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**
	Half cells	Full cavity
Bath mixture	21 % H_2SO_4	90 % H_2SO_4
	24 % HF	10 % HF
	38 % H_3PO_4	
	17 %Butanol	
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_2SO_4, H_3PO_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].

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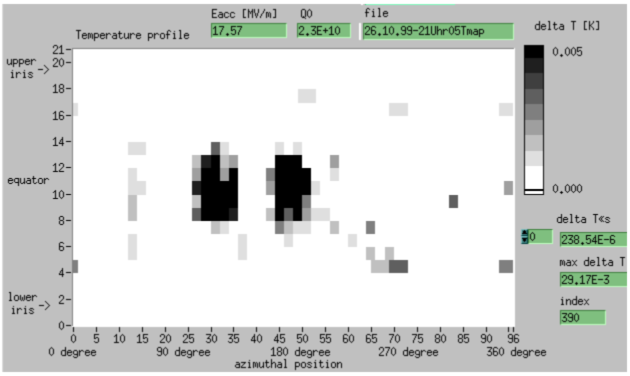

Figure 1: Temperature map showing heating around the equator during multipacting at 17, 5 MV/m.

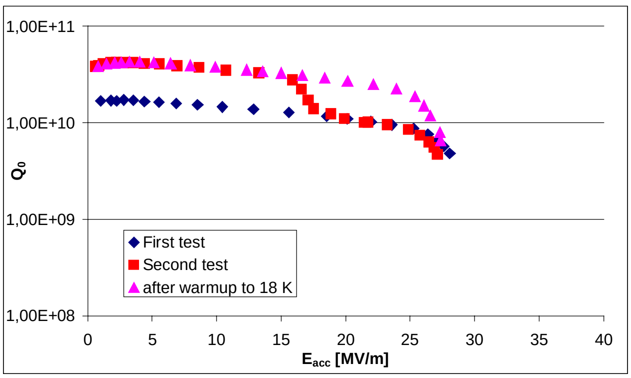

Figure 2: Q-degradation during multipacting. The first breakdown events are typically seen at 17 MV/m.

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}^{16} 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.

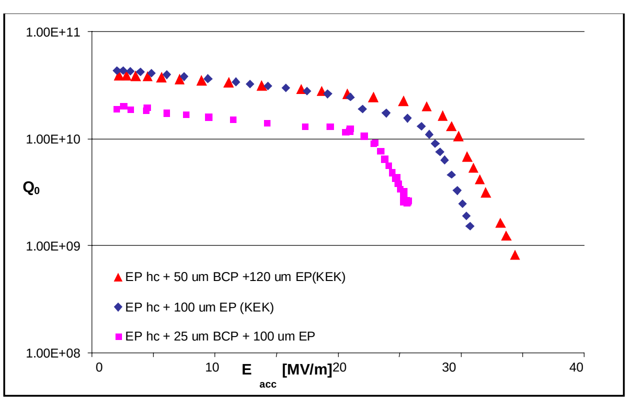

Figure 3: Q_0 drop in electropolished cavities. Only low X-ray levels were measured.

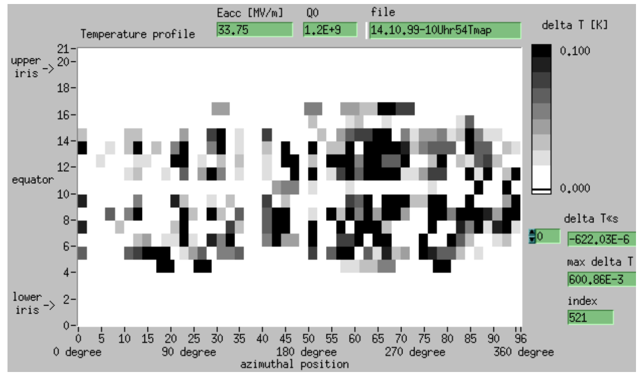

Figure 4: Temperature map at E_{acc} = 33 MV/m before in-situ bakeout.

