HOM SUPPRESSION IMPROVEMENT FOR MASS PRODUCTION OF EXFEL CAVITIES AT RI

A. Sulimov, J.-H. Thie, DESY, Hamburg, Germany
M. Pekeler, D. Trompetter, RI Research Instruments GmbH, Bergisch Gladbach, Germany

Abstract

During cold RF tests of the European XFEL (EXFEL) cavities at DESY it was observed that the damping of the second monopole mode (TM011) showed the largest variation, which was sometimes up to 2-3 times lower than the originally allowed limit. It was concluded that this TM011-damping degradation was caused by cavity geometry deviation within the specified mechanical tolerances. The particular influence of different mechanical parameters was analyzed and additional RF measurements were carried out to find the most critical geometry parameters. Stability of the equator welding and regularity of chemical treatment were investigated for different cavity cells. In spite of the high fabrication rate during EXFEL cavity mass production the TM011 suppression was improved to an acceptable level.

STATISTICS

Some of the EXFEL cavity production engineering data can now be presented as well as final measurements results (see Fig. 1) for Q-factor of the highest frequency (9th peak) in the spectra of TM011 (TM011_9).

The problem with the Higher Order Modes (HOM) suppression efficiency for EXFEL linac [1] made us analyze the whole sequence of cavity production in deeper detail.

To estimate the influence of different factors on TM011 damping efficiency (Q_{load}), we concentrated on the dimensions of the most critical components and inner cavity shape.

The efficiency of HOM extraction depends on the coupling with electromagnetic field through the HOM coupler. It is foreseen to get an asymmetrical field for the TM011 mode with a maximum in cell #1 (managed by the shape of the two end cells). Thus the short end group (EGS) dimensions and the position of its HOM coupler (Fig. 2) are important for investigations.

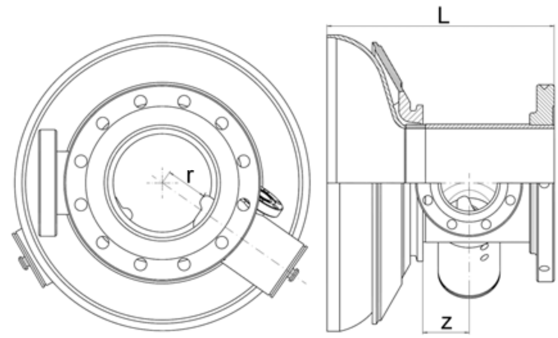

Figure 2: Position of the HOM coupler #1 in EGS: L – length; z – distance between coupler and connecting flange, r – distance between cavity axis and F-part.

The results of statistics analysis and calculations of Q-factor sensitivity (dQ/dM) to these parameters (M = L, z and r) are presented on Figure 3 and summarized in Table 1. One can see that TM011 damping is very sensitive to EGS length and to distance between coupler and connecting flange, but the fluctuation of these values causes the deviation of Q_{load} to less than 20 000. Nevertheless this factor cannot explain the complete range of Q_{load} variation during production (Fig. 1).

The second major parameter is the inner shape accuracy. It was a guess that improvement of subcomponents fabrication accuracy could decrease the average value and deviation of Q_{load}. The shape (Fig. 4) of the end groups for a long side (EGL) and short side [2], as well as the shape of both half-cells of all dumb-bells (DB) were controlled during the serial production (Fig. 5).

The analysis of the 3D shape was done quantitatively. Only the number of points were counted, whose deviation from the ideal shape was between 0.2 mm and 0.3 mm. Their positions were not in consideration, as this would require analyzing all points individually (200 points per half-cell, roughly 1.5e6 points).

No correlation between shape accuracy and HOM suppression efficiency was found.

