Investigation on Barrel Polishing for Superconducting Niobium Cavities

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Abstract

Barrel polishing was applied to L-band niobium cavities instead of buffing. For the TRISTAN superconducting cavities, buffing had been used for every half cell as the pre-finishing of electropolishing. It demands specialists and a rather high cost. For the mass-production as a superconducting linear collider like TESLA, an easier and cheaper method has to be developed. Barrel polishing seems to satisfy these requirements. Using combination of this method and electropolishing, field gradient higher than 30 MV/m with Qo ~ 10^{10} has achieved by a comparatively small amount of removal thickness.

1. Introduction

For the TRISTAN superconducting cavities, the buffing has been used to each half cell and to all the EBW seams as a mechanical grinding. The role of these mechanical grindings is not sure even now, but we believe that it contributed somewhat to keep the high quality control. 30 cavities in 32 ones satisfied our specification; Eacc > 5 MV/m, Qo > 2×10^9 with enough margin in the first vertical test [1].

For the future project like TESLA, a very high quality control is required as well as a cost reduction for a large fabrication, so that we have to establish how to get it by using cheaper technologies. By the experience of the TRISTAN, buffing is expensive and has several disadvantages; 1)it has strong personal dependence, 2) it can be used only for half cells so that another special grinding is needed to EBW seams for the completed structures. On the other hand, barrel polishing can be used for the completed structures and very simple as described later. Automation is also easy to this method. We considered the barrel polishing is the best grinding method for cavities. The R&D have been started about mechanical grinding; 1) to change the grinding method in the TRISTAN to the more reasonable method, 2) to make sure how the mechanical grinding contributes the cavity quality control. The polishing performance was investigated, and it was applied to L-band niobium single cell cavities as the pre-finishing of electropolishing (EP) or chemical polishing (CP). The cavity performance was measured and the excellent results were obtained. The results of the study are reported in this paper.

2. Experiment for barrel condition

2-1 What is barrel polishing ?

Barrel polishing, which has been often called tumbling for cavities, is a kind of mechanical grinding, rotating a cavity with chips, water and compounds (see Fig. 1).

As easily guessed, this method is very simple and convenient. It can grind whole the inner surfaces including the EBW seams. It is available to any multi-cell structures. The parameters to be controlled are the rotation speed, amounts of chips, water and compounds.

2-2. Survey of polishing conditions

Our most interested polishing properties are the removal speed and the finishing roughness. At the beginning, to see which item affects the removal speed, the parameters were surveyed with the most popular chip. The ceramic chip "SGT-10x8" out of PMG Co. Ltd. was used. The shape is a trigonal prism with 10 mm sides, and with 8 mm height.

Small niobium samples (24ϕ x 2.5t) were set at the equator section of the model cavity made of SUS, and grounded with this method (see Fig. 1).

(1) Rotation speed

At first, the relationship between rotation speed and removal speed was examined. Here, removal speed was evaluated from removed weight. The other terms were temporarily fixed as followings; amount of compounds = 1 % of water (v/v), amount of chips = 2 kg, and

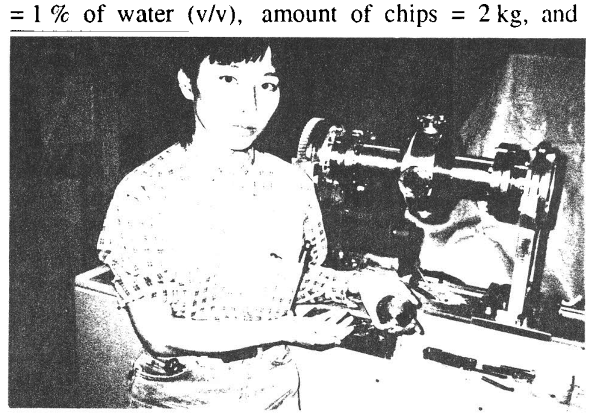

Fig. 1 Equipment of the barrel polishing and samples.

amount of water = 1300 cc. The experimental result is shown Fig. 2 with the mark;■. Here, the maximum rotation speed was limited to 110 rpm by the equipment. One can see the maximum polishing speed is 80 - 100 rpm under this condition. After this experiment, fixing the rotation speed at 83 rpm, the relationships between other terms and removal speed was surveyed. As described later, it was developed the amount of chips affects much on the removable rate. After the survey of the relation between the other parameters (including the amount of chips) and removal speed, removal speed for various rotation speed was examined again for 300 g and 1 kg of chips. These data are shown together in Fig. 1 with the marks; ▲ for 300 g and ○ for 1 kg. From this figure, one notices that the removal rate increases proportionally to the rotation speed if the amount of chips is little, and increasing chips a peak appears around 90 rpm.

