DEVELOPMENT OF A 1.8K LEVEL COOLING SYSTEM AND CRYOSTAT FOR A SUPERCONDUCTING CAVITY

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Abstract

In Toshiba, superconducting cavities have been developed and high field gradients of E_{acc}>30MV/m obtained under the collaboration with KEK. As a next stage, we designed and manufactured a test cryostat module consisting of a cooling unit and a horizontal cavity cryostat. The cryostat includes a 1.3GHz single cell cavity with some coupler ports. The cooling unit has 1.8K, 4K and 80K cooling lines. We adopted a cooling scheme that 1.8K superfluid helium is beforehand produced in a cold box with one Joule-Thomson(J-T) valve, and then transferred to cavity cryostat(s). We consider that this cooling scheme is likely to enable cryogenic operation to be easier than in the system which a cavity cryostat has an indivisual J-T valve, because of a decreasing number of ones to control. This contribution presents the results of the cooling and RF field tests.

1 INTRODUCTION

In Toshiba, superconducting cavities have been developed under the collaboration with KEK. So far, L-band single cell niobium cavities and a three-cell structure have been fabricated. As the results of RF field tests in vertical cryostat, the high field gradient of E_{acc}>30MV/m is obtained in single cell cavities and also E_{acc}=34.3MV/m in the three cell structure[1][2]. R&D of brazing or hot isostatic pressing treatment to join niobium and stainless steel has been established and these technologies have been applied to the connection of niobium beam pipe and stainless steel flange[3]. Besides R&D of hydroforming is proceeding to fabricate seam-less cavity, and as a feasibility study, L-band copper single-cell cavities have been successfully fabricated by hydroforming[1][4]. As a next stage, we started to study on cryomodules. We have developed a cooling scheme that 1.8K superfluid helium is beforehand produced in a cold box with one Joule-Thomson(J-T) valve, and then transferred to cavity cryostat(s). According to this scheme, the number of J-T valve is decreased compared to the system in which a cavity cryostat has an individual J-T valve. Therefore cryogenic operation should be easier in such a scheme. In order to verify the merit of this scheme, we designed and manufactured a test cryomodule consisted of a cooling unit and a horizontal cavity cryostat as shown in Fig. 1. The cooling unit has 1.8K, 4K and 80K level cooling lines. A GM/JT and GM refrigerator are used for the 4K and 80K level lines respectively. They make the cooling unit small-sized as shown in Fig. 2, and ease the

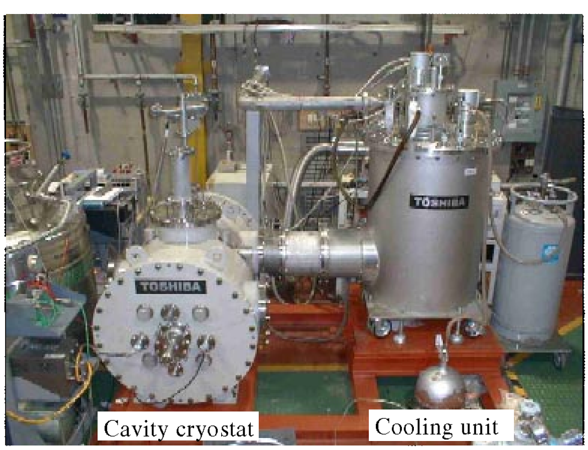

Figure 1: Cryomodule in a cooling test

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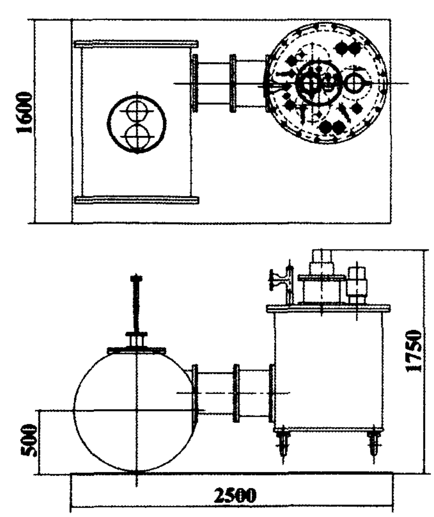

