Discovery of the Needless of Outgas Annealing after Horizontally Continuously Rotated Electropolishing with Niobium Superconducting RF Cavities

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Abstract

Eletropolishing has a superiority for high gradient: Eacc > 30 MV/m with superconducting niobium bulk cavities, however a hydrogen out gas procedure is inevitable. This requirement makes the surface treatment procedure complicated and more expensive. The requirement was fixed in the R&D of TRISTAN sc project. That time the R&D schedule was so tight and that investigation was not always enough. There is a room to be reconsidered it on the horizontally continuously rotated electroplishing (HRC-EP). We have studied the relationship between the successive material removals by a step of 40µm with HRC-EP and hydrogen Q-disease. Any Q-diseases were not observed in every material removal up to 240µm and the needless of the annealing even with a heavy electropolishing was discovered. This contribution describes the results.

1 INTRODUCTION

The hydrogen Q-disease with electropolished niobium cavities is well known. Today it is a common agreement that a heat treatment to degas hydrogen absorbed during electropolishing is needed after a heavy electropolishing. In order to find out a cost effective surface treatment method for TESLA or a superconducting proton LINAC application in KEK/JAERI joint project [1], recently we tried a surface treatment method combined CP (120µm) and then EP (50µm), and non heat treatment for 1300 MHz niobium single cell cavities. We never observed the hydrogen Q-disease by this procedure even after exposing the cavity at 100 K for one night. This is a new method itself which can save the heat treatment against the hydrogen Q-disease [2], and it motivated us to reconsider the hydrogen Q-disease with electropolishing again. In the R&D of the TRISTAN sc project, which was done in 1983 to 1987, we tried to eliminate the heat treatment after electropolishing but we had to give up it [3]. Considering the R&D situation, we have to say there is still a room to investigate this problem. By our recent understanding, the hydrogen Q-disease is inevitable if electropolishing is done after mechanical grinding [2]. This procedure was included in the TRISTAN. There is a possibility to save the heat treatment if electropolishing is done without mechanical grinding. We have to study this possibility. If one can succeed to save the heat treatment, it reflects on the cost effectiveness but also on mechanical strength of the niobium cavity, which is a very important issue in the pulse operation of sc cavities. One 1300 MHz virgin niobium single cell cavity was removed the material successively by steps of 40µm from the surface up to 240 µm and cold tested to check the hydrogen Q-disease. In these chemistries we never took any heat treatment for this cavity. Any Q-disease was not observed. We discovered that electropolishing has no responsibility for the hydrogen Q-disease in principle.

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2 EXPERIMENTS

One 1300 MHz single cell niobium bulk cavity ; K-26 manufactured with RRR=200 niobium material from Tokyo Denkai was removed the material from the surface by steps 40 µm up to 240 µm with HRC-EP. In order to see the hydrogen Q-disease, the cavity performance was carefully tested for the every material removal. It was measured at first by fast cool down in 45 minutes from room temperature to 4.2K and the temperature dependence of the surface resistance was measured from 4.2 K to 1.5 K. Then Qo-Eacc curve was measured at the lowest temperature. After this cold test it was warmed up to 100K and exposed to this temperature for one nigh or 2 hours in some cases. Then it was cooled down to 4.2K and the same measurement was done again.

The chemical procedure is following; EP 40 µm by the HRC-EP [2], hot water rinsing in a megasonic bath with ultrapure water at 60^{o}C for one hour (hot rinsing), high pressure water rinsing (HPR) with filtered (0.02µm) demineralized water (10MΩcm). Vacuum evacuation is done by a conventional system consisted of a rotary pump (200l/s) and a turbo-molecular pump (50 l/s) up to ~ 1x10^{-7} torr with 85^{o}C baking for one night, then switched to ion pump. The final vacuum pressure was about 1 x 10^{-9} torr, then the cavity was sealed off with a metal valve, fixed on a vertical test stand then cooled down. In order to evaluated the residual surface resistance Temperature dependence of the surface resistance was fitted by the following formula:

$$Rs(T) = \frac{A}{T} \cdot \exp(-\frac{\Delta}{k_B T}) + Rres \quad (1).$$

3 RESULTS

The measurement results of the temperature dependence of surface resistance are presented in Figure 1. The fitting

