RF test results of an L-band single-cell niobium cavity installed in a horizontal cryostat

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Abstract

An L-band (1.3GHz) single-cell niobium cavity with four ports on the beam tubes was fabricated in our company and tested in the vertical cryostat in 1998. A new horizontal cryostat and a 1.8K refrigerator system were developed. The cavity was installed in this cryostat and cooled successfully. The RF test were carried out in this system, but degradation of the cavity performance was observed.

1 Introduction

Since 1995, we have continued a collaboration with KEK on superconducting cavities. Two L-band single-cell niobium cavities and an L-band three-cell structure have been fabricated in our company and tested at low temperature. A maximum field gradient of $E_{acc,max}$>30MV/m was attained in these cavities[1,2]. An L-band single-cell niobium cavity with ports was fabricated and tested in 1998. A maximum field gradient of $E_{acc,max}$=24.5MV/m was attained in the vertical test[3].

We are proposing a central refrigerator system for a superconducting linear accelerator, in which superfluid helium produced by one 2K refrigerator is transferred and distributed to superconducting cavity cryostats. In order to verify this system, the cryostat and the refrigerator system were developed for the L-band single-cell cavity with ports as a prototype of the system [4,5].

2 L-band Single-cell Niobium Cavity

An L-band single-cell cavity with four ports (an RF input coupler port, a pickup port and two HOM coupler ports) was made of high purity niobium sheets (RRR>200) of 2.5mm thickness except for the flanges, which were made of SUS316L. The fabricated single-cell niobium cavity with ports is shown in figure 1 and its specifications, calculated using SUPERFISH code, are summarized in table 1.

Regarding the surface preparations of the cavity, the inner surface layer of 90μm at the equator was removed by barrel polishing, and a further 150μm on average was removed by electropolishing. The cavity was vacuum annealed at 760°C for 5 hours within a titanium box, and rinsed with high pressure (85kgf/cm^2) deionized pure water (12MΩcm). These preparations follow the same procedure as all cavities made by our company. After the treatments, the cavity was tested at 1.7K in the usual vertical test stand. A maximum field gradient of $E_{acc,max}$=24.5MV/m (@Q_0=5x10^9) was attained, though the field emission was observed.

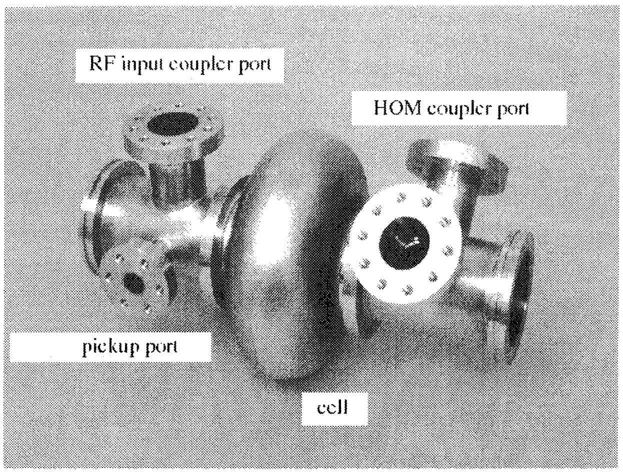

Figure 1 L-band single-cell niobium cavity

Table 1 The specifications of L-band single-cell cavity

Frequency	1296.63[MHz]
R_{sh}/Q	110[Ω]
G	265[Ω]
E_{sp}/E_{acc}	1.85
H_{sp}/E_{acc}	42.8[Oe/MV/m]

3 Surface Treatment for Horizontal Test

After the vertical test, the L-band single-cell niobium cavity was disassembled and left in a class 100 clean room for nine days. It will be possibilities that the cavity performance degrades because of indium or dust contamination on the cavity surface during disassembly. High pressure rinsing of a cavity is one promising method to avoid such possibilities[6]. Therefore, the cavity was rinsed with high pressure deionized pure water for one hour. The RF input coupler, the pickup antenna and two extension stainless steel beam tubes were megasonic rinsed with ultra pure water and were carefully installed on the cavity in a class 10 clean room. After the assembly, the cavity was evacuated to $1.2x10^{-6}$ Torr and sealed under vacuum.

