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Cool-down test of HWR cryomodule for RAON

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Abstract

The heavy ion accelerator that will be built in Daejeon utilizes four types of superconducting cavities. Cryomodules holding the superconducting cavities in them supply thermal insulation for cavities operating in 4.3 K or 2.1 K. A Prototype of cryomodule which holds two HWR (Half Wave Resonator) cavities was fabricated and tested. Since the operating temperature of the HWR is 2.1 K, the superfluid helium was generated with warm vacuum pumping system. The cyromodule was successfully cooled down below lambda point temperature of helium and any detectable leak was not observed during the test. The static thermal load at 4.2 K was measured. The result and the experience for the cool-down below lambda point of helium are reported in this paper.

Keywords: cryomodule, thermal insulation, boil-off calorimetry

1. INTRODUCTION

The heavy ion accelerator called RAON to produce rare isotope beams has been designed. The complex consists of a heavy ion linear accelerator as the driver, called as Driver Linac, for the IF(In-flight Fragmentation) system, a proton cyclotron as the driver for the ISOL(Isotope Separation On-Line) system and a post-accelerator for the ISOL system as shown in Fig. 1. The driver linac is divided into three different sections such as SCL1, SCL2, and SCL3. SCL1 and SCL3 has same configuration. The driver linac utilizes four types of superconducting cavities made of Niobium (Nb). The QWR (Quarter wave resonator, β=0.047) and HWR (Half wave resonator, β=0.21) are installed in SCL1 and SCL3, and SSR1 (Single Spoke Resonator, β=0.3) and SSR2 (β=0.51) are installed in SCL2 in order to accelerate the ion beams. QWR cavity operates in 4.3 K but the others operates in 2.1 K.

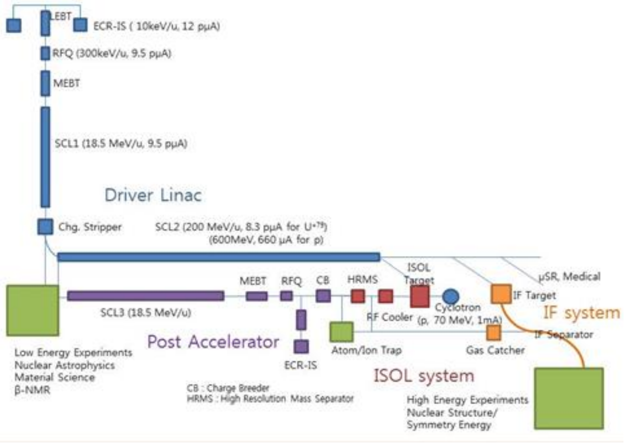

Fig. 1. Schematic layout of the heavy ion accelerator.

Those cavities are installed in the dedicated cryomodules that supply thermal insulation and alignment to the cavities. Five types of the cryomodule are necessary for the four types of the cavities since there are two kinds of cryomodule for the HWR cavities. One holds two cavities in it while the other holds four cavities in it.

Currently, some components of the driver linac such as superconducting cavities, cryomodules, and so on have been prototyped and tested. The prototype of the cryomodule holding HWR cavities is fabricated and tested. The cool-down, static load measurement at 4.2 K and 2 K pump-down results are reported in this paper.

2. HWR CRYOMODULE

The HWR cryomdoule which holds two cavities is fabricated by the domestic companies, Vitzro tech and CVE. Two HWR cavities, couplers and tuners are the main components of the cryomodule as shown in Fig. 2. The coupler supplies RF power to the cavity and the tuner controls the resonant frequency of the cavity by squeezing and releasing the beam port of the cavity. However, the cavities, couplers and tuners installed in the prototype cryomdoule are mock-ups made of stainless steel since they are currently under developing and testing. The cavities are fixed on the strong-back and suspended by the vertical and horizontal support rods.

The thermal shield is cooled by 40 K gaseous helium suppled from the helium refrigeration system. To reduce the conduction thermal load, the 40 K thermal intercepts are connected with the thermal shield with copper braided wire. 4.5 K supercritical helium whose pressure is approximately 3 bar is supplied from the cryogenic plant and expands through the first JT (Joule-Thomson) valve to produce liquid helium. Then, the liquid helium stored in the