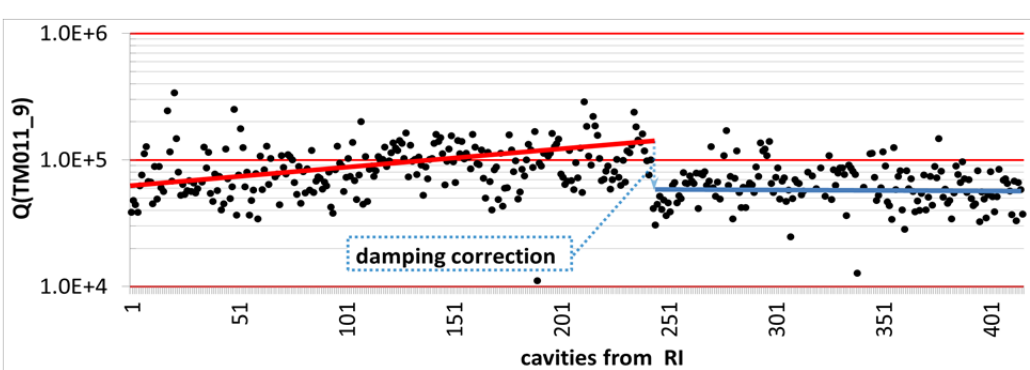

Figure 1: Measurement results of the Q_{load} for the TM011 (zero-mode) at 2K.

ISBN 978-3-95450-169-4

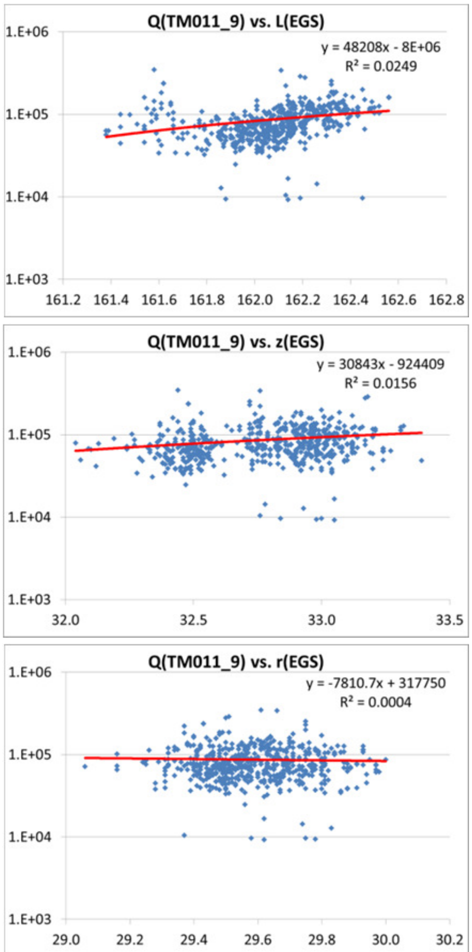

Figure 3: Sensitivities of quality factor for TM011 (y) to EGS geometry deviations (x = L, z and r) in mm.

Table 1: TM011 Damping Sensitivity to EGS Geometry

Parameter (M)	$\lvert dQ/dM \rvert$, 10^3 mm^{-1}	Standard deviation (S), mm	Q-deviation $\lvert dQ/dM \rvert$ * S, 10^3
L	48.2	0.21	10
z	30.8	0.26	8
r	7.8	0.16	1.2

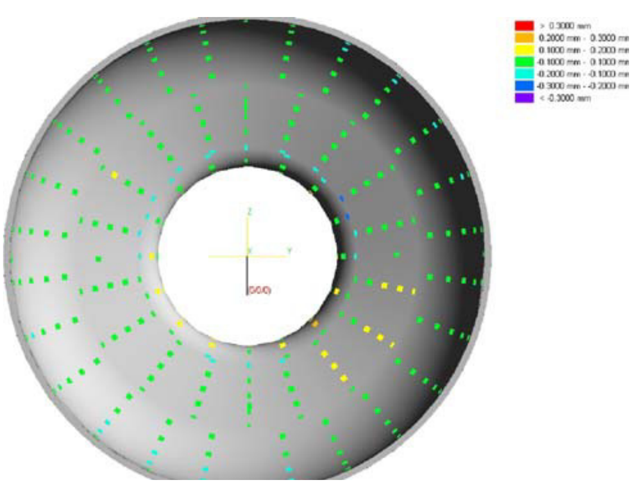

Figure 4: Results of 3D-measurements of cavity half-cell.

