PREPARATION AND HANDLING OF SUPERCONDUCTING RF CAVITIES

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1. INTRODUCTION

Superconducting RF cavities have been studied at more than twenty laboratories and universities for application to either ion accelerators or electron machines.

For ion accelerator, several types of cavities such as helix, quarter wave, split ring, interdigital resonator, etc. have been developed, and in most cases they are made of Nb or lead- plated copper. All cavities for electron machine, on the other hand, have similar shape of spherical or elliptical, and are made of pure Nb except for the Nb-sputtered copper cavities for LEP. Recent development of producing high purity Nb and preparation method of cavities has improved the cavity performance. Accelerating field of more than 20 MV/m with high Q-value is achievable for single cell cavities at 1500-3000 MHz, for multi-cell cavities Eacc of 10 MV/m is obtained at any frequency range[1].

These excellent results in the laboratory tests make it possible to consider a superconducting cavity as a real tool for particle accelerators and large scale projects are now under way. For example, at KEK the first sixteen 5-cell cavities have been installed to the TRISTAN Main Ring and operated successfully. The last sixteen cavities have already been completed and will be operated in this autumn[2]. At DESY, CERN and CEBAF, construction of cavities have been started respectively[3,4].

In these large scale applications, reliable and reproducible production of cavities is needed not to disturb the project schedule.

In this paper, recent preparation methods of superconducting cavities used in various laboratories and universities are introduced and the problems of the cavity fabrication at KEK, as an example of mass production, are reported.

2. PREPARATION AND HANDLING

For large scale applications, the technique of industrial mass production of SC cavities has to be developed. Today, Eacc of 10 MV/m has been obtained by prototype cavities of multi-cell structure, but reliability and reproducibility for achieving this field level seem to be rather poor. Many tests with single cell cavities suggest that the field limitation around 10 MV/m is due to the dust particles or contaminations on the cavity surface, and that not only the use of high purity Nb but also strict control of the cavity surface and clean working environments are essential to improve the reliability of the cavity performance.

The fabrication procedures used by various laboratories differ from in many details, but consist of the same basic processes as shown in Table 1 for electron accelerators and in Table 2 for ion machines. For large scale production these processes have to be made with more reliability.

Material

Checking and selection of raw Nb sheet are important process where mechanical properties, waviness, thickness and surface defects have to be checked as well as RRR.

RRR is well known as a convenient gauge of thermal conductivity of Nb at low temperature, Nb with higher RRR >100 is used at every laboratory as shown in Table 1. Today Nb sheets with RRR of 100-300 are commercially available. This industrial success of increasing RRR is due to making a high purity Nb ingot by increasing the melting times, slower melting rate and improvement of furnace vacuum[2,5]. Further improvement of RRR is achieved by titanification or yttrification to obtain RRR of 600 [5].

Inhomogeneous distribution of mechanical properties and thickness of a sheet leads to the distortion of the formed cell. This distortion along the welding plane is a severe problem of welding the cavity with defect-less seams. Mechanical properties of Nb such as the yield strength and elongation are very sensitive to the purity, production processes and the annealing conditions[5]. To obtain the desired uniformity of the sheet properties, the

Table 1: Fabrication procedure for electron accelerators.

Laboratory	Los Alamos	U.Wuppertal	Cornell U.	Saclay	KEK	DESY	CERN
Frequency (MHz) Number of cell	805, 3000 1	2995 1 / 5 / 20	1500 1	1500 1 / 5	508 5	500 1 / 4	351 4
Material RRR Checking	>200 visual	100 rust,visual	>300 visual	160 visual	110-180 rust,visual	200-300 rust,anodize	212-224 rust,visual
Forming Buffing Checking	deep draw No visual	deep draw No visual	deep draw No rust,HCl,H_2SO_4	hydro form No endoscope	deep draw Yes HCl,rust	spinning No vis,anodize	spinning No vis,ano,CP(70)
Welding beam from Grinding seam	outside No	out(iris),in Yes	in,out(equa.) Yes,No(equa.)	inside No	outside Yes	in, out No	inside No
Surface treatment Removed thickness (μm)	C.P. 100	C.P. 200	C.P. 75	C.P. 50	E.P. 88	C.P. 50	C.P. 100
Rinsing water (MΩ-cm) Duration & times Ultra sonic bath H_2O_2 rinsing	under con- struction No No	18 3 times Yes No	18 10times, 1.5H Yes Yes	18 20min Yes No	10 18 5000L/4H, 500L Yes Yes	18 20min x 4times Yes No	10 18 8000L/2H, 550L No No
Heat treatment	No	1250°C x 8H	1350°C x 4-8H	No	(700°C x 1.5H)	No	No
Clean room (class) Drying before assembling Vacuum (torr) Baking	10 No 10^{-6} No	10-100 Yes $<10^{-7}$ No	10-100 Yes $<3x10^{-8}$ No	100 Yes 10^{-8} No	<100 No $<10^{-8}$ 110°C x 10H	100 No $<10^{-7}$ No	100 pumping $<10^{-7}$ No
Lab. test Highest Q_0 Maximum Eacc (MV/m) Limitation Processing & its duration	Not yet	5-10 x 10^9 27 / 13 / 7 BD / FE / FE No	1-3 x 10^{10} 25 FE He 0.5-1H	2 x 10^{10} 23 / FE RF, He 0.5H	3-4 x 10^9 >11 FE No	No Test	No test
After fully equipped Clean room for Full assembling (class) Highest Q_0 Maximum Eacc (MV/m) Limitation Processing & its duration		10-100 9 X 10^9 / 6 / 5 FE He		100	100,gas flow 2 X 10^9(8MV/m) 9 FE RF 2-4H	100 2.8 X 10^9 9 / 5 FE He 1 day	10000,gas flow 3.3 X 10^9 9 FE RF 1-20H

production processes from melting ingots to rolling Nb products have to be controlled sufficiently.

Defects and impurities on the sheet surface, which are inspected visually or emphasized by rust checking with immersing the sheet in water or 1%-HCl, or by anodizing in a NH_4OH bath, are ground off carefully. This process should be taken before material annealing.

