Superconducting Accelerator modules for the JAERI FEL

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Abstract

We have been developing and constructing a free electron laser (FEL) driven by a superconducting accelerator at Japan Atomic Energy Research Institute, Tokai. A multi-refrigerators system, originally designed for a superconducting accelerator module, has worked well for many weeks. And cold rf tests are performed after these are installed in accelerator vault and connected with beam line.

In this paper, present status of cooling system and results of cold rf tests of the accelerator modules are described.

I. INTRODUCTION

Construction of a superconducting linac driven FEL system for far infrared oscillation has been continued at JAERI. An outline of the JAERI FEL program has been reported elsewhere [1]. The superconducting accelerator consists of two pre-accelerator modules with a single-cell cavity and two main accelerator modules with a 5-cell cavity. Main parameters of the accelerator are summarized in Tab. 1 and a schematic layout is shown in Fig. 1. The status of injection system has been reported elsewhere [2].

All of the four superconducting accelerator modules were made by Siemens A. G. and already installed in the JAERI FEL accelerator vault in this January. A multi-refrigerators system for the superconducting accelerator module has worked well to keep liquid He level for many weeks. Cold rf tests are performed and the accelerator produced its first beam in this June.

In this article, the status of the superconducting accelerator modules is described briefly.

Table 1 Main parameters of the accelerator.

Item	Specification
Beam Energy	13.5 - 20 MeV
Energy Spread	< 0.2 %
Peak Current	> 10 A
Pulse Width	40 ps
Repetition	10.4 MHz

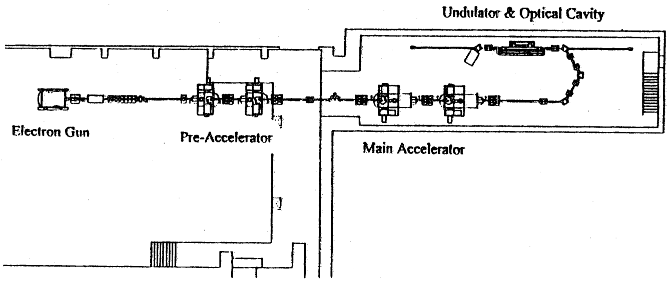

Fig. 1 Schematic layout of the superconducting accelerator.

II. SUPERCONDUCTING ACCELERATOR MODULE

The 500 MHz superconducting cavity was fabricated from 3 mm Nb sheet with RRR = 150. The geometry of the cavity follows DESY one including higher order mode (HOM) couplers and so on. Evaluated values for the cavity are an accelerating gradient of 5 MV/m at 4.2 K and a quality factor of 2×10^9 or more. An external Q (Q_{ext}) value of a main coupler is adjustable over 3.5 decades in range from 5×10^5 to 1×10^9. The Q_{ext} is adjustable to change beam currents. A center conductor of the main coupler is designed to be cooled down by cold gaseous N_2 evaporated from a liquid N_2 container.

Figure 2 shows the cryostat and the multi-refrigerators system for the JAERI superconducting accelerator module. The multi-refrigerators system is originally designed to avoid a regulation under a domestic Japanese pressure vessel code, and to develop a highly-efficient cooling system. We use closed-cycle He gas refrigerators as a recondenser and a shield cooler [3].

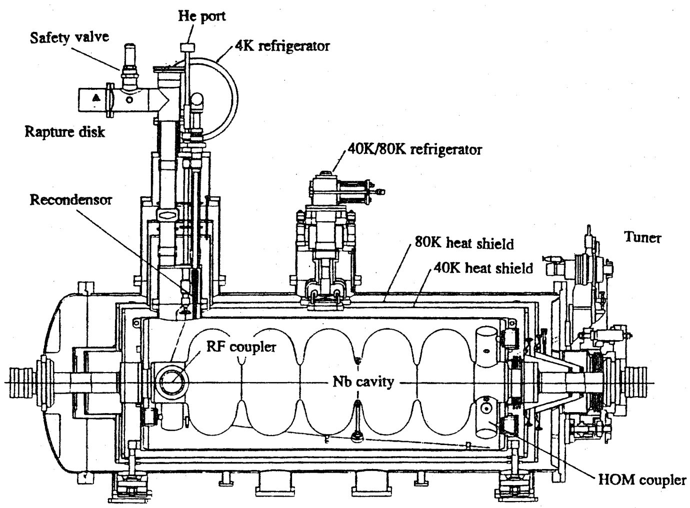

Fig. 2 Structure of the superconducting accelerator module and multi-refrigerators system.

A 4-K refrigerator cools down and recondenses vapored cold gaseous He around a heat exchanger of the 4-K refrigerator in a He container. This 4 K refrigerator's efficiency is about one half of liquefier's one, but it has no transfer losses of liquid He since gaseous He is recondensed in the liquid He container. So total efficiency of the cooling system is as good as that by use a liquefier. A prototype of the 4 K refrigerator has cooling power of 8 W at 4.5 K. A limited cooling power of the 4 K refrigerator restricts heat loads of the cryostat. An rf loss of the 5-cell cavity is about 50 W with $Eacc$ = 5 MV/m and $Q_0 = 2\text{x}10^9$ and reduced to less than 1 W with 1 % duty factor. We assume that heat loads must be less than one half of cooling power of the 4 K refrigerator for safety margin. So evaluated value of total heat loads must be less than about 4 W and of static heat loads less than 3 W.

