The TRISTAN Superconducting cavities

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1. Introduction

In KEK, TRISTAN electron positron colliding ring has been operated at the energy of 26 GeV by using normal conducting cavities, which were installed in three of four RF sections of Main Ring (MR). For upgrading the energy to 33 GeV, thirty-two superconducting 5-cell cavities are to be installed in the last RF section and construction has been started.

For this purpose development of 500 MHz superconducting cavity has been continued in KEK since 1979[1,2], the first multi-cell cavity was built and tested in TRISTAN Accumulation Ring(AR)[3,4]. The 5-cell cavities were followed since 1985[5,6]. Figure 1 shows the maximum acceleration field at first cold test of these cavities. Recent efforts are concentrated on establishing the simple and reliable fabrication method of the cavity which has the Q-value of 2×10^9 at the field level of 5 MV/m.

Four cavities have already been constructed and tested in a vertical cryostat. Two of them are fabricated for the beam test in TRISTAN Accumulation Ring (AR) scheduled in this October. The others are the first couple of cavities for MR. The results of these cavities are reported in this paper.

2. Cavity

MR 5-cell cavity is shown in Fig.2. The diameters of irises are 170 mm and those of beampipes are 180 mm. An input port, a monitor port and two HOM ports are arranged on beampipes. Main parameters of the cavity are listed in Table 1.

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Table 1. List of the main parameters of TRISTAN 5-cell cavity.

Frequency	508.58	MHz
Total Length	1953.5	mm (MR)
	1933.9	mm (AR)
Effective length	1473.7	mm
R/Q	600	Ω
Geometrical Factor	269	Ω
E_{acc}	$16.55 \times \sqrt{PQ}$	V/m
E_{sp}/E_{acc}	1.97	
H_{sp}/E_{acc}	40.6	Gauss/MV/m
Coupling	1.5	%

AR cavities have the same shape as MR except for additional two HOM coupler ports on an end cell and for the length of beam tubes.

3. Fabrication process

Summary of fabrication process is shown in Table 2.

Table 2. Fabrication processes.

Checking of Nb sheets (water dipping).
Forming of half cells.
    spinning for AR cavities.
    deep drawing for MR cavities.
Buffing the inside surface.
Checking of surface by water dipping.
Machining of both sides of half cells.
EB welding of the equator of single cells.
Grinding the underbeads.
EB welding of irises of a 5-cell cavity.
Grinding the underbeads.
Electropolishing (80 μm).
Vacuum heat treatment.
Pre-tuning.
Electropolishing (5 μm).
Assembling in the clean room.

3-1. Material

Thickness of Nb sheets for AR cavities is 2.5 mm and 2.35 mm for MR cavities, that is due to the difference of forming method of the half cell.

The surfaces of all sheets are checked carefully, bad spots such as scratches and inclusions found by water dipping are ground off smoothly. Measured RRR of the sheets are ~100 for AR cavities and ~120 for MR, respectively.

3-2. Forming and welding

While the half cells for AR cavities were made by spinning, the deep drawing has been adopted to the MR half cells. This technique has the advantage of less reduction of the thickness of the cavity wall and getting smoother surface of the cells than those obtained by spinning technique.

After forming whole inside surface is buffed and checked by water dipping. Then the half cells are dipped in HCl to remove inclusion.

Defocused electron beam welding from outside of the cavity has been used to make cavities. "Rhombic raster welding"[7] is now under testing.

After welding the equators, the underbeads are ground. Irises are welded finally and their underbeads are also ground.

3-3. Polishing

Electropolishing processes are carried out twice to the fabricated cavity. The inner surface of the cavity is polished by 80 μm at the first electropolishing (EP I). The second treatment of 5 μm (EP II) is performed to the cavity after annealing and pre-tuning in order to remove the contaminants brought into the cavity during such processes.

These EP processes are performed in horizontal position instead of vertical one[3]. The layout of the system is shown in Fig.3. A cavity is set horizontally and pure aluminum pipe (cathode) is installed into the cavity. All ports of the cavity are sealed off. The solution, consisting of concentrated H_2SO_4 and 40 % HF in a ratio of 85:10 by volume, is fed into the cavity through the cathode up to the half level and circulated through the storage tank and the cavity during the process. Flow rate is 60 l/min. Electric voltage of about 25 volts is supplied continuously to keep optimum current density at about 50 mA/cm^2, and temperature is kept at ~30 °C during polishing. This process is done rotating the cavity at 0.4~1 rpm.

The thickness of removed layer is estimated from total current and measured by ultrasonic thickness gauge. Typically the layer of 120 μm was removed at irises and 60 μm at the equator.

