# RECENT RESULTS ON 1.3 GHz NINE-CELL SUPERCONDUCTING CAVITIES FOR THE EUROPEAN XFEL

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### *Abstract*

The most recent production of superconducting nine-cell cavities of the TESLA [1] shape in preparation for the European XFEL [2, 3] is currently under test at DESY. The goals are training of companies in cavity preparation, streamlining the cavity preparation process and a better comparison of final treatments. The current measurements are compared to the previous production cycles.


## GOALS OF THE ONGOING XFEL NINE-CELL PROGRAMM

### *Training of Industry*

The main goal is the training of industry. In previous production runs for the TTF at DESY, companies have fabricated the cavities. Additional quality control steps were introduced in the fabrication process. Most recently, a high resolution optical inspection system has been obtained from Kyoto University and KEK. This will be put into operation in the near future to further improve weld quality.

In the recent production run, the damage layer removal after fabrication was done by industrial companies. The process planned to be used in the XFEL production run is electropolishing (EP). So far, industrial electropolishing of multi-cell cavities was only available in Japan.

The final surface preparation (see below) for this production cycle was done at DESY. For the XFEL pre-series this process will also be transferred to industry.

### *Streamlining Procedures for XFEL*

More efficient processes a desirable for the XFEL project in order to save cost. Several changes were introduced into the cavity preparation and assembly cycle.

Although the final treatment for the XFEL cavities has not yet been decided, tank welding at an early stage of the cavity process was considered a potential cost saving. The tank welding process was introduced after the furnace treatment and before the vertical test (For a detailed sequence of the assembly steps see next section).

The serious disadvantage of putting the tank on at such an early stage is that temperature mapping of the cavity is not possible anymore. In addition, a repair using EP is not viable either.

A second idea following along the same lines is to mount the HOM antennas already after the tank welding. The reason for this is, that a final cleaning. process i.e. high pressure rinsing with ultra-pure water can be done after the potentially particle-generating assembly processes.

It is a disadvantage, that assembled HOM antennas do not allow full passband mode measurements due to the narrow-band nature of the filter in the TESLA HOM couplers.

During vertical low-power continuous wave RF tests in some cavities Q-switches were observed. The effect disappears, when the HOM couplers are not equipped with antennas. During pulsed operation with HOMs these effects have never been observed. The nature of these effects is not fully understood yet, but is likely related to a temperature effect either at the feed-through or the antenna tip.

### *Comparison of Final Surface Treatment*

The final surface treatment critically affects the cavity performance. The last treatment step is still under discussion for the XFEL. In the previous production run it turned out, that both a short final etch (10 µm) or a short EP (40 µm) followed by an ethanol rinse had good performance in terms of a reduction of field emission. The maximum gradient of the electropolished set of cavities seemed to be higher. To get a larger data set it was decided to test 10 cavities with each of the two choices of treatment.

## CAVITY PREPARATION

The 30 fine-grain niobium cavities in the recent program have been subjected to the following processes::

- Damage layer removal: 150µm EP inside
- 10µm etching (BCP) outside,
- Degassing: 800 C firing
- Frequency and field flatness tuning
- Tank-welding
- followed by either
    - final EP 50 µm, ethanol rinse
- or
    - final BCP ("EP+") of 10µm
- HPR (High-pressure rinsing with ultra-pure water)
- Antenna assembly,
- HPR
- 130 °C bake
- Low-power Test

For simplification several additional cleaning steps like ultrasonic cleaning are not listed here.

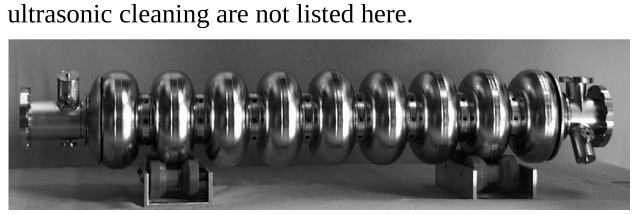

Figure 1: A TESLA 9-cell cavity with a length of about 1m.

