Spare Cavities for TRISTAN 508 MHz SC Cavities

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Abstract

Four 508 MHz 5-cell niobium SC cavities were manufactured as spare cavities for TRISTAN SC cavities. In the final vertical measurements, average Q_0 at low field and maximum accelerating field ($E_{acc,max}$) were 3.3×10^9 and 13.1 MV/m, respectively. One cavity, 18b, marked the highest $E_{acc,max}$ of 15.1 MV/m. In the horizontal tests, however, one of the cavities, 17b, showed a serious degradation and had to be re-treated. Moreover, another cavity, 17a, suffered an accidental mechanical kink during its disassembly. Nevertheless both of them recovered to show a good performance after repair. The details are presented in this paper.

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1. Introduction

Thirty-two superconducting (SC) accelerating cavities were manufactured and have been operated in the TRISTAN main ring [1,2]. Only a few cavities degraded and did not recover by warming up [3]. To replace the degraded cavities, we started manufacturing four spare cavities in 1989. The procedure for the fabrication was the same as those produced previously [4]. The technology and technique to obtain 10 MV/m-level cavities have been matured for 500 MHz 5-cell cavities, but the problem that the performance turns out to be deteriorated in the horizontal tests by about 30 % on average remains to be solved [1].

2. Summary of vertical measurements

The results of the final vertical measurements are summarized in Table 1. Unloaded Q is plotted against E_{acc} in Fig. 1. The inverse of unloaded Q, which is proportional to the total loss on the cavity surface, is plotted against the square of surface peak electric field, E_{sp}^2 in Fig. 2. Non-linear part of this curve indicates electron loading. As one can see in this figure, 18a showed the strongest electron loading due to field emission. Field enhancement factor, β, also showed the highest value as shown in Table 1.

3. Fabrication and surface treatments

Results of fabrication and pre-tuning are summarized in Table 2. In Table 3, processes of final surface treatments, what we call EP II, are shown with their goals and consumed time. In Table 4, conditions of final surface treatments of spare cavities are summarized.

4. Repair of 17a and 17b

One cavity, 17b, was found to be degraded in the horizontal measurement. Its $E_{acc,max}$ was only 3 MV/m. Since there are two 5-cell cavities in one horizontal cryostat, 17a, the other cavity in the same cryostat, also had to be disassembled to retreat 17b. An accident took place when these cavities were being disassembled.

When 17a was suspended with two Nylon ropes and crane, it kinked suddenly as shown in Fig. 6(a) probably because of too much torque concentrated on the iris between the two ropes.

Repair processes of 17a and 17b are summarized as follows,

17a (Accidental inelastic deformation, Fig.6(a)

1) Restore the shape of the cavity using the fixtures used for pre-tuning.

2) Anneal for stress release.

3) Pre-tuning for field flatness and to restore the resonant frequency.

4) Standard final surface treatment (Table 4, EP 10 μm).

17b (Degraded after horizontal assembly)

1) Vertical measurement and temperature mapping (Figs. 4 and 5).

2) Inspection of inner surface and sanding off the defects found (e.g., Fig. 6(b)).

3) EP of 10 μm and rinse (1st and 2nd rinse in Table 3).

4) Inspection of inner surface.

5) Standard final surface treatments (Table 4, EP 10 μm).

For 17b, temperature mapping with Allen-Bradley carbon resistors was performed on the first 2 cells from HOM-side because these cells were suspected to be the cause of the degradation from the side-bands measurements in the 2nd vertical measurement [5]. The results of the mapping are shown in Fig. 5. They showed heated spots around the iris between the two cells. Figure 6(b) shows one of the defects found on the iris during the inspection.

Q_0-E_{acc} curve of 17a after the repair process is shown in Fig. 3 along with the curve before this accident. The changes of Q_0-

E_{acc} curves of 17b after different processes are also shown in Fig. 4. Finally in both cases, repair processes were successful and E_{acc} reached well above 10 MV/m.