After final EP, the cavity is rinsed with pure water (10 MΩ·cm at the inlet) and dipped into ultrasonic bath for 30 minutes. This U.S.B. rinsing is repeated several times. Finally, all ports and beampipes of the cavity are sealed with cleaned blind flanges, and the ultra pure water rinsings are made. The cavity is opened and assembled in a clean room (class 100).

For surface treatment of MR cavities, 30 minutes H_2O_2 rinsing in an ultrasonic bath has been adopted to MR 5-cell cavities because of the following results of surface measurements of Nb test pieces.

According to the X-ray and Auger electron spectroscopy analyses on the Nb surfaces treated by EP, CP, OP and H_2O_2 rinsing[8)], a stable and dense Nb_2O_5 layer of about 30Å is formed on the Nb surface and this layer can be a protective film which covers the active Nb surface since no additional adsorptions are detected after exposing to the air for 24 hours.

3-4. Vacuum heat treatment

After EP I, cavities are annealed in a vacuum furnace in order to be degassed and to reduce the strain received at welding. The cavity is set in a Ti box and annealed at 700 °C (900 °C for AR) for 90 minutes. Vacuum pressure at that temperature is $5\sim1 \times 10^{-5}$ Torr. Typical spectrum of partial pressures is shown in Fig. 4.

The RRR of samples before and after annealing AR cavities were compared and no change of RRR was found.

For the sake of selection the annealing temperature, some sample test is performed. The samples were removed of 90 μm by EP and CP, respectively. The difference of the amount of hydrogen gas from samples were compared (Fig. 5). Though the gas is more adsorbed by EP than by CP, it can be reduced by annealing at temperature higher than 600 °C.

3-5. Pre-tuning

Before final EP, pre-tuning is performed to the cavity in order to correct the resonant frequency and the field profile of acceleration mode. This correction is attained by deforming the cavity length inelastically.

The tuning system is shown in Figs. 6 and 7. Main parameters for calculation of deforming quantity are as follows.

Table 3. Main parameters for calculation of tuning

Coupling k/2		0.00773
Sensitivity of each cell		450 kHz/mm
Temperature dependence	T-273K	3.9 kHz/K
	273K～4.2K	655 kHz
Target frequency at 4.2 K		508.16 MHz

The cavity is hung up with three springs and evacuated (～1 Torr) for pre-tuning in order to reduce disturbance factors such as friction, deformation caused by evacuation and so on.

Field profiles of π-mode before and after the pre-tuning are shown in table 4 and Fig. 8. The profiles in lengthening the cavity up to 4 mm were also measured, but little change was observed. To get final profile, each cell needed a few times of deformation. Field irregularity of ±20 % that the fabricated cavity has could be reduced to ±1 % by this system.

Table 4. Field ratio of MR 1a and 1b.

MR-1a	Cell No. 1	2	3	4	5	expected freq. at 4.2K	Meas.Freq. at vertical test
before tuning	0.884	0.937	0.958	1.137	1.062	508.34 MHz	
after tuning	0.991	0.996	1.000	1.004	1.008	508.16	508.26 MHz
lengthening by 4mm	1.000	1.006	0.996	1.002	0.995	508.49	
MR-1b	**Cell No. 1**	**2**	**3**	**4**	**5**	**expected freq. at 4.2K**	**Meas. Freq.at vertical test**
before tuning	1.197	1.136	0.908	0.901	0.880	508.53 MHz	
after tuning	1.000	0.995	0.999	0.997	1.010	508.15	508.27 MHz

The resonant frequency of flat-π-mode could be adjusted to the target frequency within 10 kHz. There was, however, some difference between target frequency and the measured one at cold test. This is understood as follows; the cavity was hung vertically in a cryostat and accepted gravity and buoyancy from LHe. This effects was estimated to raise the resonant frequency by 80 kHz using measured elastic constant of the cavity (~100 kg/mm). For this reason the difference between expected resonant frequency and measured one is concluded to be about 40 kHz.

Length of the cavity was measured after pre-tuning. MR-1a, MR-1b are both shorter by 7 mm than designed value at the operation frequency. This problem will be solved by trimming half cells longer than the present size.

4. Cold test

The results of these cavities are summarized in Table 5 and in Fig.9 typical field dependence of Q-value is shown.

The Q-values of over 3×10^9 were obtained for all recent cavities at first cool down test. The best value of 3.8×10^9 was obtained at 2nd test of AR-2 after warming up and baking again.

Table 5. Summary of cavity tests.