Figure 2: Dimensions(mm) of the cryomodule

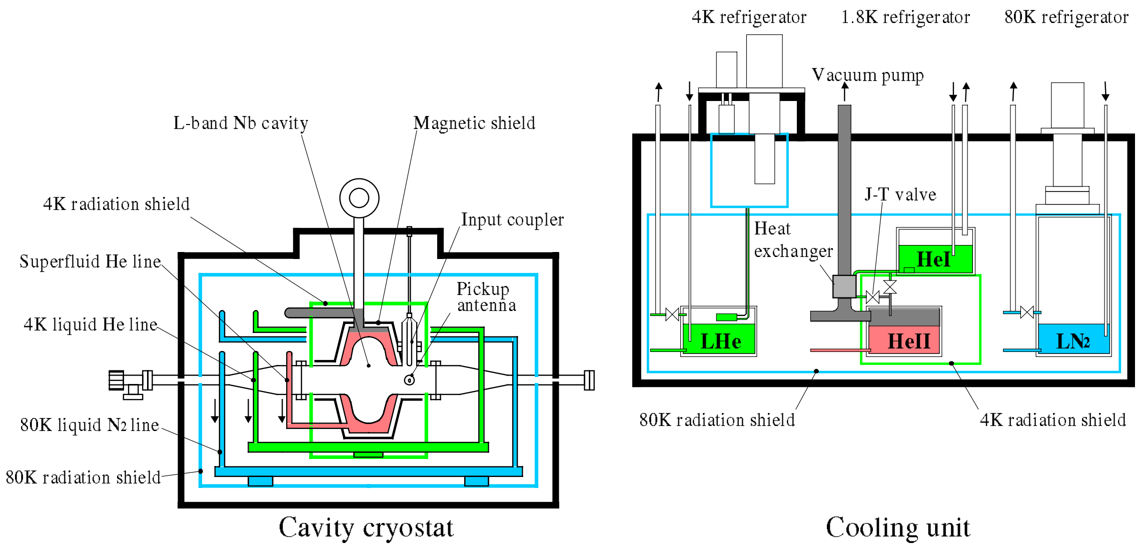

Figure 3: Schematic graph of the cryomodule

operation of the unit since they allow the lines to be closed system. The cavity cryostat includes a L-band single cell cavity with one input coupler port, one pickup port and two HOM coupler ports. The cavity cryostat is made of carbon steel and works as a supplementary magnetic shield. In this scheme, Cooling tests and RF field tests were carried out and the performances of this module were investigated.

2 CRYOGENIC SYSTEM

The cryomodule consist of 1.8K, 4K and 80K level lines. The schematic graph of it is shown in Fig. 3. Saturated superfluid helium, about 1 bar liquid helium and liquid N_2 circulate in these lines. These liquids are transferred to the cavity cryostat by the liquid level difference between the bathes in the cooling unit and cavity cryostat. The cooling pipes between the cooling unit and cavity cryostat are omitted in the Fig. 3.

2.1 80K and 4K Level Lines

The 80K level line consists of a GM refrigerator for making N_2 gas re-condensed, a liquid N_2 bath(LN_2) to store re-condensed N_2 and a cooling pipe circulating in the cavity cryostat. In the cavity cryostat, a 80K radiation shield, beam pipes, a input coupler, a pickup antenna and a pipe connected to a rapture disk for safety are cooled down by the cooling pipe. Thus this line absorbs the static heat load from room temperature level, and then reduces the static heat load to the 4K level.

The 4K level line consist of a GM/J-T refrigerator for making helium gas re-condensed, a liquid helium bath(LHe) to store re-condensed helium and a cooling pipe circulating in the cavity cryostat. In the same way as the 80K level line, the 4K level line cools down some components such as a 4K radiation shield in order to reduce the static heat load to the 1.8K level from 80K level.

