CRYOGENIC PERFORMANCE OF THE PROTOTYPE CRYOMODULE FOR ADS SUPERCONDUCTING LINAC

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Abstract

Under the collaborative program between Japan Atomic Energy Research Institute (JAERI) and High Energy Accelerator Research Organization (KEK), a prototype cryomodule containing two 9-cell superconducting cavities has being constructed for the superconducting LINAC to be used in the Accelerator Driven System (ADS). The first cool down of this prototype was performed from room temperature to 2.05 K and the thermal performance was measured. This paper describes the thermal design of the cryomodule and the test results.

INTRODUCTION

JAERI and KEK are constructing the J-PARC (Japan Proton Accelerator Research Complex) [1] under the joint project from 2001. As the first phase of this project, two institutes will have completed a 181 MeV linac, a 3 GeV rapid cycling synchrotron and a 50 GeV synchrotron in 2006. In the second phase, a superconducting linac will be constructed for the nuclear waste transmutation system (ADS) [2] so that proton beam will be accelerated to the energy of 600 MeV. For this superconducting linac, the R&D studies on the superconducting cavity, the cryomodule and the cryogenic system started from 2002 in collaboration between KEK and JAREI. A prototype cryomodule and cryogenic equipments have been constructed, and the first cool down test of the system [3] was performed in June/2004. In this test, the temperature profile of the system during the cool down and thermal load at 4.2 K were measured. The measured thermal loads are compared with the design in this paper.

THERMAL DESIGN OF CRYOMODULE

The prototype cryomodule is shown in Figure 1. The cryomodule mainly consists of two nine-cell niobium cavities with helium vessels, input couplers, a liquid helium reservoir tank, two control valves and a vacuum vessel. The cavities were designed to operate at 2 K. The design values of heat load are listed in Table 1, and the total heat load to liquid helium at 2 K was estimated to be 4.80 W. In order to reduce the heat load from the input couplers and the frequency tuning system, they are thermal-anchored by helium gas less than 5 K and liquid nitrogen. One of two valves is used for JT expansion to get superfluid helium at 2 K in the reservoir tank and the other is used for cool down. For measuring temperature profile in the cryomodule, 21 thermocouple thermometers and 16 resistance temperature sensors are installed.

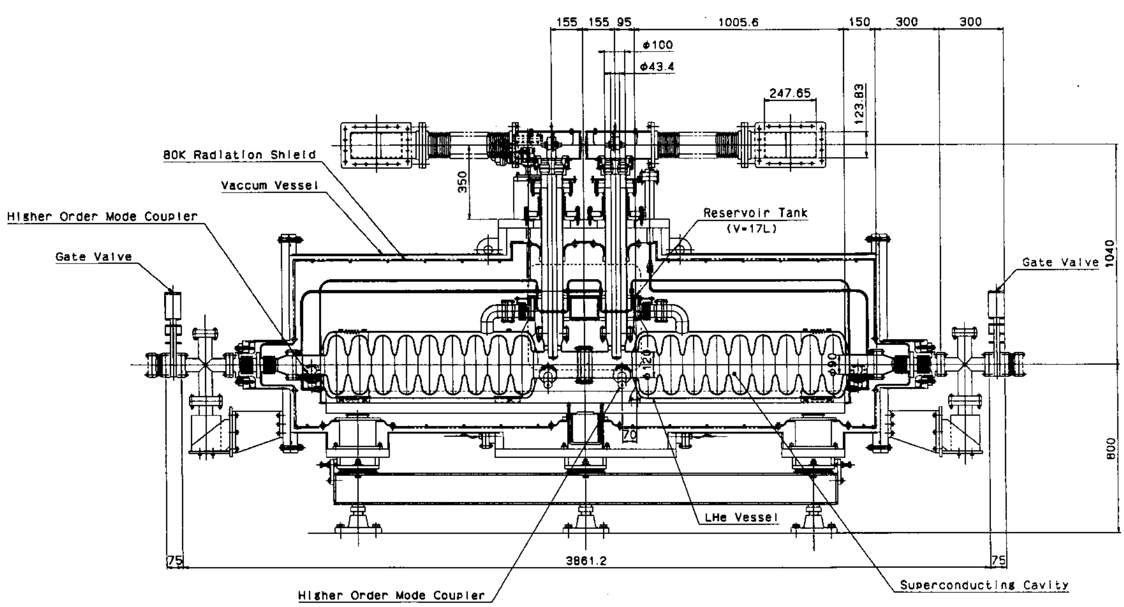

Figure 1: Prototype of cryomodule.