(2) Amount of compounds

The relationship between the amount of compounds and removal speed was investigated. The result is shown in Fig. 3. Under the fixed rotation speed (83 rpm) and the amount of water (1300 cc), the amount of compounds was varied from 0 to 10 % by the volume of the water. The maximum removal speed was obtained at 1 %, which was the recommended value by the firm.

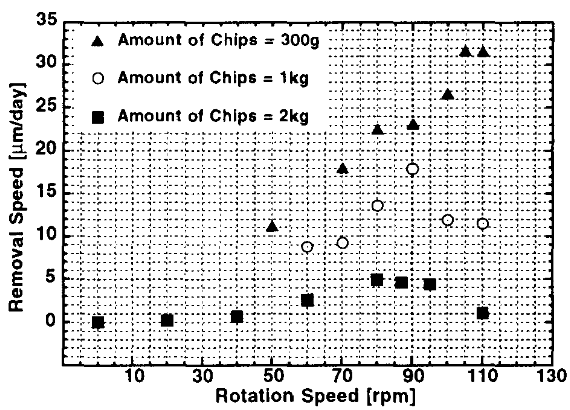

Fig. 2 Effect of rotation speed on the removal speed.

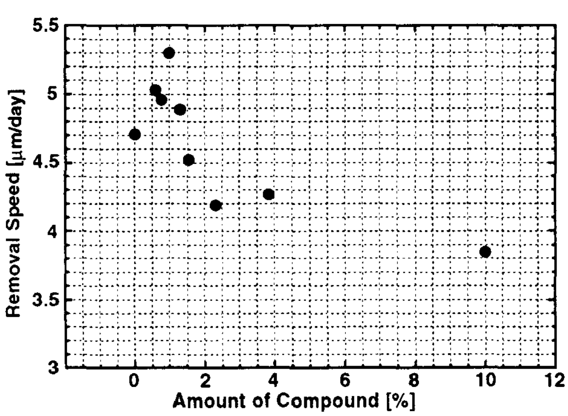

Fig. 3 Effect of amount of compounds on the removal speed.

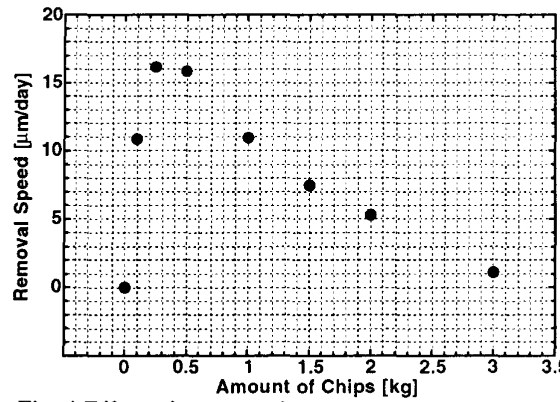

Fig. 4 Effect of amount of chips on the removal speed.

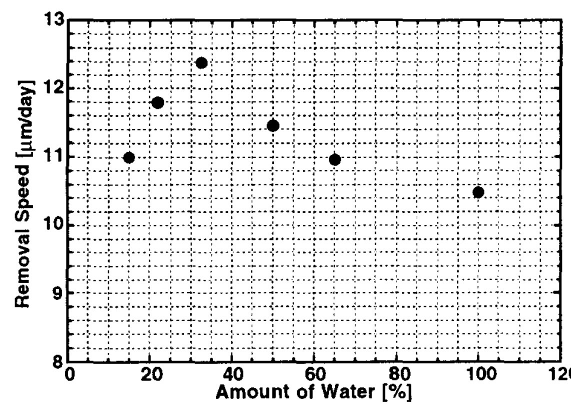

Fig. 5 Effect of amount of water on the removal speed.

However, the amount of compounds has a small effect on the removal rate.

(3) Amount of chips

Under the following conditions; rotation speed = 83 rpm, amount of compounds = 1 %, amount of water = 65 % by weight of chips, the amount of chips was examined. The result is presented in Fig. 4. The maximum removal speed was obtained around 300 g of chips. However, this amount is too little so that only the equator section of the cavity was polished. The chips more than 1 kg are necessary to polish all the inner cavity surface. The amount of chips has a large effect on the removal speed.