2.2 1.8K Level Line

The cryogenic system of 1.8K level line consists of a 4.2K liquid helium bath(HeI), a heat exchanger, a J-T valve, a cold box(HeII), a rotary pump and a cooling pipe circulating in the cavity cryostat. Liquid helium in HeI is cooled down by counter flow exchanging with pumped helium vapor. An isenthalpic expansion into the HeII bath is then carried out via the J-T valve. By the regulation of the J-T valve, the liquid level in the cryostat is kept constant. Level sensors in HeI, HeII and cavity vessel monitor the liquid levels. The vapor from the cavity vessel is returned to the cooling unit. It is warmed up with the vapor from the HeII bath through the heat exchanger, and pumped out by room-temperature rotary pump.

2.4 Cooling Capacity and Static Heat Load

The cooling capacity and static heat load of the cryomodule are shown in Table 1. The static heat load to the 1.8K line is nearly zero and most of the cooling

Table 1:Thermal design of cryostat module

cooling lines	static heat load			cooling capacity
	cavity cryostat	refrigerator cryostat	total	
1.8K line	0.5W	0.01W	0.5W	8W@1.8K
4K line	3.5W	0.2W	3.7W	5W
80K line	17W	13W	30W	70W

capacity is used for the surface RF loss of the cavity. The static heat loads to the 4K and 80K lines are designed to be less than the cooling capacities. This allows the lines to be operated continuously without additional cryogen after the lines are cooled down enough.

3 COMPONENTS OF CAVITY CRYOSTAT

The cavity has stainless steel flanges joined by brazing technology at the niobium beam pipe and coupler ports. The RF performance was confirmed prior to this horizontal assembly as shown in Fig. 6(x)[3]. After this measurement, the cavity was only rinsed with high pressure deionized pure water subsequently. Tapered beam pipes and input coupler were mounted on it in a class 10 clean room and then inner side of the cavity was sealed off in vacuum. The cavity vessel was welded to the stainless steel rims that were brazed on the niobium beam pipes.

Concerning the magnetic shielding, double-walled shell structure is adopted. The outer shell is the cavity cryostat made of carbon steel and the inner shell made of high permeability material covers closely around the cavity vessel as shown in Fig. 3. The material used for the inner shell maintains the high permeability even at 4.2K. This design can offer a good magnetic shielding costeffectively; due to the magnetic shielding effect of the cavity cryostat, the mass of the expensive inner shell can be decreased. The magnetic effect is evaluated by the formula for spherical shell in Fig. 4[6]. Assuming that μ_2 is 1/10 of the catalogue specification, μ_1=200, R_{1o}=0.41m, R_{1i}=0.42m, μ_2=7000, R_{2o}=0.157m and R_{2i}=0.159m as the parameters in Fig. 4, the internal field become below a few mGauss. In addition, internal field will be below 10mGauss at μ_2=2000. There is a possibility to apply a normal high permeability material to the inner shell, of which permeability become poor at low temperature.

Shielding factor S = Bo / Bi
Bo = external field
Bi = internal field

$$S \approx 1 + S_1 + S_2 + S_1 \cdot S_2 \left(1 - \left(\frac{R_{2o}}{R_{1i}}\right)^3\right)$$

$$S_k \approx \frac{2}{9}\mu_k \left(1 - \left(\frac{R_{ki}}{R_{ko}}\right)^3\right), \quad k = 1,2$$

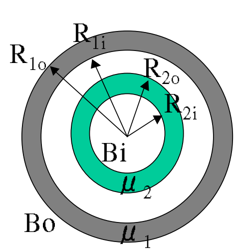

Figure 4: Formula of magnetic shielding for spherical shell[6]