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Table 1: Design values of static heat load.

Helium at 2 K	W
Frequency tuning system	0.2
Cavity supports	0.6
Signal wires	2.4
JT-Valve and bayonet	0.7
etc. (conduction)	0.4
Thermal radiation	0.5
Total	4.8
Helium < 5 K for thermal anchor	15.5
Liquid nitrogen for anchor and shield	64.2

COOLING SYSTEM

Figure 2 shows a flow diagram of the cooling system. The system consists of a valve box including a heat exchanger, a connection box, a pump and the cryomodule. In the connection box, two 1000 L liquid helium containers and a 200 L liquid nitrogen container are connected to the cooling channels. For cooling two cavities, liquid helium from these containers is transferred. Two control valves are installed in the liquid helium lines in this box and they are used for exchange of these containers. The evaporated helium gas is returned to a gasbag, and the helium gas is recompressed by the recovery system at the rate of 60 Nm^3/h. The pump for reducing the pressure of liquid helium in the cryomodule has a capacity of 1900 m^3/h at 30 Pa. Figures 3 and 4 show the set-up of the cryomodule, the valve box, the connection box and the liquid helium containers.

The heat exchanger in the valve box pre-cools the liquid helium at the saturated pressure with the evaporated helium gas from the cryomodule. This heat exchanger is designed so that the incoming liquid helium at 4.45 K and 125kPa is cooled to the temperature of 2.91 K with the helium gas at 2.73K and 3.12 kPa from the cryomodule. The mass flow rate of helium is 0.975 g/s for this design. The temperature of helium gas at 3.12 kPa is increased to 3.82 K at the outlet of the heat exchanger. The heat loads of this system in design are listed in Table 2.

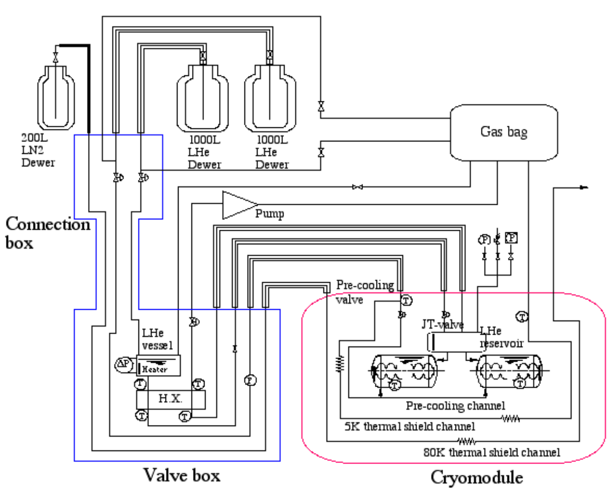

Figure 2: Flow diagram of cooling system.

Figure 3: Valve box and cryomodule.

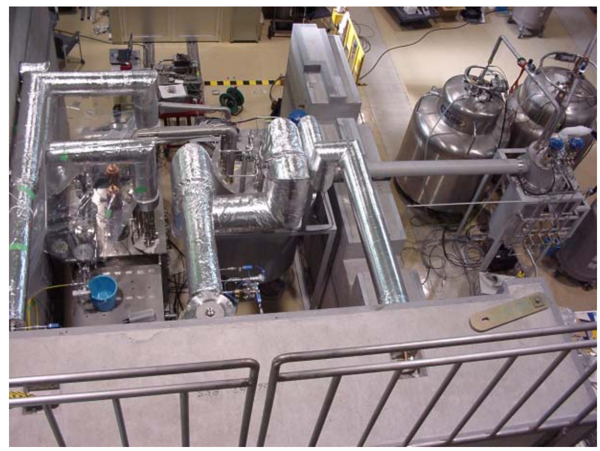

Figure 4: Two 1000 L liquid helium containers, connection box (right side), valve box and cryomodule.

Table 2: Design values of heat loads of the system.

Cryomodule at 2K	
including dynamic load	15 W
Two helium transfer lines	
bet. H.E. and cryomodule	8 W
5K helium lines	
for thermal anchors	30 W

COOLDOWN TEST

Figure 5 shows the cooling conditions of the cryomodule. The liquid nitrogen began to flow at zero on the time axis, and temperatures of the frequency tuning system (shown as tuners in Fig. 5) decreased with a quick thermal response. For cooling the two cavities, liquid helium was transferred through the pre-cooling lines from the 1000 L container. The liquid helium was divided into the 5 K helium channel before the pre-cooling valve. The liquid helium through the pre-cooling valve cooled two cavities in parallel without any temperature difference. The cold mass of the cavities with helium vessel and the helium reservoir was 33 kg of stainless steel, 100 kg of titanium and 117 kg of niobium. For cooling this cold mass from 290 K to 7.5 K, the liquid helium of 430 L was used with 9 hours. The helium gas after cooling the cavities was returned to the valve box and cooled the heat exchanger.