(4) Amount of water

Relation between amount of water and removal speed was investigated. Under the conditions; rotation speed = 83 rpm, 1 % compounds, 1 kg chips, the amount of water was varied from 15 to 100 % by the weight of chips. The result is shown in Fig. 5. The maximum removal speed was obtained at 30 %. However, the amount of water has a small effect on the removal speed.

(5) Result of the polishing condition surveys

From above experiments, the rotation speed and the amount of chips affect mainly on the removal speed.

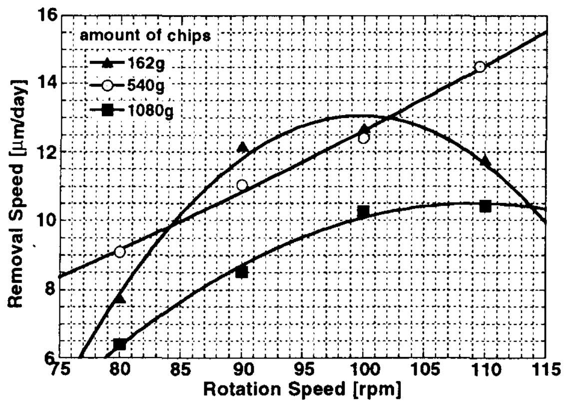

Fig. 6 Relation between rotation speed and removal speed.

The amount of compounds or water has a small effect on it. According to these experiments, the best condition which gives the maximum removal speed is as followings;

rotation speed = 80 - 100 rpm,
amount of chips ~ 1 kg,
amount of water = 300 cc,
amount of compounds = 1 % of water (v/v).

With these values, the evaluated removal rate was 18 µm/day.

3. Optimization of barrel polishing condition for cavities

3-1 plastic chips

Before going forward the experiment with niobium cavities, we have reconsidered about the material of chips. From the less work hardness point of view, we decided to use plastic chips. Three kinds of chips out of PMG Co. Ltd.; PV-1-10 (for rough grinding), PW-1-10(for fine grinding) and PK-1-10 (for ultra fine grinding) were used. Every chip is a cone with 10 mm diameter in the base and 10 mm height.

From the previous experiments, the rotation speed and the amount of chips mainly contribute the removal speed, so the sample tests on the removal speed were done for three amounts of chips; 162, 540, 1080 g using the model cavity. The results are shown in Fig. 6 and Table 1. The maximum removal speed of 11 - 16 µm/day was obtained for the these plastic chips with the following conditions;

rotation speed = 110 rpm,
amount of compounds = 1 % of the water (v/v),
amount of chips = 540 g ,
amount of water = 300 cc.

The finishing roughness is 4.4, 2.3 and 0.9 µm for rough grinding, fine one and ultra fine one respectively.

3-2. Contamination by the abrasive grains

Mechanical grinding using abrasive grains often makes a contamination problem on the polished surface[1]. Barrel polishing also occurs this problem. The contamination spots about 4 µm size were found out on the barrel polished surface by the microscope and SEM. If 10 µm polished off by EP or CP, the contamination is eliminated.

3-3. Exhausting effect of chips

Especially plastic chip "PV-1-10" exhausts. In three days, its removal speed drops to 1/3. So one has to change it for new one three times (every three days) to grind off 50 µm. However, the other plastic chips have not the remarkable exhaustion.

3-4. Conditions with niobium cavities

Finally we tested the plastic chips with L-band single cell cavities. The results are summarized in Table 1. Comparing to the sample tests, the removal ratio is lower by factor 2 for rough grinding and 3 for fine or ultra fine grinding. The reason is that samples were set on the equator section which gave the maximum removal speed, but for the cavity the removal speed was the average over the whole inner area including beam tubes.

4. Barrel polishing and EP/CP

Since we use the barrel polishing as the pre-finishing of EP or CP, we investigated its effect on EP/CP. Niobium samples with different roughness were prepared with the barrel polishing. Then we much electropolished or

Table 1. Barrel polishing of plastic chips

	Sample Test				Cavity Test		
Chip	finishing Roughness [µm]	Chips [g]	Rotation [rpm]	Removal Speed [µm]	Chips [g]	Rotation [rpm]	Removal Speed [µm]
PV-1-10 (for rough grinding)	4.36±0.76	540	110	14.5	750	110	7.5
PW-1-10 (for fine finishing)	2.32±0.36	540	110	16.3	750	110	3.7
PK-1-10 (for ultra fine finishing)	0.92±0.23	540	110	11.9	680	110	3.4
					750	110	3.8
					864	110	3.3