5. Horizontal measurements

After connecting two 5-cell cavities in a horizontal position and adding 4 HOM couplers and extension beam pipes in a clean environment, we install these cavities in a horizontal cryostat [1]. After this so-called horizontal assembly, these cavities are cooled down with LHe and tested in the radiation shield blocks by the assembly area. The results of the horizontal tests are summarized in Table 5. As one can see, $E_{acc,max}$ became lower than that of vertical measurements, although the exact maximum values were not reached because we did not raise the input power in fear of serious damage due to discharges.

6. Vacuum and $E_{acc,max}$

In Fig. 7, pressures inside the cavity before pre-cooling with liquid N_2 and during the vertical measurements are shown for all the TRISTAN cavities and spare cavities as a function of $E_{acc,max}$. As one can see, it seems that a pressure on the order of 10^{-10} Torr during the measurements is necessary to obtain the gradient higher than 12 MV/m.

7. Conclusion

The technology to obtain 500 MHz 5-cell cavities which have accelerating fields of higher than 10 MV/m has been matured. The highest $E_{acc,max}$ was 15 MV/m so far. We have, however, some problems associated with the degradation after the horizontal assembly. We have not clarified the reason for this degradation. What we have to do in the future will be to solve this problem and to investigate on the limitation of the accelerating fields so that we can get higher gradient and stable cavities.

Acknowledgements

Continuous encouragements by Prof. Kimura and Dr. Kojima are appreciated. We would like to thank Dr. K.Asano and Dr. K.Saito and for discussions and suggestions. We also would like to thank Mr. Miwa and Mr. Fukuda for working on surface treatments of spare cavities very carefully.

References

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[2] K.Akai : ibid [1] 189.

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[5] K.Saito et al. : ibid [1] 635.

[6] T.Tajima et al. : ibid [1] 821.

Table 1. Results of final vertical measurements of spare cavities.

Cavity #	17a	17b	18a	18b
Meas. date	28 June 91	12 June 91	30 Jan. 91	7 Feb. 91
f_0 (MHz)	508.240	508.178	508.204	508.218
Q_{15D} 1) ($\times 10^{11}$)	3.33	2.57	2.49	3.03
Q_0 at low field ($\times 10^9$)	2.8	3.6	3.3	3.4
$E_{acc,max}$ (MV/m)	13.5	12.8	11.1	15.1
Limitation	Saturation of amplifier	Saturation of amplifier	Breakdown	Capacity of He ret. line
γ	17.6	17.5	18.4	15.8
β ($\Delta 1/Q$)	-	-	279	78,606 2)
β (elec.)	-	-	520	-
β (X-ray)	483 3)	302	750	385
Vacuum dur. Meas. (10^{-10}Torr)	6.7	2.5	6.8	2.6

1) Q_{ext} of monitor port.
2) This value was different according to the range of E_{acc}.
3) This value is inaccurate due to the big scatter of the data in F-N plot.

Table 2. Results of fabrication.

Cavity #	17a	17b	18a	18b
RRR	140-193	165-198	187-209	148-182
EBW	Defocus	Defocus	Defocus	Defocus
EP I	80 μm	80 μm	80 μm	80 μm
Anneal	700°C×1.5H in Ti box	700°C×1.5H in Ti box	700°C×1.5H in Ti box	700°C×1.5H in Ti box
Vacuum at 700°C (Torr)	$2.1\text{-}3.9 \times 10^{-5}$	$2.5\text{-}4.5 \times 10^{-5}$	$1.8\text{-}3.1 \times 10^{-5}$	$1.8\text{-}3.1 \times 10^{-5}$
Pre-tuning				
f_0 at 4.2 K[1)] bef. tuning (MHz)	507.906	508.205	508.289	508.296
Field flatness bef. tuning (%)	81	93	93	94
f_0 at 4.2 K[1)] aft. tuning (MHz)	508.13	508.119	508.123	508.132
Field flatness aft. tuning (%)	99	99	99	99
Contraction by evacuation (mm)	5.73	4.52	4.48	4.62

1) Calculated from measured frequency [6].

