STATUS OF THE EUROPEAN XFEL 3.9 GHZ SYSTEM

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Abstract

The injector of the European XFEL will use a third harmonic RF system at 3.9 GHz to flatten the RF curvature after the first accelerating module before the first bunch compression stage. This paper presents qualification tests of the prototype cavities and the status of the activities for the realization of the third harmonic section of the European XFEL towards its commissioning due in 2014.

INTRODUCTION

The European XFEL third harmonic section follows the first 1.3 GHz accelerating module after the photocathode gun, before the first bunch compressor stage [1-3]. The system is similar to the ACC39 built by FNAL for the FLASH linac at DESY [4-7]. The XFEL 8-cavity module will provide a maximum voltage of 40 MV, with gradients well within the cavity performances already achieved by the FLASH experience.

In this paper, we report on the status of the main different components of the 3.9 GHz section, namely the ongoing testing of prototype cavities and the finalization of the 3rd harmonic system design.

CAVITY PROTOTYPES TESTING

The baseline fabrication process for the 3.9 GHz resonators follows closely the experience gained by the TESLA Collaboration for 1.3 GHz TTF cavities, and, in view of the "moderate" specification of 20 MV/m maximum gradient, the surface preparation process is based on standard bulk chemical processing (BCP). In preparation for the realization of the final system three prototype cavities (3HZ01-3) have been tendered for fabrication and processing at E. Zanon SpA, one of the qualified vendors for the XFEL main linac resonators [2]. Minor adaptations were performed to the FLASH FNAL cavity design, mainly in order to conform to the different module design or to adapt to standard components (e.g. flanged HOM/PU feedthroughs) from the main linac production.

After fabrication and processing, vertical testing of the cavities has been performed at INFN/LASA, where the cavity preparation area and vertical RF test station was refurbished, adapted for the 1.3/3.9 GHz XFEL workprogram and qualified through test of 1.3 GHz monocells of proven performances provided by DESY.

The cavity production phase was finalized with the experience of Cu and Nb mockups. After the mechanical fabrication, a bulk BCP etched 150 um from the inner surface and an 800 °C UHV oven treatment (at DESY) was performed to remove the hydrogen content. The cavities were tuned to a final Field Flatness to > 95 %, with a length spread of ±0.4 mm from the nominal dimensions, well within the structure length specifications.

Each cavity has then undergone the final light BCP chemistry (10-30 um), HPRs and final preparation for cold vertical test.

3HZ01

3HZ01 was the first 3.9 GHz cavity tested at INFN LASA with the upgraded infrastructure. Several minor glitches in the newly re-commissioned test infrastructure, new high-frequency PLL hardware, and an error in the variable coupler setup prevented a consistent characterization of the cavity, with indications of high losses, possibly located in the antenna region, but the absence of a comprehensive temperature diagnostic could not confirm it.

Moreover, due to changes in the cryogenic system with respect to the past and as a measure to limit LHe consumption, we performed LN_2 precooling, resulting in a long permanence of the cavity between 77 K and 150 K, possibly driving "Q-disease" effects. To rule this effect out, the cavity has been heat-treatment again after warmup and it is now waiting the final chemistry and testing.

Although the first test did not allow to fully characterize the RF behaviour structure, it was very important for the final commissioning of the 3.9 GHz test infrastructure and to highlight the need of improved diagnostics. During the cryogenic operation, the overall static losses of the test stand were measured at values lower than 1 W. The low He consumption required for operation thus allowed avoiding LN_2 precooling in successive tests.

3HZ02

After the final commissioning of the facility with the 3HZ01 test, the RF feed was changed to a fix coupling scheme through the cavity main coupler port. Cavity 3HZ02 was therefore sent to measurement after a light final BCP chemistry of 10 um.

After the subcooling from 4.2 K to 2.0 K the surface resistance reached a final value of about 320 nΩ. The cavity reached a maximum field of 15 MV/m with a Q_0 of $8 \cdot 10^8$ (see Fig. 1), without any detectable X-Ray or field emission. Analysis of the fundamental pass-band modes power rises indicate that the limiting cells are #2 or #8

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(numbering starts from the coupler side), but do not allow discrimination between the two.

Given the high residual resistance with respect to the foreseen value and to the FNAL experience [5], we proceeded by removing further 20 um from the cavity surface with a further BCP etch. The subsequent RF vertical test was comparable to the previous one, reaching a maximum accelerating field around 15 MV/m with a Q_0 of $6 \cdot 10^8$, without indications of X-Ray or field emission.

