

EFFICIENCY OF HIGH ORDER MODES EXTRACTION IN THE EUROPEAN XFEL LINAC

A. Sulimov, J. Iversen, D. Kostin, W.-D. Moeller, D. Reschke, J. Sekutowicz, J.-H. Thie (Deutsches Elektronen-Synchrotron, DESY, Notkestrasse 85, 22607 Hamburg, Germany),
 D. Karolczyk, K. Kasprzak, S. Myalski, M. Wiencek, A. Zwozniak (Instytut Fizyki Jądrowej PAN, IFJ-PAN, ul. Radzikowskiego 152, 31-342 Kraków, Poland)

Abstract

The serial production of components for the European XFEL linac was started in 2011 and reached the planned level of 8 cavities (1 module) per week in 2013. The measurements of High Order Modes (HOM) characteristics under cryogenic conditions (2K) are being done at the Accelerating Module Test Facility (AMTF) by the IFJ-PAN Team in collaboration with DESY groups.

More than 50 % of the cavities have been already produced and 30 % of the whole amount were measured during either cavity vertical tests or module tests.

We present first statistics of these measurements and analyze the efficiency of HOM extraction.

HOM DAMPING REQUIREMENTS

The most important high order modes for XFEL cavities are presented in figure 1 [1].

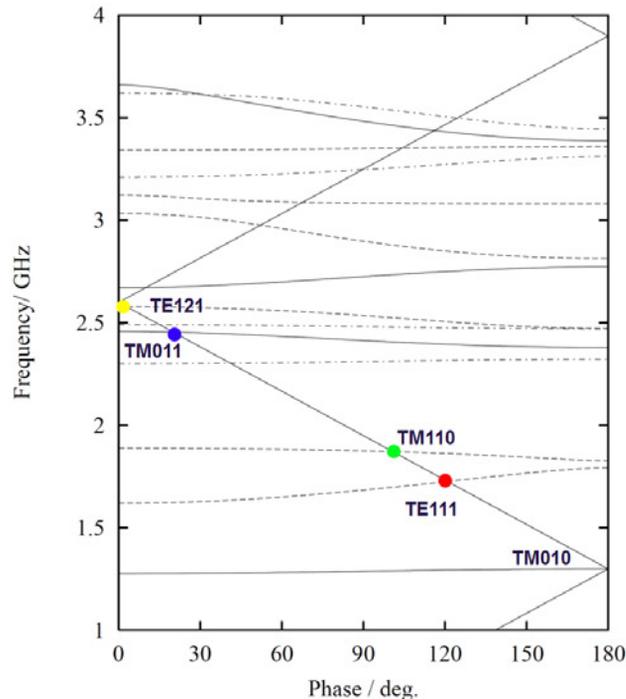


Figure 1: Dispersion curves for monopole (solid line), dipole (dashed line) and quadrupole (dash-dotted line) modes. The dots mark the most critical HOM.

The most critical modes, which could be generated by the beam, are marked with points. The two first dipole modes: TE111 (red) and TM110 (green) are usually used for beam diagnostics as beam position monitors [2]. The second monopole TM011 (blue) does not cause a critical

beam perturbation, but increases the cryo losses in the linac due to a very high value of $R_{sh}/Q = 155 \text{ Ohm}$, only 6 times less than the shunt impedance of fundamental TM010 pi-mode, where $R_{sh}/Q = 1010 \text{ Ohm}$. The third dipole mode TE121 (yellow) is the most dangerous one for the beam dynamics [3]. Unfortunately it is very difficult to identify it without a beam. So, only three HOM pass-bands are used for XFEL cavities quality control (see figure 2).