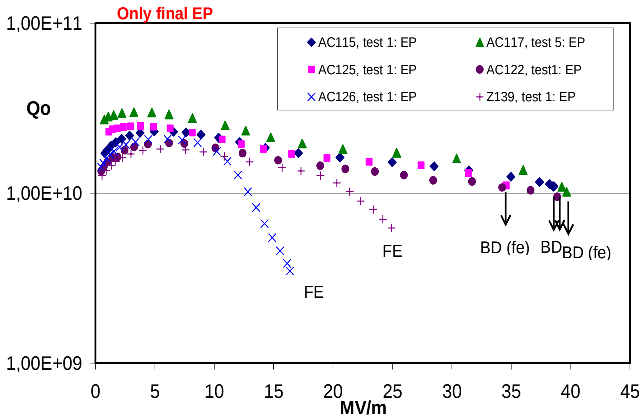


Figure 2 a): Vertical test results of most recent cavity production after EP as a final surface treatment. Strong field emission (FE) has been in two cavities causing a strong degradation of the quality factor. In two other cavities much smaller levels of radiation have been observed causing no significant degradation.

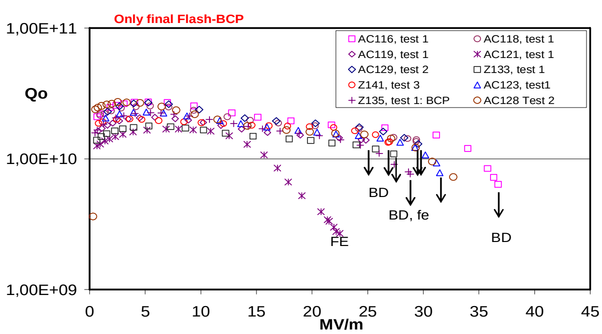


Figure 2 b): Vertical test results of most recent cavity production after etching (BCP=Buffered chemical polish) as a final surface treatment. One cavity shows strong FE.

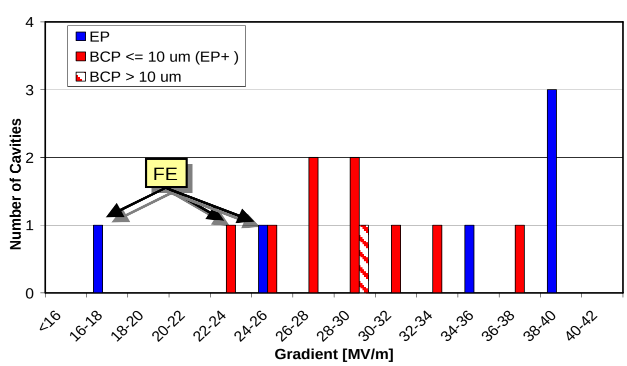


Figure 3: Comparison of the vertical test results for the final surface treatments.

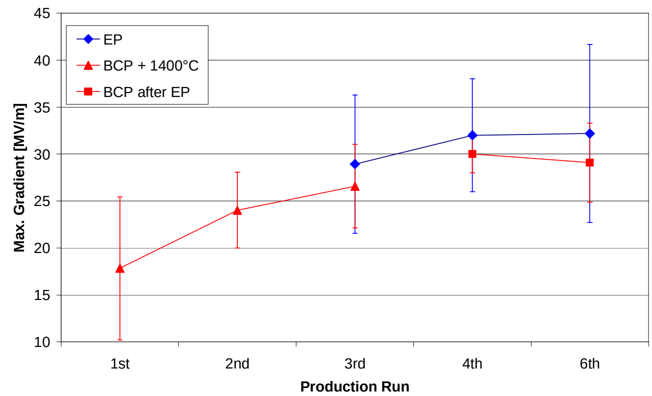


Figure 4: Comparison of final surface treatments for the cavity production runs at DESY. For comparison the maximum gradient in the last test of each cavity is shown. Note that data set for EP in 6th production is only six cavities so far. Re-tests of cavities with additional treatment have not yet been done. Other data sets include typically 10 – 20 cavities.

## RESULTS OF RF TESTS

The first cavities have now been tested. So far, three cavities have shown severe fabrication defects. They are not included in the data set in the following sections. The results are shown in figure 2 a) and b) for EP and the short BCP process, respectively.

Firstly, both processes have yielded three cavities in total that show strong field emission. These cavities will be re-treated with HPR only. In case this should not remove the field emitter, another short etching could be done without disturbing the field profile of the cavity too much.

