Activities on Superconducting Cavities at TOSHIBA

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Abstructs
R&D activities on superconducting cavities at TOSHIBA are presented. Two L-band single-cell niobium cavities and an L-band three-cell structure were fabricated in our company and measured at KEK. The maximum field gradient of $E_{acc,max}$>30MV/m in both single-cell cavities and $E_{acc,max}$ =18MV/m in the three-cell structure were attained respectively. An optimization study on the annealing temperature for the hydrogen Q-disease is reported. R&D of hydroforming to fabricate seamless cavities is also presented.

1 Introduction

Since 1995 the collaboration with KEK about superconducting cavities have been continued. Two L-band single-cell niobium cavities and a three-cell structure were fabricated in our company and measured at low temperature[1,2]. The effect of annealing temperature for hydrogen Q-disease was studied with an L-band single-cell niobium cavity treated at several annealing temperature (400~770^{o}C). R&D of hydroforming has started in our company to fabricate seamless cavities. As a feasibility study, an L-band copper single-cell cavity was fabricated by hydroforming.

2 Single-cell cavities

2.1 Fabrication

Two L-band(1.3GHz) single-cell cavities were made from high purity niobium sheets(RRR=200) of 2.5mm thickness. A series of fabricating processes such as forming by deep drawing of niobium sheets, trimming of formed half cells and electron beam welding were carried out. Beam tubes were made from

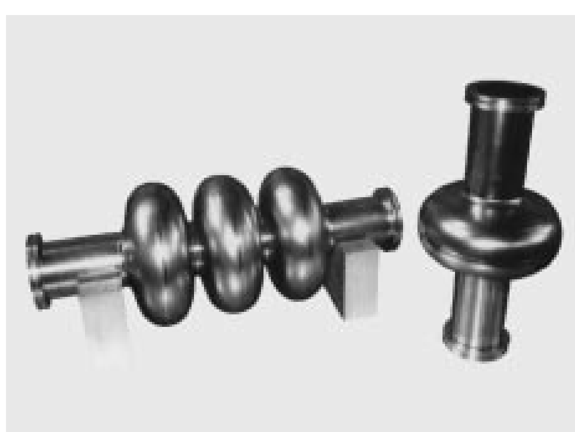

Figure 1 L-band niobium superconducting cavities

Table 1 Superconducting cavities specifications

	single-cell	three-cell
Frequency[MHz]	1295.43	1299.23
Rsh/Q[Ω]	102	317
G[Ω]	274	274
Esp/Eacc	1.78	2.58
Hsp/Eacc[Oe/MV/m]	43.8	41.9
Coupling[%]	-	2.3

rolled niobium sheets, then welded by electron beam. One cell and two beam tubes were joined by electron beam welding. The fabricated single-cell cavity as well as three-cell cavity are shown in Figure 1 and their specifications calculated by SUPERFISH code are summarized in table 1.

2.2 Surface preparation

Inner surface of two cavities were removed by 30µm at the equator by barrel polishing[3], and 100µm on the average by electropolishing (EP)[4]. These cavities were annealed at 800°C for 5 hours with the titanium box to degas hydrogen, and rinsed with high pressure (~80kgf/cm^2) deionized pure water(12MΩcm).

2.3 Experimental results

After the treatments, they were evacuated to 1x10^{-7}Pa and sealed in vacuum. The fast cool down to 4.2K was carried out in one hour. The measured Q_0(unloaded Q value) of two cavities as a function of accelerating field gradient(E_{acc}) are shown in Fig.2. In the case of T-1 cavity, with open circle, Q_0 were 2x10^{10} and the residual surface resistance(R_{res}) was about 7nΩ at low field. The Q_0 did not degrade so much at high field, and the maximum field($E_{acc,max}$) reached to 32.9MV/m. The X-ray was observed above E_{acc}=27MV/m.