Table 3. KEK standard final surface treatments for Nb 500 MHz 5-cell SC cavities. (1/2)

Process	Method	Goal	Time (min.)
Electropolish	H_2SO_4:HF=85:10 Circulation of EP solution Rotation[1)] of cavity (1 rpm)	Removal of inner surface by 10 μm	26
1st rinse	Overflow with demineralized water in a vertical position	pH of outlet water ≥ 3	27-30
Disassembly	Cables, fixtures and extraction of cathode bag	No dirt on cathode bag and joints	35-40
2nd rinse	Shower with demineralized water	pH of outlet water ≥ 5	30
H_2O_2 rinse	10 w% H_2O_2 Rotation (3 rpm) with H_2O_2 filled horizontal Immersed vertically in a warm (50-55 °C) ultrasonic bath	No indicator Removal of carbon and formation of stable Nb_2O_5 layer are expected.	20×2 (Rev. rotation) 40
Rinse	Shower with demineralized water after dumping. H_2O_2	Rinse off H_2O_2	10

(Continued)

Table 3. KEK standard final surface treatments for Nb 500 MHz 5-cell SC cavities. (2/2)

Process	Method	Goal	Time (min.)
3rd rinse	Immersed in a warm (50-55 °C) ultrasonic bath Overflow with deminaralized water	Specific resistivity of overflowing water ≤ 0.5 % of the initial value	10-15 160-190[2)]
4th rinse	Overflow with ultra-pure water in the same way as above in a warm US bath Rotation (3 rpm) on the bed Overflow with ultra-pure water	No indicator Removal of particles smaller than 10 μm, bacteria and TOC[3)] is expected	5 5×2 (Rev. rotation) 5
Final rinse	Shower with ultra-pure water	Removal of residues is expected	1
Seal & package	Sealed with filtered N_2 gas	Prevention of airborne contamination is expected	35-40

1) All rotations are performed in a horizontal position about cavity axis.
2) This depends on how long it takes to attain the goal.
3) Total Organic Carbon .

Table 4. Conditions of final surface treatments of spare cavities.

Cav. No.	17a	17b	18a	18b
EP depth	10μm	10μm	10μm	10μm
Set cav. Temp (°C)	31.8	31.4	31.7	31.3
Reservoir Temp. (°C)	27.6	26.7	27.6	27.5
Voltage (V)	24.0	25.6	25.0	25.7
Average Current (A)	967.5	952.0	938.9	931.0
Av. Current density (mA/cm^2)	53.3	52.4	51.7	51.3
pH aft. 1st water rinse	3.00	2.80	3.14	2.8
pH aft. 2nd water rinse	4.90	4.70	4.82	4.77
Res. of 3rd rinse water (Mohm·cm)	7.0	6.9	6.8	6.9
Res. of 4th rinse water (Mohm·cm)	7.9	6.9	8.7	8.6

Other common parameters are

Total electropolishing area: 18150.0 cm^2,

H_2O_2 rinsing time : 80 min,

Cavity rotation during EP : 1.0 rpm,

Flow rate of EP solution : 60 liters/min.

Table 5. Results of horizontal measurements.

Cavity #	17a	17b	18a	18b
Q_L ($\times 10^6$) (band wid.)	0.822	0.721	.768	0.905
Q_L ($\times 10^6$) (200W decay)	0.899	0.747	0.863	1.005
Q_L ($\times 10^6$) (E_{acc}=5MV/m)	0.830	0.784	0.766	1.003
Q_{15D} 1) ($\times 10^{11}$)	3.10	2.71	2.53	2.82
$E_{acc,max}$(MV/m)	6.82 2)	>7.00	>6.16	>7.00
Q_0 ($\times 10^9$) (6 MV/m)	2.29	2.57	1.38	2.63
β (electron)	no electron (-6.5 MV/m)	433 (6.0-7.0 MV/m)	886 (4.8-5.5 MV/m)	451 (6.0-7.0 MV/m)
Δf/load(Hz/kg)	552.2	558.0	563.2	533.8
Spring constant (kg/mm)	158.9	148.9	130.1	151.8
Δf/length (kHz/mm)	87.7	83.1	73.3	81.0
Piezo storoke (kHz)	≅7.4	≅7.4	≅7.2	≅7.3
f_0 at load free (MHz)	508.307	508.276	508.286	508.328
HOM filter a (MHz)	508.53	508.53	≅508.75	508.62
HOM filter b (MHz)	508.58	508.46	508.57	508.65
Tatal loss at 6 MV/m (W)	84.8	78.5	126.1	81.1
Static loss of cryostat (W)	27	27	31	31

1) Q_{ext} of a monitor port below input coupler.