Table 2: Fabrication procedure for ion accelerators.
Details of plating processes are described in [6].

Laboratory	A.L.Munich U.	U.Washington	JAERI
Frequency (MHz) Number of cell	170 Reentrant	150 QWR	130 QWR
Material RRR Checking	Pb/Sn-Cu No	Pb-Cu visual	Nb >80 visual
Forming Buffing Checking	plating	plating	machine Yes visual
Welding beam from Grinding seam			in, out Yes
Surface treatment Removed thickness (μm)			E.P. 80-120
Rinsing water (MΩ-cm) Duration & times Ultra sonic bath H_2O_2 rinsing	 No	5 No	18 2.5H Yes Yes
Heat treatment	No	No	1000°C x 6H
Clean room (class) Drying before assembling Vacuum (torr) Baking	No No 10^{-5} No	100 Yes 10^{-7} 80°C x 12H	1000 Yes 10^{-7} 75°C x 1day
Lab. test Highest Q_o Maximum Eacc (MV/m) Limitation Processing & its duration	 7×10^8 6.1 FE He, RF 3H	 5×10^8 3.5 FE He, RF 1H	 2×10^9 7 FE He, RF 0.5-1H
After fully assembled Clean room for Full assembling (class) Highest Q_o Maximum Eacc (MV/m) Limitation Processing & its duration	No	100	No

Fabrication

Forming and welding methods of Nb cavities are summarized in [7]. As shown in Table 1, deep drawing (DD) and spinning (SP) method are usually adopted to form half cells.

At KEK, DD was tested and compared with SP before making 320 half cells for TRISTAN MR. Because of following advantages for such mass production, DD was selected; less attenuation of thickness (Figure 1), less inclusions, smoother surface and no need of well-trained specialist. On the other hand, larger sheets and better uniformities of both material thickness and mechanical properties are required for DD than those for SP.

Surface checking of formed cells is an important process, thorough inspection is made at all laboratories. Defects and impurities are ground off carefully and HCl and H_2SO_4 rinsing are followed at Cornell. In KEK, after whole inner surface of half cells is mechanically polished, HCl rinsing is performed. At CERN, 1st chemical treatment of 70 μm is made to formed half cells.

Great care has to be taken for welding cavities to get a defect-less inner seam. The seam with sputtering beads, micro cracks, poor penetration and pores can be the causes to limit the accelerating field. In general, the allowance of optimum condition to obtain a good inner welding seam is very severe. For example, if the thickness of Nb sheet is 2 mm, then the allowed mismatch of the diameter and thickness along the welding seam may be less than 0.1-0.2 mm. To satisfy this requirement, high precision and reproducibility of forming technique is required as well as the uniformity of material thickness.

Practically, various style of welding procedure have been tried to obtain good seams as shown in Table 1. In Wuppertal, the irises of cells are welded from outside and the equatorial seams are from inside. Reversely, the irises are welded from inside and the equatores are from outside at Cornell with rhombic raster technique[7]. Careful inspection of the welding seam and, if necessary, mechanical grinding are usually performed. At DESY, welded cavities are tumbled to remove sputtered beads[8]. Because of the wider tolerable parameters, internal welding with small inner gun, which is performed at

CERN[9], is advisable for large size cavities. But for smaller ones, development of new technique will be needed in the future. The use of much higher RRR materials will require the improvement of welder vacuum not to degrade RRR of the heat affected zone.

Surface Treatment

The surface are treated either by buffered chemical polishing (CP) or by electropolishing (EP) and removed by 50-100 μm. In Table 1, total removed thickness of primary and final chemical treatments are given.

The surface roughness of greater than 0.5 μm and scratches enhance the secondary electron emission coefficient of Nb surface below 1.5 KeV[10] as shown in Figure 2, in which the coefficients of the buffed (MP), scratched and etched (rough) Nb surface are compared. In general, the roughness of chemical polished surface is an order of 1 μm, on the other hand, that of electropolished is 0.2 μm. In this sense, electropolishing has an advantage for the reduction of electron emission, but in the range of Eacc up to 10 MV/m there seems to be little difference of the cavity performance between CP and EP.

At KEK, whole inner surface of the half cells is removed by 30 μm with emery papers #80-800 before electropolishing in order to eliminate the scratches and to obtain smoother surface. The roughness of electropolished surface depends on that of before the polishing as shown in Figure 3, so that before the polishing, the surface should be finished with the emery paper which has the number of more than #800. On the other hand, much pollution with the abrasive material is left on the cavity surface and contaminate the acid mixture used for chemical treatment. This contamination causes a severe problem for the control of the mixture.

Quality control of acid mixture is an important factor for large scale production. Large amount of mixture must be stored for long time and be used for polishing many cavities. Contaminations from not only cavities but the materials of a polishing system may be condensed in the mixture and left on the cavity surface. To minimize the contaminations, the materials of the

polishing system should be selected carefully and cavities have to be degreased sufficiently before polishing. A simple way for the concentration check of the mixture has to be established.

In the electropolishing system for TRISTAN cavities, three kinds of Teflon namely PTFE, PFA and PVDF have been chosen as the materials for all parts such as a 1000 liter acid tank, pipes, seal gaskets, etc. A PTFE filter is equipped to reduce the contaminations in the mixture. Furthermore, to minimize the impurities brought into the mixture with cavities, 100 liters of acid is used for primary polishing (3 μm) and then thrown away. Concentration of the mixture is checked before every polishing process by a sample test where the resistivity of mixture is measured.

Another problem of contaminations is the creation of sulfur during electropolishing like as the creation of phosphate during buffered chemical polishing[11]. In the KEK system, 85% of contaminations precipitated in the mixture tank is sulfur. The effects of the sulfur to the cavity performance are still unknown, but some solution to this problem has to be found in the future.

Heavy electropolishing creates the hydrogen rich layer on the cavity surface and causes to the degradation of the Q value. Heat treatment at >600°C has to be followed for degassing after the heavy electropolishing[12].