4 Cryostat and Refrigerator System

The new horizontal cryostat and the refrigerator system are shown in figure 2. The structure of the cryostat and the cavity is shown in figure 3. The cryostat consists of the 2K line for superfluid helium, and the 4K line and the 80K line for the thermal shielding. The 4K shield and the 80K shield were cooled through thermal conduction of liquid helium and liquid nitrogen, respectively. A helium vessel, made of stainless steel, was welded to the cavity. The helium vessel was filled with superfluid helium and the cavity was cooled down to less than 1.8K. The cavity equipped with the RF input coupler and the pickup antenna was covered with the 4K shield. The 4K shield was covered with the 80K shield and the vacuum vessel.

Before the RF test of the cavity, the cooling characteristics of the cryostat were tested. Its refrigeration capacity was more than 10W at 1.8K, and

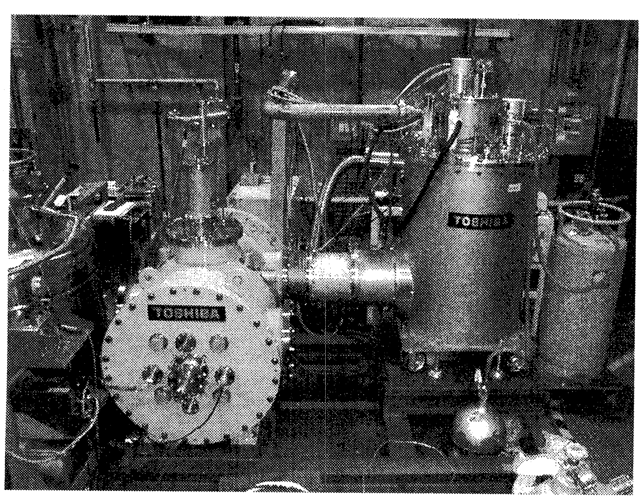

Figure 2 cryostat and refrigerator system

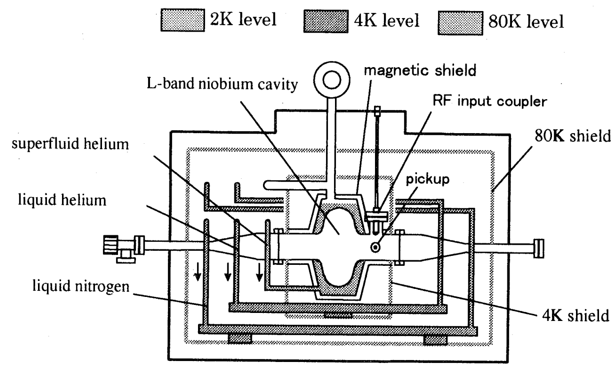

Figure 3 Cryostat for the L-band single-cell cavity

25 hours operation with 5W heat load was achieved.

5 Horizontal Test Results

The cavity was cooled to 4K using liquid helium for two days after a pre-cooling of two days using liquid nitrogen. The 2K line was evacuated to generate superfluid helium and the cavity was cooled to 1.5K. An RF power was inputted in the cavity through the input coupler. The measured Q_0 (unloaded Q value) of the cavity as a function of the accelerating field gradient (E_{acc}) is shown in figure 4 and indicated by closed triangles. At low fields, the Q_0 value was $2x10^{10}$. However Q_0 began to drop remarkably and X-rays were detected over E_{acc}=5.7MV/m. The X-ray intensity increased with increasing E_{acc}. This observation was considered to be due to field emission from surface contamination. The maximum field gradient was limited to 8.3MV/m (@ $Q_0=2.9x10^9$) by a large amount of X-rays. While warming the cavity from 1.5K to 4.2K, the temperature dependence of the surface resistance (R_s) of the cavity was measured. Using the temperature dependence of the R_s, the residual surface resistance was calculated to be 13.8nΩ.