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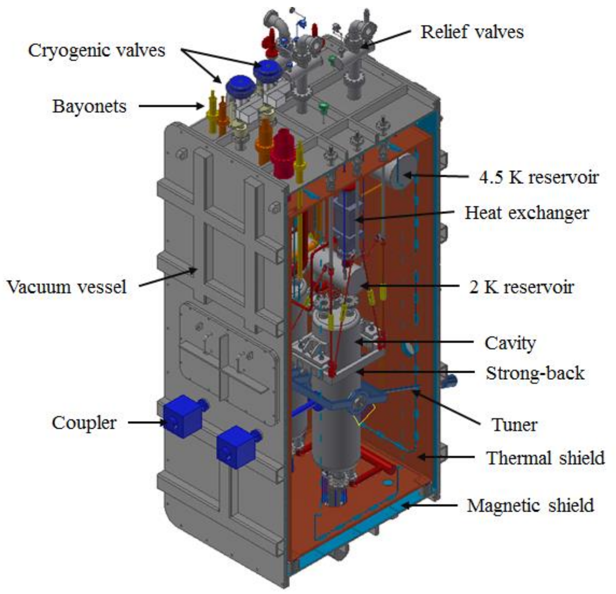


Fig. 2. 3D section view of the HWR cryomodule.

4.5 K reservoir flows into the heat exchanger. The temperature of the liquid helium goes down by exchanging heat with evaporated gaseous helium from the 2 K reservoir. Pre-cooled liquid helium expands again through the second JT valve and flows into the 2 K reservoir whose internal pressure is maintained at 4.1 kPa. The liquid in the 4.5 K reservoir is also utilized to cool the 4.5 K thermal intercepts by the loop thermosiphon as shown in Fig. 3.

The cryomodule and transfer line are connected by the bayonets for independent replacement of cryomodule while other cryomdoules stays cold. The bayonets for 40 K helium supply and return, 4.5 K helium supply and return and low pressure return are installed on the top of the vacuum vessel. Each reservoir has own safety system [1], that is the relief valve and the rupture disk installed in parallel. The cavities and the vacuum vessel are evacuated by the separate vacuum pumping systems.

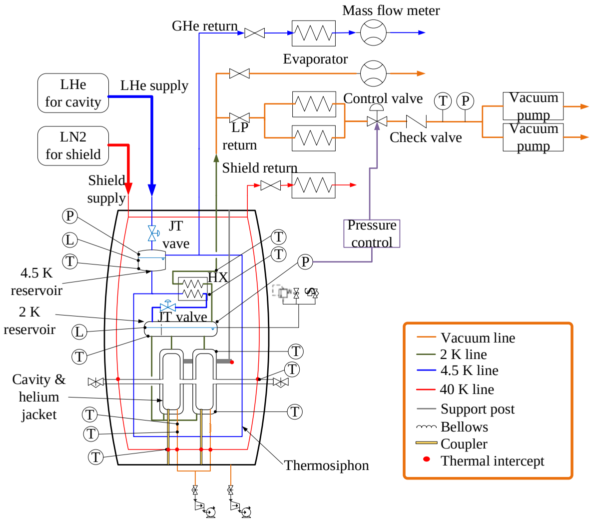


Fig. 3. Schematic diagram of experimental apparatus.

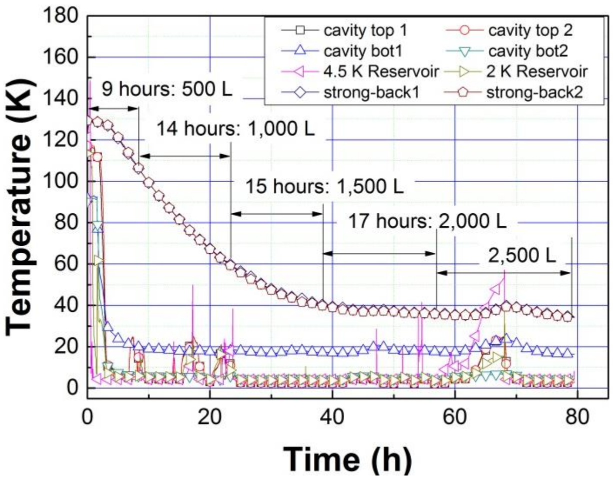


Fig. 4. Cool-down history of the HWR cryomodule.

3. PERFORMACE TEST

3.1. Experimental setup and cool-down

The objectives of the performance test were to measure the static thermal load of the cryomodule and to verify the leak tightness of the connections in the cryomodule when the superfluid existed in the helium jacket and 2 K reservoir.

Thermal shield was cooled by the liquid nitrogen and cavity was cooled by the liquid helium supplied from a portable liquid helium dewar as shown in Fig. 3. Vacuum pumps were located at the LP (low pressure) return line in order to pump down the helium jacket and 2 K reservoir. The control valve varied its opening according to the pressure of the 2 K reservoir in order to maintain the constant pressure.

Temperatures were measured by the Cernox sensors (Lakeshore) on the subcomponents such as top and bottom of the cavities, bottom of each reservoir, thermal intercepts, strong-back, and so on in order to verify the conduction thermal load. Pressure and liquid level were measured in both reservoirs.