Cavity No.	Structure	Fabrication & treatment	EP solution & rinsing	Q_0 at low level	E_{acc}^{max}	Q_0	Q_0 at 5 MV/m	β $(I_e/E_{sp}^{2.5})$	Comments
				x 10^9	MV/m	x10^9	x 10^9		
AR 1 (#06)	5-cell	Spinning EP(50 μm) to half cells Annealed at 900 °C	EP I fresh EP II refreshed Ultra pure water	3.2	6.4	1.1	2.5	——	Breakdown.
AR 2 (#07)	5-cell	Spinning Annealed at 900 °C	Refreshed Ultra pure water	3.3	5.8	0.7	1.3	——	Vacuum leak.
				3.8	5.7	1.1	2.0	380	Baked again.
MR test 1	Single (no port)	Deep drawing "Rhombic" EBW at the equator Annealed at 700 °C	Refreshed	3.3	9.3	0.9	2.6	——	
			Ultra pure water + H_2O_2	3.0	9.0	1.0	2.6	261	After He process(2hrs).
MR test 2	Single with 4 ports on beampipes	Deep drawing Annealed at 700 °C	Refreshed Ultra pure water	2.3	9.2	0.7	1.9	——	
				2.3	7.2	0.8	1.9	522	After He process(2hrs).
MR 1a	5-cell	Deep drawing Annealed at 700 °C	EP I refreshed EP II fresh U.P.water + H_2O_2	3.7	9.7	1.8	3.0	180	
MR 1b	5-cell	Deep drawing Annealed at 700 °C	EP I refreshed EP II fresh U.P.water + H_2O_2	3.3	7.0	2.0	2.8	517	

Maximum E_{acc} of 9.7 MV/m was obtained for MR-1a without any processing. The Q-value at this level still kept $1.8x10^9$, although emitted electron was observed. This electron current of 60 nA was measured at this field level by pick up antenna which was set on a beampipe flange and supplied voltage of 230 V.

Fowler-Nordheim plot on the electron current is shown in Fig.10. Though maximum field level of AR-1 was limited by breakdown, that of the other cavities by electron loading.

The degradation of Q_0 caused by electron loading seems to be due to the contaminants in the acid used for surface treatment. These cavities are electropolished with the same acid that had been storaged in a tank and refreshed several times by adding HSO_3F and H_2O. On the other hand, MR cavities were treated with fresh solution at the final EP. This repeated employment of the solution might have raised up the number of contaminants.

Helium processing was tried to two single cell cavities (MR test1, MR-test2) which were made by the same way as MR 5-cell cavities. Two hours of processing had almost no effect and the Q_0 at low level rather damped by 10%.

5.Conclusion

The maximum Eacc of 9.7 MV/m was obtained for the first TRISTAN MR cavity. The Q_0 at this field level was $1.8x10^9$. The performance of the other MR cavity exceeded the desired Q_0 and Eacc sufficiently.

All MR cavities which have been fabricated at the rate of two 5-cells a month are going on, they are to be measured in a vertical cryostat before installing to the horizontal cryostats. The operation of the first sixteen 5-cells are scheduled in next Autumn.

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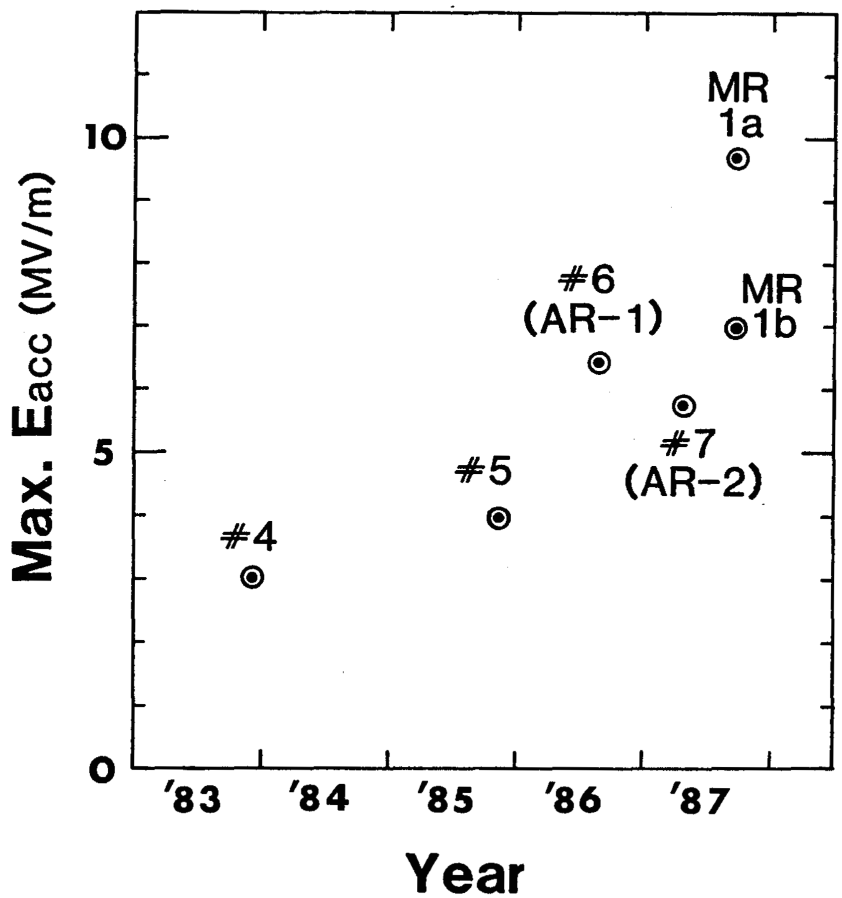

