Electropolishing and in-situ Baking of 1.3 GHz Niobium Cavities

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Abstract

Three electropolished one-cell cavities were measured before and after in-situ bakeout under ultra-high vacuum conditions. Before bakeout the cavities showed a strong reduction in quality factor at fields above 25 MV/m. After the bakeout the Q drop was no longer present and gradients of up to 39 MV/m were achieved. This indicates that electropolishing yields highest accelerating gradients in niobium cavities only in combination with in-situ bakeout.

1 ELECTROPOLISHING OF NIOBIUM CAVITIES

1.1 Motivation

Electropolishing (EP) has been successfully applied at KEK since several years [1] leading to very high gradients without Q-drop [2,3]. In contrast to this, BCP cavities usually show a strong drop in $Q_0$ above 20-25 MV/m. A collaboration between CEA, CERN and DESY has been set up, to understand the mechanism of electropolishing and why it leads to higher accelerating gradients. Up to now the program has been focused on cavities, which have not gone through any furnace treatment.

CERN KEK

<table>
<thead>
<tr>
<th>Bath mixture</th>
<th>Half cells</th>
<th>Full cavity</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 % H$_2$SO$_4$</td>
<td>90 % H$_2$SO$_4$</td>
<td>86 % H$_2$SO$_4$</td>
</tr>
<tr>
<td>10 % HF</td>
<td>10 % HF</td>
<td>9 % HF</td>
</tr>
<tr>
<td>38 % H$_3$PO$_4$</td>
<td>17 % Butanol</td>
<td>15 % Butanol</td>
</tr>
</tbody>
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| Temperature | 20° Celsius | 30–35° Celsius |
| Removal rate | 1 – 2 μm/min | 0.5 μm/min |

Table 1: Parameters of the different polishing baths.

1.2 Description of the EP system

A total of 15 one-cell cavities of the TESLA geometry were made of RRR300 niobium. Firstly, all half cells were electropolished using a mixture of HF, H$_2$SO$_4$, H$_3$PO$_4$ and butanol (Table 1). After electron beam welding the full cells, the first two cavities were chemically etched to remove weld spatter. Finally, all three cavities received another electropolishing with a mixture of hydrofluoric and sulphuric acid developed at Siemens and later used at KEK. The cavities are mounted horizontally in the EP setup as proposed by KEK [1].

1.3 Handling of the cavities

The cathode in the CERN setup is made from copper. To avoid a possible copper contamination after the EP the cavities were rinsed twice with HNO$_3$, pure water, HF and pure water. This was followed by a high pressure water rinsing to remove chemical residues from the surface. Then the cavities were rinsed with pure alcohol and dried under vacuum (10$^{-3}$ mbar) overnight.

Two cavities were then put either under vacuum or nitrogen atmosphere for transport to CEA and DESY. The third cavity was rinsed with high pressure water again for subsequent testing at CERN. After arrival at CEA or DESY the cavities were equipped with antennas and high pressure water rinsed before the rf test.

2 MEASUREMENTS

2.1 Multipacting

All three cavities have shown two-point multipacting (MP) beginning around 17 MV/m. The phenomenon is seen as a breakdown of the cavity field together with a sudden flash of electrons and X-rays. A temperature map shows the location of the MP (Figure 1). After processing this spot, the heating occurs in another place. Normally, it takes several minutes to process through the MP barrier. This is consistent with results from Cornell, where a more detailed analysis took place on 1.5 GHz cavities [4]. Similar results were obtained in a TESLA nine-cell cavity, which was electropolished at KEK [3]. Unfortunately, the barrier could not be processed away in that cavity.

After processing of the MP region, the $Q_0$ of the cavity was reduced by a factor of about two. This is illustrated in Figure 2. After a thermal cycle to 18 K the original higher $Q_0$ was restored and no further multipacting was observed. The Q degradation after MP may be due to frozen-in magnetic flux, as suggested in [4].
2.2 Q-slope

After electropolishing all the cavities showed a Q-slope at high fields (Figure 3). The surface resistance rises proportional to $E_{acc}^4$ at high field. The heating is in the region of the high magnetic field, as shown in figure 4. It is a global effect taking place on a large part of the cavity surface. X-rays due to field emission were seen, but on a very small level.

Figure 3: $Q_0$ drop in electropolished cavities. Only low X-ray levels were measured.

Figure 4: Temperature map at $E_{acc} = 33$ MV/m before in-situ bakeout.

2.3 Bakeout

Experiments at CEA [5,6] and TJNAF [7,8] show that baking the cavity in-situ at 100 °C and 145 °C respectively under UHV conditions can improve the performance. Especially, the BCS surface resistance $R_{BCS}$ decreases after baking. Our cavities were baked at 100 °C and 120 °C respectively. The mass spectrometer data indicate that the desorbed gases are mostly water and hydrogen. After baking, $R_{BCS}$ drops by a factor of 2 (Figure 5), the Q-slope disappears in all 3 cavities and the accelerating gradient is improved by 5-7 MV/m (Figure 6). The ultimate limit of the best cavity was a quench.

An interesting question is the long-term stability of the EP surface. A test has shown that a short exposure to air (< 8 hours) in a cleanroom with subsequent high pressure water rinsing has shown no negative impact on cavity performance. Although there was no new bakeout, the Q-drop was absent, however the multipacting reappeared.

Figure 5: Reduction of $R_{BCS}$ by bakeout. The residual resistance $R_{res}$ is nearly unchanged.
Presently it is unclear why the in-situ bakeout is more efficient on EP surfaces than on BCP surfaces. The limiting breakdown field is much higher in electropolished cavities than in those with standard chemical etching.

In the present tests no cavity was postpurified to increase the RRR. This, together with the KEK results [2,3] may indicate that very high RRR is not needed to achieve high accelerating gradients.

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6 REFERENCES