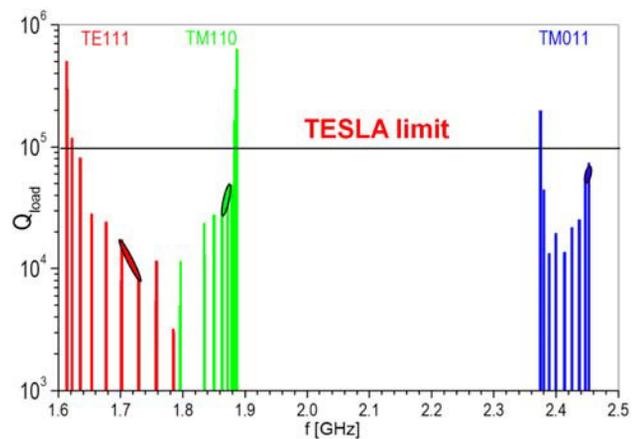


Figure 2: Example of $Q_{load}(f)$ for TE111, TM110, TM011.

The HOM damping requirements for cavities in the TESLA project [4] were also used for the European XFEL. Typically it is planned to analyze only Q_{load} values for the strongest modes (marked with black ovals in figure 2):

- TE111 (both polarizations of modes 6 and 7),
- TM110 (both polarizations of modes 4 and 5),
- TM011 (mode 9).

All values for Q_{load} have to be lower than 10^5 .

The first two dipole modes for all XFEL cavities always fulfill this requirement.

Thus, special attention in this article will be given to the second monopole measurements.

STATISTICS

Before the XFEL cavities serial production was started, HOM couplers' orientation and configuration were designed in order to achieve optimal efficiency for HOM damping, corresponding to TESLA project requirements.

The zero-mode for TM011 has the highest frequency (9th peak in the spectra) and is labeled as TM011_9.

The measurement results of $Q_{load}(TM011_9)$ for 9-cell TESLA shape cavities under cryo conditions at DESY are presented in figure 3.

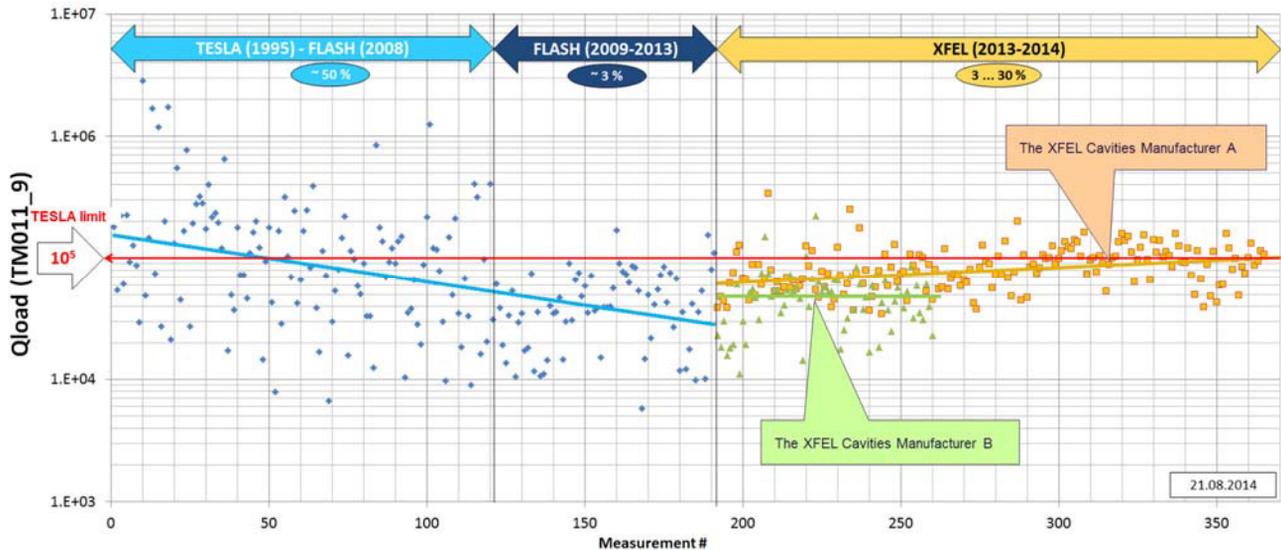


Figure 3: Measurement results of HOM damping for 9-cell TESLA shape cavities under cryogenic conditions at DESY.

