RF ANALYSIS OF ELECTROPOLISHING FOR EXFEL CAVITIES PRODUCTION AT ETTORE ZANON SpA

A. Sulimov, DESY, Hamburg, Germany
A. Gresele, M. Giaretta, A. Visentin, Ettore Zanon S.p.A., Schio, Italy

Abstract

After successful finishing of superconducting cavities mass production at Ettore Zanon S.p.A. (EZ) for the European XFEL (EXFEL), the authors had the possibility to provide a detailed analysis of the electropolishing (EP) process. The analysis of EP material removal is based on specified RF measurements and was used for the determination of both, the ratio between cavity's iris and equator and uniformity in different cells. A comparison of the RF measurements results with mechanical measurements is presented.

STATISTICS

The measurements of cavity weight before and after the EP process during serial cavity production at EZ allowed us to calculate the average value of removed material from the cavity surface on the level of (154 ± 6) μm. The minimal and maximal values are correspondingly 143 μm and 183 μm.

The results of the statistical analysis of more than 300 cavities are presented on Figure 1.

The relative errors of frequency changes (δF_{pi}) and frequency sensitivity determination ($\delta(dF_{pi}/d\bar{R})$) are about 15 %. It means that the average value of removed material from the cavity surface can be determined with relative error of 30 %, which corresponds to the values (153 ± 44) μm.

The usage of additional RF measurements helps to estimate also the average values in different cavity regions (irises and equators) [1].

One can notice that the pi-mode frequency change (dF_{pi}) not only depends on the average amount of removed material from the inner cavity surface but also on the ratio of removed material between iris and equator – *dRi*/*dRe*. Extra material removal from the iris reduces the pi-mode frequency deviation due to EP and it has to be taken into account in the analysis of the mean removal value along a cavity.

ALGORITHM OF ANALYSIS

The three calculation methods will be described in this part:

- removed material along one cell;
- mean removal along a cavity;
- removed material in different cavity cells.

Removed Material Along One Cell

The amount of removed material along one cell is a function:

$$dR_{cell} = f(z), \tag{1.1}$$

which is determined in the range $\boldsymbol{z} \in [-\frac{L_c}{2}, \frac{L_c}{2}]$, where L_c is the length of a cell.