We adopt a shield refrigerator to reduce static heat loads to less than our requirements. The shield refrigerator cools down 40 K and 80 K heat shields to minimize heat invasion to 4 K region from 300 K region. The shield refrigerator generates two stage cooling points, 40 W at 40 K and 120 W at 80 K, respectively. Cold heads of the shield refrigerator are connected with each heat shield by flexible wires of copper to insulate from a vibration of the shield refrigerator. Thermal anchoring positions of the heat inflow components are determined to divide the static heat loads into two stages of 80 K and 40 K. Thickness of the heat shields shall be 2 mm or more for thermal conductivity and 3 mm for construction.

The safety of the liquid He container is a severe problem because cavities can not withstand high pressure. We designed a large safety line with a low pressure burst disc. For moderate pressure increase, the cooling power of the 4 K refrigerator increase. When heat loads exceed the cooling power of the 4 K refrigerator, safety valves relieve over 1.7 kg/cm^2 abs. If all liquid He lost in less than 3 minutes, the cryostat and the cavity itself will be undamaged. Cold gaseous He goes out of the buildings through safety duct.

III. EXPERIMENTAL RESULTS

Acceptance tests of the accelerator modules was carried out during last year at facility in German. Results of these tests are summarized in Tab. 2. The cryostat showed stand by losses of about 3.5 W at 4.5 K. The static heat loads do not depend on the scale of cryostat. The major heat leaks is from signal wires, for example thermometers.

Table 2 Test result of the accelerator modules.

Module	Q_0 (at 5MV/m)	E_{acc} max (at Q_0=1x10^9)	Cryostat standby losses (at 4.2 K)
Pre #1	2.5x10^9	7.3 MV/m	3.6 W
Pre #2	2.1x10^9	6.8 MV/m	3.0 W
Main #1	2.2x10^9	6.4 MV/m	3.5 W
Main #2	2.0x10^9	6.4 MV/m	3.5 W

The cold rf tests have been done at JAERI in April this year. The cool down is continuously done by the shield refrigerator and 4 K refrigerator from room temperature. After temperature of the liquid He container is below 20 K, about 2 weeks after, liquid He is transferred from dewars to the liquid He container. The pre-accelerator module has about the 100 litter liquid He container, but liquid He of about 160 litter (80 litter x 2) is needed due to the transfer losses. Cooling power of the 4 K refrigerator is about 11 W or more, which is enough for our requirements. After the transfer, the 4 K refrigerator keeps liquid He level over one month.

Temperatures of the heat shields are lower than our evaluation.

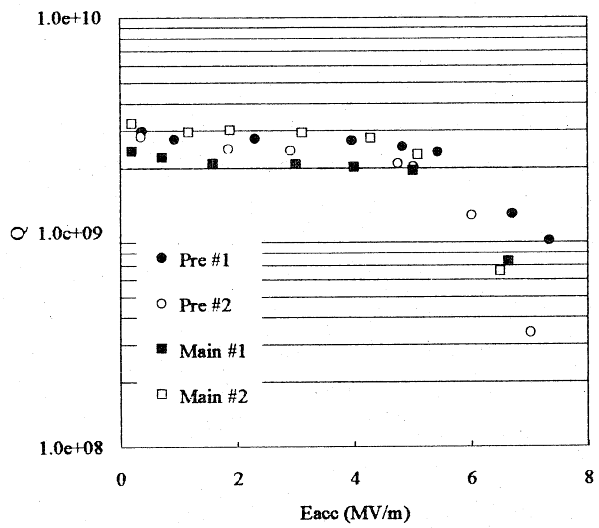

Fig. 3 Performance of the accelerating cavities.

The performances of the superconducting accelerating cavities are shown in Fig. 3. It seems that Q degradation due to slow cooldown is not observed. The frequency sensitivity of the cavities for He pressure is about 35 kHz/(kgf/cm^2). The He pressure is expected to vary by 0.2 kgf/cm^2. The He pressure will be controlled by a electric heater to keep a constant pressure.

Due to the high Q_{ext} value with which superconducting cavities are operated, vibration is an inherent problem. The vibrational amplitude of the cavity due to the shield refrigerator is larger than that due to the 4 K refrigerator. To reduce the vibration by the refrigerators, the 4 K refrigerator is mounted on a lifting frame and connected with bellows and the shield refrigerator is supported on anti-vibration support rods. The vibration affect not only fluctuation of frequency but also fluctuation of the coupling factor of the main coupler. The vibrational amplitude and speed of frequency fluctuation can be compensated by piezo electric tuners. Vibration of vacuum vessel vibrate a center conductor of the main coupler. The fluctuation of the coupling factor is a serious problem. To reduce the vibration from shield refrigerator, we make changes for the better in the support of shield refrigerator by mounted on supporting arch over the accelerator module.

IV. CONCLUSION

The superconducting linear accelerator has been constructed and tested. The multi-refrigerators system has worked well for many weeks to keep liquid He level. To reduce the vibrational amplitude due to the shield refrigerator, we modified supporting rods.

The performances of the cavities are better than evaluated values, Q0 > 2×10^9 at E_{acc} = 5 MV/m. The Q degradation due to slow cooldown is not observed.

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