PERFORMANCE OF COMPACT REFRIGERATORS SYSTEM FOR SRF CAVITIES IN JAERI FEL

Nobuhiro KIKUZAWA, Ryoji NAGAI, Masaru SAWAMURA,
Nobuyuki NISHIMORI, Eisuke MINEHARA and Yasuo SUZUKI
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 compact closed-cycle helium refrigerator operated at 4.2 K to keep liquid helium level constant and a Gifford-McMahon cycle refrigerator to cool duplex heat shields. By applying the compact refrigerators, the cryogenic system can be operated for long, continuous periods 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 nitrogen or cold helium gas. Performance of the cryogenic system 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 a single-cell cavity and two main accelerator modules of a five-cell cavity. Figure 1 shows the layout of the JAERI FEL. 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 2×10^9, respectively.

Design goal of a cryogenic system for the superconducting rf linac was to realize low cost and easy operation. Therefore, we have developed a built-in cryogenic system using compact closed-cycle helium gas refrigerators for the superconducting accelerator module [1], because the compact refrigerators have been available commercially for many years. Each cryomodule has the cryogenic system independently and is individually powered. The cryogenic system consists of a 4K refrigerator (Sumitomo SRJ-2008) and 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 recondense 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 nitrogen or cold helium gas. The temperatures of the stages vary with the applied heat loads in the range of 40 K to 80 K for the first-stage and in the range of 10 K to 20 K for the second-stage.

2. Cryostat Design

Figure 2 shows a cross sectional view of a cryostat for the main accelerator module. Liquid helium of 400 liters is stored in the main accelerator module and that of 100 liters in the pre-accelerator module.

The 4K refrigerator consists of a refrigerator unit, compressor unit and interconnecting pipes for compressed helium gas. The refrigerator unit supported by a supporting frame over the accelerator module provides its helium mist coolant to a recondenser. The recondenser inserted in the liquid helium container is located in the gas phase. The refrigerator's helium mist coolant in the recondenser suppresses gas phase pressure inside the liquid helium container and it indicates recondensation of evaporated helium gas inside the liquid helium container. Therefore a liquid helium transport system and a helium gas recovery system are not equiped in the JAERI FEL.

The shield refrigerator is built into the cryostat of 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 by flexible copper braids and cooled down by heat conduction through the braids. 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 estimated for example 1.5 watts at accelerating field strength of 5MV/m and 3% duty pulse mode operation, so the total refrigeration power of about 5 watts is required[3]. Since measured cooling power of the 4K refrigerator is 11.5 watts at 4.3 K, the 4K refrigerator has enough cooling power for the main accelerator module.

3. Cool-down

Initial cool-down of the accelerator modules from room temperature was carried out by the 4 K refrigerator and shield refrigerator without liquid nitrogen or cold helium gas. Before the refrigerators were started, the liquid helium container was evacuated to remove air 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 in the liquid helium container was cooled down by the 4 K refrigerator and heat convection and radiation cooling by the inner heat shield. Cool-down curves of the temperatures measured on the heat shields and liquid helium vessel are shown in fig. 3. After approximately 6 days of operation, the liquid helium vessel of the pre-accelerator module reached a temperature of approximately 50 K and liquid helium was transferred from helium dewars. For the main accelerator module, cool-down time was about 10 days for pre-cooling from the room temperature to 50 K and about a half days to fill the liquid helium from helium 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. The total cool-down time was typically 6 days for the pre-accelerator modules and 11 days for the main accelerator module. We have tried to use liquid nitrogen for pre-cooling to shorten the cooling time.

Temperatures of the cold heads of the shield refrigerator were measured in pre-accelerator module #1 at thermal equilibrium of the duplex heat shields. The final temperatures of the first and second stage cold heads were 42 K and 10 K, respectively. 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).

4. Operation of the Cryogenic System

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. Current of the heater fixed outer surface of the liquid helium container bottom 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.

The heater is used to compensate fluctuation of heat load of rf loss. 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].