Rinsing and Clean Environment

Rinsing after chemical treatment is considerably important process to reduce the field emission. Ultra-pure water with a resistivity of 18 MΩ-cm is usually used under ultra-sonic agitation. At CERN, a beneficial improvement that the onset of field emission goes up to >5 MV/m without additional RF and He processing by rinsing the cavity with large amount of pure and ultra-pure water has been reported[9].

The water system for pure and ultra-pure water are described in detail by P. Kneisel[13]. The quality of the output water and the life of the components depend on that of the input water, so that the combination of system com-

ponents should be selected so as to match the quality of the input water. The quality of output water such as the resistivity, number of particles, organisms, silica, total organic carbon, etc. should be monitored periodically.

Monitoring of water resistivity is useful to control the rinsing process. In the rinsing procedure for KEK TRISTAN cavities, six steps are successively performed as shown in Table 3, where a pH meter or a resistivity meter is used to inspect the rinsing processes. During the overflow rinsing for 170 min., the resistivity of the water which comes out from the cavity increases exponentially and reaches to the same value as that of the input water at the end of the rinsing[14].

H_2O_2 rinsing is adopted at Cornell and KEK. The effect to the cavity performance is still not clear but H_2O_2 rinsing removes carbon on the surface and forms the stable Nb_2O_5 layer[15], which may be expected to reduce field emission. The rinsing would rather be performed under ultra-sonic agitation.

Rinsing with dust-free methanol (LSI Class 1/2) is applied to the cavity after heat treatment at Cornell. Methanol rinsing were adopted as a final rinsing to the test cavities at KEK, but has been abandoned for TRISTAN cavities, because of the problems of the safety and waste disposal.

Intensive studies of SC cavities with thermometric diagnostics show that the dust particles carried into the cavity and the condensation of residual gas behave as electron emission sources[16,17]. The use of clean rooms of Class 100 is now popular to assemble the superconducting cavities and produces satisfactory results in laboratory tests(Table 1). But it may be difficult for industrial mass production to apply the same procedure of clean work as for the test cavity, because clean work is contrary to the efficiency of the work. Many steps of assembling such as equipping input and HOM couplers, cavity alignment and installation to the cryostat should be done cleanly and speedily by well-trained workers.

In many laboratories, degradation of Q and Eacc has been observed after opening the cavity to atmosphere. This degradation is believed to be due to the dust coming into the cavity during re-assembling. To avoid this risky

opening, cavities are to be measured after full equipping at DESY and CERN, ceramic blind-plates for the insulation of vacuum between the cavity and the demountable input coupler are used at CEBAF not to open the cavity after laboratory tests .

No degradation of performance up to Eacc of 10 MV/m has been observed by a single cavity at KEK in which the activated surface by RF measurement was

Table 3: Rinsing procedure of 508 MHz 5-cell cavities at KEK.

Overflow rinsing for 30 min.		
	demineralized water	10 MΩ-cm
	flow rate	20 l/min.
	continued until pH > 3	
Showering for 30 min.		
	demineralized water	10 MΩ-cm
	flow rate	20 l/min.
	continued until pH > 5	
H_2O_2 rinsing for 80 min.		
	concentration of H_2O_2	10 %
	with rotating a cavity	40 min.
	with ultra-sonic	40 min.
Showering for 10 min.		
	demineralized water	10 MΩ-cm
	flow rate	20 l/min.
Overflow rinsing for 170 min.		
	demineralized water	10 MΩ-cm
	with ultra-sonic agitation	
	use of the resistivity meter	
	flow rate	20 l/min.
Ultra-pure water rinsing		20 min. x 2 cycles
	water resistivity	18 MΩ-cm
	with ultra-sonic agitation	

exposed to filtered (>99.99999999 % removal of 0.05 μm particles) air and N_2 gas(Figure 4). Similar results has been obtained for clean air at Cornell[18]. These results suggests that pressurizing and counter flowing of pure N_2 gas during the assembly are useful to prevent dust particles from coming into the cavity for not only assembling after a laboratory test but re-assembling after any trouble.

As shown in Table 1, rinsed cavities are dried in a clean room before evacuation at several laboratories. It does not seem to be necessary. After rinsing, cavities are pumped down without drying at CERN and KEK. No degradation of cavity performance has been observed at KEK by baking at 110°C for 10h. Baking at 275°C for 6h was made to a 1.5 GHz cavity at Cornall with flowing Ar gas surrounding the outer wall to prevent oxidation, and no change of the performance was observed[16].

Heat Treatment

The beneficial effects of a high temperature treatment have been obtained at Wuppertal and Cornell. Details of the treatment will be reported by H. Padamsee in this workshop. 1.5 GHz single-cell cavities were surrounded by Ti sheets and heated at 1350°C for 4-8h in a UHV furnace. The Ti sheets were covered with an outer Nb box to prevent Ti vapour from reaching the inner surface. After the heat treatment, the outer wall of the cavity was chemically etched to remove the Ti-rich layer. This skillful heat treatment improved the Eacc of chemical polished cavities by a factor of 2, and Eacc of 22 MV/m was achieved[17].

This high temperature heat treatment is performed to rather small 1.5-3 GHz cavities but not to larger size cavities due to the absence of the big furnace with good vacuum pressure. At KEK, heat treatment at 700°C for 1.5h is made with a Ti box under several x 10^{-5} torr. The purpose of the treatment is degassing of H_2 which is absorbed on the surface during electropolishing[12].

Even such a low temperature heat treatment is able to repair the cavity performance. At KEK, the surface of a prototype cavity was contaminated with plasticizer which dissolved into rinsing methanol from vinyl tube, and

degradation of the performance was observed. This degradation could not be recovered by electropolishing. After the heat treatment was given to the cavity with subsequent electropolishing, both Eacc and Q could be recovered.

3. CAVITY PRODUCTION AT KEK

Three years ago, the construction of thirty-two 508 MHz 5-cell SC cavities was started for TRISTAN Main Ring. In the early stage of the construction period, our efforts had to be concentrated to improve the reliability and reproducibility of fabrication processes for such large scale production. R&D of these processes will be described in [14].