2) Coupler arc discharge.

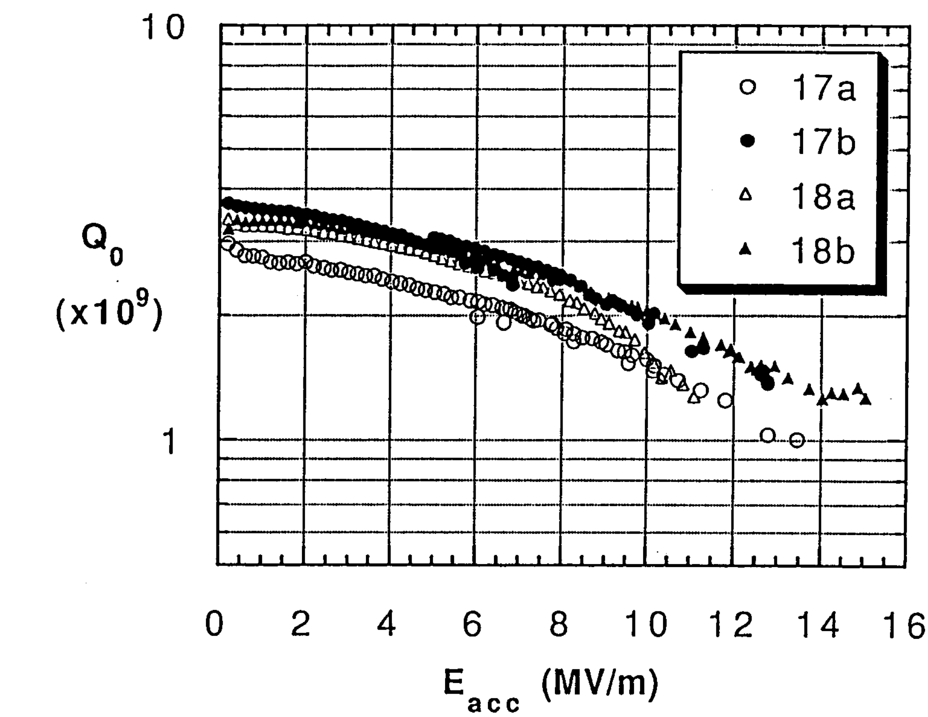


Fig. 1. Q-E curves of four cavities obtained from final vertical measurements.

