STATUS OF THE EUROPEAN XFEL 3.9 GHZ SYSTEM

P. Pierini#, A. Bosotti, P. Michelato, L. Monaco, C. Pagani, R. Paparella, D. Sertore, INFN Milano/LASA, Italy
E. Vogel, DESY, Germany
E. Harms, FNAL, USA

Abstract

The third harmonic system at 3.9 GHz of the European XFEL injector section will linearize the bunch RF curvature, induced by first accelerating module, before the first compression stage. This paper presents qualification tests on cavity prototypes and the on-going activities towards the realization of the third harmonic section of the European XFEL in view of its commissioning in 2014.

INTRODUCTION

The European XFEL injector foresees a third harmonic section after the RF photocathode gun and the first 1.3 GHz accelerating module [1-3], just before the first bunch compression stage. The 3rd harmonic system is similar to the ACC39 module built by FNAL [4-7] and nowadays operated at FLASH in DESY Hamburg.

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.

This paper reports on the status of the main on-going activities related to different components of the 3.9 GHz section, namely testing of prototype cavities, procurement of components and finalization of the 3rd harmonic system design.

CAVITY PROTOTYPES

The baseline fabrication process for the 3.9 GHz resonators is based on the experience earned by the production of the 1.3 GHz TTF cavities. Moreover, since the maximum gradient required for these kinds of resonators is 20 MV/m, we chose a standard chemical processing (BCP) as bulk treatment. Minor adaptations were performed to the FLASH FNAL cavity design, mainly in order to conform to the different module design or to adapt them to standard XFEL components (e.g. flanged HOM/PU feedthroughs). In preparation for the realization of the final system, three full dressed 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].

To finalize the production phase, Cu and Nb mockups were used. 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.

After fabrication and processing, vertical testing of the cavities has been performed at INFN Milano - 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 single cells of proven performances provided by DESY.

TEST RESULTS

3HZ01

This was the first 3.9 GHz cavity tested at LASA with the upgraded infrastructure. Besides few glitches due the infrastructure commissioning, an error in the variable coupler setup prevented a consistent RF characterization of the cavity. We had indications of high losses, possibly located in the antenna region, but the absence of a complete temperature mapping of the cavity prevent its confirmation.

Moreover, due to the new changes in the cryogenic system 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 that were concurrent, in our interpretation, with antenna losses.

To rule this effect out in preparation for a new test, the cavity has been newly heat-treated after warmup and it is now waiting the final chemistry and further testing.

Although the first test was not fully successful, it was a very important step for the final commissioning of the 3.9 GHz test infrastructure and highlighted the need for improved diagnostics. During the cryogenic operation, the overall static losses of the test stand were measured at values lower than 1 W. The lesson learned in this first cooldown and low He consumption required for operation allowed avoiding LN_2 precooling in the successive tests.

3HZ02

After the commissioning of the facility with the 3HZ01 test, the RF power 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. For this test temperature sensors were installed on the cavity.

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

#paolo.pierini@mi.infn.it

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8 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 (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 10^8, without indications of X-Ray or field emission. This time OST (Oscillating Superleak Transducers) (provided by FNAL and Cornell) were installed around the cavity [8] to detect second sound signals produced during cavity quenches. For this task we developed the signal processing electronics, the data acquisition system and the quench region reconstruction software.

Even if the spatial resolution of the OST reconstructed signal is still not precise enough to allow identify precisely the position of the quench origin, the analysis of the OST signals correlated with the result from the mode analysis shows that all the cell except #2 and #8 could reach approximately 20 MV/m and cell #2 is most likely the limiting one because its maximum field is similar to the overall cavity maximum field. Moreover, the OST signal shows cell #2 as quench origin and not cell #8 confirming the results of the mode analysis [9].

A cross-check of the quench locations with the optical inspection survey of the cavities does not allow identifying any geometrical features on the inner surface as quench origins. Further analysis will be also 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.