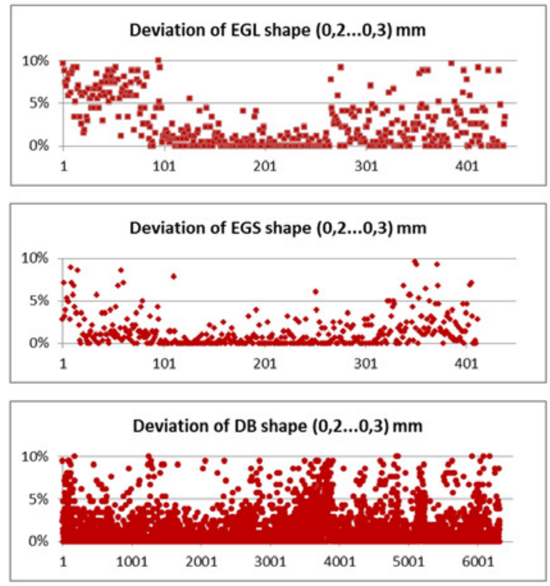

Figure 5: Part of subcomponents shape with accuracy deviation over 0.2 mm.

We can see that the HOM damping was improved around cavity 250 when the trimming correction was established. It is even (slightly) visible that the damping improves even more towards the end of production. Many EGS were on stock and trimming with the correction started with cavity 334. Only EGL were trimmed with the correction after cavity 250 directly. The value of the trimming correction (positive for EGS and negative for EGL) was increased stepwise from 0.03 mm to 0.06 mm at the end.

The trimming correction of the EG for cavities 255-262 was 0.10 mm for both, EGS (more trimming) and EGL (less trimming). The effect is clearly visible as all cavities do show a Q_{ext} of TM011_9 lower than the average of all other cavities later.

EQUATOR WELDING AND ELECTROPOLISHING

The accuracy of shape and dimensions for all cavity subcomponents is controlled only before equator welding (EW) and electropolishing (EP) of the cavity. The modern methods, which are based on RF measurements, allow us to estimate the longitudinal and transverse deviations of the cavity shape during these processes [2, 3]. Analysis of the average eigenfrequencies deviations for all 9 cells during EW and EP were done for 12 cavities from different parts of production.

No unplanned shape changes during equator welding were found and all cells frequencies stayed stable in the margin of errors (Fig. 6, red line).

The influence of all operations, which can change the cavity shape (Fig. 6, black line), on cells characteristics shows the high systematic eigenfrequencies deviations (about 400 kHz) for the end cells (relative middle cells).

This irregularity has to be compensated during fundamental mode tuning. To prevent a reduction of the necessary field asymmetry for TM011, correction of cavity end-groups trimming is required.

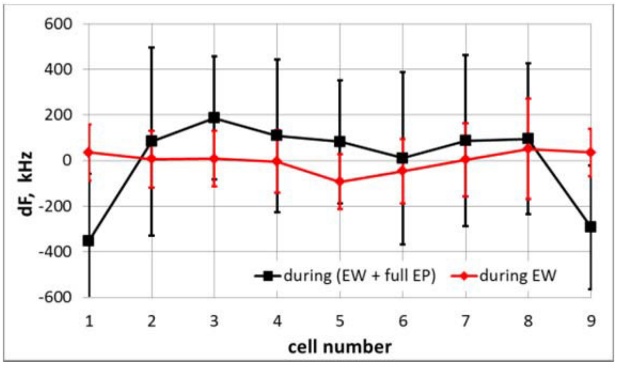

Figure 6: Calculated frequencies deviations in different cells during EW and EP.

High random errors during all processes exist for the first cavities (from the beginning of XFEL production). Usually these errors are due to cavity deformations, which cannot be ignored during analysis. Excluding of these cavities from analysis not only reduce the random error but also the reliability of the results.