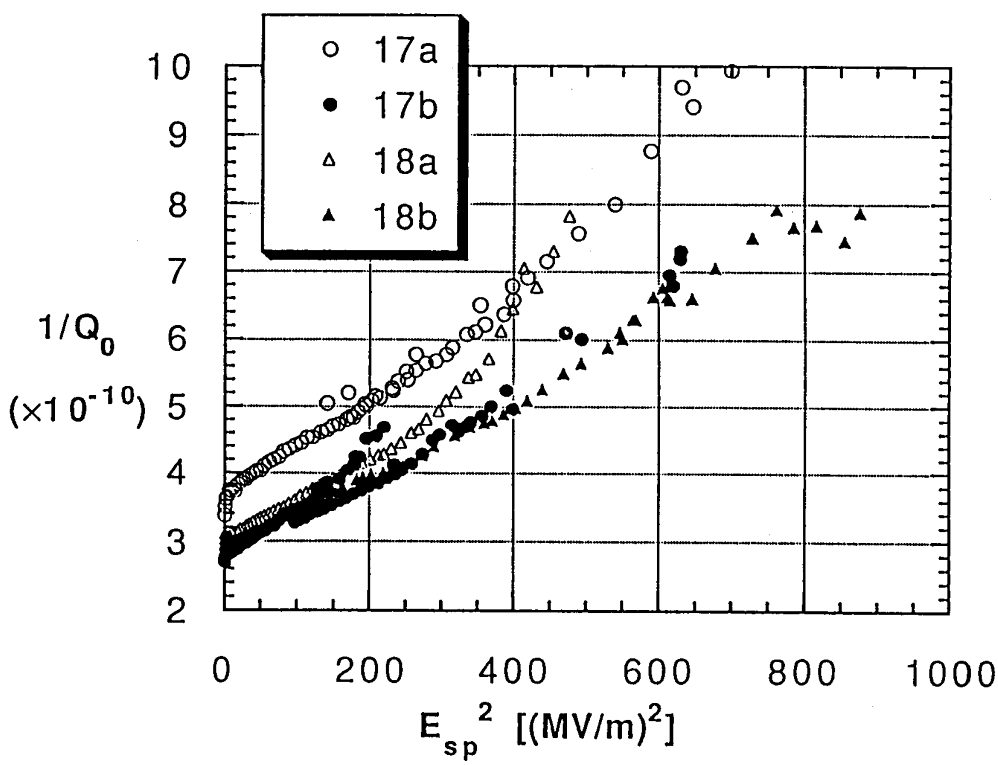


Fig. 2. $1/Q_0$ vs E_{sp}^2 at the final vertical measurements.

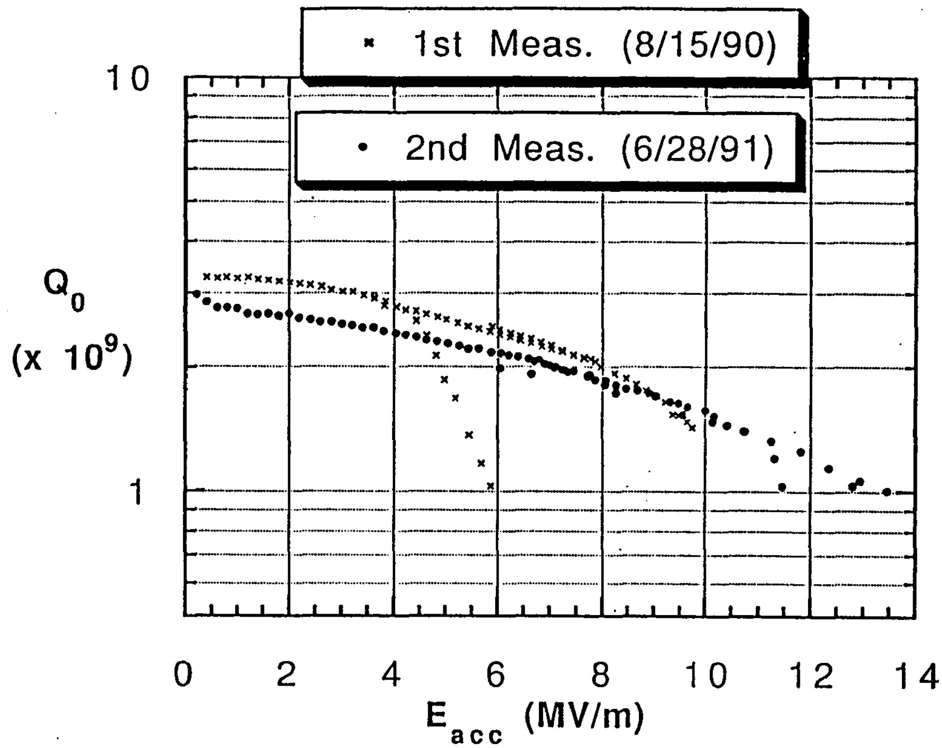


Fig. 3. Vertical measurements of 17a. 2nd measurement was performed after repairing the accidental kink of the cavity.