In the case of T-2 cavity, measurements were carried out twice. In the first measurement, as shown in Fig.2 with open square, Q_0 were sufficiently high at low field, however Q_0 began to drop at E_{acc}=17MV/m. The maximum field was limited to 28.2MV/m due to thermal quench. No X-ray was observed up to the maximum field. After the measurement, the inner surface was inspected with a CCD camera[5]. The oxidation and pits that were generated in the trouble during EP were found at the inner surface. To remove these irregularities, the cavity surface was treated with chemical polished(CP) by 30µm, and rinsed with high pressure deionized pure water. As shown in Fig.2 with open triangle, Q_0 were sufficiently high at low field, however Q_0 began to drop at E_{acc}=25MV/m

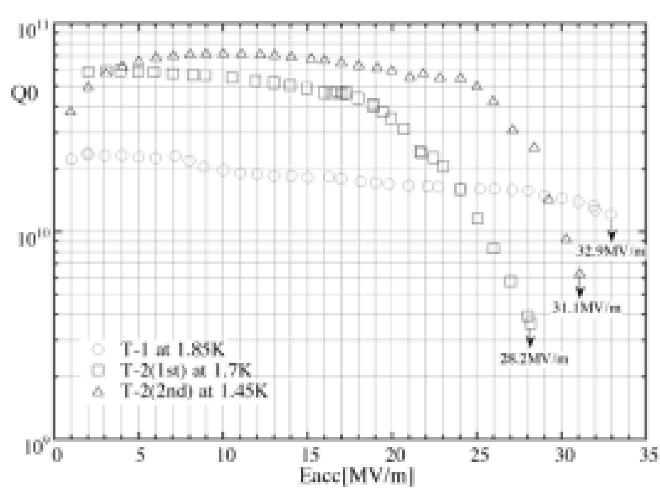

Fig.2 Q_0-E_{acc} plots on single-cell cavities No X-ray was observed up to the maximum field.

and $E_{acc,max}$ was limited to 31.1MV/m due to thermal quench.

The T-1 cavity attained the maximum field of $E_{acc,max}$>30MV/m without drop of Q_0. The T-2 cavity reached to $E_{acc,max}$=30MV/m, but Q_0 began to drop at E_{acc}=25MV/m in the second measurement.

3 Three-cell cavity

3.1 Fabrication

An L-band three-cell cavity was fabricated by the same procedure as single-cell cavities. Joining of the iris of each cell were done by electron beam welding from the outside of the cavity. The three-cell cavity is shown in Fig.1 and the specifications are summarized in table 1.

3.2 Pre-tuning

After completing the cavity, a pre-tuning was performed to get flat field strength in each cell equal. Figure 3 shows electric field distribution on beam axis before and after pre-tuning. After the pre-tuning, the field flatness in the π-mode was better than 96%. The cell to cell coupling as determined from the pass band modes frequencies was 2.5%.

3.3 Surface preparation

The three-cell cavity was prepared by the same procedure as single-cell cavities. Inner surface of the cavity was removed by 80μm at the equator by barrel polishing, and 100μm on

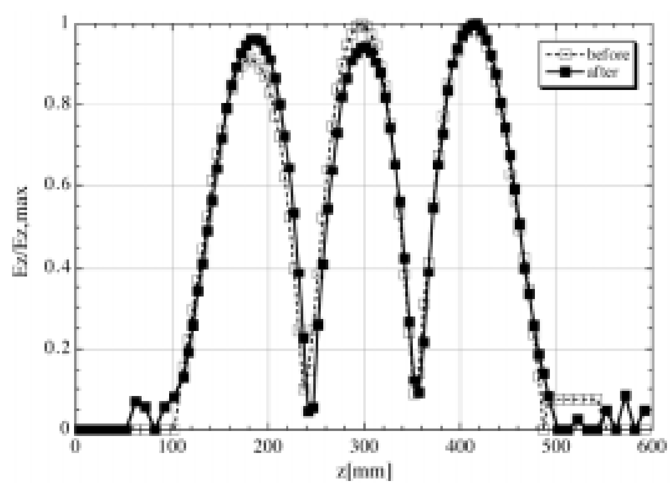

Fig.3 Electric field distribution after
pre-tuning for three-cell cavity

the average by EP. The cavity was annealed at 710°C for 5 hours with the titanium box to degas hydrogen, and rinsed with high pressure (85kgf/cm^2) deionized pure water.