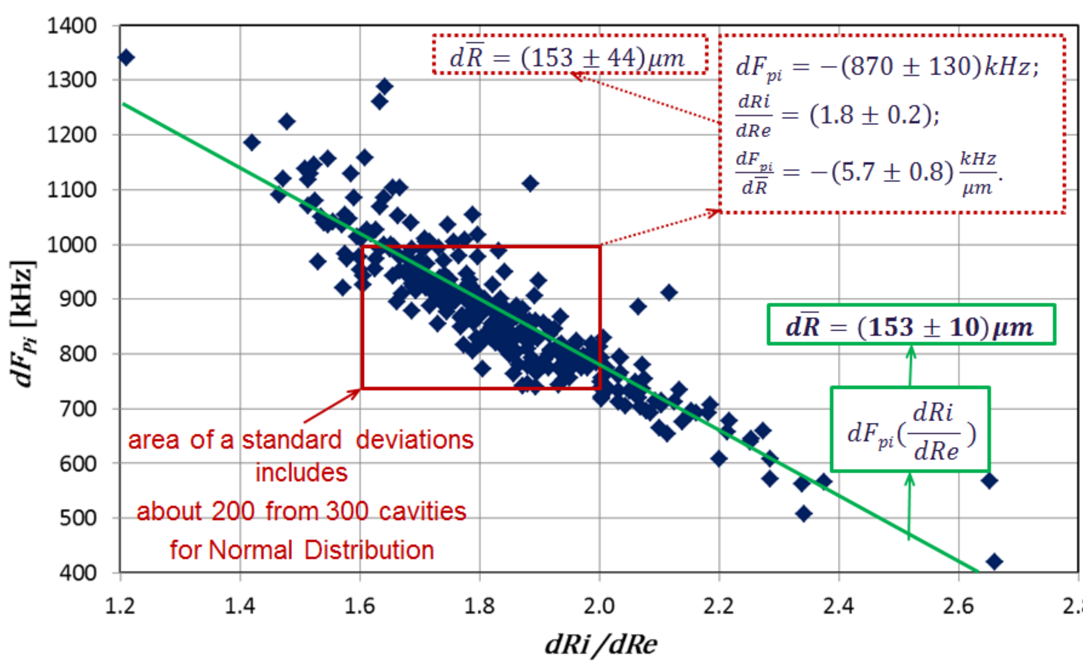

Figure 1: Deviation of EXFEL cavities parameters during EP at E.ZANON (for 300 cavities).

The function f(z) depends on the distance between the electrode of EP and cell's surface, local shielding of the cathode, temperature of the working liquid and other parameters. The integral of this function, however, is determined by the average material removal from the cell ($d\bar{R}_{cell}$):

$$\int_{-L_c/2}^{L_c/2} f(z)dz = L_c\, d\bar{R}_{cell}. \qquad (1.2)$$

For the smooth f(z) distribution (Fig. 2, black dash line) the removed material from iris $dRi = \mathrm{f}(\pm\frac{L_c}{2})$ and equator $dRe = \mathrm{f}(0)$ can be found from matrix equation [1]:

$$\begin{bmatrix} dRi \\ dRe \end{bmatrix} = A \begin{bmatrix} dFo \\ dFpi \end{bmatrix}, \qquad (1.3)$$

where $A = \begin{bmatrix} -280.19 & 279.20 \\ -76.56 & 7.91 \end{bmatrix}$ µm/MHz,

dFo and $dFpi$ are frequency changes of zero- and pi-mode correspondingly.

Mean Removal Along a Cavity

Taking into consideration the statistics results, we can supplement the calculation with frequency correction (F_c) due to changes of the ratio dRi/dRe relative average value:

$$\mathrm{F}_c = \mathrm{B}\cdot\left(\frac{dRi}{dRe} - \left(\frac{dRi}{dRe}\right)_{aver}\right), \qquad (2.1)$$

where B = 622 kHz – sensitivity factor;
$(\frac{dRi}{dRe})_{aver} = 1.84$ – average ratio of removed material between iris and equator (see Fig. 1).

The average amount of removed material ($d\bar{R}$) can be calculated by the pi-mode frequency deviation (dF_{pi}):

$$d\bar{R} = {(dF_{pi} - F_c)}\Big/{\frac{dF_{pi}}{d\bar{R}}} \qquad (2.2)$$

where: $\frac{dF_{pi}}{d\bar{R}} = 5.7\ \frac{kHz}{\mu m}$ – pi-mode frequency sensitivity to material removal from cavity surface during EP process.

The formulae (2.1) and (2.2) increase the accuracy of $d\bar{R}$ determination. The difference between two methods, which are based on RF and weight measurements, is below 5 % now.

Removed Material in Different Cavity Cells

The mean removal value in a cell can be calculated by the equation:

$$d\bar{R}_{cell} = {dF_{cell}}\Big/{\frac{dF_{pi}}{d\bar{R}}} \qquad (3)$$

where dF_{cell} – deviation of eigenfrequencies of cavity cell during EP, which can be determined, based on RF measurements (spectra and field amplitudes), after cavity welding [2] or calculated from subcomponents frequencies, taking into account the deviations during equator welding.

Correction of $d\bar{R}_{cell}$ deviation due to the instability of the ratio $\frac{dRi}{dRe}$ can be done by comparison of the sum of 9 cells radius changes with average value for the cavity.

This method is not accurate enough to estimate the deviation during 10 µm BCP and is usually used for "large" amounts of removed material (more than 100 µm).