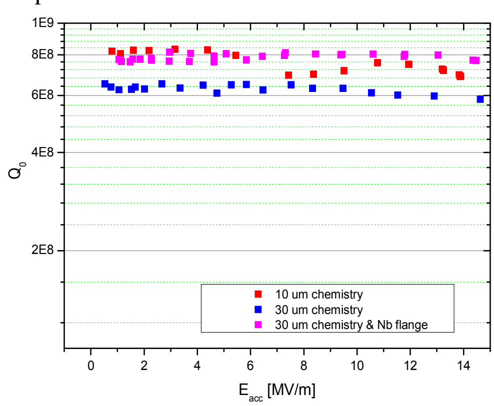

Figure 1: Q_0 versus E_{acc} at 2.0 K for cavity 3HZ02 in three tests following different treatments: 10 um BCP, 10+20 um BCP and after installation of a Nb-sputtered flange. In all cases, the maximum field at 15 MV/m was limited by a hard quench, without X-Ray and field emission activity.

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. We installed also a temperature sensor on the flange to detect possible temperature increase. This third test confirmed the previous results, ruling out contribution of additional dissipation effects at the beam pipe flanges. We observed temperature rise on HOM cans.

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 10^8, limited by quench. The Q_0 increases to 1 10^9 at 1.8 K, where we 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.

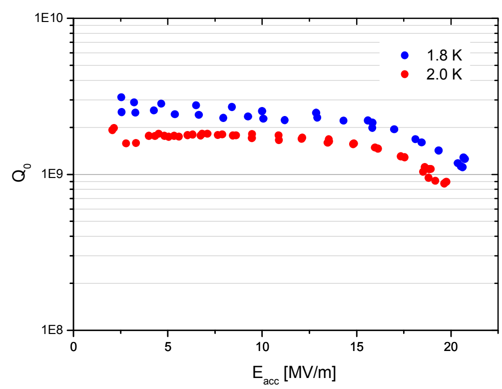

Figure 2: Q_0 versus E_{acc} for cavity 3HZ03 at 2.0 K and 1.8 K. The cavity is quench limited without X-ray or field emission.

Figure 3 shows the power rise 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.

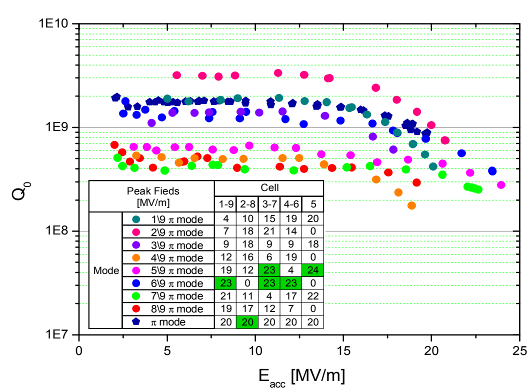

Figure 3: Q_0 vs E_{acc} for all fundamental pass-band modes of cavity 3HZ03. The mode analysis shows that cells #2 and #8 are limiting the cavity performance in the π mode, while the other individual cells reach 23 MV/m and above (values highlighted in green).

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.

Future Activities

The vertical testing program is now focused on the qualification of 3HZ01 and later on a second round of tests for qualification of the three cavities with HOM antennas installed. The HOM tuning procedure has been tested on the Nb mockup cavity and the cavity HOM antennas fabrication will start soon.

After this second round of tests, the three prototypes will be integrated with the helium tanks (nearly ready) prior to horizontal test qualification with power couplers.

"QUENCH SIMULATOR" FOR OST

In order to check the OSTs response and to validate and calibrate the reconstruction routines, we have developed a "quench simulator", based on pulsed resistors placed at known locations around the cavity in the LHe bath. At present, we have installed two SMD two ceramic supported resistors.

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 on-going to increase this resolution.