Fig. 1. Maximum E_{acc} at the first cold test of 500 MHz multi-cell cavities in KEK.

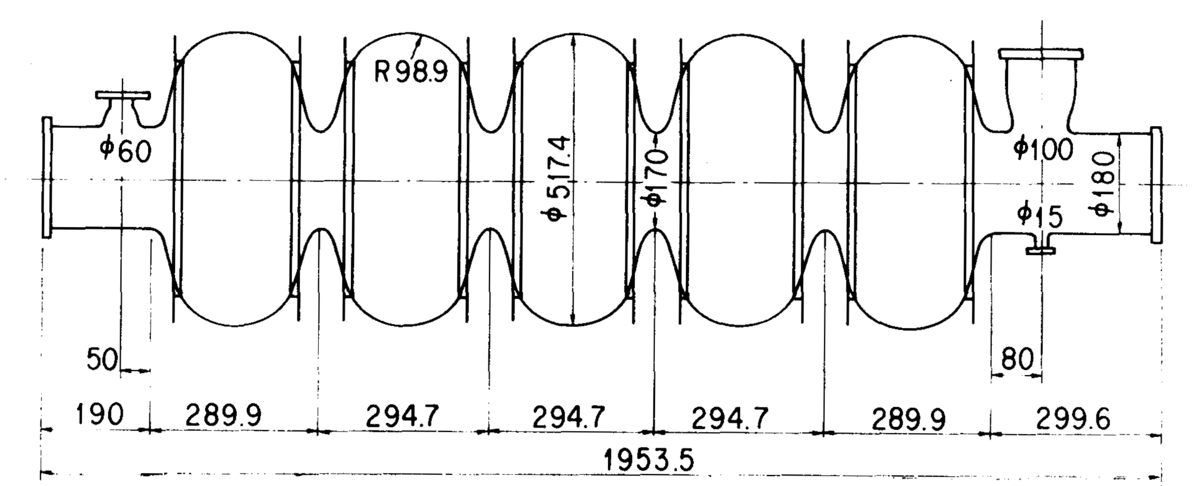

Fig. 2. The shape of 5-cell cavity for TRISTAN Main Ring in KEK.

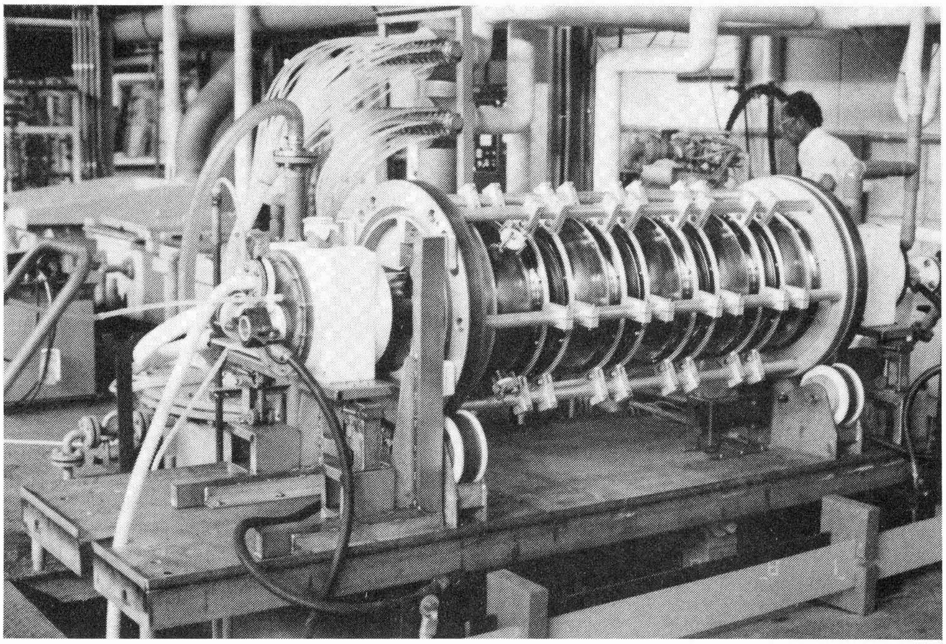

Fig. 3. The layout of electropolishing system.