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 J-T valve of the 4K refrigerator and liquid helium evaporates about 20 liters during the recovery. In the beginning of October 1995, the cryogenic system had a lot of troubles related the compressor unit and refrigerator unit of the 4K refrigerator. By modifications of the 4K refrigerator, troubles could be reduced to a few times a year[5].

5. Summary

The built-in cryogenic system using the compact refrigerators for the superconducting accelerator modules has been driven successfully without any maintenance or operation crew about the cryogenic system. After the modifications related to the 4K refrigerator, the cryogenic system had been operated routinely during 11 months without any major failure. The cryogenic system is halted only during failures of electricity or water supplies.

The refrigerators were used for cooling down the superconducting cavities without liquid nitrogen or cold helium gas. It has proved that the cool-down time from the room temperature to 77 K was about 7 days to fill the liquid helium from helium dewars. We have been tried to use liquid nitrogen for pre-cooling to shorten the cooling time.

References

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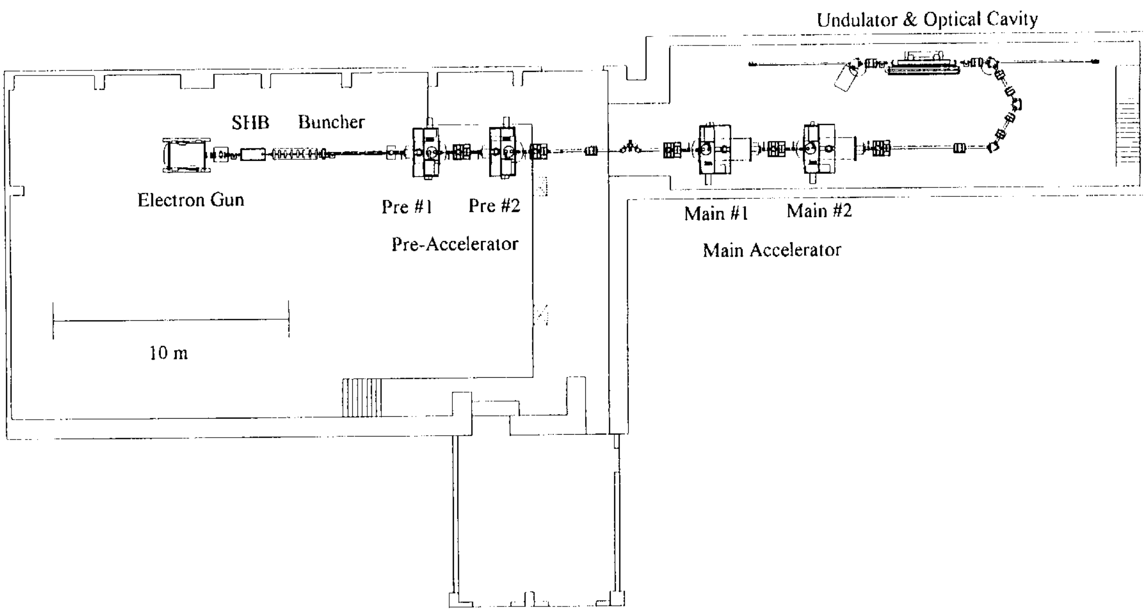

Figure 1. Layout of the JAERI FEL.

