Cool-down by Compact Refrigerators System for SRF Cavities in JAERI FEL

Nobuhiro KIKUZAWA, Ryoji NAGAI, Masaru SAWAMURA, Nobuyuki NISHIMORI and Eisuke MINEHARA
Free Electron Laser Laboratory, Japan Atomic Energy Research Institute,
Tokai-mura, Naka-gun, Ibaraki, 319-11 JAPAN

Abstract

We have developed a built-in cryogenic system using compact refrigerators for the JAERI FEL superconducting accelerator modules. The cryogenic system consists of a refrigerator operated at 4.2 K to keep liquid helium level and a Gifford-McMahon cycle refrigerator to cool duplex heat shields. By applying the compact refrigerators, the cryogenic system can be operated successfully without an operator of the cryogenic system.

A Cool-down of the JAERI superconducting accelerating cavities by the compact refrigerators system was carried out without liquid N_2 or cold helium gas. The cool-down will be reported and discussed in detail.

1. Introduction

The JAERI FEL driven by a superconducting rf linac has been developed to demonstrate a high average power and long pulse far-infrared FEL. By applying the superconducting rf linac, long pulse or quasi-cw and high average power may be readily attained at the JAERI FEL. The superconducting rf linac consists of two pre-accelerator modules of single-cell cavity and two main accelerator modules of five-cell cavity. The resonant frequency of the cavities is 499.8 MHz and design values of the accelerating field strength and Q-value for the cavities are 5 MV/m, and $2x10^9$, respectively.

We have developed a built-in cryogenic system using compact closed-cycle helium gas refrigerators for the superconducting accelerator modules[1]. The cryogenic system design goal was to realize low cost and easy operation. The cryogenic system consists of a 4K refrigerator (Sumitomo SRJ-2008) and 20K/80K shield refrigerator (Sumitomo SRD-220). The 4K refrigerator has the disadvantage of limitation of cooling power, but has advantages of compact size and easy operation. The 4K refrigerator is adopted to re-condense evaporated helium gas inside the liquid helium container and to maintain liquid helium. The shield refrigerator that is a two stage Gifford-McMahon cycle refrigerator cools duplex heat shields directly by heat conduction without liquid N_2 or cold helium gas.