3.4 Experimental results

After the treatments, it was evacuated to 1x10^{-7}Pa and sealed in vacuum. The fast cool down to 4.2K was carried out in one hour. Three pass band modes were measured at 1.9K. The results are shown in Fig.4. In π-mode, with open square, Q_0 were 2x10^{10} and R_{res} was about 9nΩ. These Q_0 did not degrade at high field, and the maximum field gradient($E_{peak,max}$) was limited to 38.7MV/m (E_{acc}=15MV/m). The X-ray begun to appear at E_{peak}=20MV/m. In (2/3)π-mode, as shown in Fig.4 with open triangle, the X-ray began to be observed at E_{peak}=28MV/m, and $E_{peak,max}$ was limited to 34.5MV/m. In (1/3)π-mode, with open circle, Q_0 were sufficiently high at low field, however Q_0

began to drop remarkably and the X-ray began to appear at E_{peak}=19MV/m. The maximum field was limited to 28.3MV/m. Measured frequencies of three pass band modes are summarized in table 2. Experimental results were almost in agreement with calculation.

In these measurements, the X-ray increased with E_{peak} increasing. This phenomenon was considered as field emission by surface contamination or defects. In order to remove

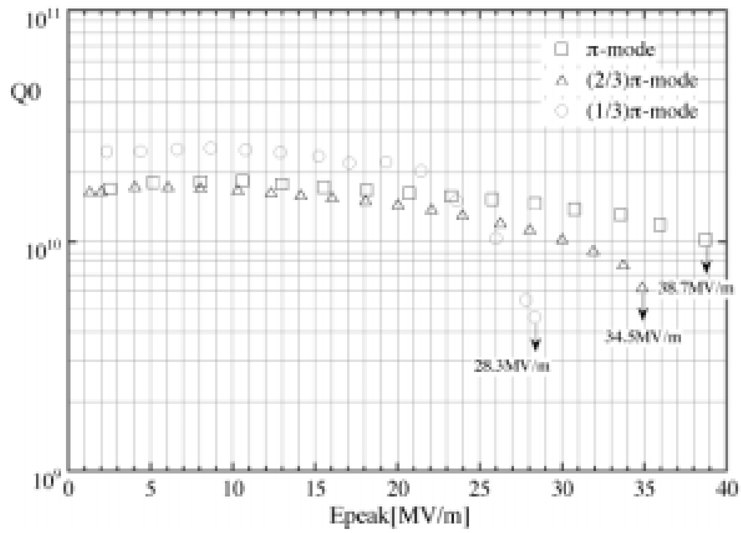

Fig.4 Q_0-E_{peak} plots of each mode
on three-cell cavity

		Measured	
	Calculated	room temp.	1.9K
(1/3)π-mode[MHz]	1269.76	1269.16	1270.58
(2/3)π-mode[MHz]	1288.67	1290.28	1292.05
π-mode[MHz]	1299.23	1301.06	1302.89
Coupling[%]	2.3	2.5	2.5