The cavities were successfully cooled down to 2.05 K by reducing the pressure of liquid helium with the pump. However, this condition was attained without the heat exchanger and the JT valve, and the further study on the heat exchanger have to be done to handle the cryogenic system well.

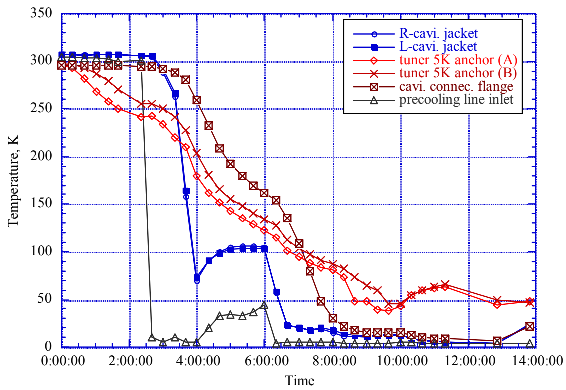

Figure 5: Temperature changes of two cavities. The temperatures of the right and left cavities are represented by the symbols of plus and closed square, respectively.

HEAT LOAD MEASUREMENT

The heat load of the cryomodule was measured by the evaporation rate of the saturated liquid helium at 4.2 K in the reservoir tank. The measurements were performed 9 times. In Fig. 6, the measured heat loads are shown with the temperatures of the frequency tuning system, the alignment stage of the cavity and the connection flange of two cavities. As the result, it was found that the cooling time over 50 hours was required so that the heat load became stable and the change of heat load with time was due to the cooling process of the alignment stage which had a function of support. The heat load as the typical value was 11.3 W, compared with the design value of 4.8 W for the 2 K helium. The measured heat load was over the twice as much as the expected value.

From the temperature profile at the measurement of 11.3 W, the heat load for individual part was calculated and listed in Table 3. The total heat load was 10.4 W and this value is almost consistent with the value by the helium evaporation. The main sources of heat load were heat conductions through the frequency tuning system and the cavity alignment stage.

As shown in Fig. 6, the temperatures of the frequency tuning system did not decrease below 34 K while this system was expected to cool down to 15.6 K and 6.4 K for the inner and outer shafts, respectively. Since the helium temperatures at the inlet and outlet of the cooling channel for 5K thermal anchors were 4.31 K and 5.85 K, respectively, it is considered that the heat transfer to helium gas at these shafts was insufficient. For reduction of heat load through the tuning system, the heat transfer area of helium gas at the 5 K anchors should be enlarged.

The temperature of the alignment stage was 41 K, compared with the design temperature of 7.4 K, which was calculated for the helium vessel of 2 K. Presently, this large temperature difference between calculation and measurement can not be explained, however, we should make a precise thermal model with FEM to understand this problem.

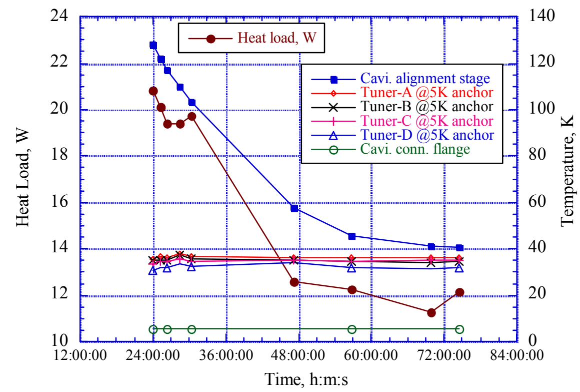

Figure 6: Measured heat load and temperature changes with time.

Table 3: Heat loads from measured temperature profile.

Frequency tuning system	2.9 W
Cavity alignment stage	4.1 W
Signal wires	1.7 W
Valves and bayonet	1.0 W
etc. (conduction)	0.1 W
Thermal radiation	0.5 W
Total	10.4 W

SUMMARY

The prototype cryomodule for ADS superconducting linac has been constructed under the collaborative program between JAERI and KEK. The first cool down test was performed, and thermal characteristics of the cryomodule and the cryogenic system were measured. The cavities were successfully cooled down to 2.05 K, however, the heat load to the liquid helium was over twice of design value. To understand this system precisely, the further study should be performed.

ACKNOWLEDGEMENTS

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