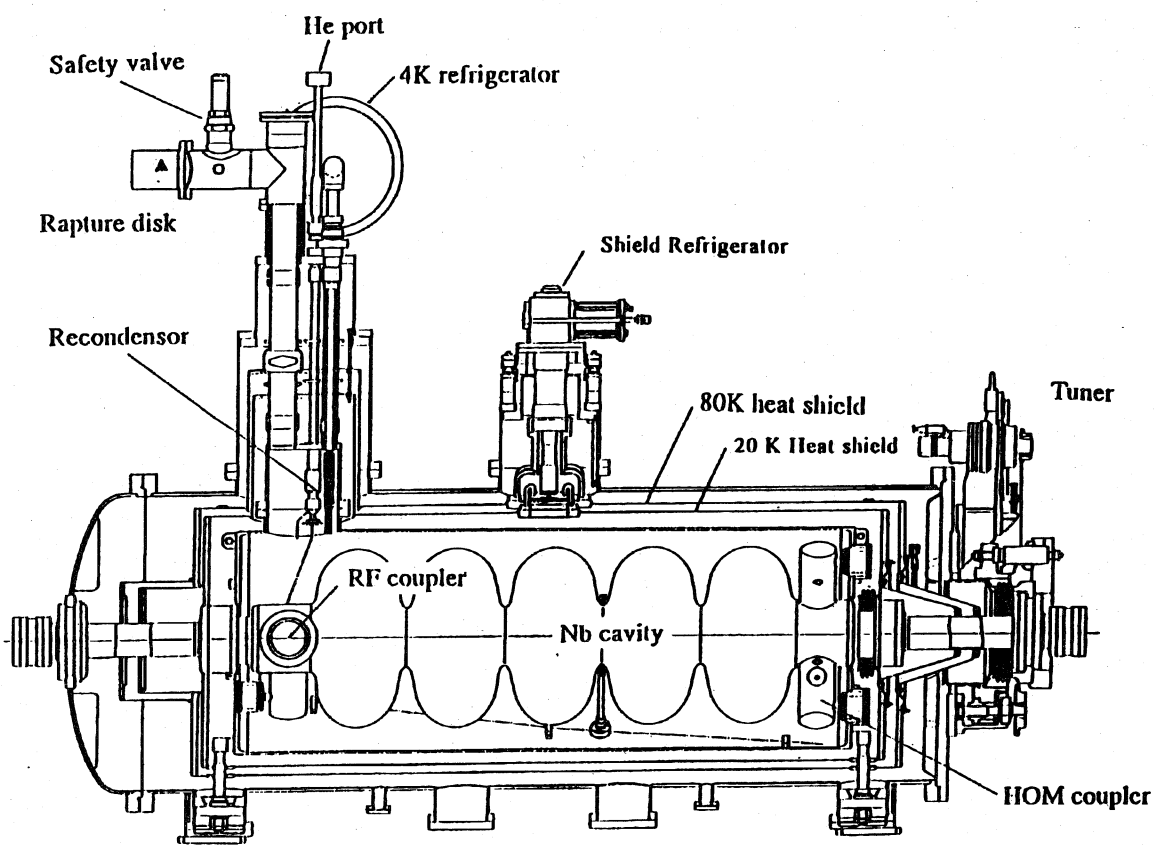

Figure 1. Cross sectional view of the main accelerator module.

2. Cryostat Design

Figure 1 shows a cross sectional view of a cryostat for the main accelerator module. The 4K refrigerator consists of a refrigerator unit, compressor unit and gas helium line. The refrigerator unit is supported by a supporting frame over the accelerator module. A heat exchanger of the refrigerator unit is directly inserted in the liquid helium container and re-condenses evaporated helium gas inside. Therefore a transport system for liquid helium is not required in the JAERI FEL. Cooling power of the 4K refrigerator is 11.5 watts at 4.3 K.

The shield refrigerator is attached to the accelerator module and fixed with the supporting frame in order to isolate vibration of the shield refrigerator. The shield refrigerator cools duplex thermal radiation shields and thermal anchors placed in the cryostat to reduce static heat loads[2]. The heat shields are made from 3 mm thick copper sheet connected with cold heads of the shield refrigerator and cooled directly without liquid N_2. Cooling capacities of the shield refrigerator are 20 watts at 20 K and 120 watts at 80 K.

Static heat load of the cryostat is about 3.5 watts and the rf loss of the main accelerator module is for example 1.5 watts at Eacc=5MV/m and 3% duty pulse mode operation, so the total refrigeration power of about 5 watts is required[3]. The 4K refrigerator has enough cooling power for the main accelerator module.

For stable operation of the cryogenic system especially for pressure sensitive superconducting cavities, it is necessary to keep the pressure constant in the liquid helium container. A heater that fixed on the bottom of the liquid helium container is used to compensate fluctuation of heat load. By the compensation, fluctuation of the pressure in the liquid helium container could be reduced less than 2 hPa during operation of the JAERI FEL[4].

3. Cool-down

Cool-down from room temperature to 4 K was carried out by the 4 K refrigerator and shield refrigerator without liquid N_2 or cold helium gas. Before the cool-down, air in the liquid helium container was pumped out and helium gas was re-filled from helium gas bottles. The heat shields were cooled down by the shield refrigerator by heat conduction and the helium gas was cooled down by the 4 K refrigerator and heat convection and radiation cooling by the inner heat shield.

Cool-down curve of the temperatures measured on the heat shields and liquid helium vessel are shown in fig. 2. It took about 7 days for pre-cooling to transfer liquid helium from dewars. Liquid helium was required approximately 160 liters for the pre-accelerator module and about 480 liters for the main accelerator module in this process. We have tried to use liquid N_2 for pre-cooling to shorten the cooling time.

Temperatures of the cold heads of the shield refrigerator were measured in pre-accelerator module #1. The temperatures were about 42 K (first stage) and 10 K (second stage). Static heat loads for the cold heads estimated by the temperatures and cooling power diagram were about 42 watts (first stage) and 6 watts (second stage).

