the cryogenic hydrogen system in J-PARC: Preliminary operation by helium gas

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A cryogenic hydrogen circulation system to cool the moderators for the spallation neutron source in J-PARC has been constructed. This system provides supercritical hydrogen at the temperature of 20 K and the pressure of 1.5 MPa to three moderators and absorbs nuclear heating produced in the moderators. The cryogenic hydrogen system commissioning was started. In January 2008, for the first time, we carried out a cryogenic test of the whole system, in which helium gas was used in stead of hydrogen. The cryogenic hydrogen system can be cooled down to 18 K within 30 hours, and be kept to be the rated condition for 36 hours without any problems. We confirmed the soundness of each component such as circulation pump and operation control system.

INTRODUCTION

The JAEA (Japan Atomic Energy Agency) and KEK (High Energy Accelerator Reseach Organization) have proceeded with the project of the Japan Proton Accelerator Research Complex (J-PARC), and constructed a 1 MW pulse spallation neutron source (JSNS) for expanding the fundamental researches in material and life science [1]. The cryogenic hydrogen system for the JSNS plays a role in supplying supercritical hydrogen at a temperature of 18 K and pressure of 1.5 MPa to three moderators, in which spallation neutrons generated in a mercury target are reduced to cold neutron by the collision with the hydrogen atom [2, 3]. Figure 1 shows an overview of the cryogenic hydrogen system, which consists of a helium refrigerator system and a hydrogen circulation system. The hydrogen circulation system is composed of a hydrogen-helium heat exchanger, three moderators, a hydrogen heater, an accumulator, two circulation pumps, an ortho-para hydrogen converter and others.

The construction of the cryogenic hydrogen system has been completed, and its commissioning was started in November 2007. As the first step of our off-beam commissioning, the cryogenic tests (TEST #1 and #2) of the cryogenic hydrogen system without being connected to the moderators, in which helium was used instead of hydrogen, have been conducted in November and December 2007 [4]. We have established an automatic operation sequence of the cryogenic hydrogen system based on the cryogenic test results.

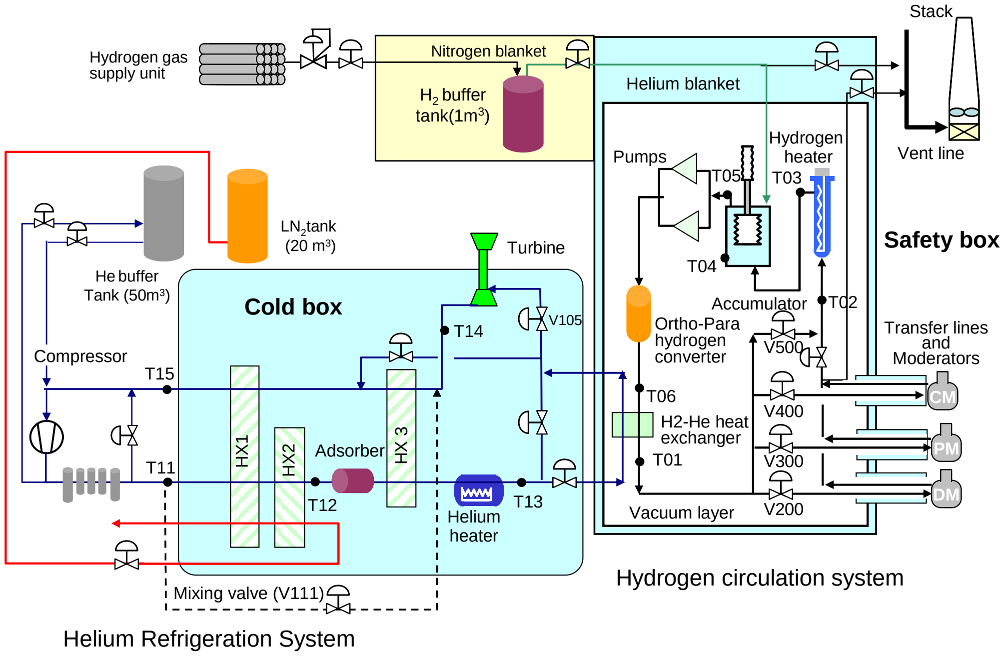

Figure 1 Overview of the cryogenic hydrogen system

In January 2008, for the first time, we conducted the cryogenic test (TEST #3) of the whole cryogenic hydrogen system that included the moderators. Figure 2 shows the test record of the main operation parameters in the cryogenic hydrogen system. This paper reports the results of the cryogenic test.