For all Nb sheets, the following items are checked; mechanical properties, thickness, surface impurities and RRR. The thickness of each sheet is measured at 57 points, and the sheets which have the inhomogeneity of a thickness of more than 0.2 mm are rejected as long as it can be allowed. Before annealing, all sheets are immersed into a water bath for more than 10h to find rust on the surface. Figure 5 shows the distribution of RRR for all Nb sheets used for TRISTAN cavities.

Table 4: Electropolishing parameters at KEK.

Acid mixture		
	98% H_2SO_4 / 40% HF = 85 /10 (by volume)	
	1000 liters / four 5-cell cavities	
Optimum parameters		
	current density	30 - 100 mA/cm^2
	temperature	25 - 35 °C
	flow rate of acid	60 l/min.
	rotating speed	0.4 - 1.2 rpm
	supplied voltage	25-27 Volts

After forming, whole inner surface of the half cells is removed by 30 μm with emery papers. The half cells are dipped in a HCl bath (18% concentration) for 3h, the rust checking is performed by immersing them in a water bath for more than 10h.

The welding planes are guarded with silicon rubber caps and stored in a special handling box. The cells are welded from outside with a 40 kV defocused electron beam at the pressure of $<10^{-4}$ torr. To find the optimum beam current and focusing parameters, sample tests are usually performed before welding. All inner seams are ground off smoothly and inspected visually using an optical system.

One cavity is electropolished twice; before annealing (80 μm) and after pre-tuning as a final treatment (5 μm). The use of horizontal and rotational electropolishing system[12] makes it possible to electropolish 5-cell cavities without harmful grooving by H_2 gas [19] and to eliminate the polishing process of the half cells.

1000 liters of sulfuric and hydrofluoric acid mixture is used for polishing four 5-cell cavities within 4 months. To minimize the contaminations of the mixture, the polishing system is made of Teflon and a primary polishing (3 μm) is performed. The composition of the mixture is always checked by a sample test before polishing, and if necessary, the mixture is refreshed by adding fluorosulfuric acid to keep the optimum polishing conditions listed in Table 4. Above all, the current density is the most important parameter, and to keep it to the optimum value, 25-27 Volts is supplied.

Table 5: Quality of the ultra-pure water for TRISTAN cavities.

particles (> 0.2 μm)	19 counts/ml
(> 1 μm)	0 counts/ml
living organisms	0 counts/ml
silica	25 ppb
total organic carbon	<50 ppb

After the final electropolishing, the cavity is rinsed for 5h with 5500 liters of pure and ultra-pure water as described before. The ultra-pure water system consists of reverse osmosis, ultraviolet sterilization, mixed-bed polisher and UF filter unit. The quality of the ultra-pure water are listed in Table 5.

3-1. DEFECTS ON THE SURFACE

As shown in Figure 6(a), The designed specification of 5 MV/m has been achieved in thirty cavities without any rework. Eacc of 10 MV/m were obtained by nineteen cavities at the 1st vertical test without any processing, Eacc of other cavities were limited by strong field emission or thermal breakdown.

To eliminate the defects, the surface of the cavities were visually inspected at every fabrication stage; material, half cells, welded single-cell cavities, welded 5-cell cavities and electropolished 5-cell cavities. In spite of these strict surface checking, Eacc of two cavities were limited by thermal breakdown due to surface defects and did not achieve 5 MV/m.

At the 1st vertical test of #6a cavity, Qo switching was observed at 1.8 MV/m and Eacc was limited at 2.4 MV/m (Figure 7). The field gradients of five passband modes were measured and compared to find the breakdown cell. In Figure 8, calculated field profile along the beam axis and the positions of maximum Eap for all modes are shown also. Maximum Eap of the modes, where the highest Eap was built at the center cell were limited at 5 MV/m. Then 384 carbon resisters were affixed to locate the bad spot on the center cell. After warming up, the cavity was visually inspected and a large fissure (8 cm) was confirmed near the equatorial welding seam (Figure 9). X-ray photographs could give no informations. This fissure was ground off with subsequent electropolishing and measured again. The Eacc of the cavity could be improved by repeating these processes twice and reached to 7.6 MV/m. After the first rework, the fissure seemed to be removed completely, but the Eacc were limited at 3.5 MV/m and the carbon thermometers indicated the heating spot at the same position as before. To eliminate the fissure completely, it was necessary to remove this spot by 0.3 mm.

The position of such a defect can be confirmed by the the conventional thermometric diagnostics, but the size and depth are not able to be defined by them. It is desirable to develop some device which can be used at room temperature to know whether the defect is eliminated completely or not.

At the 3rd SC Workshop, the test of a prototype device using scanning laser acoustic microscope(SLAM) with high resolution was reported, where the device had been applied to pure Nb plates and the defects not only on the surface but on the subsurface could be confirmed[20]. If such kind of device is modified for the completed cavities, production yield of high quality SC cavities would increase so much.

3-2. CLEAN ENVIRONMENTS

Figure 6(c) shows the maximum Eacc of fully equipped cavities at horizontal tests. Though sufficient RF aging has not given to the cavities, some of them show the degradation of Eacc and Q_0 as compared with that of the vertical tests.

Between the tests of vertical and horizontal, the following processes are there; vacuum breaking with slow N_2 gas feed (0.5 l/min.), pairing two cavities and equipping HOM couplers in a clean room (Class 100), installing into a horizontal cryostat and mounting input couplers in a movable clean box (Class 100), evacuation and vacuum leak test, vacuum breaking with slow N_2 gas feed, equipping gate valves in another movable clean tent (Class 1000), evacuation and leak test. Before cold tests, the input couplers are aged at room temperature.

The input couplers and gate valves were equipped in a 'normal' assembly hall, two movable clean huts were used and N_2 gas was always fed into the cavity against slipping dusts into the cavity. However, just before connecting the input coupler with the cavity, the ports had to be exposed to 'normal' air for about 1 minute.

This risky opening may be a main reason for the degradation of cavity performance. Another possible cause may be the sputtered substances from input couplers.

The input couplers rinsed with ultra-pure water were RF aged and kept in

a vacuum until equipped to the cavities. However, additional aging was needed before and after cooling down the cavity. At the aging of some cavities, shining 'dusts' were found just under the input couplers. In another case, the surface of a cavity was sputtered with copper from the input coupler due to sparking.

