# HIGH GRADIENT MULTICELL SUPERCONDUCTING CAVITIES

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*Abstract*

The cavity manufacture and preparation is essential to achieve the performance goals of an accelerating gradient of 23.5 MV/m for TESLA500 and 35 MV/m for TESLA800 will be reviewed. Results from the 1.3 GHz 9-cell superconducting niobium cavities will be shown. It will be shown that very high gradients above 40 MV/m are achieved reliably in electropolished one-cell cavities. First test results on 9-cell cavities showing TESLA800 performance will be discussed.

## 1 STANDARD PREPARATION OF CAVITIES FOR TESLA-500

For superconducting cavities at very high electrical and magnetical surface field great care has to be taken during manufacturing and preparation for beam acceleration. For example, the preparation and assembly in in clean rooms and ultrapure water supplies for rinsing the surfaces are a must. A quality control on the niobium sheet material is necessary. Today, a very detailed specification exists for the sheet material, the handling during manufacturing, the electron-beam welding and the final surface preparation to reliably achieve gradients at the TESLA500 goal.

Figure 1: A TESLA niobium 9-cell cavity. The length of a cavity is about 1m.

As the manufacturing process and the preparation of the 1.3 GHz TESLA niobium cavities (Fig. 1) have been described in detail elsewhere [1,2], here a list of the most important steps will be given:

- High quality niobium sheets (RRR=300) are subjected to eddy-current scanning to avoid foreign material inclusions like tantalum and iron
- Industrial production of full 9-cell cavities:
- Deep-drawing of subunits (half-cells, etc. ) from the niobium sheets
- Chemical cleaning before welding, clean room preparation
- Electron-beam welding according to detailed specification
- 800 °C high temperature heat treatment to stress anneal the Nb and to remove hydrogen from the Nb
- 1400 °C high temperature heat treatment with titanium getter layer to increase the thermal conductivity (RRR=500)
- Chemical etching to remove damage layer and titanium getter layer
- High pressure water rinsing as final treatment to avoid particle contamination

### *1.1 Example: Eddy-current scanning*

As an example of quality control for the niobium sheet material an eddy-current scanning system which currently is used for SNS (build by company based on a design by Bundesanstalt für Materialforschung and DESY) is shown in figure 2. A similar system is in use for the TESLA cavities. A scan with a signature from the rolling process is shown in figure 3 (left). The eddy-current system also allows to certain degree to determine the type of inclusion. An example of a iron inclusion is shown in figure 3 (right). Any niobium sheet showing defects is rejected from the cavity manufacturing process. The rejection rate is about 5 %. Most of the rejected sheets will be recoverable by applying some chemical etching. The iron inclusions were caused by mechanical wear of the rolls used for sheet rolling. In the meantime new rolls have been installed. The eddy-current check has turned out to be an important quality control not only for the cavity manufacturer but also for the supplier of the niobium sheets.

Figure 2: Setup for quality control of niobium sheet material for SNS

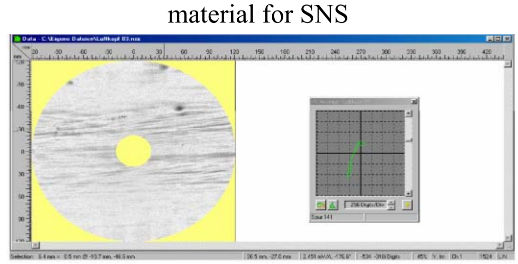

Figure 3 Left: Global view where rolling marks and a defect areas can be seen. Right: Real and imaginary part of the conductivity at a defect, which shows in this case a typical Fe signal

### *1.2 Cavity performance in the acceptance test*

An important means of control of manufacturing and preparation procedures is the continuous wave (cw) acceptance test of the cavities. For this purpose the bare cavities are equipped with matched antennas, mounted to a vertical bath cryostat and powered by a solid-state amplifier (input power 200-500W).

To date about 90 9-cell niobium cavities from 3 different production series (between 20-30 cavities each) have been tested. Figure 4 shows results from the vertical acceptance tests of 9-cells. The averages were taken from the maximum accelerating gradient when the quality factor $Q_0$ was still above $10^{10}$. It can be seen that after the introduction of eddy-current scanning and a detailed specification of the electron-beam welding procedure, a clear improvement in the average gradient can be seen from first to third production.