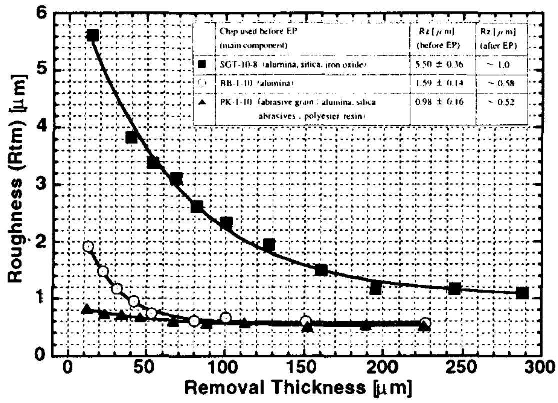

Fig. 7 Relation between roughness and removal thickness of EP.

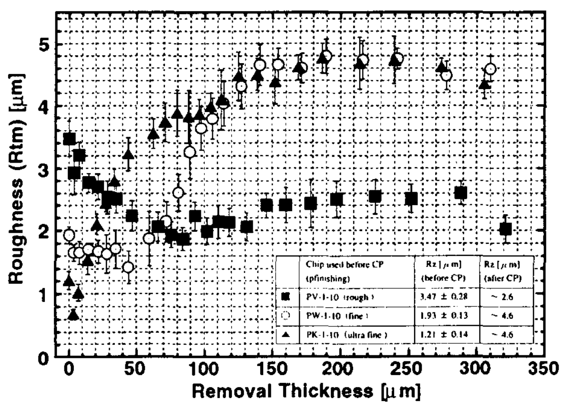

Fig. 8 Relation between roughness and removal thickness of CP.

chemical polished measuring the surface roughness. The result is presented in Fig. 7 and 8.

EP makes the surface smooth exponentially with the amount of removal thickness, and never makes rough deferent from CP. The initial roughness effects strongly on the polished roughness. If one wants to finish the surface smooth by EP, the initial surface also should be smooth less than 2 μm.

On the other hand, CP makes the surface even rougher in the heavy etching (~ 100 μm). The final roughness depends on the grain size (see Fig. 8).

According to these sample experiments, 10 μm polishing looks enough if one pre-finished the surface by 1 μm, saying from the surface roughness point of view.

5. Performance of barrel polished cavities

To see the effect of the mechanical polishing on the cavity performance, the following issues have been investigated using three virgin cavities;

1) Influence on the underneath by barrel polishing,
2) what thickness should be barrel polished
3) influence of mechanical polishing on Qo-disease.

5-1. Influence on the underneath by barrel polishing

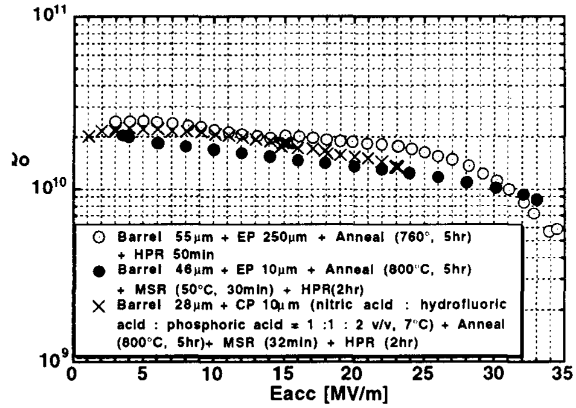

Fig. 9 Performance of barrel polished cavities.

One cavity was removed 55 μm with barrel polishing for 11 days, then electropolished by 250 μm, annealed for 5 hours at 760°C in order to degas hydrogen, and successively high pressure rinsed (HPR) for 50 min. Here, the heavy EP was done to eliminate the influence on the underneath by barrel polishing. The result of cold test is shown in Fig. 9. This cavity achieved the excellent performance; Eacc = 34.6 MV/m, Qo~10^{10}.

Another cavity was ground off 46 μm by barrel polishing for 10 days, then electropolished by 10 μm and annealed for 5 hours at 800 °C. Finally, it was water rinsed with megasonic rinsing (950 kHz, 30 min) and HPR(1 hr). This cavity had also the excellent result; Eacc = 33.1 MV/m with Qo ~10^{10}. See Fig. 9.