He processing is well known as a final processing technique for SC cavities, however, the process has not been adopted to TRISTAN cavities. The application of He processing to real SC accelerators may need special care as follows; careful protection system for arcing or heating of high powered input couplers and complete removal of residual He gas in vacuum system in order not to prevent the leak test of accelerator vacuum.

CONCLUSION

Today, field gradients of more than 20 MV/m are obtained by 1.5-3 GHz single cavities, for multi-cell cavities Eacc of 10 MV/m are available at any frequency range. But it should be emphasized for large scale applications to fabricate the cavities with much higher reliability and no rework. The successful construction of thirty-two cavities for TRISTAN at KEK is due to the careful checking of the surface and quality control of all processes against the surface defects and contaminations.

Eacc of 5 MV/m has been achieved by 94% of TRISTAN cavities at the 1st cold test, but 6% of them had to be reworked because of the surface defects. These defects could not be detected by an X-ray photograph or visual inspections during the fabrication processes.

For fabricating superconducting cavities with much higher reliability, it is desirable to develop some method which can be used for a welded cavity at room temperature to confirm defects without cold measurements.

Continuing progress in achieving higher field gradients of superconducting RF cavities will require much severer control of fabrication processes and clean environments to keep its performance. For successful and stable operation of superconducting cavities, whole system not only for fabrication and

assembly but for operation and protection in the accelerator should be designed not to degrade the cavity performance.

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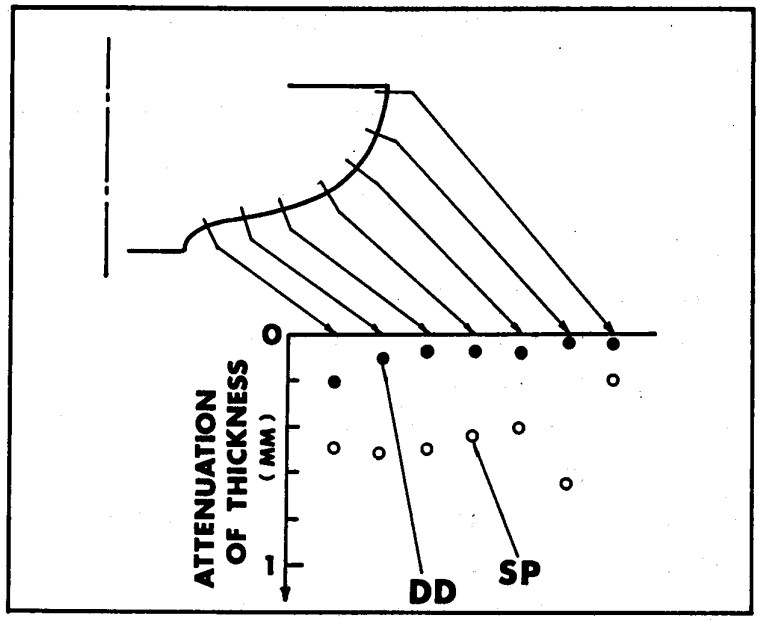

Figure 1: Comparison of the thickness attenuation between deep-drawing(DD) and spinning(SP); large attenuation causes the variety of thickness at the welding planes.

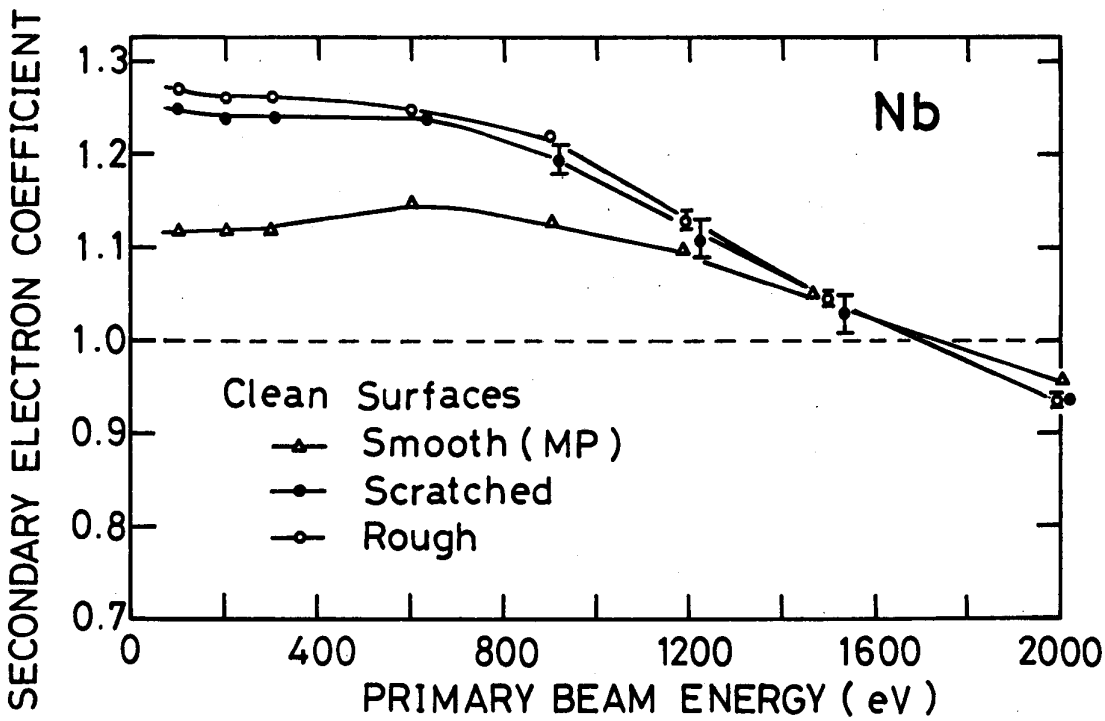

Figure 2: Secondary electron emission coefficient of Nb; mechanically polished(MP), scratched and etched (rough) surface (ref.[10]).