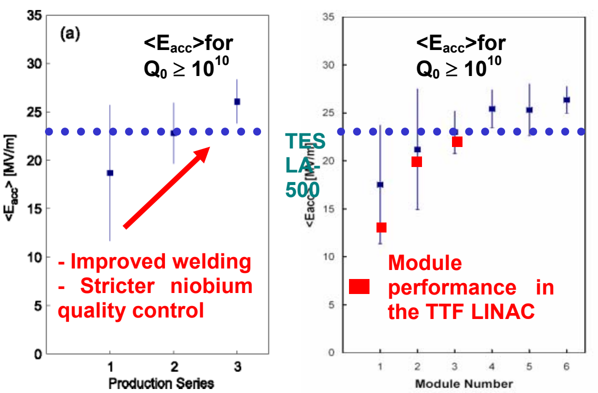


Figure 4: Results from the vertical acceptance tests of 9-cells. Left: Improvement in the average gradient in the more recent production series. Right: Expected module performance from the acceptance test results compared with cavity performance in the linac (with beam).

### *1.3 Cavity performance in the full systems test*

After the acceptance test cavities are equipped with helium tanks and high power input couplers. It was shown that again in average there is no performance loss in going from the acceptance test to the full power test without beam. The average gradient achieved in the vertical and the horizontal tests are quite similar (Fig. 5). In a few cases the performance was reduced in the horizontal test due to field emission. In other cavities the maximum gradient was improved to gradients above 30 MV/m by the fact that the cavities are operated in pulsed mode instead of the cw operation in the vertical test. This can be understood because a number of cavities was limited by the available RF power in the acceptance test.

For the TESLA Test Facility the cavities are grouped in cryomodules containing 8 cavities each. From the vertical test an estimate on the performance in the machine can be made. In figure 4 (right part) the accelerating gradient of the modules with beam is shown. It is also very important to note that the scatter of cavity performance has reduced again for the recently produced six module build for TTF.

The results show that the gradient which is needed for TESLA at 500 GeV is at hand. Nevertheless, the standard preparation seems to be limited at accelerating gradients between 25-30 MV/m. In the next section it will be shown that this limit can be overcome by a superior surface treatment.

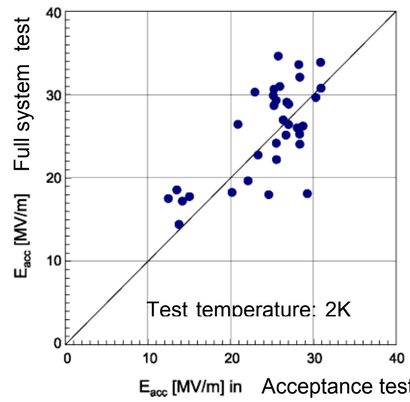


Figure 5: Comparison of cw acceptance test with full systems test (without beam)

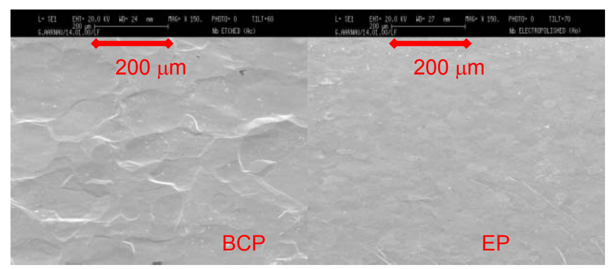


Figure 6: SEM surface picture of etched (BCP=Buffered Chemical Polish) and electropolished surface.

## 2 R&D ON HIGH ACCELERATING GRADIENTS FOR TESLA800

### *2.1 Improvement of the surface quality*

There has been an R&D program on single-cell cavities in laboratories inside and outside of the TESLA collaboration with the goal to push the achievable gradients to 35 MV/m or above, which is essential for the upgrade of TESLA to 800 GeV. For a number of years several remarkable results have been obtained at KEK [3,4] with electropolishing single-cell niobium cavities, obtaining gradients close to 40 MV/m.

In contrast to the chemical etching applied to the cavities at TTF, which leads to a rather rough surface, electropolishing leads to a very smooth and shiny surface (Fig. 6). KEK and CEA Saclay have convincingly demonstrated that electropolishing raises the obtainable accelerating field substantially compared to the BCP treatment [5].