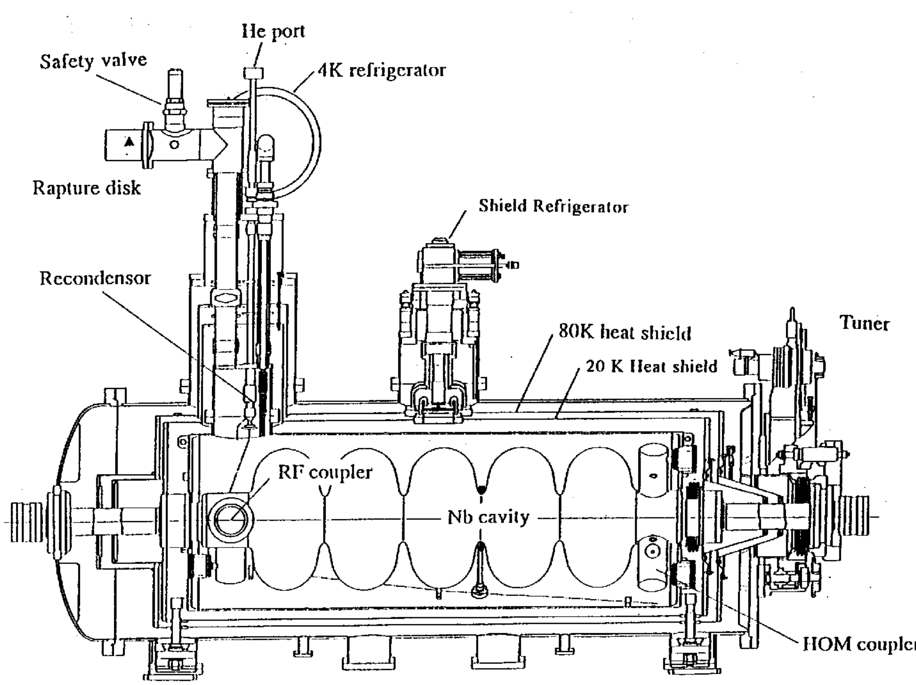

Figure 2. Cross-sectional view of the main accelerator module.

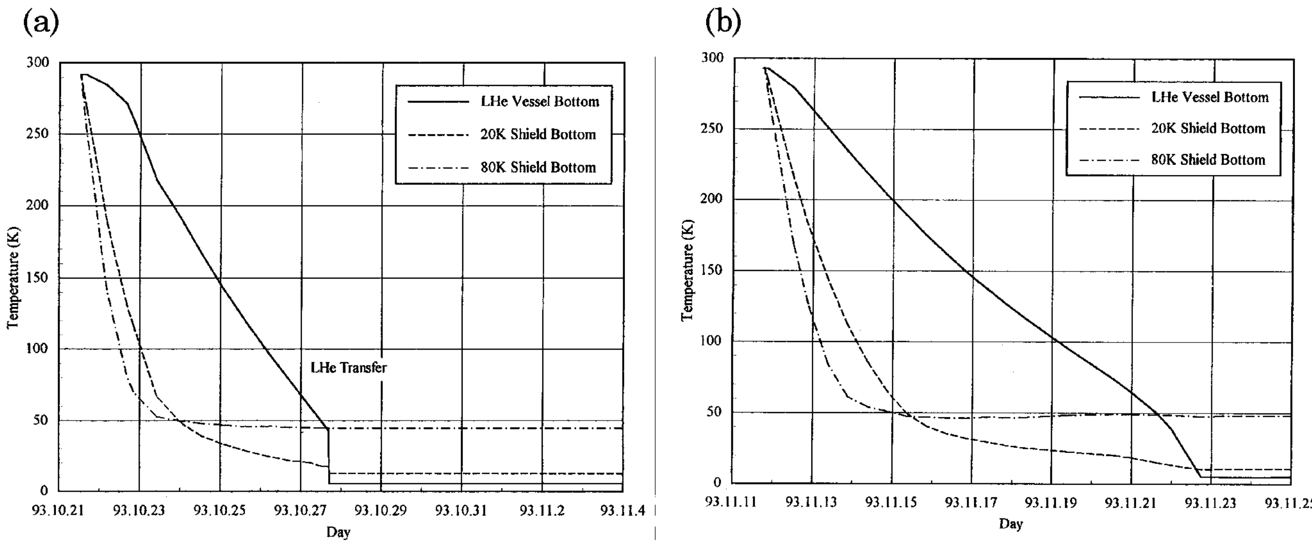

Figure 3. Cool-down curves of the accelerator modules: (a) pre-accelerator modules #2 and (b) main accelerator module #1.