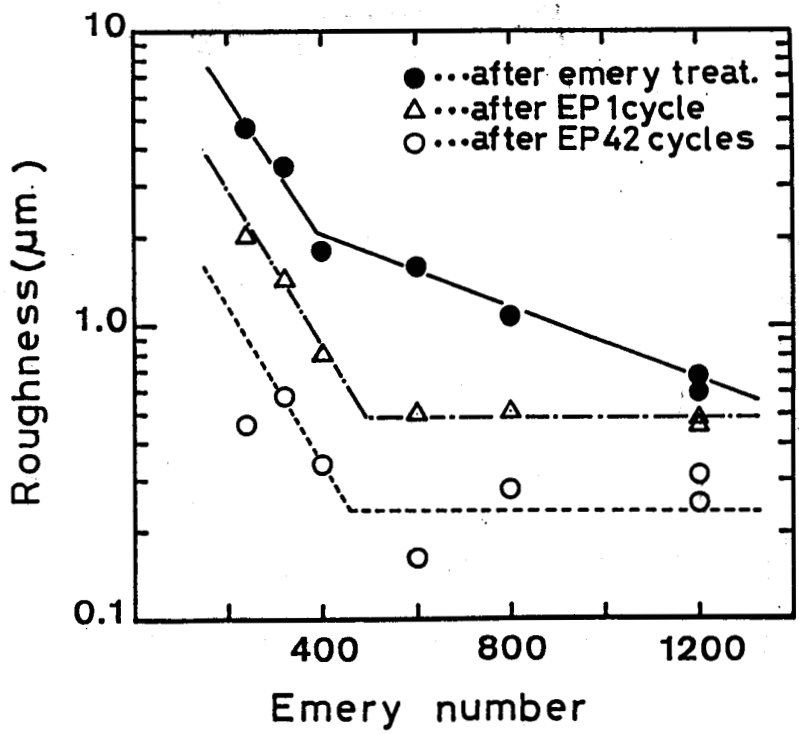

Figure 3: Effect of emery number to the surface roughness; after mechanically finished with various emery papers, and after subsequent electropolishing (1 cycle = 2 μm).

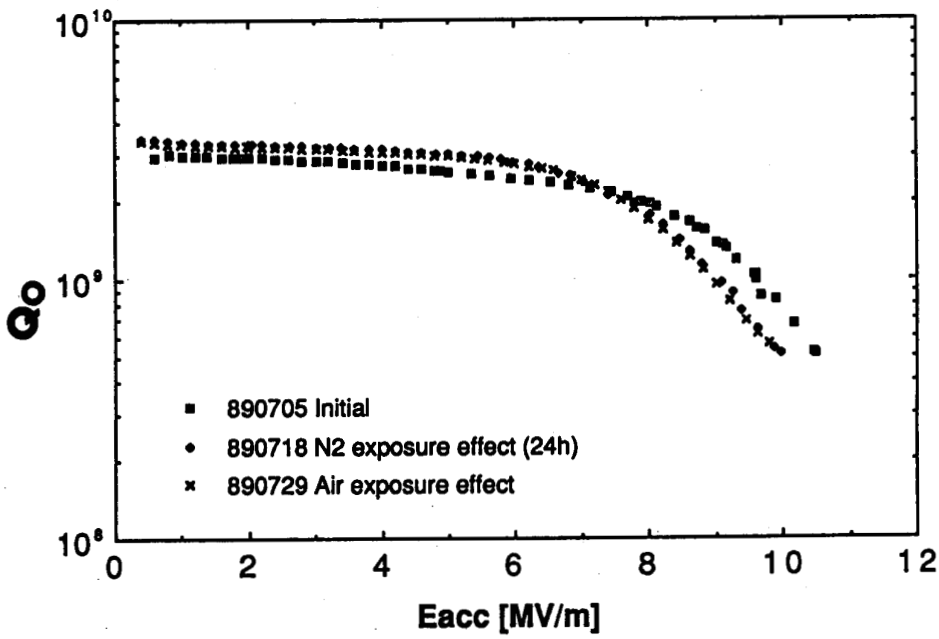

Figure 4: Performance of a single cavity exposed to filtered N2 and air at KEK.

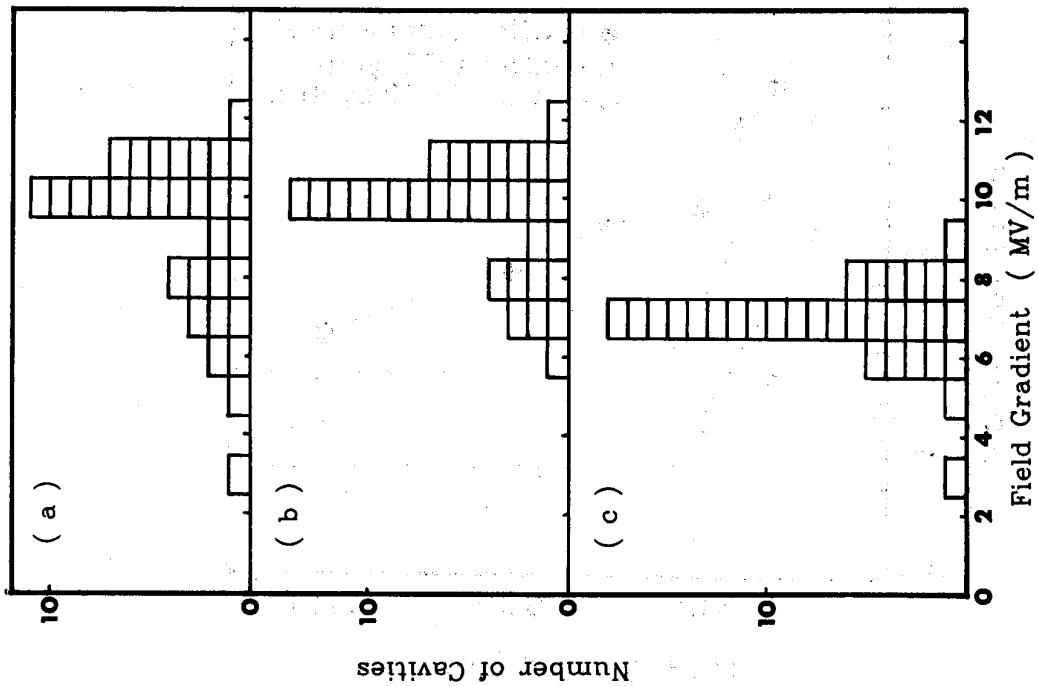

Figure 6: Eacc of TRISTAN cavities; (a) 1st cold test, (b) after grinding or re-treatment, (c) after fully equipped (Horizontal Test).