CALCULATIONS AND COMPARISON

The first results of EP analysis were obtained for the first 4 cavities and presented on the occasion of SRF2013 [3]. These calculations were based on ultrasonic measurements of cavity wall thickness in different points before and after EP (values marked red on Fig. 2 and Fig. 3).

A new RF analysis of removed material distribution along one cell and in different cells was done for 12 cavities at different times of production (values marked black on Fig. 2 and Fig. 3).

A comparison of mean removed material analysis along one cell is presented on Figure 2. Some unsmooth behaviour of ultrasonic measurement data between the iris and equator could be explained by the influence of EP-cathode shielding and inaccuracy of the measurements. Material thickness measurements at the iris area were not possible because of stiffening rings (Fig. 2) presence.

The calculations of dRi and dRe are based on results of RF measurements and on the assumption that:

- frequency changes are caused only by radius increase, due to EP;
- material removal f(z) is smooth and symmetrical relative equator;
- all geometry changes are identical for all 9 cells.

The form of function f(z) was chosen to satisfy the condition (1.2) and dependency on the distance between the cathode and cell's surface.

Good correlation between the ultrasonic measurements and RF calculations indicates the high accuracy of both methods and confirm the correctness of our assumptions.

One can see on figure 2 that for the average ratio $(\frac{dRi}{dRe})_{aver} = 1.8$ the relative differences for maximal and minimal values are $(dRi - d\bar{R}_{cell})/d\bar{R}_{cell} = 0.38$ and $(d\bar{R}_{cell} - dRe)/d\bar{R}_{cell} = 0.24$. We assume that these deviations have to be constant for a fixed ratio dRi/dRe. In addition, they can be used for estimations of dRi and dRe for other $d\bar{R}_{cell}$ values.

For calculation of mean removed material in different cells (Fig. 3) we used the eigenfrequencies deviations during equator welding (EW) and EP, comparing the cells' frequencies after EP with subcomponents characteristics before EW.

To analyse the processes of EW and EP separately additional RF measurements were required.

The comparison of the new analysis with data from SRF 2013 shows:

- good agreement for middle cells (#3…#7);

ISBN 978-3-95450-169-4

- deviations for cells #2 and #8 are at margin of errors;
- high discrepancy for end cells.

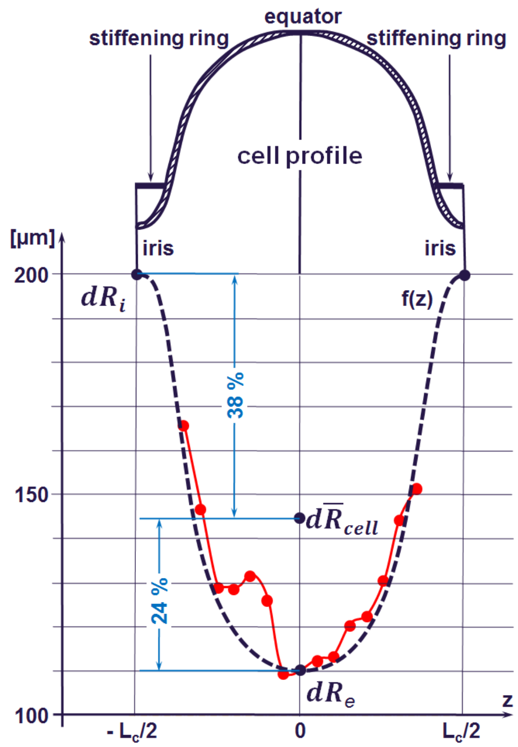

Figure 2: Mean removal value along a middle cell: red line – ultrasonic measurements, black dots – RF analysis.