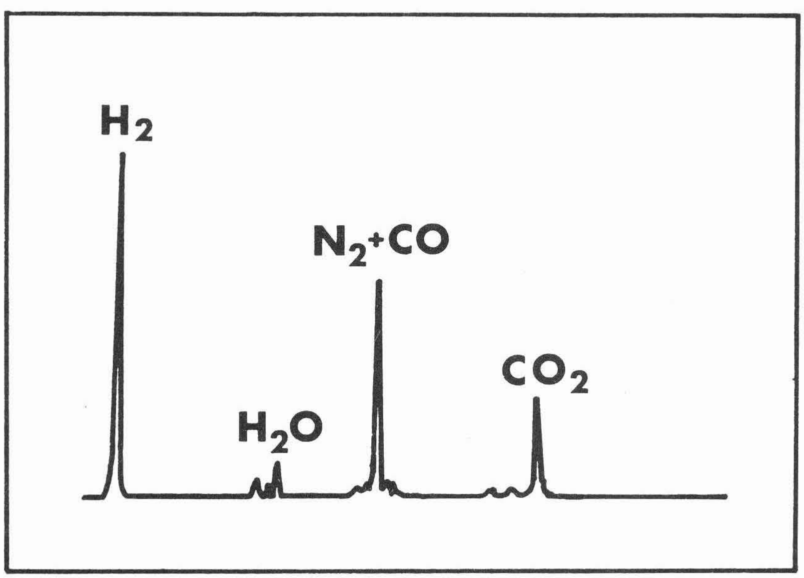

Fig. 4. Typical gas spectrum in the furnace at the pressure of 5×10^{-5} Torr. The annealing conditions were 700 °C and 90 minutes.

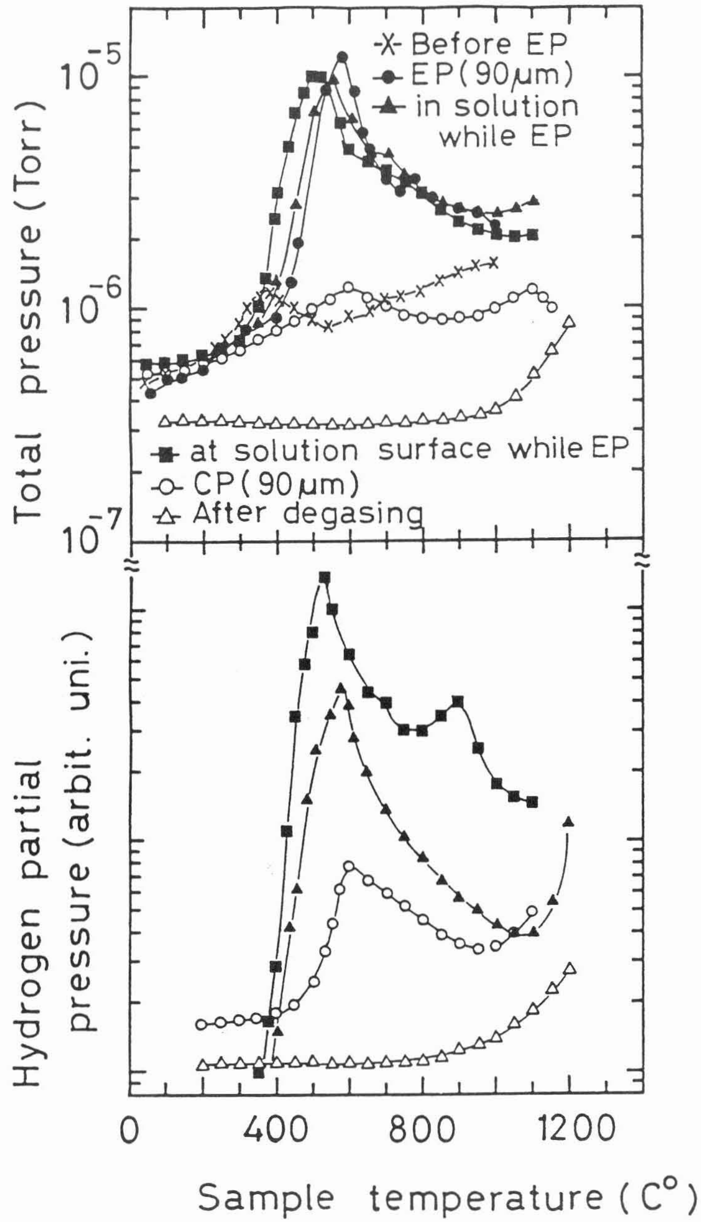

Fig. 5. Thermal desorption curve of Nb samples.