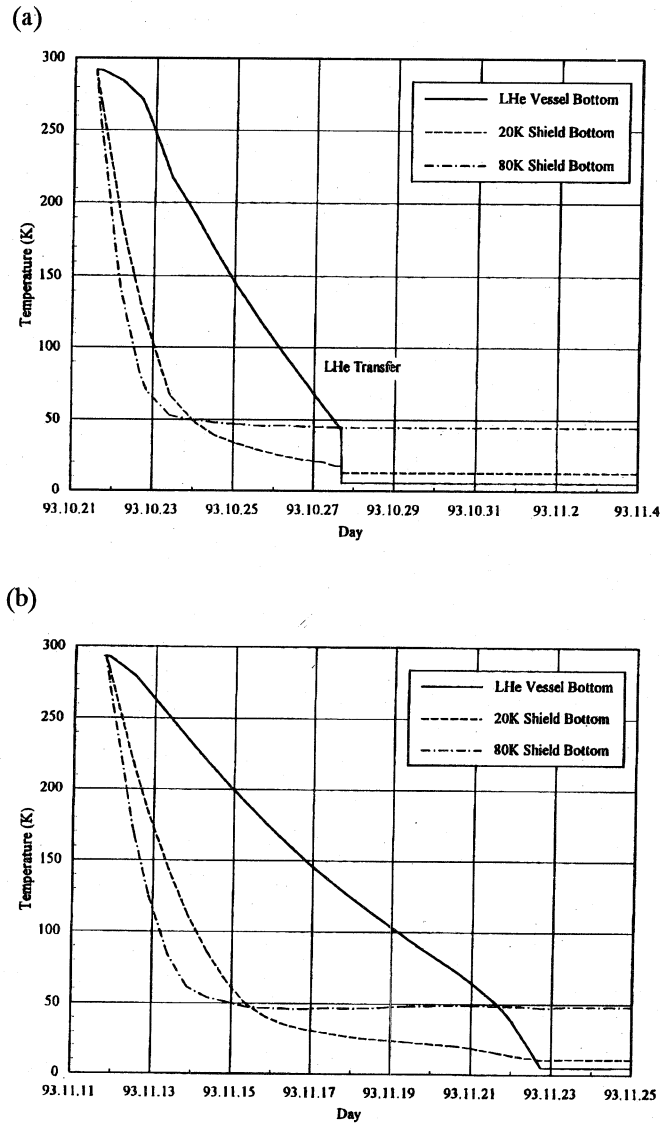

Figure 2. Cool-down curves of the accelerator modules: (a) pre-accelerator module #2 and (b) main accelerator module #1.

4. Operation

The refrigerators system has been operated routinely without a specialist for the cryogenics through the year. The refrigerator should be overhauled once a year and time spent for the overhaul is about a week. When the malfunction of the 4K refrigerator occurs, the refrigerator and compressor units of the 4K refrigerator are replaced by spare units. It usually takes about four hours to exchange and to adjust the 4K refrigerator and liquid helium evaporates about 20 liters during the recovery. By

modifications of the 4K refrigerator, troubles could be reduced to a few times a year[5].

Current of the heater fixed on the bottom of the liquid helium container is controlled by a PID loop to keep the pressure constant. We can determine surplus cooling capacity of the 4K refrigerator by the heater power. In order to get enough cooling capacity of the 4K refrigerator, a Joule-Thomson (J-T) valve of the 4K refrigerator should be adjusted manually so to increase the cooling power, that is, to increase the heater power. After the adjustment, the maximum surplus cooling capacity of the 4K refrigerator is about 6 watts at 4.2 K.

5. Summary

The compact refrigerators system for the accelerator modules has been driven successfully without a specialist about cryogenics. By modifications of the 4K refrigerator, troubles could be reduced to a few times a year. The refrigerators are halted only during failures of electricity or water supply.

The refrigerators were used for cooling the superconducting cavities without liquid N_2 or cold helium gas. It has proved that it took about 7 days for cool-down by this manner. We have been tried to use liquid N_2 for pre-cooling to shorten the cooling time.

References

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