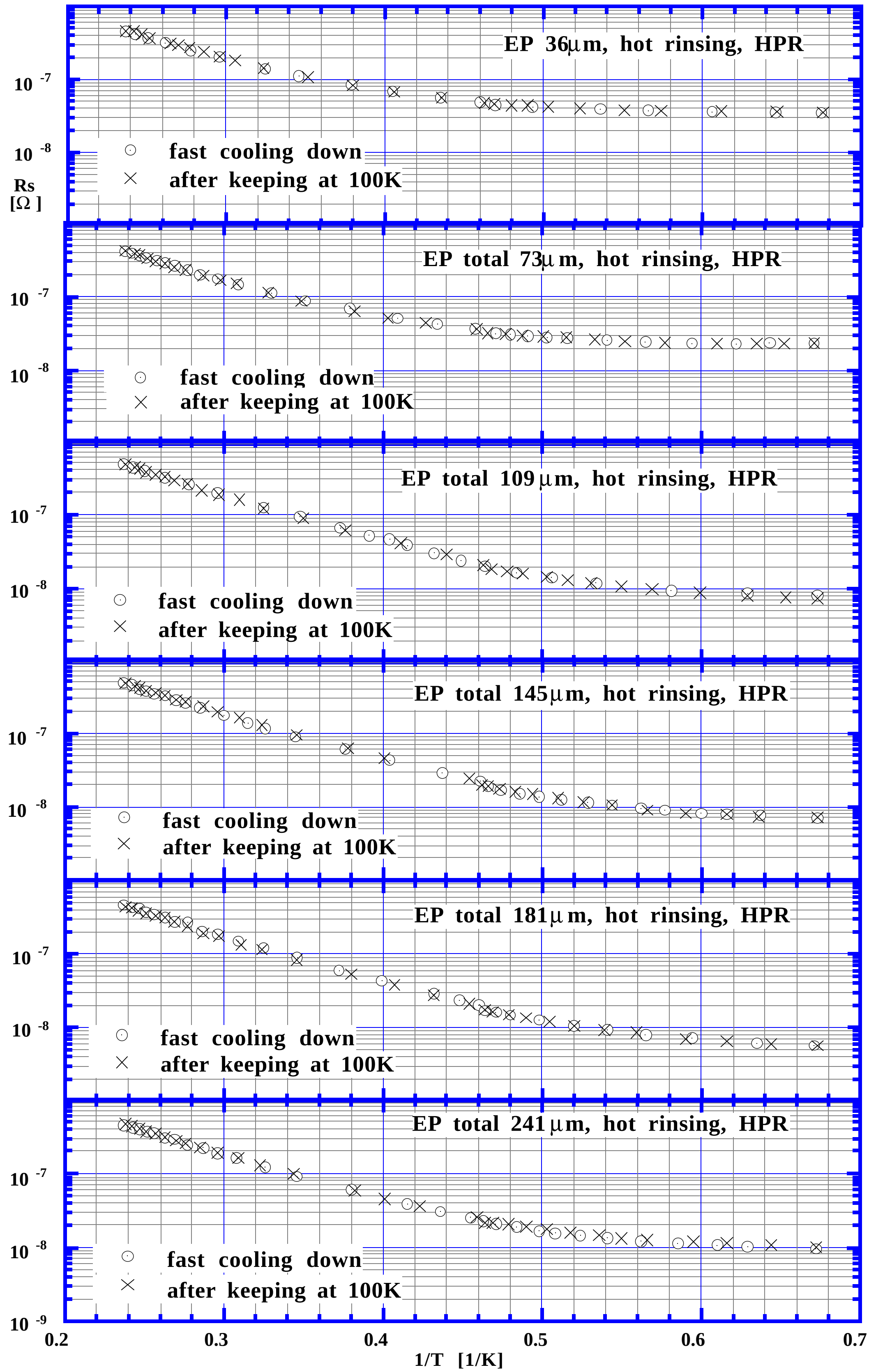

Figure 1: Surface resistance in the sucesive material removal

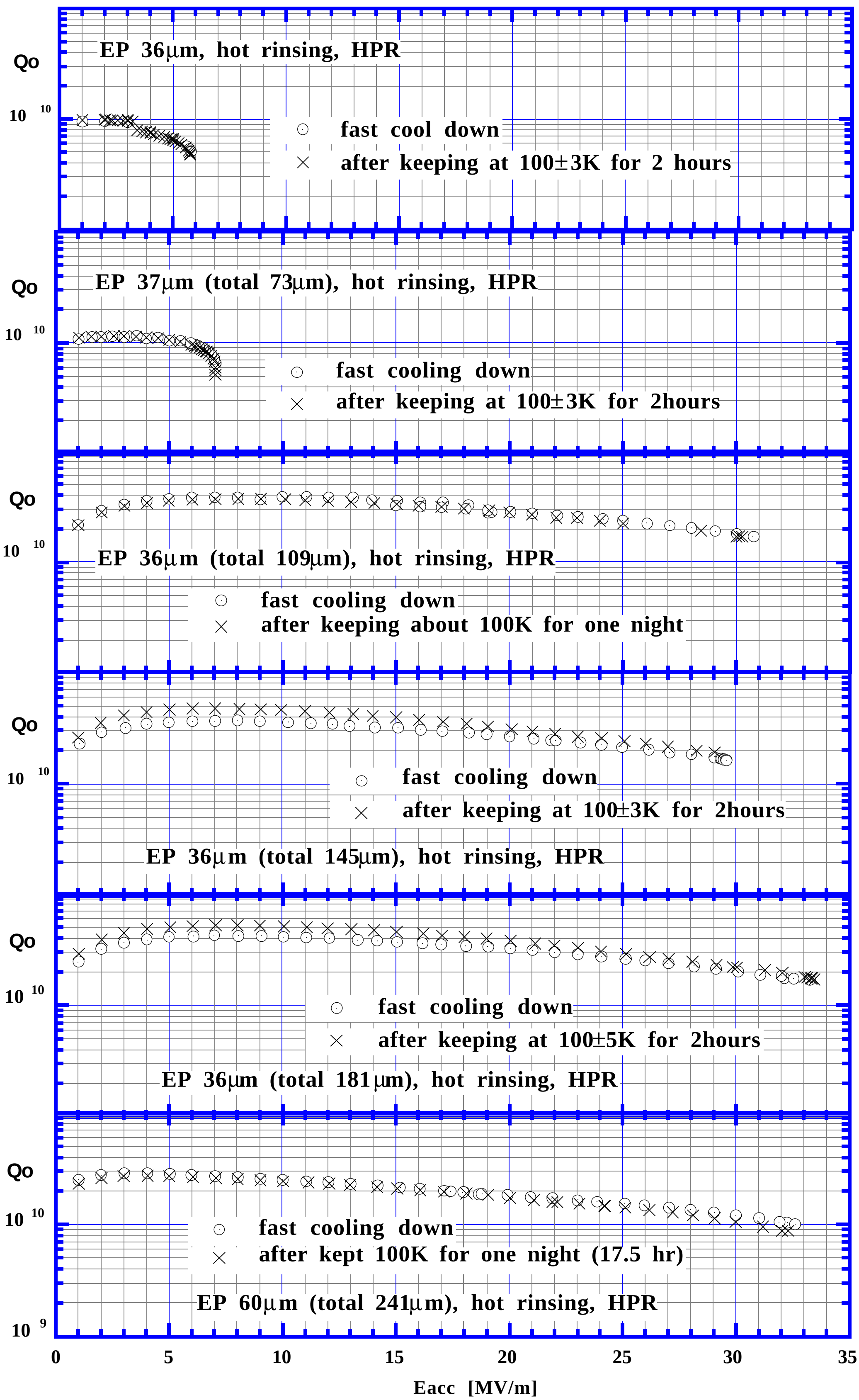

Figure 2 : Qo-Eacc curves for the succesive material removal

results by the formula (1) were summarized in Table 1. In the measurement after exposed to 100K, which most pronounces the hydrogen Q-disease [4], any additional surface resistance is not observed in every material removal. In Figure 2 all the Qo-Eacc curves are presented. Any additional Q-degradation is seen in the high field performance after exposing to 100K. These facts mean that the hydrogen Q-disease does not happen in the electropolished cavity by HRC-EP even in the case of no annealing.

4 DISCUSSION

So far our understanding was that the hydrogen Q-disease is very serious for heavy electropolishing and in order to eliminate it an annealing is inevitable to degas hydrogen. This result is against the common sense. Here, a question comes out why such a misleadingness had established. By our recent experiments the hydrogen Q-disease happens seriously in a chemistry after mechanically grading. An example is presented in Figure 3. In this experiment, a 1300 MHz niobium cavity was removed with barrel polishing by 30µm and electropolished by 12 µm, then without annealing it was measured by fast cool down (Δ). In this case even by the fast cool down, a light hydrogen Q-disease was observed in the Qo-Eacc curve. After this measurement it was warmed up to 100K and exposed to the temperature for 2 hours and tested again (●). A very serious Q-disease happened. Finally it was annealed at 760^{o}C for 5 hours and tested (O). The hydrogen Q-disease has gone. From this experiment we understood that the hydrogen Q-disease can not be prevented even by the fast cool down in the case of the combined preparation a mechanical grinding and an electropolishing. There is no way except for a heat treatment to eliminate the Q-disease. In the TRISTAN sc project we took buffing for every half cell from QA control point of view. The electropolishing was done after accomplishment of a cavity structure. One reason of the misunderstanding is in the combination procedure of mechanical grinding and electropolishing.