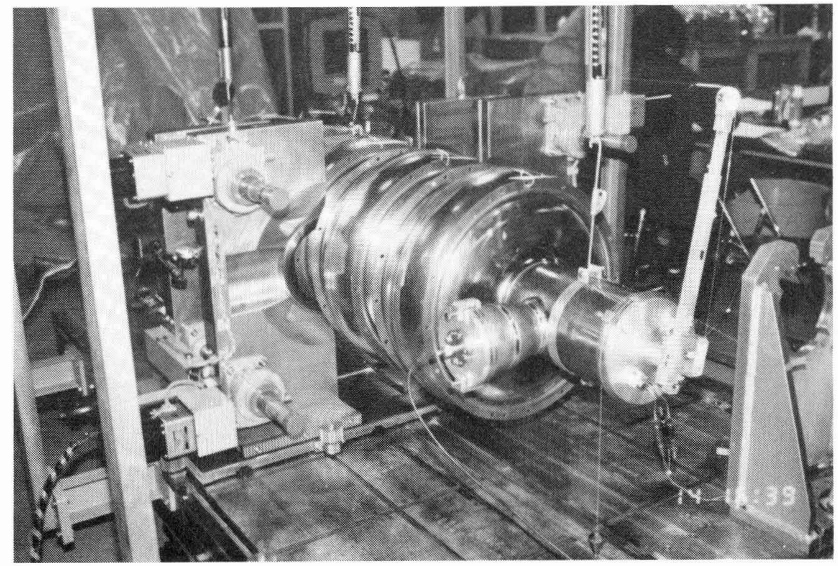

Fig. 6. The pre-tuning device.

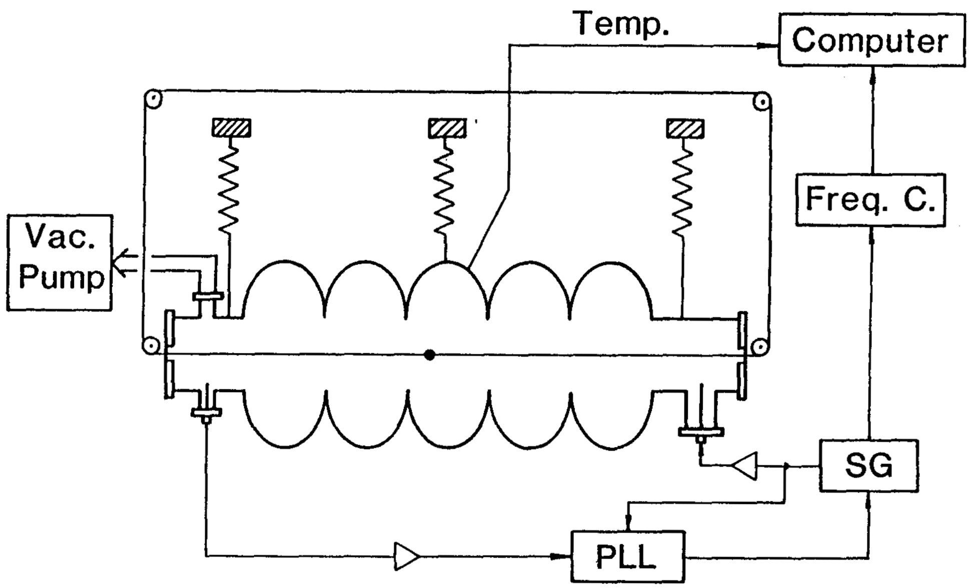

Fig. 7. The scheme of pre-tuning system.

