

RF Analysis of Electropolishing for EXFEL Cavities Production at Ettore Zanon S.p.A.

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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

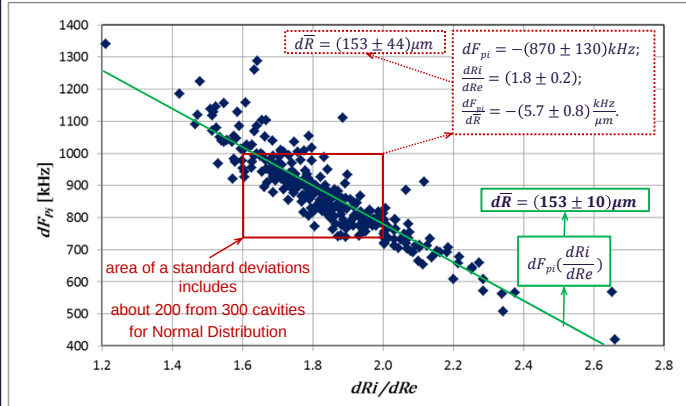


Figure 1. Deviation of EXFEL cavities parameters during EP at E.ZANON (for 300 cavities).

Algorithm of Analysis

Removed material along one cell:

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

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

The function $f(z)$ depends on the distance between the electrode of EP and cell's surface, local shielding of EP cathode, temperature of the working liquid and other parameters. However, the integral of this function:

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

The real form of the function cannot be found by the analysis of RF measurements.

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

$$\begin{bmatrix} dR_i \\ dR_e \end{bmatrix} = A \begin{bmatrix} dF_{pi} \\ dF_{pi} \end{bmatrix}, \quad (1.3)$$

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

dF_{pi} and dF_{pi} are frequency changes of zero- and pi-mode correspondingly.

Mean removal along a cavity:

Frequency correction (F_c) due to changes of the ratio dR_i/dR_e relative average value:

$$F_c = 622 \cdot \left(\frac{dR_i}{dR_e} - 1.84 \right) \text{ kHz}, \quad (2.1)$$

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

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

where $\frac{dF_{pi}}{d\bar{R}} = 5.7 \frac{\text{kHz}}{\mu\text{m}}$ – frequency sensitivity for EP process.

Removed material in different cavity cells:

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

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.

Calculations and Comparison

Mean removal along cavity

$$d\bar{R} = (153 \pm 10) \mu\text{m}$$

First results of EP analysis were done for the first 4 cavities and presented on SRF2013 [3] (values marked red).

New RF analysis was done for 12 cavities of different time of production (values marked black).

Removal material along one cell

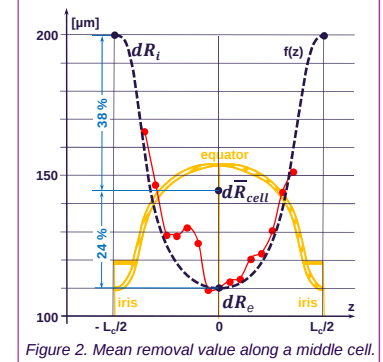


Figure 2. Mean removal value along a middle cell.

Removal material in different cells

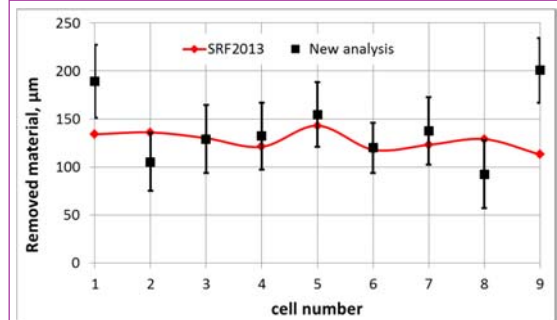


Figure 3. Mean removal value in different cells.

Results

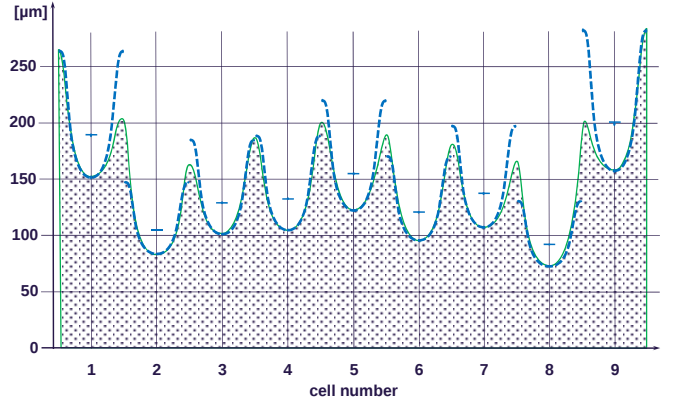


Figure 4. Estimation of removed material along a cavity (green line) and in separate cells (blue dashes).

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.

References:

- [1] A. Sulimov, G. Kreps, J. Sekutowicz, "Estimation of Small Geometry Deviation for TESLA-shape Cavities due to Inner Surface Polishing", Proceedings of SRF2013, Paris, France, p. 537
- [2] J. Sekutowicz et al., "A Different Tuning Method for Accelerating Cavities", Proceedings of 4th Workshop on RF Superconductivity, KEK, Tsukuba, Japan, 1989, p. 849
- [3] M. Rizzi, A. Gresele, A. Matheisen, N. Steinhilber-Kühl, P. Michelato, "Electropolishing for EXFEL Cavities Production at Ettore Zanon SpA", Proceedings of SRF2013, Paris, France, p. 220