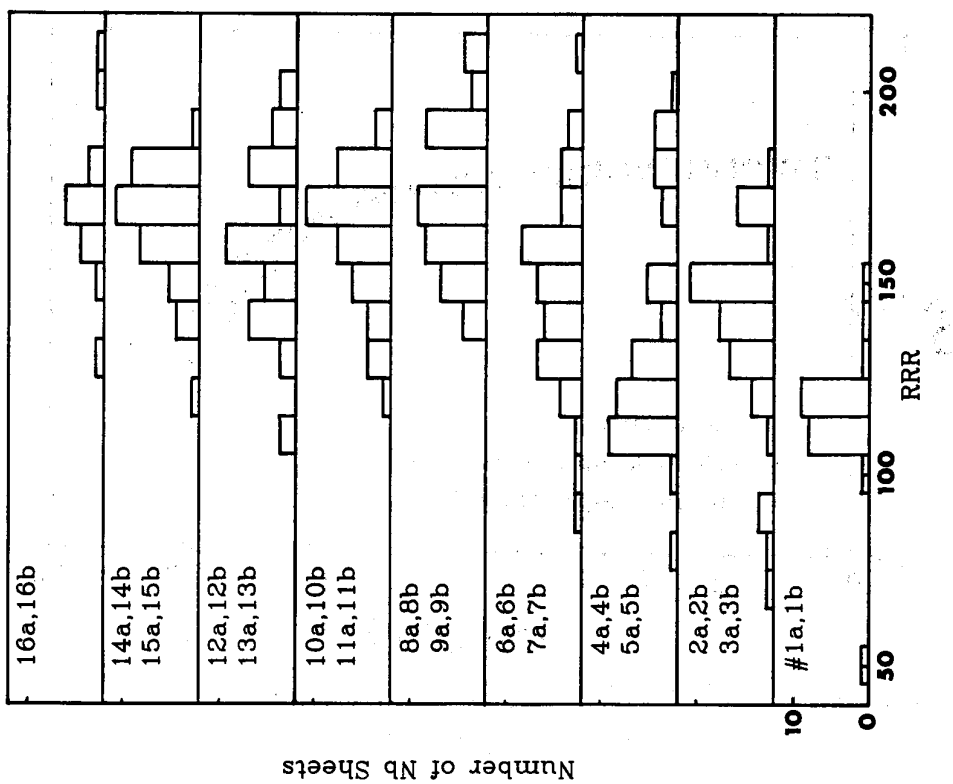

Figure 5: RRR of Nb used for TRISTAN cavities.

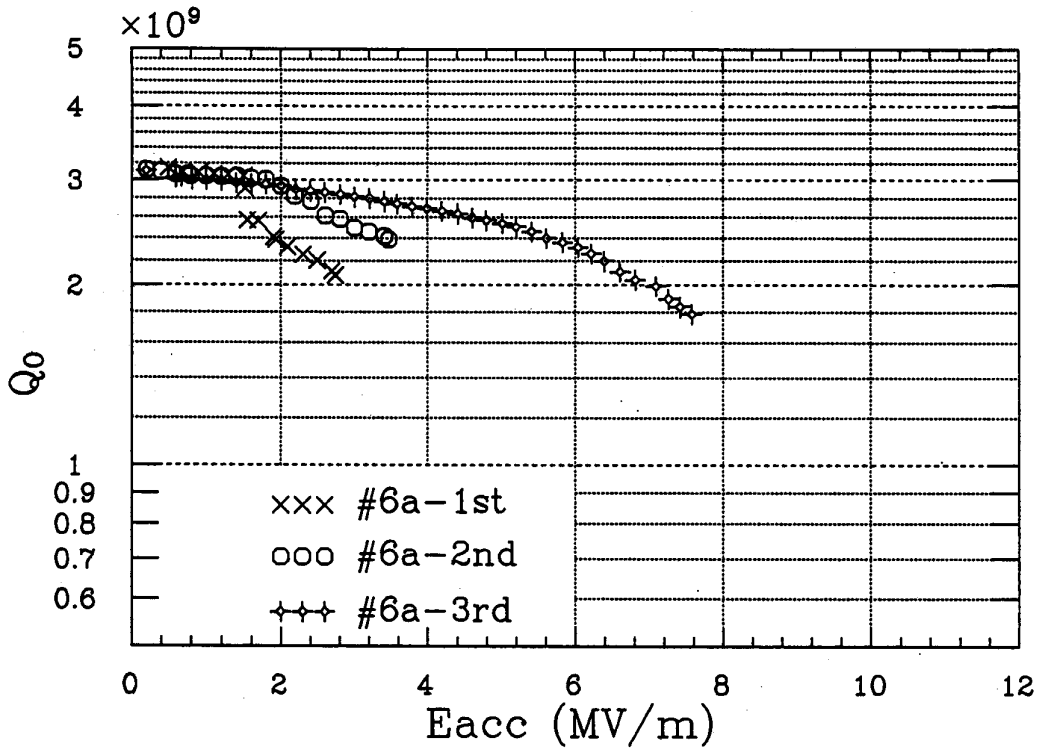

Figure 7: Q0 and Eacc of TRISTAN #6a cavity.