4 EXPERIMENTAL RESULTS

4.1 Cooling Tests

Cooling tests were carried out using 11000L/min rotary pump at KEK. The cooling capacity was measured from the relation between the output of a heater in the cavity vessel and superfluid helium temperatures. The temperatures were measured at three positions; at the HeII bath, the bottom and top of the cavity equator. The result of cooling test is shown in Fig. 5. The experimental data is in good agreement with the design values. For the heater output of 7.6W, the temperature of superfluid helium was balanced at 1.8K and also at1.96K for 14.8W from Fig. 5. This means that the cooling capacity is 7.6W at 1.8K and 14.8W at 1.96K. Furthermore, since the temperature difference between HeII and cavity vessel is below 0.01K as shown in Table 2, this scheme can make uniform cooling. In this experiment, design value is satisfied enough and uniform cooling is obtained.

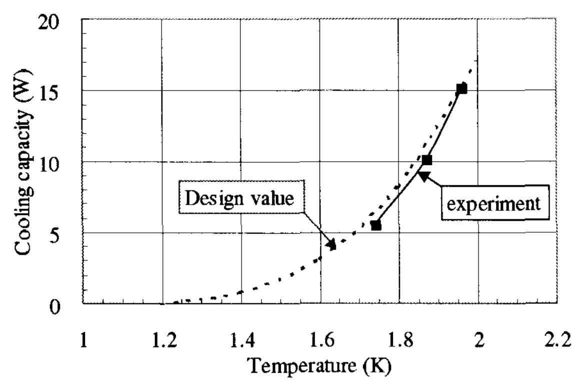

Figure 5:Cooling capacity of 1.8K line

Table 2:Temperature distribution of superfluid helium

heater output (W)		5.17	9.76	14.82
temperature (K)	cavity top	**1.74**	**1.87**	**1.96**
	cavity bottom	**1.74**	**1.87**	**1.96**
	HeII bath	**1.74**	**1.86**	**1.95**

4.2 RF field Test

In this scheme unloaded quality factor Q_o as a function of accelerating field was measured. The result was presented in Fig. 6 with vertical test. The maximum accelerating field gradient was 8.3MV/m in the horizontal assembly[7]. X-ray started from Eacc=5.7MV/m. This horizontal cryostat is the first handling. There might be some problems in the horizontal assembly. Further study is needed to understand the performance degradation.

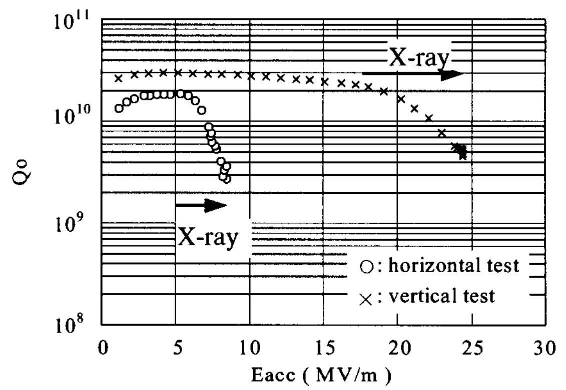

Figure 6: Quality factor as a function of accelerating field

5 SUMMARY

We developed a cryomodule combining a cooling unit and cavity cryostat. We adopted a cooling scheme that 1.8K superfluid helium is beforehand produced in a cold box with one J-T valve, and then transferred to cavity cryostat(s). This cooling scheme is expected to make cryogenic operation easier by reducing J-T valve compared to the system in which a cavity cryostat has an individual J-T valve. Indeed we manufactured this system in order to verify the merit of this scheme. As the results of cooling experiments, the cooling capacity was in good agreement with the design value and homogeneous cooling was obtained. This scheme proves to be applicable to cryogenic systems for superconducting accelerators. On the other hand, RF performance was unfortunately degraded compared to the vertical test. But this is the first handling of the horizontal cryostat and the investigation of assembly method is going ahead.

6 ACKNOWLEDGEMENTS

We would like to thank all colleagues that supported this work. They made kindly so helpful suggestions and carried out burdensome requests during design and assembly. Also, we are grateful to our group members at KEK for being able to prepare the tests smoothly.

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