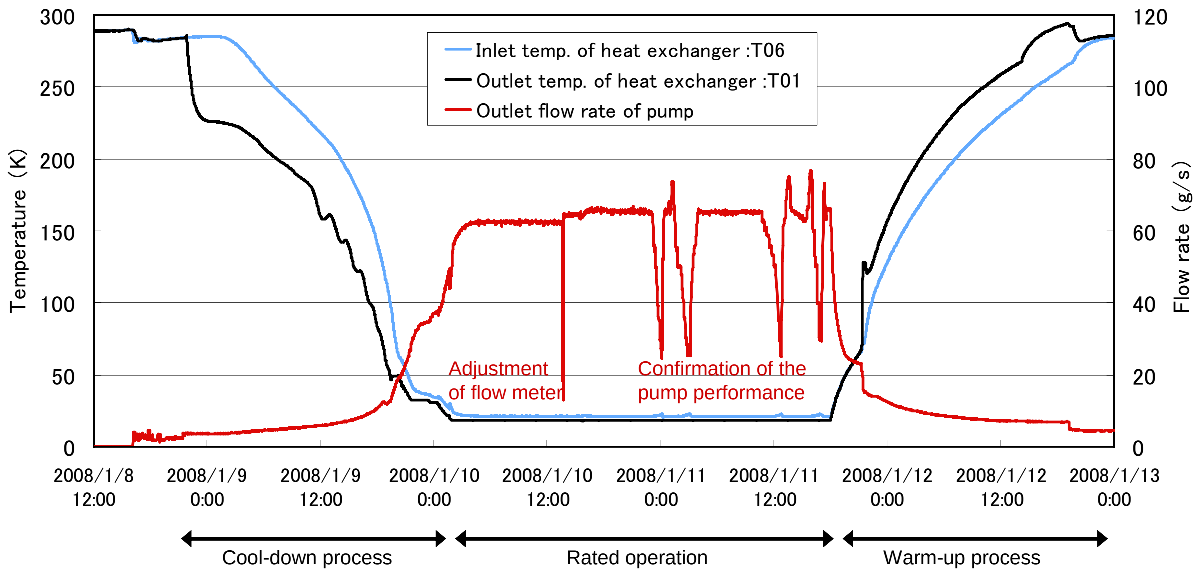

Figure 2 Records of TEST #3 at the main operation parameters

COMMISSIONING OF THE CRYOGENIC HYDROGEN SYSTEM

First cool-down operation of the cryogenic hydrogen system

The cryogenic test of the whole cryogenic hydrogen system including the moderators had been performed in January 2008. In order to verify the system soundness, helium was used instead of hydrogen in the cryogenic test. In this operation, one of two hydrogen circulation pumps was used because another was overhauled. Figure 3 shows the cool-down record of the cryogenic hydrogen system.

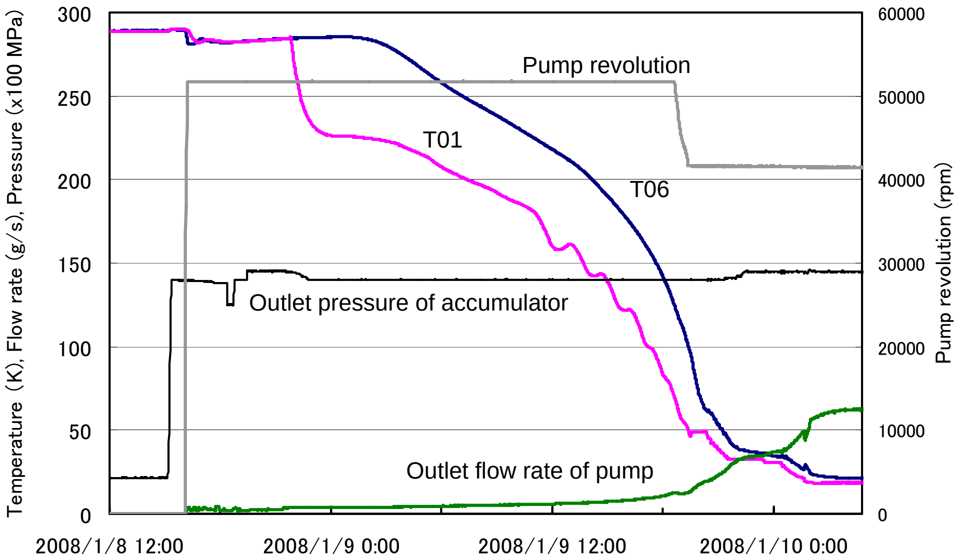

Figure 3 Situation of the cool-down process

Before the cool-down operation, it was filled with helium up to the operating pressure of 1.5 MPa. At the start of cool-down process, a helium compressor of the helium refrigeration system was operated under the rated conditions at the discharge and the suction pressure of 1.58 MPa and 0.21 Mpa, respectively. The cryogenic hydrogen system was cooled down by using an established automatic operation program.

