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COMMISSIONING RESULTS ON THE CRYOGENIC HYDROGEN SYSTEM FOR MODERATORS IN JSNS

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ABSTRACT

A cryogenic hydrogen circulation system to cool cryogenic hydrogen 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 April 2008, we carried out a cryogenic test of the whole system by real hydrogen after the test by helium gas instead of hydrogen. The cryogenic hydrogen system can be cooled down to 18 K within 20 hours, and be kept to be the rated condition for 100 hours without any problems. We confirmed the soundness of each component such as circulation pump and operation control system. At last, we have succeeded in generating first neutrons in the mercury target and providing moderated neutrons through the hydrogen moderators without any problems in May 2008

1. 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 1MW 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 converted to cold neutron [2, 3]. Figure 1 shows an overview of the cryogenic hydrogen system. The cryogenic system 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 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]. In January 2008, for the first time, we conducted the cryogenic test of the whole cryogenic hydrogen system that included the moderators using by helium gas instead of hydrogen, too [5].

As the final step, we carried out a cryogenic test of the whole system by real hydrogen after the test by helium gas instead of hydrogen in April 2008. At last, we have succeeded in generating first neutrons in the mercury target and providing moderated

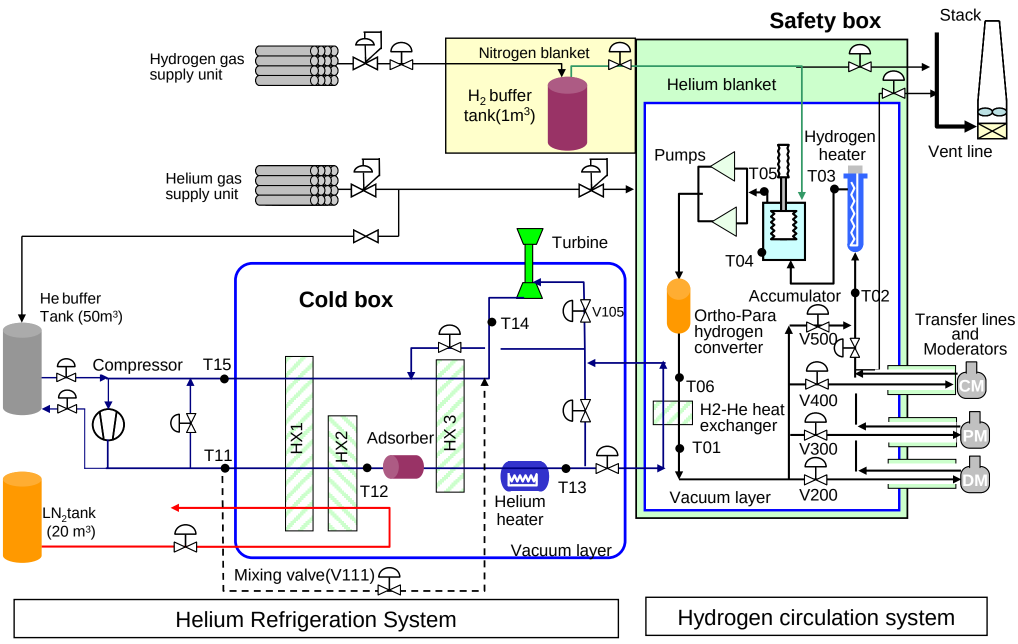


Fig.1 Overview of the cryogenic hydrogen system

neutrons through the hydrogen moderators without any problems in May 2008. This paper reports the results of the cryogenic test as off-beam commissioning, and on-beam commissioning after that.

2. Off-beam Commissioning

The off-beam commissioning, that is the cryogenic test of the whole cryogenic hydrogen system including the moderators, had been performed two times in April 2008. In order to verify the system soundness and installed sequence program, real hydrogen gas was used in the cryogenic test based on the test by used helium in January 2008. In the first operation, the normal stop of operation was tried in the warm-up process. And the emergency stop of operation was carried out in the second test.

2.1. Cool-down Process

Before the cool-down operation, it was filled with hydrogen 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 situation of a cool-down process is shown in Fig.2. The test operated the hydrogen pumps for the first time in the cryogenic hydrogen condition. At the ambient temperature, the hydrogen pumps circulated at the mass flow rate of 4.3 g/s for hydrogen.