As a final test we installed a Nb-coated flange on the upper beam pipe port to exclude the possible influence of fringe fields reaching the beam pipe flange on the overall dissipation. This third test confirmed the results obtained before, ruling out the contribution of additional dissipation effects at the beam pipe flanges.
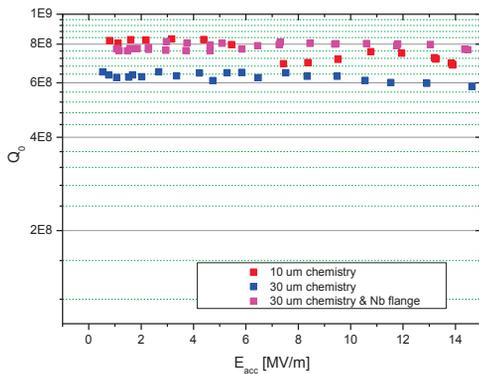

Figure 1. Q_0 versus E_{acc} for cavity 3HZ02 in three tests following different treatments: 10 um BCP, 10+20 um BCP and after installation of a Nb-sputtered flange. In all cases, the maximum field at 15 MV/m was limited by a hard cavity quench, in absence of X-Ray and field emission activity. Test temperature is 2.0 K (31 mbar).

3HZ03

The last cavity prototype, 3HZ03, underwent 30 um of surface removal by final BCP and was tested with the fixed coupling antenna.

After subcooling, the surface resistance dropped to the final value of ~90 nΩ, comparable to FNAL experience at 2.0 K [5]. The maximum accelerating field at 2.0 K is 19 MV/m with a Q_0 of $9 \cdot 10^8$, limited by quench. The Q_0 increases to $1 \cdot 10^9$ at 1.8 K, where the power rise reached a maximum accelerating field of 21 MV/m, followed by a quench. RF test results of the fundamental power rises at 2.0 and 1.8 K are presented in Figure 2. As for the previous cavities, we did not observe any X-ray or field emission activity.

Figure 3 shows the power rises of all cavity modes of the fundamental pass-band. As for the case of cavity 3HZ02, the cavity performance on the π mode is limited by cells #2 or #8. Besides these cells, all other cells have been excited to fields above 23 MV/m during the power rises. The table inset in Figure 3 summarizes the maximum accelerating field reached in each cell, and the maximum fields are highlighted in color.
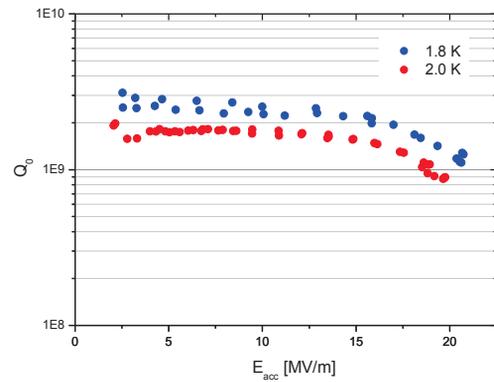

Figure 2. Q_0 versus E_{acc} for cavity 3HZ03 at 2.0 K and 1.8 K. The cavity is limited by quench without X-ray or field emission.
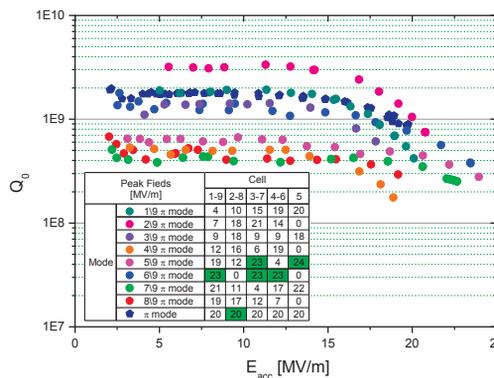

Figure 3. Q_0 vs E_{acc} for all fundamental pass-band modes of cavity 3HZ03. The mode analysis shows that cells #2 and #8 are limiting the cavity performance in the π mode, while the other individual cells reach 23 MV/m and above (values highlighted in green).

Cavity Diagnostic using OST detectors

In order to identify the cell originating the quench, which cannot be distinguished due to the structure symmetry from the pass-band measurements, a set of Oscillating Superleak Transducers (OSTs) (provided by FNAL and Cornell) [8] were mounted around the cavity to detect the second sound signals. For this task we developed the signal processing electronics, the data acquisition system and the quench region reconstruction software. In order to check the sensors response and to validate and calibrate the reconstruction routines, we have also developed a "quench simulator", based on pulsed resistors placed at known locations around the cavity.