The test operated the hydrogen pump for the first time in the cryogenic condition. At the ambient temperature, one hydrogen pump circulates at the mass flow rate of 2.5 g/s for helium.

And then, the turbine in the helium refrigeration system had been operated at the rated revolution of 2470 rps from ambient temperature. The expansion ratio of the turbine was controlled by the turbine inlet valve. The cooling rate of the helium refrigerator was controlled by the helium heater and the mixing valve that supplied high pressure stream with ambient temperature before entering the cold box to the turbine outlet stream.

The hydrogen circulation system was cooled down by the helium refrigeration system through a hydrogen-helium heat exchanger in the hydrogen circulation unit.

In this cryogenic test, the supply valves to the moderators such as V200, V300, and V400 shown in Figure 1 were opened to be 100%, and the bypass valve of V500 was opened to be 5%. As helium temperature gradually decreased, the mass flow rate has been increasing in the hydrogen circulation system. The cooling rate is due to the allowable temperature difference of 50 K at the warm and cold end of the hydrogen-helium heat exchanger until around 40 K. After that, it was maintained for 1 hour until the temperature difference of the heat exchanger by a few Kelvin. And then, the helium refrigeration system was controlled by an inner heater to be slowly decreased down to the operation temperature. It simulated the operation sequence when the system was cooled down to pass through the hydrogen critical temperature of 33 K. At the same time, the hydrogen pump revolution was changed from 52,000 rpm to the rated revolution of 42,000 rpm, because the mass flow rate increased drastically due to the increase of the density in low temperature. The bellows of the accumulator were maintained at the fully-extended location of 90.6 mm, because the helium supply valve to maintain the pressure in the bellows constant was not working. The hydrogen heater was started to control the temperature of the hydrogen loop. Finally, the hydrogen circulation system reached the rated conditions; supplying temperature of 18.6 K to the moderators, return of 19.5 K, heater power of about 400 W and pump revolution of 41,450 rpm.

In TEST #3, it took about 30 hours to cool the system down 20 K from ambient temperature without any problem.

Rated conditions

After the cool-down process, the cryogenic hydrogen system was maintained at the rated condition for about 2 days. In the helium refrigeration system, helium is compressed from 0.3 to 1.68 MPa by a screw compressor. The high pressure helium is cooled down to 16.3 K through the heat exchangers, and is heated up to 17 K by the helium heater. The circulation helium through the cold box was estimated to be 258 g/s. The high pressure helium out of the H_2-He heat exchanger is expanded and cooled to 0.3 MPa and 12.7 K by the turbine, respectively. On the other hand, the temperature at the outlet of the H_2-He heat exchanger in the hydrogen circulation system was maintained to be 18.5 K. The 18.6 K helium was provided to each moderator. And then, the temperatures coming from the coupled, poisoned and decoupled moderator were 19.5 K, 19.5 K and 19.0 K, respectively. In this cryogenic test, each supply valve was opened to be 100% initially and they were adjusted to measure heat losses of each moderator. The heat losses from each moderator were estimated to be 105 W, 110 W and 46 W, respectively, which were approximately equal to the predicted heat loss of 100 W for a moderator. It was observed that the temperatures on a bending part of the multiplex transfer line for the coupled and poisoned moderator decreased down to 273 K. It is assumed that the super insulator on the return pipe from the moderator would touch the outer vaccum pipe due to a narrow piping space. The temperature at the outlet of the hydrogen heater was maintained to be 21 K by the hydrogen heater, because of maintaining the accumulator temperature [4]. In the cryogenic test, therefore, the hydrogen circulation system was applied to around 400 W by the hydrogen heater. One hydrogen circulation pump can circulate the helium with the mass flow rate of 62 g/s with the pump head of 15 kPa. Finally, the 21.6 K helium was provided to the H2-He heat exchanger. The total heat load applied to the hydrogen circulation system, which contains the heat load by the hydrogen heater, is estimated to be 1.14 kW. It is confirmed that the total heat load of 734 W is lower than the design value of 866 W, although the heat loss from the moderator transfer lines was higher than the design value.

The pressure in the vacuum layer can be kept below 5 x 10^{-4} Pa during the cryogenic test. On the other hand, the cryogenic hydrogen system always measured the hydrogen and helium leak in the vacuum layer by using a helium leak detector and a quadripole mass spectrometer in order to detect the leak into the vacuum layer instantenously. In the cryogenic test, the helium leak was not detected.