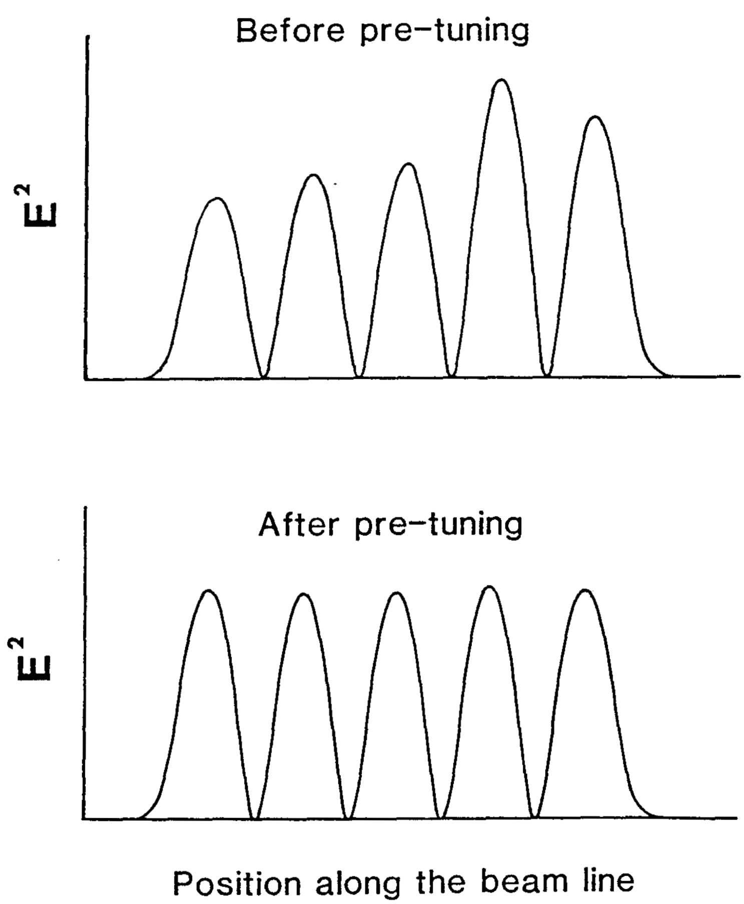

Fig. 8. Field profile before and after pre-tuning.