The cool-down and liquid helium consumption history is shown in Fig. 4. Before cooling down the cryomodule with liquid helium, the cryomodule was pre-cooled with the liquid nitrogen to save the helium consumption. It is possible to pre-cool with liquid nitrogen since the dummy cavity was installed in the cryomodule. It is not necessary to consider the Q-disease that the performance degradation of the niobium cavity due to slow cool-down [2]. It took approximately 5 hours for the cavities to reach 4.2 K. However, it took very long time for the strong-back to be sufficiently cooled down. The strong-back is a heavy structure that the cavities fixed on it to maintain their alignment. It was mechanically contacted with the cavities by the several numbers of stainless steel bolts but their thermal contact was very poor. The final temperature of the strong-back was 35 K after 80 hours cool-down and it was still decreasing.

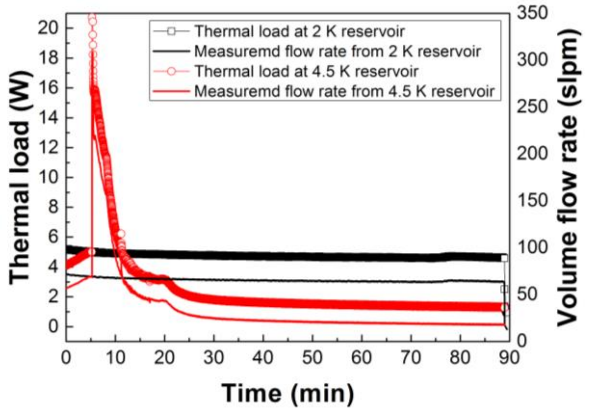


Fig. 5. Result of the static load measurement.

3.2. Static thermal load measurement

The static thermal load of the cryomodule was measured by the boil-off calorimetry at 4.2 K. The mass flow meters were installed at the GHe return and LP return line during the static load measurement at 4.2 K. The static thermal load can be calculated with the measured mass flow rate as an equation (1) [3].

$$q = \dot{m}\left(\frac{\rho_l}{\rho_l - \rho_g}\right)\cdot h_{fg} \qquad (1)$$

where q is heat ingress, $\dot{m}$ is the mass flow rate of the gas from the reservoir, ρ_l and ρ_g are the saturated density of the liquid and gas respectively under the internal pressure of reservoir, and h_{fg} is the latent heat of the liquid helium. Measured and estimated thermal load are compared in TABLE I. The estimation method is explained in [1]. The measured thermal load at 2 K part is larger than estimated value while that at 4 K part is much smaller than estimation. The equivalent thermal load [4] calculated with equation (2) of the prototype is also larger than that of estimation.

TABLE I
THERMAL LOAD COMPARISON OF THE HWR CRYOMODULE

	4 K part	2 K part	4.5 K equivalent
Measured (W)	1.7	4.7	15.8
Estimated (W)	8.0	2.3	14.7

$$q_{4.5K\,eq} = 3q_{2K} + q_{4.5K} + 0.1q_{40K} \qquad (2)$$

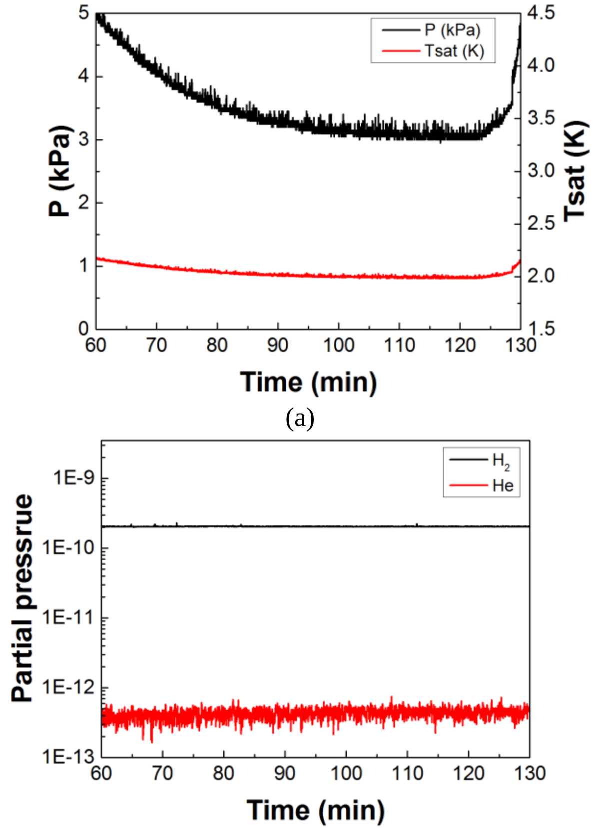
where $q_{4.5Keq}$ is the 4.5 K equivalent thermal load at 4.5 K, and q_{2K} , $q_{4.5K}$, q_{40K} are the thermal load at 2 K, 4.5 K, and 40 K, respectively.