The cryogenic test could confirm a stable operation of the cryogenic hydrogen system at the rated condition.

Performance test of hydrogen circulation pump

The hydrogen pump was designed to circulate at the mass flow rate of 162 g/s with the pump head of 0.12 MPa under the rated condition. Since the hydrogen pump was required for high reliability, two pumps were installed into the cryogenic hydrogen system as shown in Figure 1, and will be operated simultaneously with its capacity of 50 %. Even if one pump would be stopped due to its failure, the cryogenic hydrogen system can continue to be operated by the other pump with its capacity of 100 % without stopping. We developed the hydrogen pump based on the large-scale supercritical helium pump that was applicable to use for a fusion experimental reactor such as International Thermonuclear Experimental Reactor (ITER) [5]. The design conditions of the hydrogen circulation pump are shown in Table 1.

The performance of the hydrogen circulation pump was measured during the rated operation. The temperature at the inlet of the pump was 20.7 K, which was maintained by the hydrogen heater. The inlet

Table 1 Specification of the hydrogen pump

Mass flow rate	0.162 kg/s
Pump head	0.12 MPa
Adiabatic efficiency	more than 50 %
Operation pressure	0.1～1.8 MPa
Operation temperature	300～17 K
Driving	Induction motor with inverter
Bearing	Foil type self acting gas bearing
Revolution	57,000 rpm max.

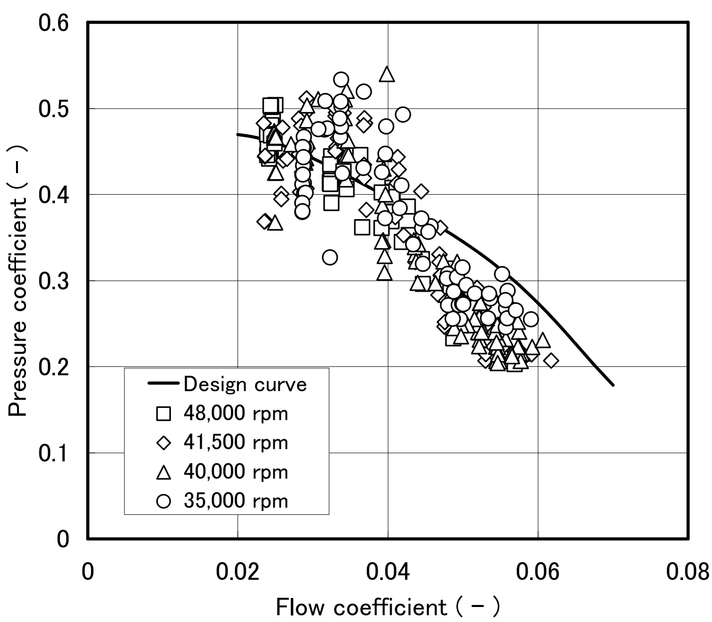

Figure 4 Characteristics of the hydrogen circulation pump

pressure was around 1.56 MPa. The pump heads and the mass flow rates were measured for various pump revolutions. The pump head was changed by controlling the supply valves to the moderators and the bypass valve. The performance result of the hydrogen pump is shown in Figure 4. For comparison, the design curve of the pump is also shown in this figure. The experimental results are almost in agreement with the design curve where the pressure coefficients are more than about 0.35. The rated point is in here. Where the pressure coefficients are less than 0.35, the experimental results are lower than the design curve. As one of the reasons, the precision of the pressure gages are low where the pump head is small, because the pump head was measured by the pressure gages with 2 MPa range. And another is that the pump is for hydrogen circulation. Therefore, it is necessary to confirm that the performance test is carried out using by actual hydrogen at the next step.

CONCLUSIONS

The commissioning of the whole cryogenic hydrogen system was carried out using helium instead of hydrogen. The system soundness such as a heat loss of the system and the performance of a hydrogen circulation pump were confirmed at the rated operation.

The cryogenic hydrogen system could be cooled down to 20 K within 30 hours, and could be maintained for about 2 days without any problem. The helium refrigeration system could circulate the mass flow rate of 258 g/s at the rated condition. One of two pumps of the hydrogen circulation system was able to circulate at the mass flow rate of 62 g/s with the pump head of 15 kPa. We confirmed the performance of a hydrogen circulation pump by the helium operation. Total heat loss in the hydrogen circulation system was about 730 W that is smaller than the design value. As the next step, we will carry out a cryogenic test using hydrogen, and the circulation system will be operated using super-critical hydrogen.

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