These two experimental results conclude that the influence on underneath by barrel polishing does not extend so deeply, and it is less than 10 μm.

5-2. What thickness to be barrel polished off

The other cavity was removed 28 μm by the barrel polishing for 5 days, chemically polished by 10 μm, then annealed for 5 hours at 800 °C, finally megasonic rinsed for 32 min and HPR for 2 hours. It achieved the Eacc = 23.1 MV/m with Qo ~ 10^{10} (see Fig. 8). It is not so good as the above two cavities. It might be due to the multipacting. Unfortunately, multipacting often occurs in our cavities, especially in the elliptical shape [2]. This cavity has the elliptical shape deferent from other two ones (asymmetric; elliptical + spherical), so we are not sure whether 28 μm is enough or not. However, one can say 50 μm is enough as the pre-finishing by barrel polishing.

5-3 Influence of mechanical polishing on Q-disease

Mechanical polishing should introduce many surface defects so that hydrogen could be easier picked up during the chemical process [3]. Our final interest is to see how serious Qo-disease happens in the barrel polished cavities. To investigate this problem, we measured two cavities (K-3, K-2) before the annealing. K-3 is with EP, and K-2 with CP. Especially with K-2 cavity, CP took place very carefully to reduce hydrogen pickup; acid temperature 7°C with 1 : 1 : 2 . They were

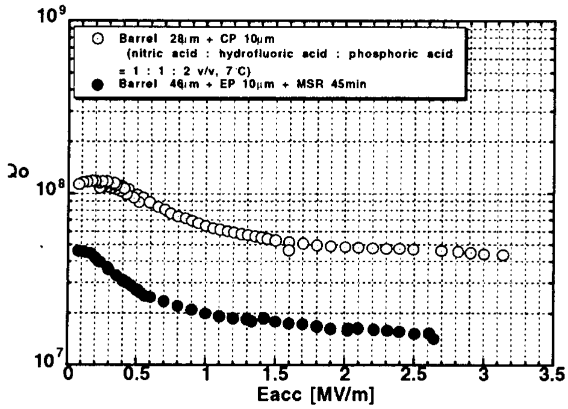

Fig. 10 Qo-disease.

pre-cooled with liquid nitrogen and kept just above liquid nitrogen temperature for half a day . The measurement results are shown in Fig. 10.

Heavy Qo-disease was appeared in the both. Especially in EP more serious Qo-degradation was occurred. These results mean that even 10 μm EP/CP, many hydrogen is doped around the defects by the mechanical grinding.

6. Discussion

We are not sure a mechanical polishing process is really necessary for quality control. For the conclusion, we have to wait the future study on the statistics. However, here next statement should be emphasized that we found the very promising method; barrel polishing by 50 μm with plastic chips, EP/CP 10 μm, annealing (760 - 800 °C) and HPR rinsing. This simpler and cheaper treatment gave the best performance in our cavities on the first vertical test; Eacc > 30 MV/m with Qo ~ 10^{10}.

The investigation on the material removal and the cavity performance has been done by Dr. P. Kneisel at CEBAF. By his result using CP, one has to remove more than 200 μm in order to get the lower surface residual resistance and the high field gradient Ep = 50 MV/m. Our result seams to be contradict with his result, but it would be in our intermediate temperature annealing. This annealing will much contribute not only to degas hydrogen but also to recover the damage by the mechanical grinding [4].

Our result is much different from that of Saclay. They do not get the high field gradient over than 30 MV/m untill the high temperature annealing(HTA, 1400 °C) was done [5]. This result has been established on their statistics. This problem, we call as "European headache", was a great concern in this workshop. Considering that CEBAF has achieved Eacc = 30 MV/m without HTA in a 1.5 GHz single cell cavity out of Teledyne and recently in a 1.3 GHz cavity out of Tokyo Denkai, and KEK has also achieved the same field gradients without HTA in four 1.3 GHz single cell cavities out of Tokyo Denkai and two cavities out of Fansteel, the reason might be in the material. However, still some problems might be behind fabrication processes. This problem should be investigated from the several points of the material and the fabrication. We have much attentions to the mechanical grinding as the different process from the other Laboratories in the fabrication.

7. Conclusion

We have investigated the barrel polishing. This method has been established as the reasonable grinding method to be changed into the buffing. Using it as pre-finishing, one can reduce the amount of EP/CP. The resultant cavity performance is very excellent; Eacc > 30 MV/m, Qo = 1 x 10^{10}. Hereafter, we have to study it from statistics the point of view.

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