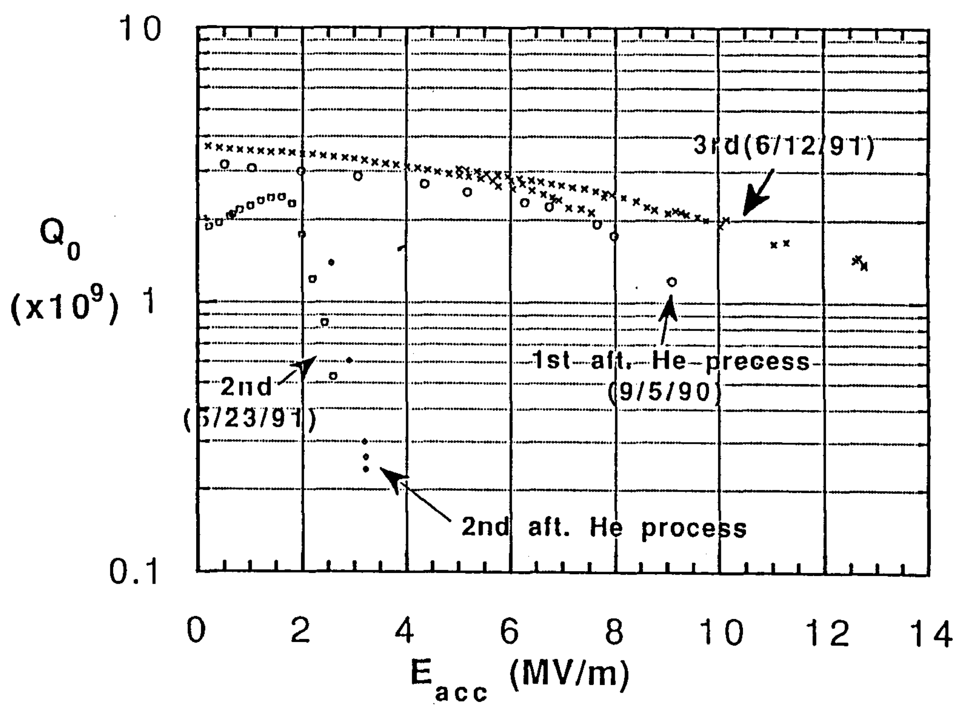


Fig. 4. Vertical measurements of 17b. 2nd measurement was done after its degradation was found at the horizontal measurement and the 3rd was performed after sanding off the defects and re-EP.