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 temprtaure before entering the cold box to the turbine outlet stream.

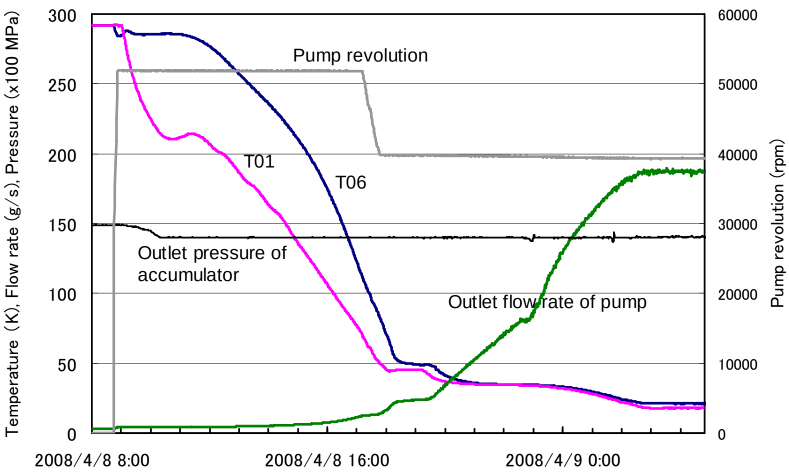


Fig.2 Situation of a cool-down process

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 Fig.1 were opened to be 100%, and the bypass valve of V500 was opened to be 5%. As hydrogen 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 40,000 rpm, because the mass flow rate increased drastically due to the increase of the density in low temperature. The bellows of the accumulator was maintained at the fully-extended location of 90.4 mm, because the helium supply valve to maintain the pressure in the bellows constant was not worked. 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 18.1 K to the moderators, return of 21.1 K, heater power of about 4,000 W and pump revolution of 39,400 rpm. The flow rate of supercritical hydrogen was achieved about 190 g/s at the pump outlet. It satisfied more than 162 g/s of the rated condition.

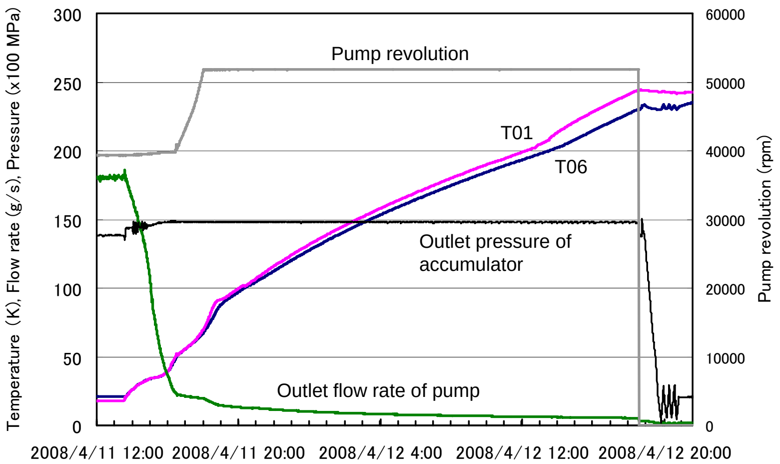
In the first test, it took about 19 hours to cool the system down 20 K from ambient temperature without any problem. The second test was shown the same situation in the cool-down process.