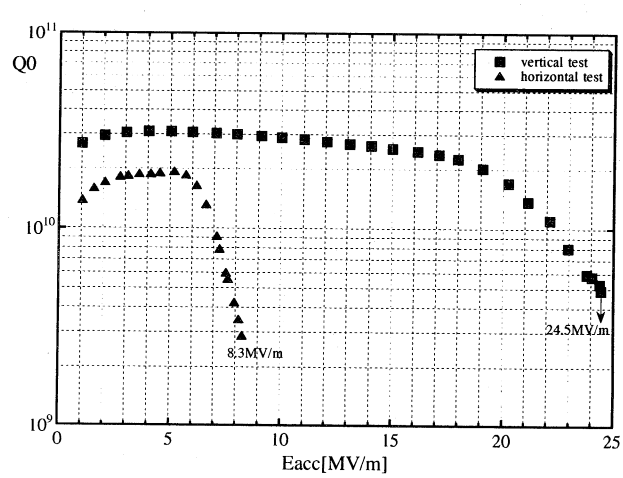

Figure 4 Q_0-E_{acc} plots on the single-cell cavity

6 Discussion

The test results of the cavity in the horizontal cryostat were compared with the vertical test results. The measured Q_0 from the vertical test are shown in figure 4, indicated with closed squares. The maximum field gradient $E_{acc,max}$, the residual surface resistance R_{res} and the limit of the accelerating field gradient of these tests are summarized in table 2. The R_{res} of the horizontal test was twice as large as that of the vertical test. In the horizontal test, the field emission started at a low field and the $E_{acc,max}$ reduced to one third of the value from the vertical test. Therefore, it is considered that the inner surface of the cavity was contaminated by dust particles before the horizontal test. The surface contamination of the cavity may originate from dust particles during assembly of the cavity or from exposure to the air during evacuation of the cavity before the horizontal test. The former origin is thought to be insufficient as assembly of the cavity was carried out carefully. It is necessary that the assembly procedure should be investigated to avoid contamination of the inner surface of the cavity. Regarding the latter origin, the turbo-molecular pump and the rotary pump accidentally stopped during evacuation of the cavity, and therefore the inner surface of the cavity may have become contaminated by oily air. As an different cause of the degradation of the cavity performance, it is considered that the RF input coupler was contaminated. In order to recover the original performance of the cavity, it is best to remove again the inner surface of the cavity by electropolishing followed by rinsing with high pressure deionized pure water. However, it is very difficult to take out the cavity from the cryostat and to prepare the inner surface of the cavity by electropolishing and high pressure rinsing.

Table 2 Measurement results of two tests

	$E_{acc,max}$ [MV/m]	R_{res} [nΩ]	limit
horizontal test	8.3	13.8	field emission
vertical test	24.5	6.3	field emission

7 Conclusion

An L-band single-cell niobium cavity with four ports was installed in a horizontal cryostat and RF testing was carried out. The cavity was cooled to 1.5K and it was able to verify the cryostat and the refrigerator system developed for the cavity. Regarding RF test results, the field emission started at low field and the maximum field gradient of $E_{acc,max}$=8.3MV/m was limited by the X-ray emission. The cavity performance of the horizontal test degraded compared to the vertical test results. Even though the degradation of the cavity performance was observed, the horizontal cryostat and the refrigerator system were worked well.

Acknowledgments

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References

[1] T. Ota et al., "First measurement of L-band superconducting cavity fabricated in TOSHIBA", Proc. of the 21st Linear Accelerator Meeting in Japan(1996), p.240.

[2] T. Ota et al., "Development of a high field three-cell superconducting cavity", Proc. of the 23rd Linear Accelerator Meeting in Japan(1998), p.277.

[3] T. Ota et al., "Development of an L-band single-cell niobium cavity with ports", Proc. of the 24th Linear Accelerator Meeting in Japan(1999), p.242.

[4] N. Kakutani et al., "Development of cryostat for the L-band superconducting single cell cavity", Proc. of the 2nd Superconducting Linear Accelerator Meeting in Japan(1999).

[5] M. Takahashi et al., "Refrigeration test of a cryostat for the L-band superconducting single cell cavity", Proc. of the 2nd Superconducting Linear Accelerator Meeting in Japan(1999).

[6] K. Saito et al., "High Pressure Water Rinsing Effect of the Cavity Performance on the Contaminated Niobium Superconducting Surface", Proc. of the 20th Linear Accelerator Meeting in Japan(1995), p.173.