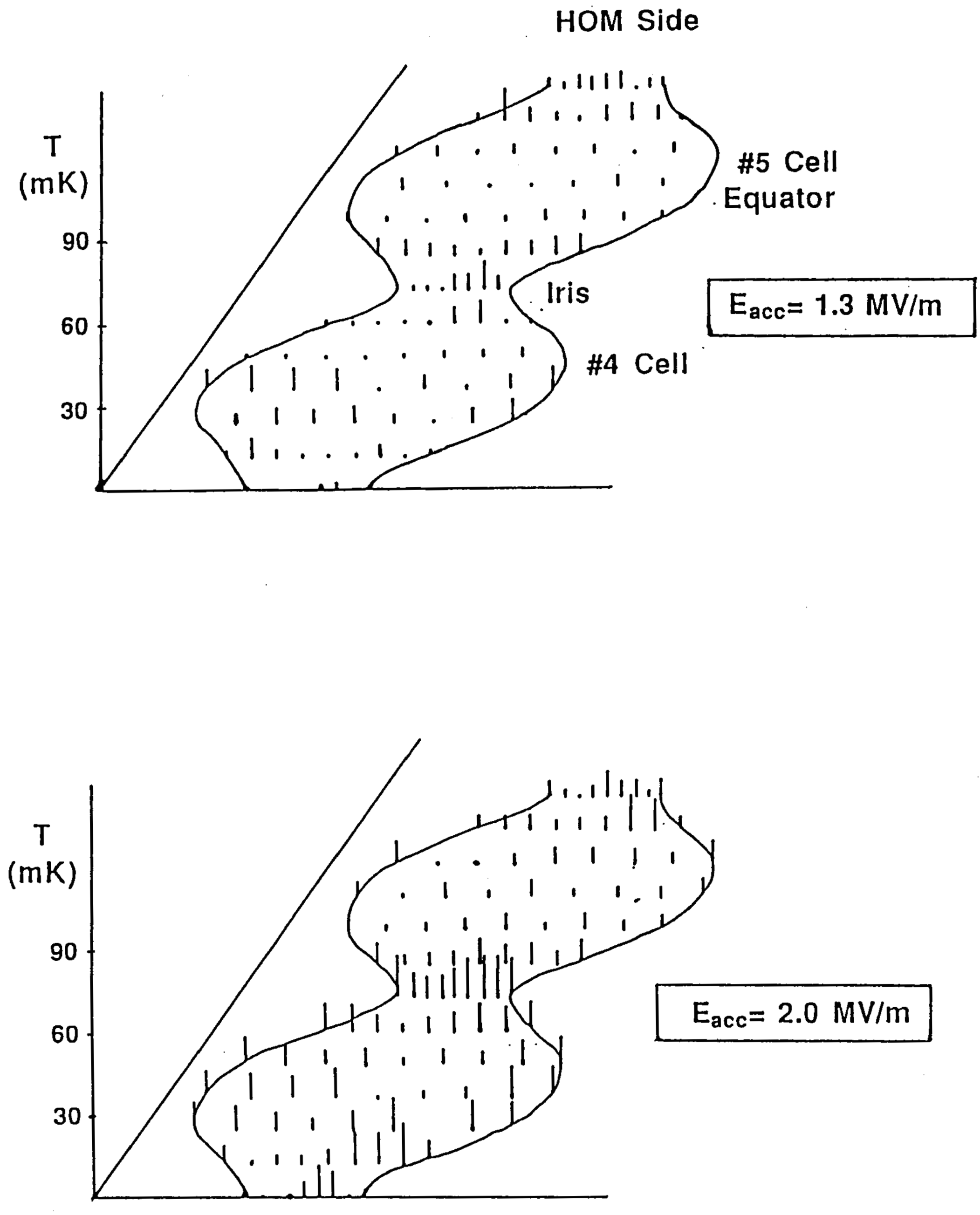
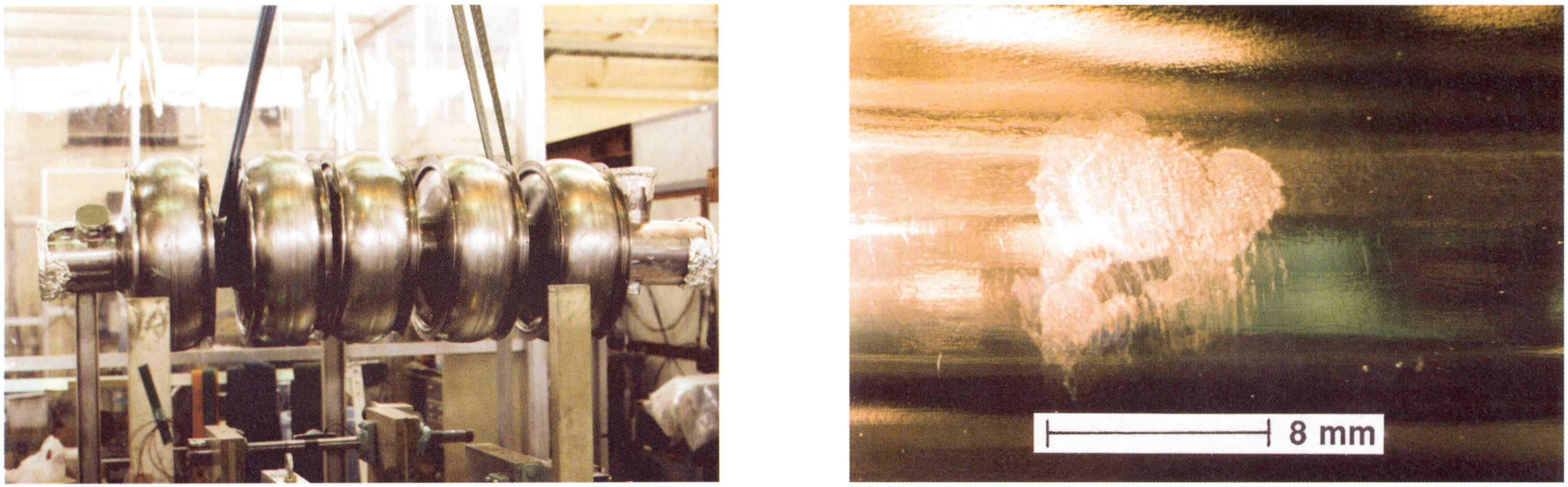


Fig. 5. Temperature mapping at the 2nd vertical measurement of 17b.