2.2. Rated Operation

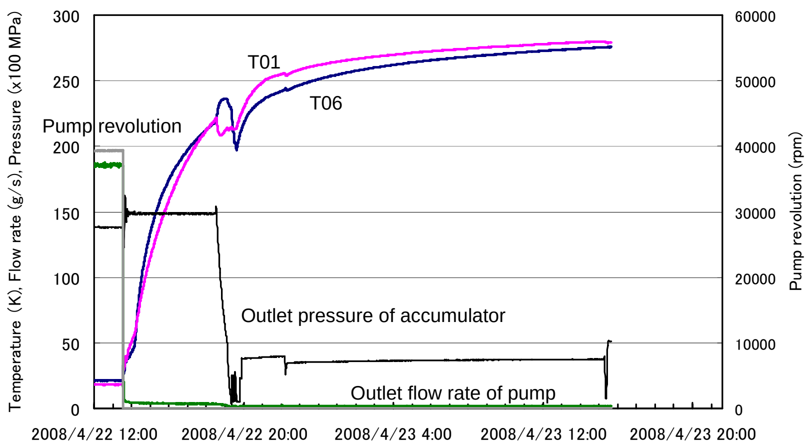
After the cool-down process, the cryogenic hydrogen system was maintained at the rated condition for about 2 days in the first test, for about 4 days in the second test. The cryogenic test could confirm a stable operation of the cryogenic hydrogen system at the rated condition. And then, we also confirmed that it could be operated by “stand-by mode” without any problem. The stand-by mode is economical operation without liquid nitrogen operation as pre-cooling in the cold box, during the accelerator interval periods. In the operation mode, helium temperature at the inlet of H_2-He heat exchanger is maintained about 18.6 K by the turbine capacity only. From the result, in the hydrogen loop, the outlet hydrogen temperature of the H_2-He heat exchanger is rise to 19.5 K.

2.3. Warm-up Process

The cryogenic hydrogen system has not a reserve tank according to our safety policy. Therefore, the system releases whole hydrogen using by the release line to the stuck of MLF building after the cryogenic operation. The warm-up operation is prepared two modes for the method of hydrogen release, which are normal stop and emergency stop. The normal stop is a regular release, and the emergency stop is an immediate release when a disaster happens. Fig.3 shows the situation of warm-up process for (a) normal stop and (b) emergency stop.



(a) Normal stop at first test



(b) Emergency stop at second test

Fig.3 Situation of warm-up processes

In the normal stop, the turbine of refrigerator is stopped at first. It is necessary to maintain supercritical conditions the hydrogen loop in order to prevent liquefaction of hydrogen. A setting value of the relief control valve changes to 1.7 MPa. We have to maintain the hydrogen concentration in the stack below the lower explosive limit of 4 %. Therefore, during warming up until 250 K, the increasing rate of the temperature is controlled by helium refrigerator. When the loop is warmed up to 250 K, all hydrogen is released down to around 0.1 MPa. And then, the loop is pursed by helium gas. It took about 32 hours to release all hydrogen gas and purse by helium in this test.

In the emergency stop, the turbine of refrigerator and the hydrogen pumps are stopped at first. And then, the vacuum layer is broken by nitrogen gas to a few Pa. However, a few Pa of nitrogen injection was too mach in this time, the pressure rise was very large. So, the injected nitrogen was re-estimated to 0.6 Pa and the sequence was changed from this result. It took about 10 minutes to release 80 % hydrogen, and it took about 6.5 hours release all hydrogen gas and purse by helium in the second test

Through the off-beam commissioning, these warm-up operations were confirmed that could be stopped the system operation safely.

2.4. Performance of the 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 Fig.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) [6]. The design conditions of the hydrogen circulation pump are shown in Table 1.

Table 1 Specification of the hydrogen pump

Mass flow rate	0.162 kg/s
Pump head	0.12 MPa
Adiabatic efficency	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	60,000 rpm max.

The performance of the hydrogen circulation pump was measured during the rated operation. The temperature at the inlet of the pump was 20.8 K, which was maintained by the hydrogen heater. The inlet 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 Fig.4. For each pump revolution, the pump head decreases with increase in the mass flow rate. With increase in the pump revolution, the mass flow rate becomes larger on condition of the constant pump head. The experimental results are in good agreement with a correlation of the flow coefficient and pressure coefficient. The maximum revolution of the pump was achieved 60,000 rpm of the specification and it was confirmed that the point is agree with the estimated chracteristics courve in Fig.5.

The centrifugal pump for cryogenic hydorgen was developed, and it was confirmed that the performance of the pump satisfied the required specifications. For the first time in

Japan, we could succeed in circulating the supercritical hydrogen with the largest flow rate of about 190 g/s.

