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

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Abstract

Electropolishing has a superiority for high gradient: $E_{acc} > 30$ 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 electropolishing (HRC-EP). We have studied the relationship between the successive material removals by a step of 40$\mu$m with HRC-EP and hydrogen Q-disease. Any Q-diseases were not observed in every material removal up to 240$\mu$m 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 heavy electropolishing. In order to find out a cost effective surface treatment method for TESLA or a superconducting proton LINAC, we tried a surface treatment method combined CP (120$\mu$m application in KEK/JAERI joint project [1], recently we method for TESLA or a superconducting proton LINAC. In order to find out a cost effective surface treatment method combined CP (120$\mu$m application in KEK/JAERI joint project [1], recently we method for TESLA or a superconducting proton LINAC. In order to find out a cost effective surface treatment method combined CP (120$\mu$m application in KEK/JAERI joint project [1], recently we method for TESLA or a superconducting proton LINAC. In order to find out a cost effective surface treatment method combined CP (120$\mu$m application in KEK/JAERI joint project [1], recently we method for TESLA or a superconducting proton LINAC.

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2 EXPERIMENTS

One 1300 MHz single cell niobium bulk cavity; K-26 manufactured with $R_{RR}=200$ niobium material from Tokyo Denkai was removed the material from the surface by 40$\mu$m up to 240$\mu$m 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 $Q_0-E_{acc}$ 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$\mu$m by the HRC-EP [2], hot water rinsing in a megasonic bath with ultrapure water at 60°C for one hour (hot rinsing), high pressure water rinsing (HPR) with filtered (0.02$\mu$m) deminerlized 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°C baking for one night, then switched to ion pump. The final vacuum pressure was about $1x10^{-9}$ 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:

$$R_s(T) = \frac{A}{T} \exp\left(-\frac{\Delta}{k_B T}\right) + R_{res}$$

3 RESULTS

The measurement results of the temperature dependence of surface resistance are presented in Figure 1. The fitting 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 40$\mu$m from the surface up to 240$\mu$m 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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Figure 1: Surface resistance in successive material removal
fast cooling down after keeping at 100–3K for 2 hours

EP 36\( \mu \)m, hot rinsing, HPR

EP 37\( \mu \)m (total 73\( \mu \)m), hot rinsing, HPR

EP 36\( \mu \)m (total 109\( \mu \)m), hot rinsing, HPR

EP 36\( \mu \)m (total 145\( \mu \)m), hot rinsing, HPR

EP 36\( \mu \)m (total 181\( \mu \)m), hot rinsing, HPR

EP 60\( \mu \)m (total 241\( \mu \)m), hot rinsing, HPR

Figure 2: Qo-Eacc curves for the successive 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 happened. Finally it was annealed at 760 °C for 5 hours and tested again (●). A very serious Q-disease happened. Finally it was annealed at 760° C for 5 hours and tested (O). The hydrogen Q-disease has gone. From this experiment we understood that the hydrogen Q-

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

<table>
<thead>
<tr>
<th>Surface treatment</th>
<th>Comment</th>
<th>A [nΩ]</th>
<th>ΔKB [nΩ]</th>
<th>Rs [nΩ]</th>
<th>Eacc,max [MV/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>EP 36μm, Hot rinsing, HPR</td>
<td>Fast cool After exposed 100K</td>
<td>1.15E-4</td>
<td>17.9</td>
<td>34.5</td>
<td>5.79</td>
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<tr>
<td>EP totally 7μm 90μm Hot rinsing, HPR</td>
<td>Fast cool After exposed 100K</td>
<td>1.31E-4</td>
<td>18.3</td>
<td>35.1</td>
<td>5.76</td>
</tr>
<tr>
<td>EP totally 109μm Hot rinsing, HPR</td>
<td>Fast cool After exposed 100K</td>
<td>1.37E-4</td>
<td>18.7</td>
<td>22.9</td>
<td>7.05</td>
</tr>
<tr>
<td>EP totally 145μm Hot rinsing, HPR</td>
<td>Fast cool After exposed 100K</td>
<td>1.48E-4</td>
<td>19.1</td>
<td>23.0</td>
<td>7.03</td>
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<tr>
<td>EP totally 181μm Hot rinsing, HPR</td>
<td>Fast cool After exposed 100K</td>
<td>1.64E-4</td>
<td>18.0</td>
<td>7.8</td>
<td>30.76</td>
</tr>
<tr>
<td>EP totally 241μm Hot rinsing, HPR</td>
<td>Fast cool After exposed 100K</td>
<td>1.30E-4</td>
<td>18.0</td>
<td>6.9</td>
<td>30.27</td>
</tr>
<tr>
<td>EP totally 36μm Hot rinsing, HPR</td>
<td>Fast cool After exposed 100K</td>
<td>1.29E-4</td>
<td>18.0</td>
<td>6.5</td>
<td>29.59</td>
</tr>
<tr>
<td>EP totally 109μm Hot rinsing, HPR</td>
<td>Fast cool After exposed 100K</td>
<td>1.65E-4</td>
<td>18.7</td>
<td>6.6</td>
<td>29.07</td>
</tr>
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<td>1.38E-4</td>
<td>18.2</td>
<td>5.3</td>
<td>33.29</td>
</tr>
<tr>
<td>EP totally 241μm Hot rinsing, HPR</td>
<td>Fast cool After exposed 100K</td>
<td>1.25E-4</td>
<td>18.1</td>
<td>5.2</td>
<td>33.45</td>
</tr>
</tbody>
</table>

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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7 REFERENCES