The first cavities, which were produced for the TESLA Test Facility and FLASH, show high deviation of $Q_{load}(TM011_9) \approx 7 \times 10^3 \dots 2 \times 10^6$.

The averaged Q_{load} value exceeds the limit (10^5) and 50 % of the cavities were outside of TESLA specification at the start of investigations in 1995 – 2008.

RF measurements based cavity production quality control, according to [5], allowed stability increase of the production and reduction of the average Q_{load} level for FLASH and XFEL-prototype cavities. Only 3 % of the cavities, measured in 2009 – 2013 were slightly above the limit.

Unfortunately, we could not keep this stability during serial production for both XFEL cavities manufacturers. One company achieved the low and stable Q_{load} results (comparable with pre-series production), whereas the other one increased the number of cavities with a $Q_{load}(TM011_9) > 10^5$ over previous fabrication time.

An average number of cavities above the limit is 30% (see statistics in figure 3 for manufacturer A), and even 50 % for the last 50 cavities.

These aspects forced us to look for the effects, which could reduce the TM011 damping efficiency.

ANALYSIS

To estimate the influence of different factors, we have analyzed the mechanical parameters and RF characteristics for cavities with high Q_{load} values and compared them with “normal” cavities.

The XFEL cavity production engineering data are not yet in a state to be published, so we will describe only the measurements and simulation results of RF characteristics. A correlation between them could be found.

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).

The distribution of the E-field on the cavity axis for TM011 (see figure 4), measured at room temperature with a bead-pull system, indicates the optimal damping, in case of planned field asymmetry (a), and its degradation, when the mode is trapped in the cavity (b and c).

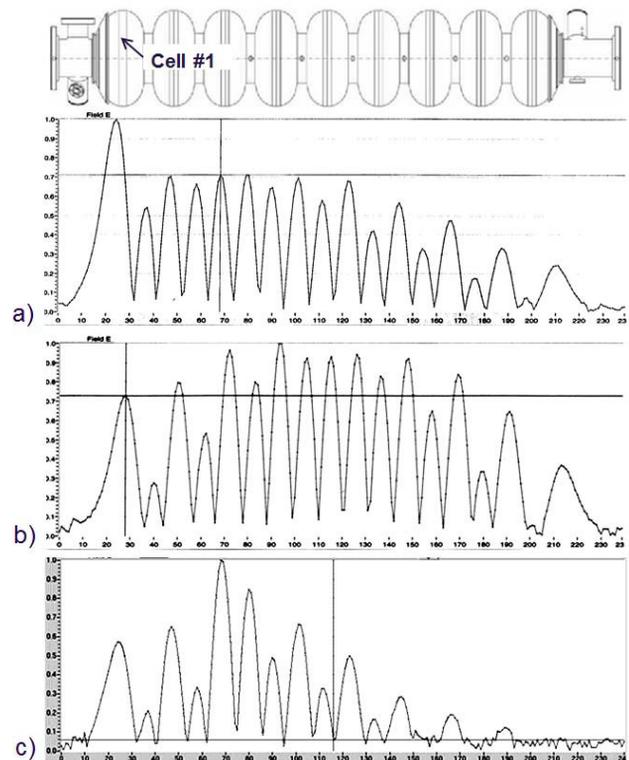


Figure 4: Field distribution of TM011_9 $|E| (r=0, z)$ for: a) optimal HOM damping ($Q_{load} = 70\ 000$); b) reduced HOM damping efficiency ($Q_{load} = 252\ 000$); c) TM011 is trapped in the cavity ($Q_{load} = 339\ 000$).

To estimate the amount of geometry deviations, which might cause similar changes, we have simulated a cavity with FEM code [6].

Two models are interesting for comparison:

1. planned geometry with an asymmetrical field distribution on TM011_9 (see figure 5 a),
2. deformed cavity (figure 5 b) with increased equator radius in cell #1 by 0.2 mm (inside the tolerance, corresponding to XFEL specification).

Cell #1 in the simulations and the following plots is on the right end of the cavity (figures 5 and 6). The length of cell #1 has to be increased by 1.5 mm to compensate the field flatness (ratio of minimal amplitude to maximal) for the fundamental TM010 pi-mode (see figure 6). In reality we do the same during cavity tuning, compensating the radius (shape) deviations with the length of cells.