(a) (b)

Fig. 6. (a) The accidental kink of cavity 17a and (b) One defect found upon the inspection of the inner surface of cavity 17b.

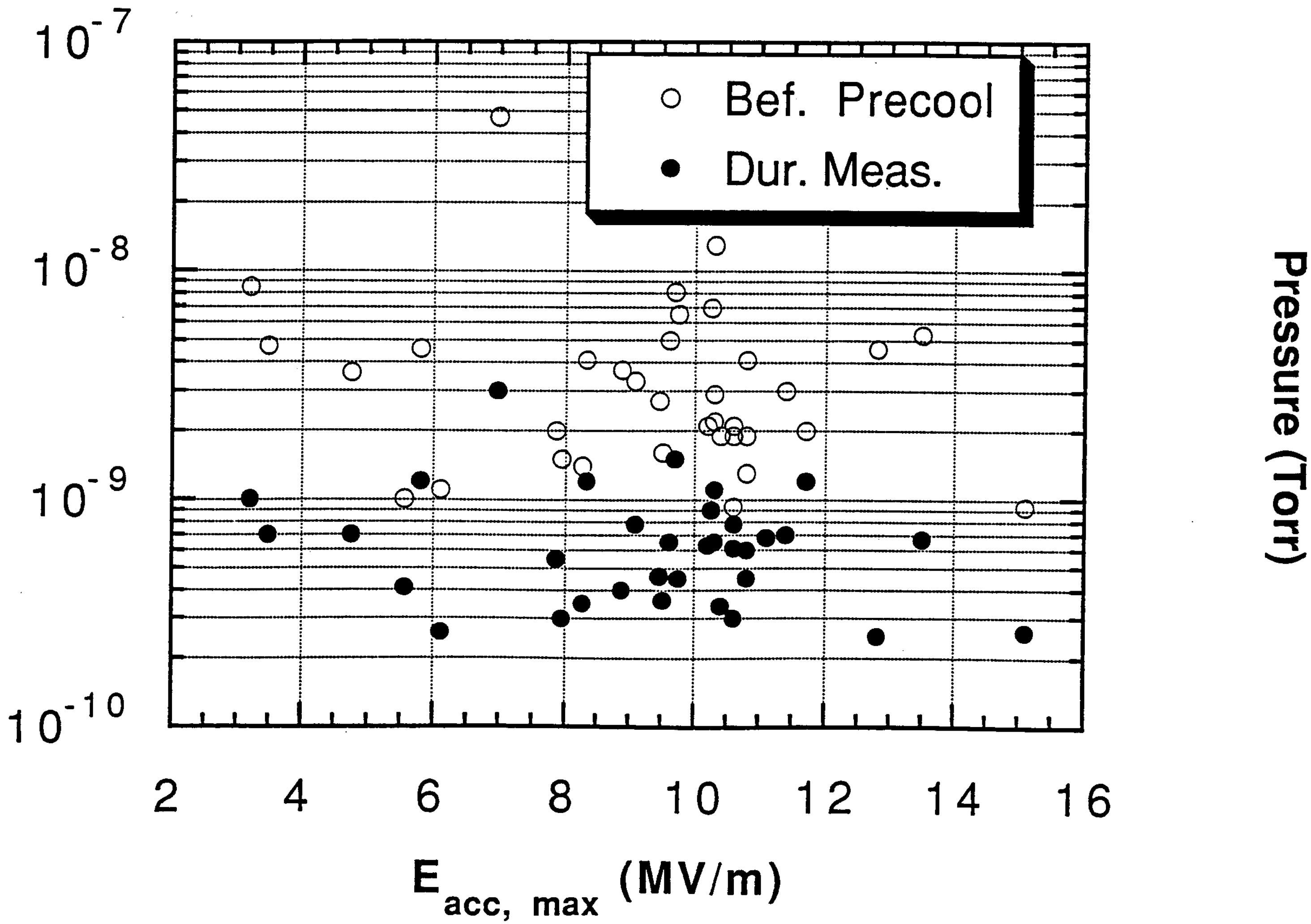


Fig. 7. Vacuum of all 5-cell SC cavities before precooling with LN_2 and during the vertical measurements as a function of $E_{acc,max}$.