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.

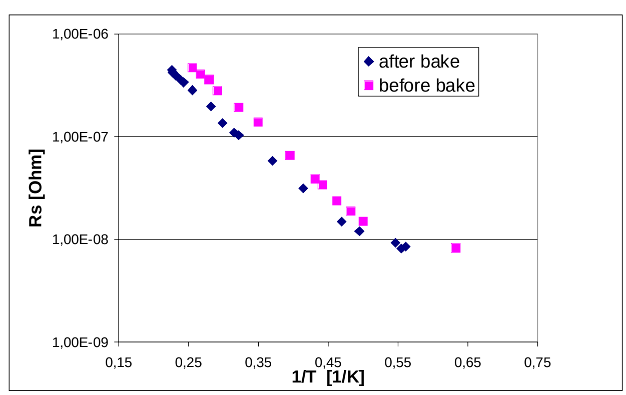

Figure 5: Reduction of R_{BCS} by bakeout. The residual resistance R_{res} is nearly unchanged.

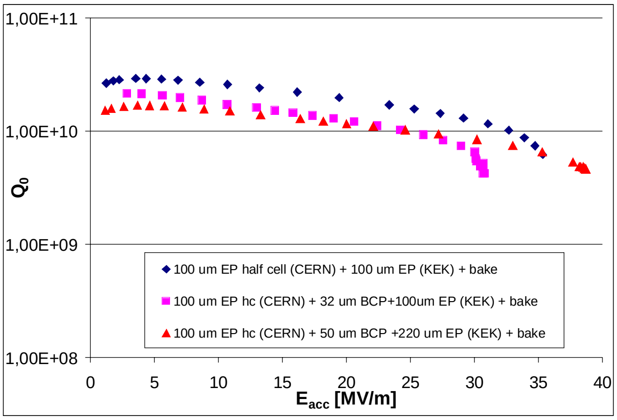

Figure 6: The cavities after bakeout show no Q-drop. One cavitiy is limited at 30 MV/m due to strong field emission and available RF power.

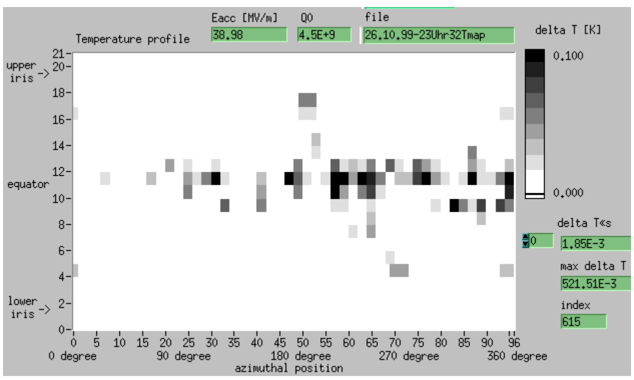

Figure 7: Temperature map at E_{acc} = 39 MV/m after bakeout. The heating of the inner surface is concentrated on the equator weld.

3 CONCLUSIONS

It has been possible to reproduce the excellent results of KEK on electropolished niobium cavities by combining EP with an additional in-situ bakeout at 100-120 °C. A bakeout of 85 °C is part of the standard procedure at KEK.

Several loss mechanisms have been proposed to explain the Q-drop at high accelerating fields. Magnetic field enhancement on the edges of the niobium grains is proposed as one loss mechanism [9]. As EP cavities have a very smooth surface, they should not suffer a Q-drop due to this mechanism.

Temperature maps show that the enhanced losses occur in the high magnetic field regions. Therefore it seems unlikely that the Q-drop in electropolished cavities is due enhanced electrical fields [10].

The observation that a baked cavity can be exposed to clean air for several hours without loosing its good performance seems to indicate that absorbed gases are not responsible for the Q drop.

Other proposed loss mechanisms are related to oxygen [10,11] or hydrogen diffusion into the bulk. There are indications that the layer influenced by the bakeout is in the order of a few hundred nm [8].

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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