The other reason should be in the electropolishing method. HRC-EP has a good structure for hydrogen gas to escape easily. When we fabricated a TRISTAN 508 MHz 3-cell prototype cavity, a slight Q-disease was experienced in the Qo-Eacc curves for the three single cell cavities at 4.2 K in the light electropolishing even after annealing at 800^{o}C [5]. This means 800^{o}C heat treatment is not a perfect cure for the hydrogen gas in electropolishing depending on the method. These cavities were electropolished by the old method [6], in which a whole cavity was immersed vertically in EP acid and a cathode bag with Teflon cloth was set the inside in order to prevent for hydrogen gas to scatter and to attack the surface. In this method, hydrogen gas was accumulated from the bottom to the top. The conductance for hydrogen gas to escape was very poor. Even a light electropolishing, we could see the traces of the hydrogen gas flow on the cavity inner surface[5]. When one has a poor conductance for hydrogen gas in electropolishing, hydrogen Q-disease might happen. This was a reason why we developed the horizontal electropolishing. In this experiment, HRC-EP method should contribute as a the hydrogen cure.

However, still a question is remained with the hydrogen Q-disease. We have experienced the hydrogen Q-disease in BCP without annealing with high purity cavities with RRR=200. On the other hand, we often have experienced also the cases in which no hydrogen Q-

Table 1: Rs fitting results of the temperature dependence of measured surface resistance

Surface treatment	Comment	A	Δ/kB	Rres [nΩ]	Eacc,max [MV/m]
EP 36µm, Hot rinsing, HPR	Fast cool After exposed 100K	1.15E-4 1.31e-4	17.9 18.3	34.5 35.1	5.79 5.76
EP totally 73µm Hot rinsing, HPR	Fast cool After exposed 100K	1.37E-4 1.48E-4	18.7 19.1	22.9 23.0	7.05 7.03
EP totally 109µm Hot rinsing, HPR	Fast cool After exposed 100K	1.64E-4 1.30E-4	18.7 18.0	7.8 6.9	30.76 30.27
EP totally 145µm Hot rinsing, HPR	Fast cool After exposed 100K	1.29E-4 1.65E-4	18.0 18.7	6.5 6.6	29.59 29.07
EP totally 181µm Hot rinsing, HPR	Fast cool After exposed 100K	1.38E-4 1.25E-4	18.2 18.1	5.3 5.2	33.29 33.45
EP totally 241µm Hot rinsing, HPR	Fast cool After exposed 100K	1.15E-4 1.15E-4	19.9 17.3	9.3 9.5	32.61 32.30

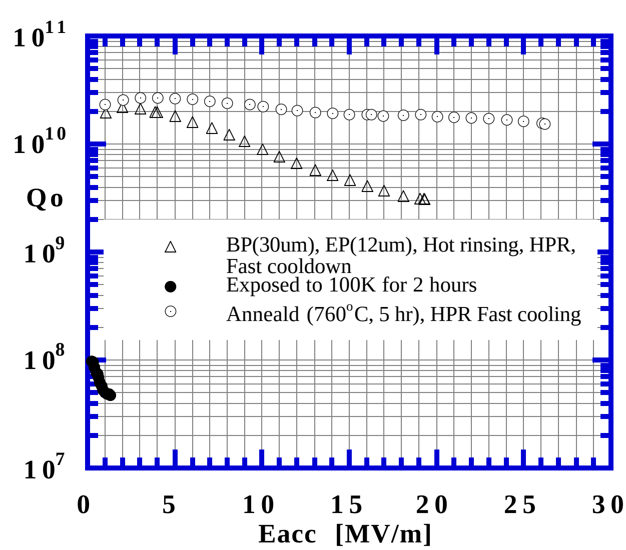

Figure 3: Hydrogen Q-disease dominated by the combination of mechanical grinding and electropolishing

disease is observed with the same procedure. We are still missing something in niobium material on the hydrogen Q-disease.

5 SUMMARY

We removed the material from the surface by every 40 μm up to 240 μm and carefully investigated the hydrogen Q-disease. No Q-disease was observed in the every material removal. We can conclude that electropolishing has no responsibility for the hydrogen Q-disease. However, this comment somehow depends on the electropolishing method or niobium material.

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