TM011 FIELD DISTRIBUTION

To estimate the coupling of the TM011_9 mode with HOM couplers we organized the E-field distribution measurements on the cavity axis (Fig. 7) at room temperature. The results of the bead-pull measurements indicate that optimal damping is reached, in case of planned field asymmetry (Fig. 7, cavity 319) or its degradation, when the mode is trapped in the cavity (Fig. 7, cavity 222).

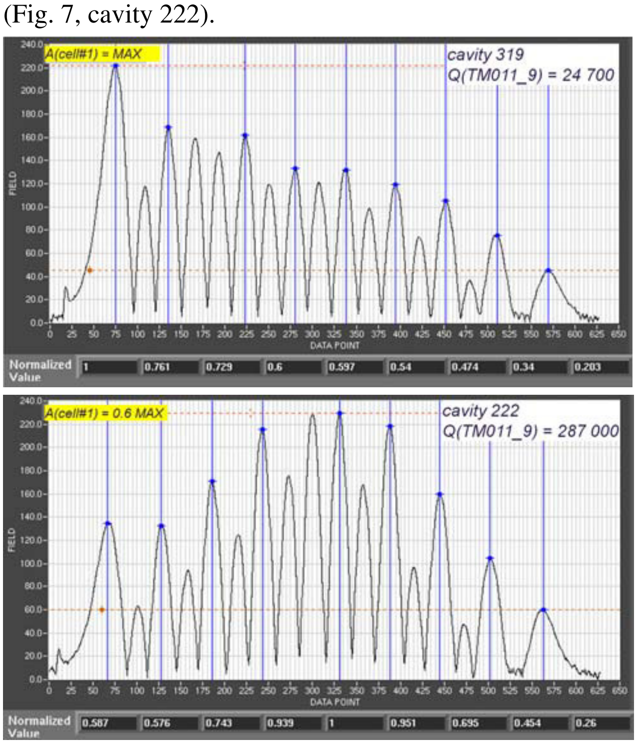

Figure 7: E-field distribution of the TM011_9 on axis for two examples: cavity 319 with asymmetrical field; cavity 222 with symmetrical "trapped" field.

This measurement was done before cavity integration into the helium tank. It provided us with a possibility to organize an additional vertical RF test with control measurements of all HOMs and thus to improve the TM011 suppression [4] in case of necessity.

SUMMARY

No considerable dependences of HOM suppression efficiency on the accuracy of cavity subcomponents shape or on positioning of HOM coupler were found.

Stability of EW for major amount of cavities was confirmed by both mechanical measurements and RF analysis.

Irregularity of eigenfrequency changes due to EP was compensated by planed additional trimming of the end groups before EW.

Measurements of the spectra and field distribution for TM011_9 at room temperature after fundamental mode tuning allowed us identification of the critical geometry changes, which cause the trapping of TM011 mode.

Significant damping correction for TM011_9 was provided by:

- increasing of TM011-field asymmetry due to correction of end group trimming;
- intensive R&D collaboration between RI and DESY.

ACKNOWLEDGMENT

We would like to thank RI and DESY colleagues who supported us in this particular research work during the European XFEL project.

REFERENCES

[1] A. Sulimov *et al.*, "Efficiency of High Order Modes Extraction in the European XFEL Linac", in *Proceedings of LINAC 2014*, Geneva, Switzerland, 2014, p. 883.

[2] A. Sulimov, "RF Analysis of Equator Welding Stability for the European XFEL Cavities", in *Proceedings of SRF2015*, Whistler, BC, Canada, 2015, p. 1272.

[3] A. Sulimov *et al.*, "RF Analysis of Electropolishing for EXFEL Cavities Production at Ettore Zanon Spa", presented at LINAC 16, East Lansing, MI, USA, 2016, paper TUPL035.

[4] A. Sulimov *et al.*, "Practical Aspects of HOM Suppression Improvement for TM011", in *Proceedings of SRF2015*, Whistler, BC, Canada, 2015, p. 1277.

ISBN 978-3-95450-169-4