Table 2 Frequency of three pass band modes

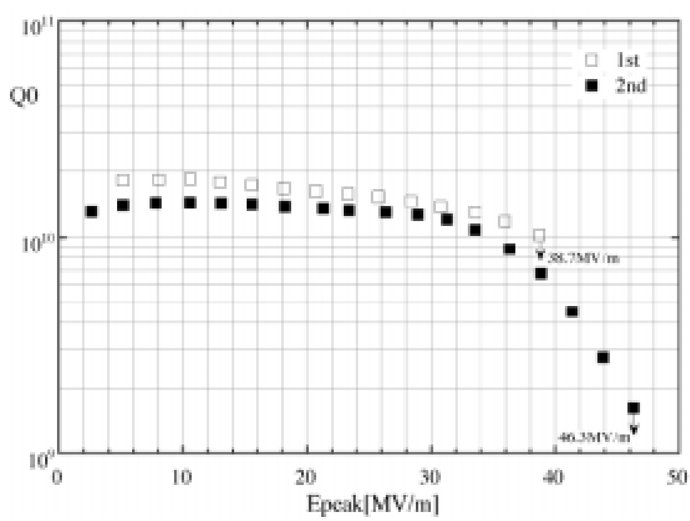

Fig.5 Q_0-E_{peak} plots on three-cell cavity the surface irregularities, the cavity was polished by 30µm on the average by EP. And the cavity was rinsed with high pressure deionized pure water. The result of measurement is shown in Fig.5 with closed square. The Q_0 began to drop remarkably at E_{peak}=32MV/m and $E_{peak,max}$ was limited to 46.3MV/m(E_{acc}=18MV/m). The X-ray began to appear at E_{peak}=36MV/m and increased with E_{peak}.

The L-band three-cell niobium cavity fabricated in our company shows the performance such as the maximum field gradient of $E_{acc,max}$=18MV/m limited by the field emission.

4 Effect of annealing temperature for hydrogen Q-disease

4.1 Hydrogen Q-disease

Buffing had been used for TRISTAN superconducting cavities as a mechanical polishing to remove surface irregularities. Recently, a barrel polishing was developed as a simpler method instead of the buffing. This has been successfully applied to L-band cavities with adopting annealing(~800°C) after surface polishing such as EP or CP. However, Q-disease in the cavity treated by a barrel polishing is not well investigated yet.

To see the effects of barrel polishing, an L-band single-cell niobium superconducting cavity prepared by barrel polishing and EP without annealing was measured. A light Q-disease was observed, though a fast cooling down of the cavity was carried out[6].

4.2 Annealing temperature to prevent the Q-disease

The cavity treated at several annealing temperature was measured to compare the performances. In these experiments, the cavity was barrel polished by 30µm to initialize its surface. Then it was electropolished by 10µm, annealed for 5 hours at a temperature from 400°C to 770°C, and rinsed with high pressure deionized pure water. The cavity was held for 1.5 hours at 100-120K before cooling down to 4.2K to make sure the condition of Q-disease.

The results of these measurements are shown in Fig.6 and summarized in table 3. No Q-disease was observed for annealing temperature higher than 600°C, and the maximum field was almost same as achieved in three KEK cavities with the same surface treatments. The result for 500°C also did not