The main reasons of the larger thermal load at 2 K part are insufficient thermal intercept and high temperature of strong-back. The 4.5 K thermal intercepts of cavity vacuum port, warm-to-cold transition beam pipes, dummy couplers were not installed during fabrication. The thermal load calculated with the measured temperature was approximately 1.0 W. By adding 4.5 K thermal intercepts, the conduction thermal load at 2 K part will decrease to less than 0.1 W. The thermal load due to the strong-back can be inferred from the temperature decreasing tendency of it shown in Fig. 4. The mass and the specific heat of the strong-back are approximately 40 kg and 58 J/kg-K at 35 K. The heat ingress from the strong-back, the same amount with the strong-back's internal energy from 40 K to 35 K, can be estimated approximately 0.4 W.

3.3. 2 K pump-down

The mass flow meter which installed outlet of the LP return line was replaced with the vacuum pump and pressure control system for the 2 K pump-down.

When the liquid levels of both reservoirs were higher than 90 %, the vacuum pump was turned on. During the pump-down, it was tried to maintain the liquid level over 50 % in the 2 K reservoir in order to measure the static load by liquid level change. However, the final liquid level of 2 K reservoir was less than 30 % when internal pressure reached 3.0 kPa. The internal pressure of 2 K reservoir during the pump-down operation is shown in Fig. 6 (a). The lowest pressure was 3.0 kPa and the saturation temperature was 1.93 K ~ 2.04 K considering the accuracy of the pressure sensor (±0.5 kPa). Since the λ-point pressure of



(a)

(b)

Fig. 6. (a) Measured internal pressure and calculated saturation temperature in the 2 K reservoir and (b) partial pressure measurement result in the vacuum vessel during the pump-down process.

the helium is 5.04 kPa, it is obvious that the superfluid was produced in the 2 K reservoir and helium jacket. The superfluid was maintained for more than an hour in the cryomodule. The residual gas in the vacuum vessel was monitored with the RGA (Residual Gas Analyzer) and the partial pressure of the hydrogen and helium are shown in Fig. 6 (b). It is concluded that the leak due to the superfluid was not detected during the operation. However, it was failed to maintain the constant pressure of 4.1 kPa in the 2 K reservoir due to poor performance of the pressure control system such as bad resolution of pressure transducer, slow response of the control valve and so on.

4. CONSLUSION

The prototype of the cryomodule which holds two HWR superconducting cavities was fabricated and tested. The super-leak was not observed during the pump-down below lambda point of the helium, but the static thermal load measured at 4.2 K was little bit larger than estimation.

The internal cooling scheme of the cryomodule will be changed as shown in Fig. 7 in order to improve the thermal performance. It is compared with the P&ID shown in Fig. 3. The 4 K reservoir will be installed in horizontal. The thermosiphons are separated to reduce the distance from the thermal intercepts. The strong-back cooling line will be added. After the 4.5 K supercritical helium cools the strong-back, it expands and produces liquid helium in the 4 K reservoir.

The thermal load at 2.1 K was not measured since the pumping capacity of the warm vacuum pump and the poor conductance of the evaporator. The 2 K pump-down system that has enough cooling capacity has been prepared by the cryogenic group of RISP. It also has 10 kW heater that can replace the evaporators in order to minimize the pressure drop of the pumping line. Currently, the modification of the cooling scheme and the 2 K pumping system is almost done. The experiment will be conducted with improved cryomodule and the pumping system in near future.

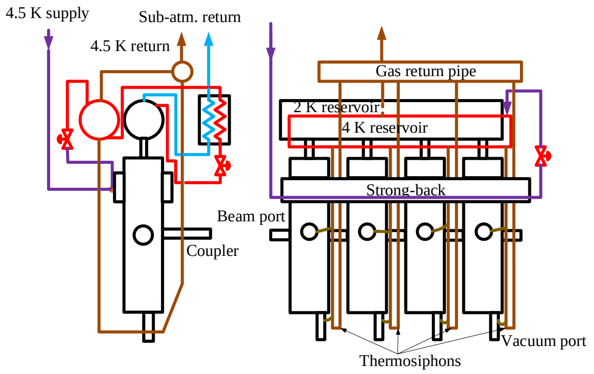


Fig. 7. Schematic of modified cooling scheme of the cryomodule.

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