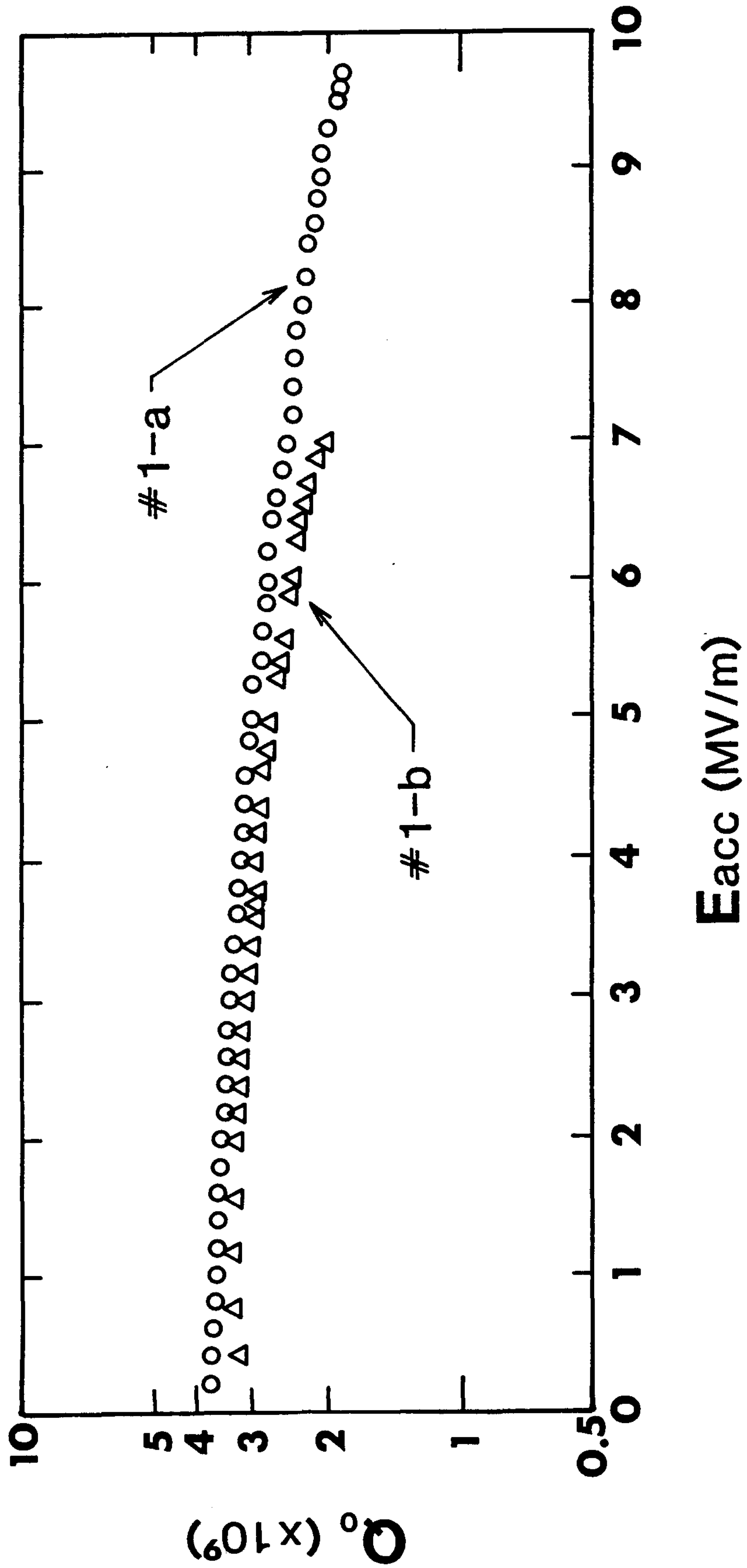

Fig. 9. Q_0-E_{acc} plots of the first MR cavities.

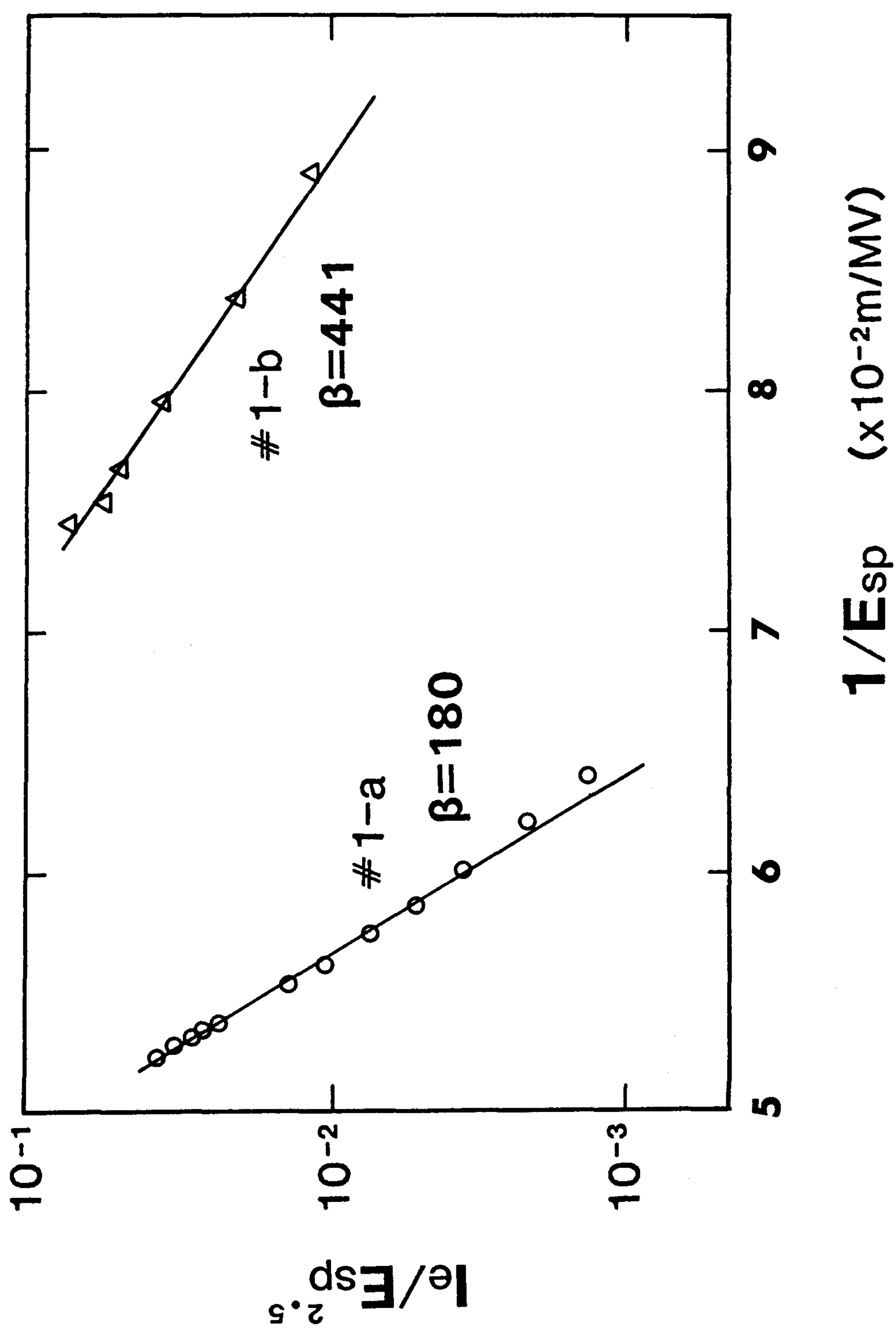

Fig. 10. $I_e/E_{sp}^{2.5}$ as a function of $1/E_p$.