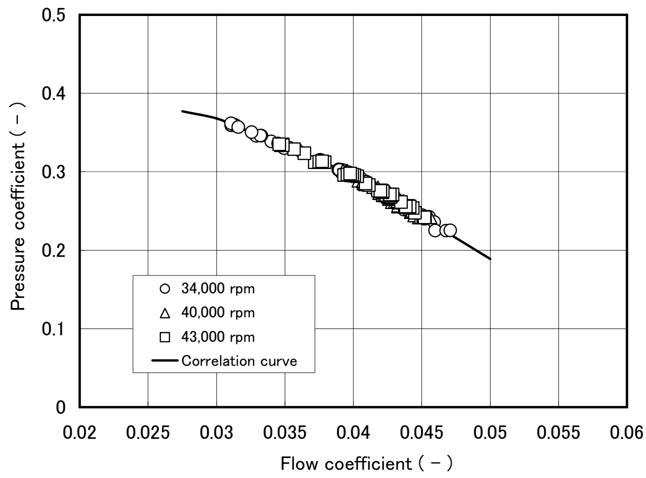


Fig.4 Non-dimensioned pump performance

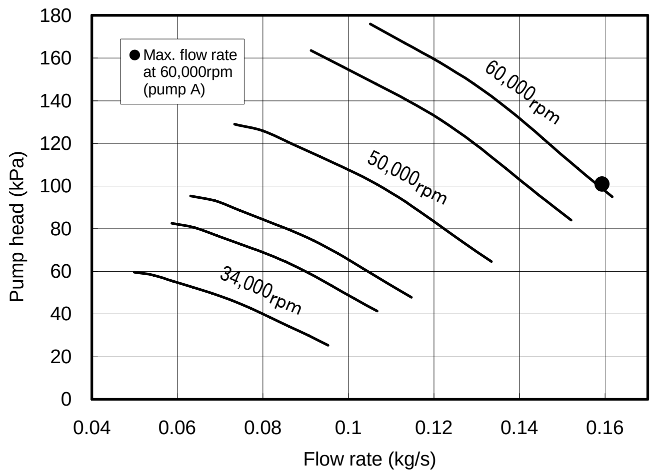


Fig.5 Characteristics curve for flow rate – pump head

3. On-beam Commissioning

From May 22 to June 2, the cryogenic system was operated for the Day-1 that was first beam reception to MLF target and first neutron beam generation at 14:25 May 30. It was achieved the rated operation of supercritical condition at May 29, and could be maintained this condition to May 30. We succeeded to cool the spallation neutron and send as cold neutron beam to neutron users of the lead of the beam line [7]. And then, the performance of the pressure control system had been confirmed as on-beam commissioning.

Performance of the Hybrid Pressure Control System

The cryogenic system has the hybrid pressure control system in order to suppress large pressure change caused by turn-on and off of the accelerator, which consists of the accumulator and the hydrogen heater. The hybrid means that the accumulator is for passive volume control by bellows and the heater is for active control to compensating heat load in the moderators.

From the first beam reception as Day-1, the beam power of accelerator had been injected at 4 kW, and had been operated at 20 kW from the autum 2008. These power was 0.4 % and 2 % for 1 MW of the future accelerator power. Therefore, the hydrogen temperature and pressure fluctuation had hardly appeared by the beam injection of 4 kW and 20 kW.

At last, the MLF target received proton beam power of 100 kW for the first time on December 9 2008, and received 300 kW on Desember 7 2009. We had confirmed the performance that the pressure fluctuation caused by 100 kW and 300 kW proton beam injection can be absorbed by the pressure control system [8].

Fig.6 shows the fluctuation by 100 and 300 kW proton beam injection. When it received 100 and 300 kW proton beam, the returen temperature from the moderator was rised 0.2 and 0.7 K, respectively. In the pressure control system, the hydrogen heater power was reduced for the injected heat load by a sequence program when the returen temperature from the moderator would be a setting value. It was a 380 W for 100 kW proton beam, and was a 1140 W for 300 kW one. And then, the pressure of the hydrogen loop is rised due to the temperarure rise in the piping from moderators to the heater, and the accumulator is performed by the pressure rise. The accumulator moved 1.1 mm and 3.4 mm in each case. The hydrogen supply temperature to moderators could be kept around 17.8 K stably. The pressure rise was within 5 kPa and 12 kPa for each beam power. It is expected that the pressure fluctuation at the 1MW beam injection can be controlled within 50 kPa. We had confirmed the effectiveness of the pressure control system.