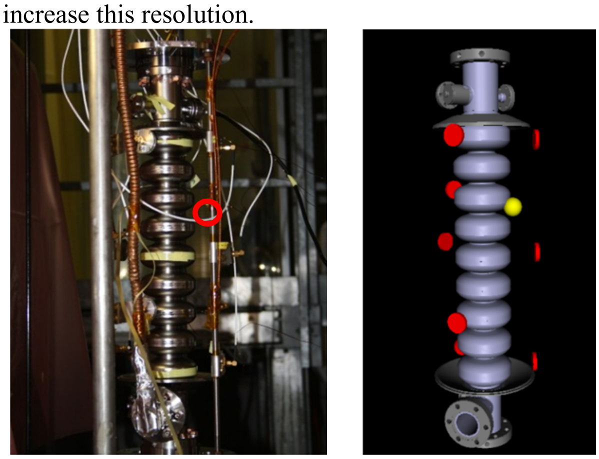

Figure 4: OSTs around the cavity (left photograph of the cavity in the insert) and reconstruction of the quench origin (model on the right). The source is highlighted by the red circle on the left and represented by the yellow sphere on the right, where OSTs are shown in red.

THE XFEL 3.9 GHZ SYSTEM

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 by FLASH ACC39 system. The general layout of the 3.9 GHz system at the XFEL injector has been presented in Ref. [3]. Since the European XFEL injector commissioning is foreseen to start in mid 2014, the procurement of the third harmonic section components is entering its final stages. Call for tenders for cavity fabrication is going to be placed late this summer.

The 8-cavity cryomodule design, which includes a quadrupole magnet placed at the beginning of the cavity string, is nearly completed. Fig. 5 shows its view with installed cavities. The call for tender is ready to be launched fall this year.

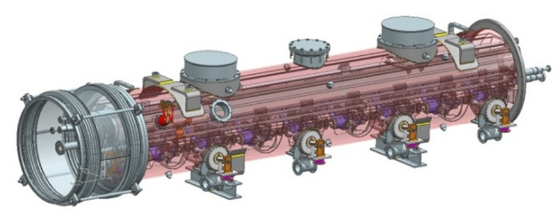

Figure 5: View of the XFEL 3.9 GHz cryomodule full equipped with cavities. Power couplers are alternated to reduce kicks to the beam.

REFERENCES

[1] E. Vogel et al. "Status Of The 3rd Harmonic Systems For FLASH And XFEL In Summer 2008," LINAC08, Victoria, BC, Canada, 2008, TUP034, p. 821.

[2] P. Pierini et al. "Third harmonic Superconducting Cavity Prototypes for the XFEL," LINAC08, Victoria, BC, Canada, 2008, THP019, p. 821.

[3] P. Pierini et al., "Status of the XFEL 3.9 GHz Injector Section", IPAC11, San Sebastian, Spain, 2011, MOPC091, p. 289.

[4] E. Vogel et al. "Test And Commissioning Of The Third Harmonic RF System For FLASH," IPAC10, Kyoto, Japan, 2010, THPD003, p. 4281.

[5] E. Harms et al, "Third Harmonic System at FERMILAB/FLASH", SRF09, Berlin, Germany, 2009, MOOBAU01, p. 11.

[6] H. Edwards et al, "3.9 GHz Cavity Module For Linear Bunch Compression At FLASH," LINAC10, Tsukuba, Japan, 2010, MO304, p. 41.

[7] E. Harms et al, "Commissioning And Early Operating Experience Of The FLASH Third Harmonic RF System," LINAC10, Tsukuba, Japan, 2010, TUP013, p. 422.

[8] Z. A. Conway et al., "Oscillating Superleak Transducers For Quench Detection In Superconducting ILC Cavities Cooled With He-II", LINAC08, Victoria, BC, Canada, 2008, THP036, p. 863.

[9] P. Pierini et al., "Status of the European XFEL 3.9 GHz system", IPAC12, New Orleans, USA, 2012, WEPPC009, p. 2224.

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