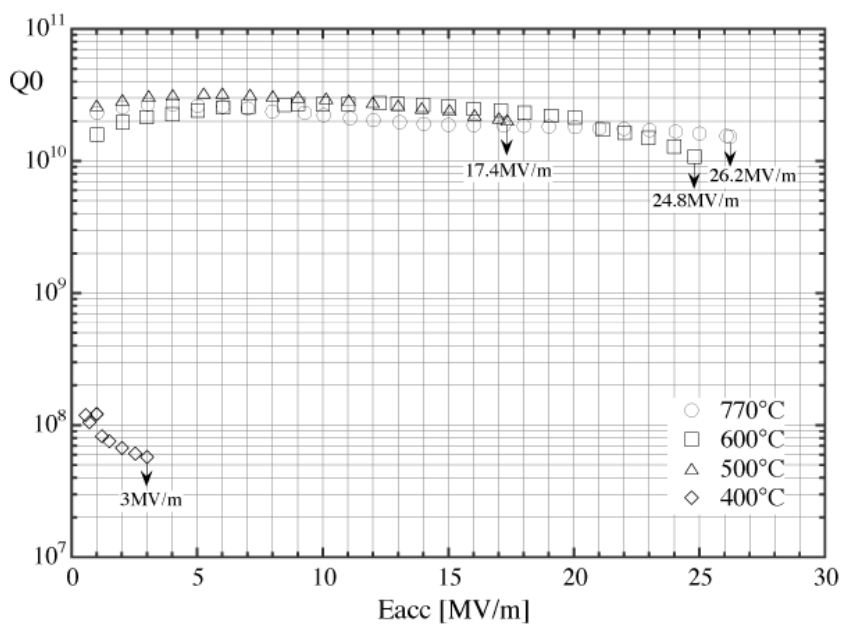

Fig.6 Q_0-E_{acc} plots on single-cell cavity for various annealing temperature

Temp.[^oC]	R_{res}[nΩ]	$E_{acc,max}$[MV/m]	Q-disease
770	6	26.2	no
600	9	24.8	no
500	7	17.4	no
400	4000	3	yes

Table 3 Summary of the cavity performance with annealing temperature

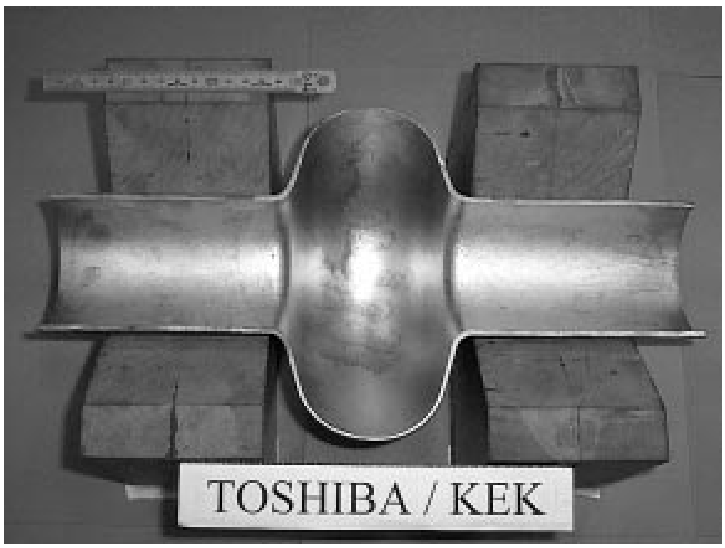

Fig.7 L-band copper cavity by hydroforming

show Q-disease, but the maximum field was lower than those for 600^{o}C and 770^{o}C. More statistics is necessary to confirm this lower $E_{acc,max}$.

On the other hand, in the case of 400^{o}C annealing, Q_0 were degraded remarkably and R_{res} was about 4μΩ. The maximum field was limited to very low field. Serious Q-disease appeared in this case.

According to these results, it was found that 600^{o}C is enough to achieve good performance, but more data are necessary for the annealing at 500^{o}C.

5 Seamless cavities

R&D of hydroforming has started in our company to fabricate seamless cavities.As a feasibility study, hydroforming was tried for the L-band copper single-cell cavity. In the first step, both end parts of a copper tube(outer diameter is 138mm, thickness is 2.5mm) for beam pipes were sank four times with intermediate annealing. After sinking, the central part of the copper tube was expanded with hydroforming for the cell. Figure 7 shows the L-band copper single-cell cavity made by the hydroforming. For getting multi-cell cavities, R&D of hydroforming technology is under way.

6 Conclusion

R&D activities on superconducting cavities at TOSHIBA are summarized as follows.

1) Two L-band single-cell niobium cavities were fabricated in our company and measured. The maximum accelerating gradient of $E_{acc,max}$>30MV/m were attained in both cavities.
2) A three-cell structure fabricated in our company was measured. The maximum field was limited to 18MV/m by the field emission. Measurements and surface treatments of the three-cell cavity will be continued to get the higher gradient ; $E_{acc,max}$>30MV/m.

3) For the cavity prepared by barrel polishing, the effect of annealing temperature was studied. It was suggested that 500^{o}C is lowest temperature to prevent hydrogen Q-disease but the effect on the attainable field is not clear.
4) R&D of hydroforming has been started to fabricate seamless cavities. As a feasibility study, hydroforming was tried for the L-band copper single-cell cavity. For getting multi-cell cavities, R&D of hydroforming technology is under way.

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