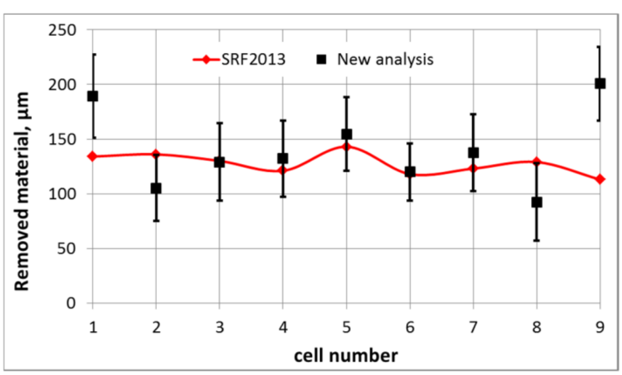

Figure 3: Mean removal value in different cells: red curve (points) – ultrasonic measurements, black dots – RF analysis.

Systematic eigenfrequency deviations for the end cells (relative middle cells) during EP have to be compensated by fundamental mode tuning. The compensation increases the uncertainties of the field distribution for higher order modes. This effect can be reduced by correction of end-groups trimming before EW.

RESULTS

Summarizing the calculation for different cavity cells and taking into consideration the deviations of *dRi* and *dRe* relative $d\bar{R}_{cell}$ we can estimate the removed material along one cavity (see Fig. 4).

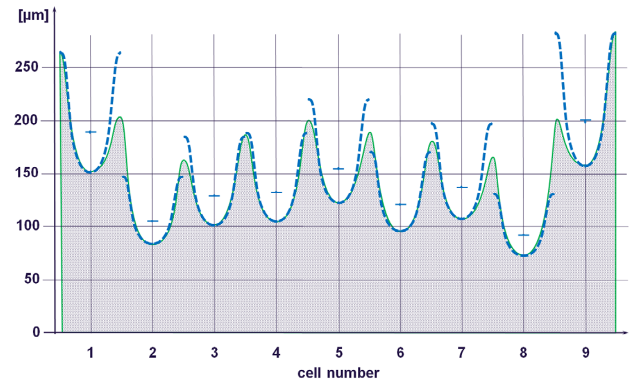

Figure 4: Estimation of removed material along a cavity (green line) and in separate cells (blue dashes).

Real distribution of removed material is more complicated and depends on many factors like electrode shielding position and thickness, temperature distribution and others.

SUMMARY

The pi-mode frequency change depends on the average amount of removed material from the inner cavity surface and the ratio of removed material between iris and equator. Corresponding correction (2.2) allows us to increase the accuracy of mean removed material for a cavity from 30 % to 7 % (see Fig. 1).

Calculated values of mean removed material along one cell (Fig. 2) and in the middle cavity cells (Fig. 3) coincide with ultrasonic depth measurements, presented in [3]. The deviations for the end cells (1 and 9) can be explained by the uncertainties of ultrasonic measurements.

Modern analysis of the cavity geometry deviations during the EP process is based on RF measurements. It provides us with very accurate calculations and is a quick tool using the results of non-contact measurements.

ACKNOWLEDGMENT

We thank the colleagues from Ettore Zanon S.p.A. for assistance with weight and mechanical measurements before and after EP, which helped us with comparison of the results and improvement of our algorithm of analysis.

REFERENCES

[1] A. Sulimov, G. Kreps, J. Sekutowicz, “Estimation of Small Geometry Deviation for TESLA-Shape Cavities due to Inner Surface Polishing”, in *Proceedings of SRF2013*, Paris, France, p. 537.

[2] J. Sekutowicz *et al.*, “A Different Tuning Method for Accelerating Cavities”, in *Proceedings of 4th Workshop on RF Superconductivity*, KEK, Tsukuba, Japan, 1989, p. 849.

[3] M. Rizzi, A. Gresele, A. Matheisen, N. Steinhau-Kühl, P. Michelato, “Electropolishing for EXFEL Cavities Production at Ettore Zanon SpA”, in *Proceedings of SRF2013*, Paris, France, p. 220.