In a collaboration including KEK, CERN, DESY, CEA Saclay and TJNAF several single-cell cavities have been electropolished and gradients around 40 MV/m were obtained in cavities produced by different manufacturing techniques (Examples in Fig. 7) [6-9]. It was discovered that baking the evacuated cavities at 75-150°C for 24 to 48 hours after the final high pressure water rinsing constitutes an essential step in reproducibly obtaining gradients around 40 MV/m at a high quality factor [10,11].

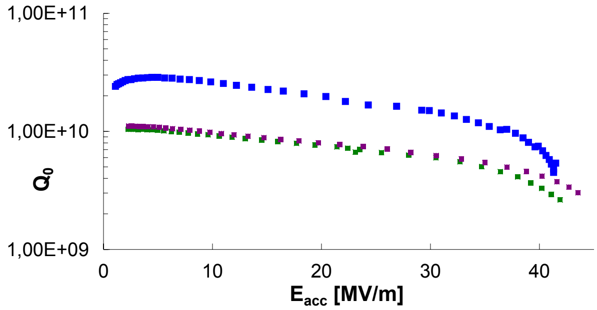


Figure 7: Example excitation curves of three welded electropolished niobium single-cell cavities. Test was done at 1.6 and 2K [9].

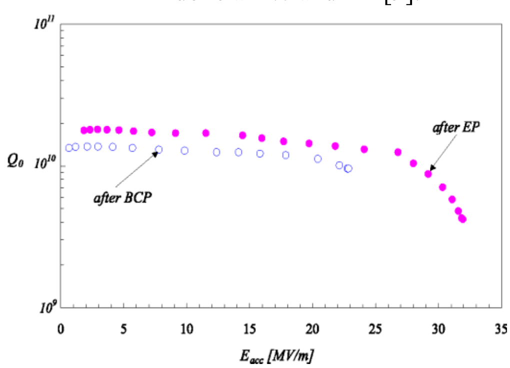


Figure 8: Result on an electropolished 9-cell cavity from the first production series. A clear improvement is seen as compared to its behavior after etching (BCP). Test was done at 2K [1].

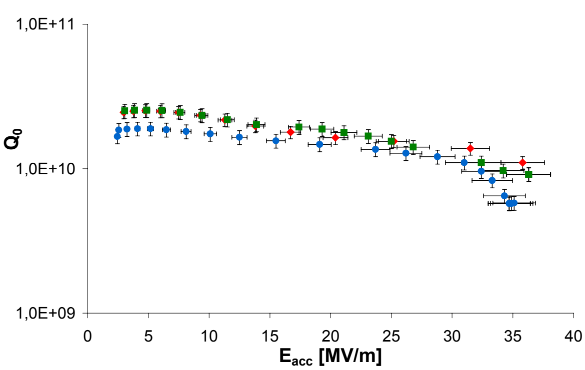


Figure 9: CW test results on three electropolished 9-cell resonators of the TESLA type from the last production series. Test was done at 2K.

## *2.2 Test results on 9-cell cavities*

To transfer these findings to 9-cell cavities, a collaboration between KEK and DESY was set up. KEK has accumulated a lot of experience on the electropolishing of multicell cavities at other frequencies (e.g. TRISTAN cavities). The electropolishing was performed at Nomura Plating. First results on an electropolished nine-cell cavity from the first production series were very promising and have achieved an accelerating gradient of 32 MV/m (figure 8).

After these first tests DESY has supplied cavities from the latest production series which have been treated according to the full procedure as mentioned in the first section, except that the final etching surface treatment was replaced by the electropolishing and a mild 'in-situ' baking at 120 degrees. The cw measurement results of three cavities are shown in figure 9. All three cavities meet the TESLA800 specification which is a $Q_0=5\times10^9$ for the accelerating gradient of 35 MV/m is met.

## 3 CONCLUSION

For the first time accelerating gradients meeting the specification for TESLA800 have been measured in three 9-cell cavities. This is the first proof that this surface preparation method can be transferred to multicell cavities. To further study this technique DESY sets up an infrastructure to electropolish nine-cell cavities. First results are expected this year. The next steps will include high RF power tests.

## 4 ACKNOWLEDGEMENT

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