The results of the two final treatment procedures are compared in figure 3. So far, the EP cavities show higher maximum gradients. This matches the experience from the previous productions (Figure 4). Due to the field emission loaded cavities, the standard deviation of the data sets is large.

The data in figure 4 indicates clearly, that there is no performance change from the $4^{th}$ to the $6^{th}$ production run. Therefore, main EP at the companies as not negatively affected the cavity performance.

## ETCHING AFTER ELECTROPOLISHING (ACCUMULATED DATA AT DESY):

Previous investigations at KEK [4] and DESY [5] have already shown that long etching of several ten µm after electropolishing deteriorates cavity performance. The reason for this deterioration is not finally understood. Grain boundary etching might play a role. At grain boundaries steps of several µm have been observed. It is not yet known, if topological defects or the chemical composition of the grain boundary area play a role.

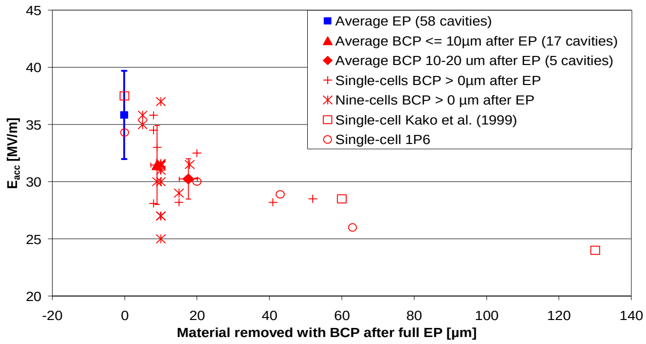


Figure 5: Cavity data for cavities with etching after electropolishing. Data includes both single- and nine-cell results as well as fine- and large-grain niobium material. For comparison older KEK data [4] is also shown. Cavities with field emission limitation and fabrication defects are excluded.

As early tank welding would exclude the option of a horizontal EP process for field emitter removal [6], other cleaning methods need to be explored. In case of field emitters sticking to the niobium surface, HPR in some cases might not be sufficient. The XFEL project therefore considers a short etching as a repair option for field emitter removal.

A critical question is whether a short etching (~10 µm) deteriorates cavity performance significantly. The results presented before indicate that already a BCP of only 10 µm is too much to get the full performance achieved with an EP final surface treatment.

To substantiate this finding we extend the cavity selection in this section to single-cells and nine-cells from both fine-grain and large-grain material after an initial full electropolishing of at least 100 µm followed either directly by an RF test or by a BCP with an RF test. Cavities with obvious fabrication defects and strong field emission loading have been de-selected from the data set. The data set includes roughly 60 cavities. Results are shown in figure 5.

A degradation of 4 MV/m is observed for a 10 µm etch after EP. For larger removal with etching a further reduction of the maximum gradient is found. Therefore field emitter removal using etching on cavities with helium tanks will degrade the maximum quench gradient.

The finding of this paper supports the choice of electropolishing as the final surface preparation process for the International Linear Collider (ILC). The current parameter set for the ILC requires a gradient of 35 MV/m at a $Q_0=10^{10}$.

For a better understanding of the performance difference between etched and electropolished surfaces additional measurements are needed. A more detailed investigation of the quench locations using high-resolution thermometry and optical inspection before and after etch processes is needed to identify the nature of the defects leading to a premature breakdown.

In previous investigations [4, 5] cavity performance could be recovered with electropolishing after etching. The amount of material removed was typically in the order of several ten µm. Whereas a typical BCP surface has a $R_a$ of 1µm, electropolishing will reduce surface roughness by a factor 10 after roughly 100 µm removal [7, 8]. To date it is not clear how much EP is needed minimally to fully recover from etching. A larger data set of cavities electropolished after etching would possibly allow distinguishing between a topological effect or the chemical composition of the surface.

## CONCLUSION

The XFEL project is being started at DESY now. The last cavity production before the XFEL production run of 800 cavities is under test. The main EP of 100 µm has been done at companies. Cavity performance has not changed. The training of companies in the preparation processes has successfully started.

A degradation of an EP surface due to subsequent etching has been observed starting already after 10 µm of etching. The mechanism of this deterioration is not understood so far. Systematic measurements using single-cells together with high-resolution temperature mapping would be highly desirable to understand the nature of the reduced magnetic peak fields.

## REFERENCES

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