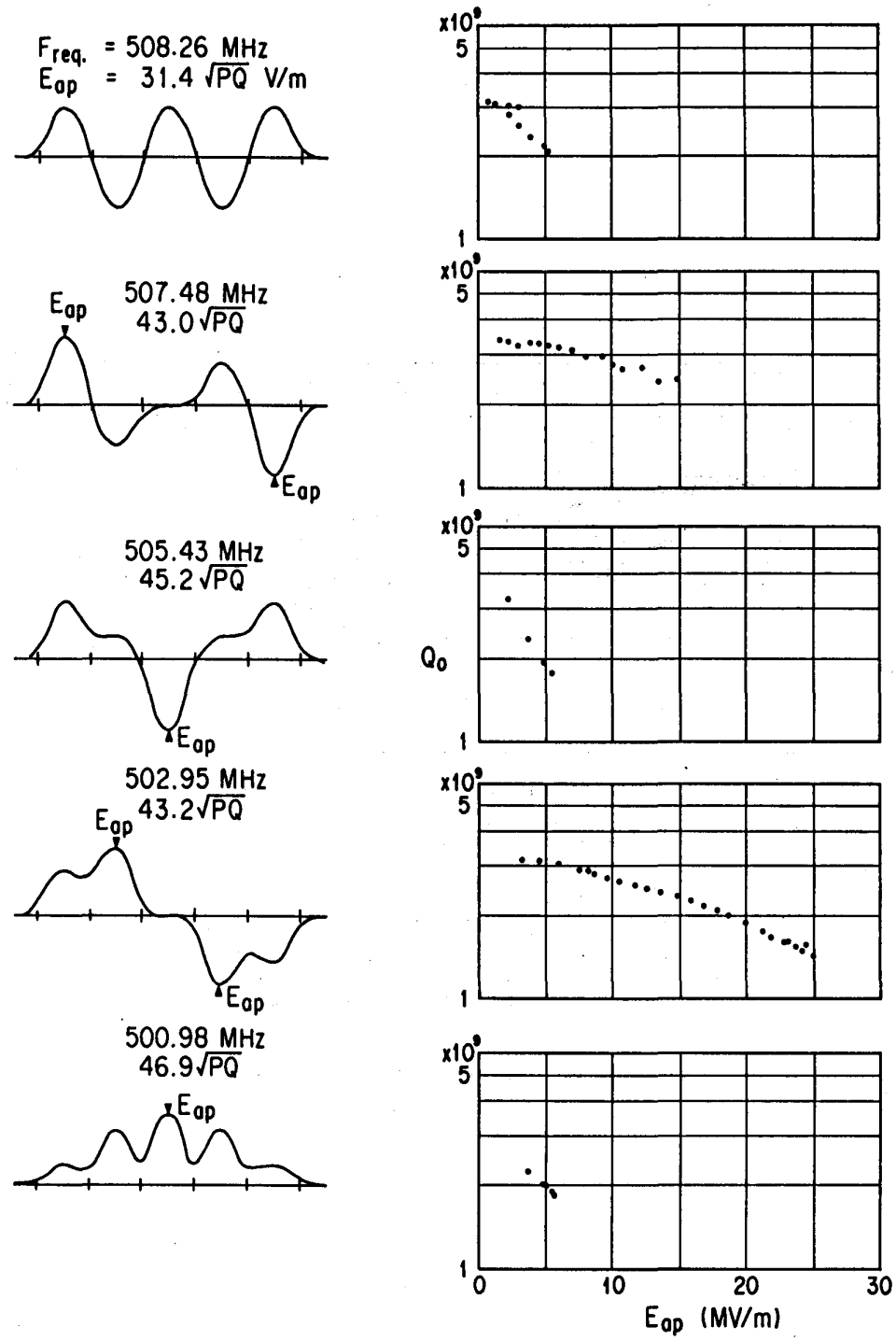

Figure 8: Passband modes measurements of #6a cavity.

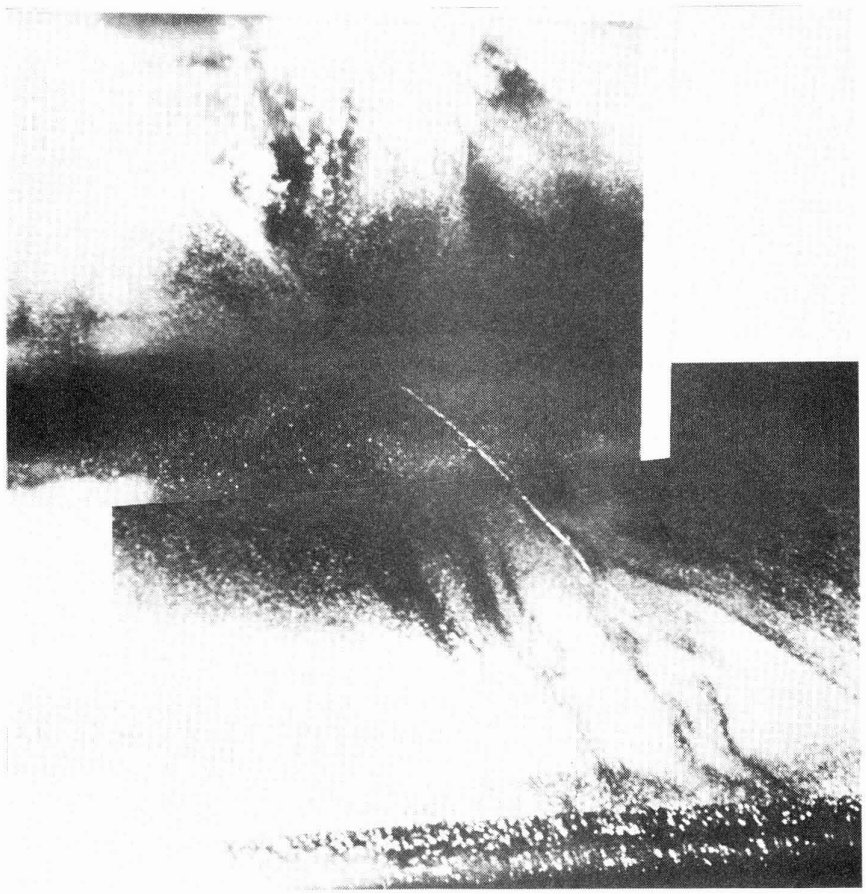

Figure 9: The fissure on the surface of #6a; this area was removed by 0.3 mm to eliminate the fissure completely.