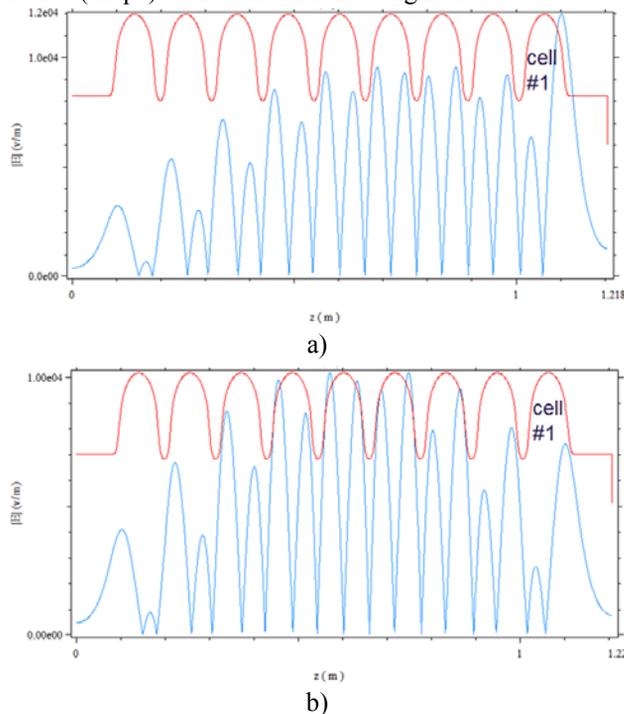


Figure 5: Simulated TM011_9 |E| (r=0, z): a) planned geometry; b) deformation in cell#1.

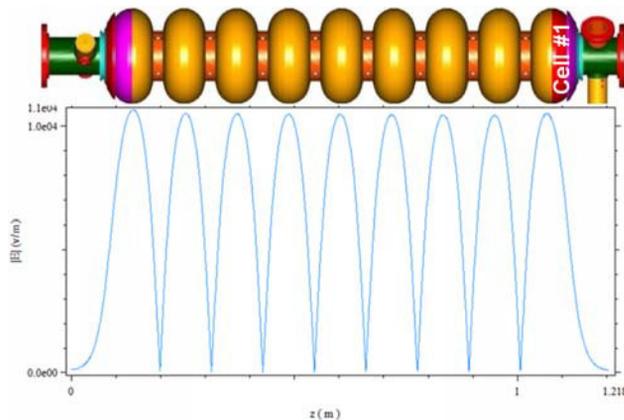


Figure 6: TM010 (pi-mode) |E| (r=0, z) for tuned cavity.

The other important aspect is the change of the shunt impedance. The value of $R_{sh}/Q = 155 \text{ Ohm}$ (figure 5 a),

which was already mentioned in “HOM Damping Requirements”, grows during trapping of TM011_9 to $R_{sh}/Q = 162 \text{ Ohm}$ for changed geometry (figure 5 b).

Similar results could be obtained for changes of other cells (as example, reduction of equator radius by 0.2 mm and length by 1.5 mm for cell #3).

SUMMARY

The reduction of a HOM damping efficiency for the European XFEL cavities is caused by some critical changes in the field distribution on TM011 (zero mode).

RF simulations show that these changes are possible even for geometry deviations of about $\pm 0.2 \text{ mm}$ in the equator radius within specific cells.

Some geometry deviation influences could be reduced by an algorithm of parts sorting during cavity fabrication. However, such shape errors, generated during cavity welding, could not be compensated without expensive and time-consuming actions.

Based on the European XFEL beam parameters, the HOM damping is not as critical as for the TESLA linac. Therefore it was decided to relax the HOM damping requirements for the monopole mode TM011_9 – change Q_{load} limit from 1×10^5 to 2×10^5 .

The further work on the HOM damping improvement is going on in collaboration with cavities manufacturers.

ACKNOWLEDGMENT

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