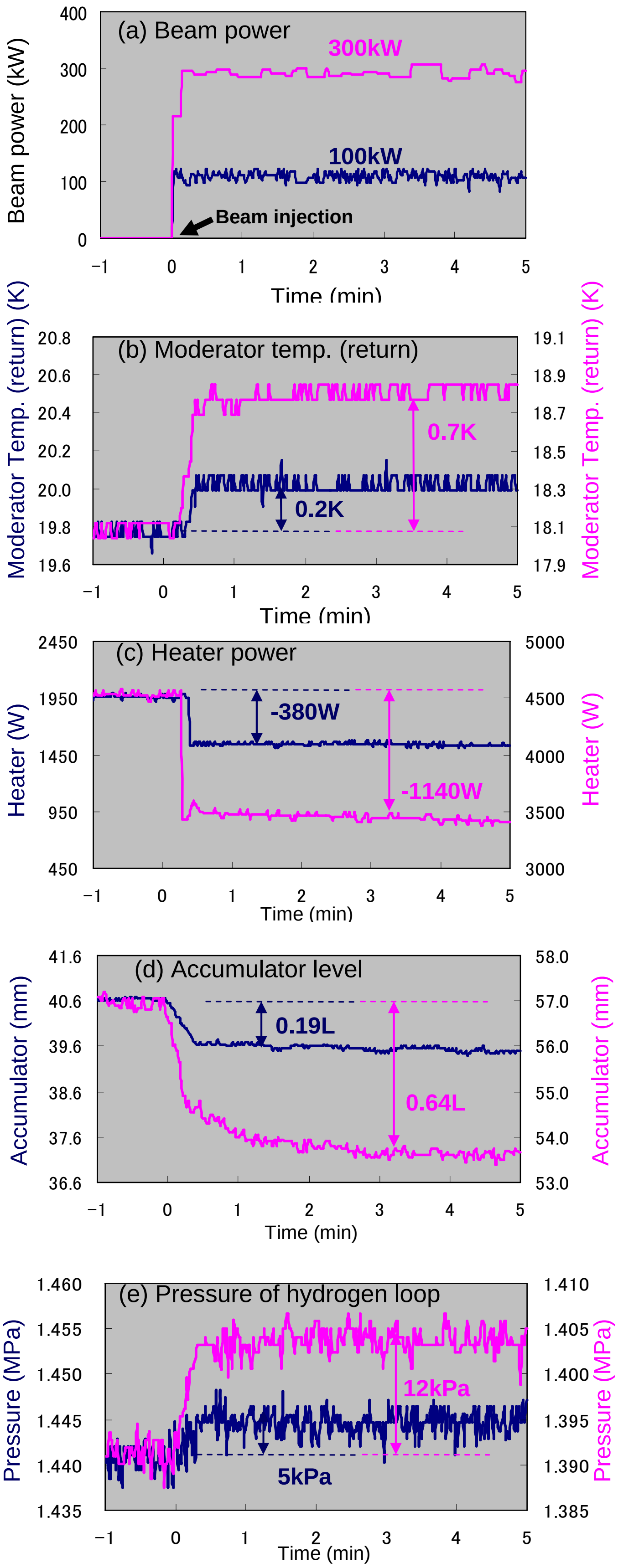


Fig.6 The fluctuation by 100 and 300 kW proton beam injection

4. Conclusions

The commissioning of the whole cryogenic hydrogen system was carried out using by hydrogen. The system soundness such as a cool-down process, warm-up process and the performance of a hydrogen circulation pump were confirmed at the off-beam commissioning. The hybrid pressure control system was worked well in the on-beam commissioning.

The cryogenic hydrogen system could be cooled down to 20 K within 19 hours, and could be maintained for about 4 days without any problem in the first test. In the warm-up process, the normal stop was taken 32 hours to release whole hydrogen, and the emergency stop was within 7 hours. Two pumps of the hydrogen circulation system were able to circulate at the mass flow rate of 190 g/s with the pump head of around 50 kPa. We confirmed the performance of a hydrogen circulation pump by the hydrogen operation.

We have succeeded in generating first neutrons in the mercury target and providing moderated neutrons through the hydrogen moderators without any problems in May 2008. The pressure fluctuation caused by a 100 and 300 kW proton beam injection can be absorbed by the developed pressure control system. We expected that the pressure fluctuation at the 1MW beam injection can be controlled as the design

5. References

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