Fig.4 shows the experimental setup (photograph on the left) and an example of reconstruction of the position of the second "quench simulator" (yellow sphere), as determined by the reconstruction routines (model on the right). The estimated position of the origin of the signal detected by the OSTs is currently within +/- 5 mm from its physical location, larger than the uncertainty associated to the absolute position of the sensors in the

setup and still not adequate for the quench origin determination in these small structures (the cavity iris-to-iris nominal distance is only 38 mm). Improvements in the quench reconstructions algorithms, to account for sensor finite dimensions and proper handling of signal propagation in the correct geometry, are needed to increase this resolution.
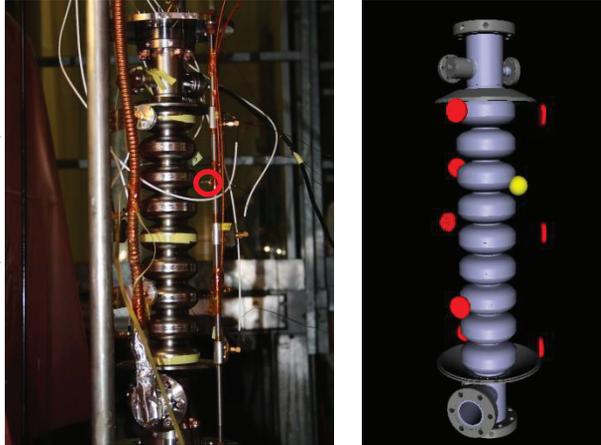

Figure 4. Position of OSTs around the cavity (left photograph of the cavity in the cryostat insert) and reconstruction of the quench origin position (model on the right). The source is highlighted by the red circle on the left and represented by the yellow sphere on the reconstruction picture, where OSTs are shown in red.

After the calibration with the "quench simulator", the second sound detection system has been used during the measurements of the power rise on the fundamental pass-band modes. Table 1 shows (for cavity 3HZ02) the maximum field in each cell (as obtained by the mode analysis described earlier) and the rough indication of the quench origin evaluated from the OST signals, often spanning two consecutive cells in view of the still large uncertainty in the reconstruction routines compared to the cavity physical dimensions. A cross-check of the quench locations with the optical inspection survey of the cavities is in progress to identify possible geometrical features on the inner surface as quench origins.

Table 1. Accelerating field in cells from mode analysis and OSTs signal origin (orange). The green underlined value indicates the maximum cell excitation achieved.

Cell #	*Fundamental band-pass mode index*								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	3	6	7	11	17	19	18	17	*15.3*
2	9	15	14	14	11	0	9	15	*15.3*
3	13	17	7	6	20	19	3	11	*15.3*
4	16	11	7	16	4	19	14	6	*15.3*
5	17	0	14	0	22	0	19	0	*15.3*
6	16	11	7	16	4	19	14	6	*15.3*
7	13	17	7	6	20	19	3	11	*15.3*
8	9	15	14	14	11	0	9	15	*15.3*
9	3	6	7	11	17	19	18	17	*15.3*

While Table 1 does not provide a fully consistent picture of the cavity quench behaviour, due to the low resolution of the quench location identification, we can still draw two conclusions on the behaviour of cavity 3HZ02, which has been limited to 15 MV/m in π mode tests. The first is that nearly all cells have been driven up to approximately 20 MV/m, with the exception of cell #2 and #8. The second is that the quench signals seem to indicate cell # 2 as the one quenching at approximately the field levels shown by the π mode. Further analysis will be performed in order to assess the presence of contaminations during welding or geometrical features that may be responsible for the quenches at these moderate field levels.

After qualification of 3HZ01, the prototype activities include a second round of vertical tests for HOM couplers and antennas qualification and the integration of the helium tanks (currently under fabrication) prior to horizontal test qualification with the power couplers.

THE XFEL 3.9 GHZ SYSTEM

The general layout of the 3.9 GHz system at the XFEL injector has been presented in Ref. [3], with a description of its main components. The European XFEL injector commissioning is foreseen to start in mid 2014, thus the procurement of the third harmonic section components is entering its final stages. The 8-cavity cryomodule design, which includes a quadrupole magnet placed at the beginning of the cavity string, is nearly completed. The 3.9 GHz complete system is provided to the European XFEL Project as an In-Kind contribution by INFN and DESY, and builds on the successful FNAL experience demonstrated with the FLASH ACC39 system.

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