STATUS OF THE XFEL 3.9 GHZ INJECTOR SECTION

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Abstract

The European XFEL will use a superconducting third harmonic section to achieve the necessary beam quality for the FEL process. The concept has been successfully proven at the FLASH linac at DESY, with a 4 cavity superconducting module built by FNAL. The design of the third harmonic system at the XFEL injector is being finalized and prototypes of the components (cavities and couplers) have been fabricated and are currently in the testing stage. The paper will provide a status of the activities.

THE XFEL 3.9 GHZ SYSTEM DESIGN

The European XFEL 3.9 GHz RF system is located right after the 1.3 GHz injector module, before the first bunch compressor, as shown in Figure 1 [1]. The system is similar to the ACC39 built by FNAL for the FLASH linac [2]. A maximum voltage of 40 MV is required in a 8-cavity module, with gradients well within the cavity and module performances already achieved by the FLASH module.

RF Cavities

The nominal accelerating field requirement for the EU XFEL 3.9 GHz cavities is below 20 MV/m and can be achieved with standard surface treatments based on Buffered Chemical Processing (BCP). The RF design of these cavities is identical to the cavities developed by FNAL for FLASH. A few variations have been made to conform to ancillaries developed for the standard XFEL cavities (e.g. HOM and pickup port flanges), to adapt to the production experience and procedures of the vendor and to adapt to the redesign of the tuner/helium package required by the different module design. The updated tuner makes use of the INFN experience on the development of the ILC blade tuners, successfully tested during the S1-Global program [3]. The cavity design variations have been reported in reference [4].

String Layout

Investigation of coupler kick effects in the beam dynamics of the EU XFEL, exploring different possible cavity arrangements, led to the decision to adopt a string layout in which offset-independent kicks to the beam compensate each other due to the symmetry [1,5]. In this configuration, which shows the smallest emittance increase, every second cavity is rotated by 180° around its axis (i.e. couplers are alternatively facing towards opposite directions). Furthermore, in order to be able to change focussing conditions and to steer the beam in both transverse planes before the first bunch compressor stage, the magnet package has been moved to the beginning of the third harmonic section, at the cryomodule entrance.

Module Design

The cryomodule for the EU XFEL third harmonic system needs to be cryogenically connected in a single string to the injector module and to accomodate the cavity string layout, described above.

The first goal has been achieved by designing the module with an identical cross-section as the main XFEL linac modules, based on the Type III TTF modules [6]. All process pipes for the different cryogenic circuits (single phase and 2 phase helium feed and return lines for cavities, shields, and cooldown/warmup procedures) have exactly the same dimensions and are located in the same position with respect to the beam axis in the module transverse cross-section. Moreover, the symmetric coupler arrangement in the 8-cavity string requires two different cavity package variants, as shown in Figure 2. The module design, shown in Figure 3, thus differs substantially from the ACC39 module built for FLASH, which is based on a larger size Type II TTF module. Furthermore, the FLASH module has no magnet package and different arrangement of the 4 cavities.

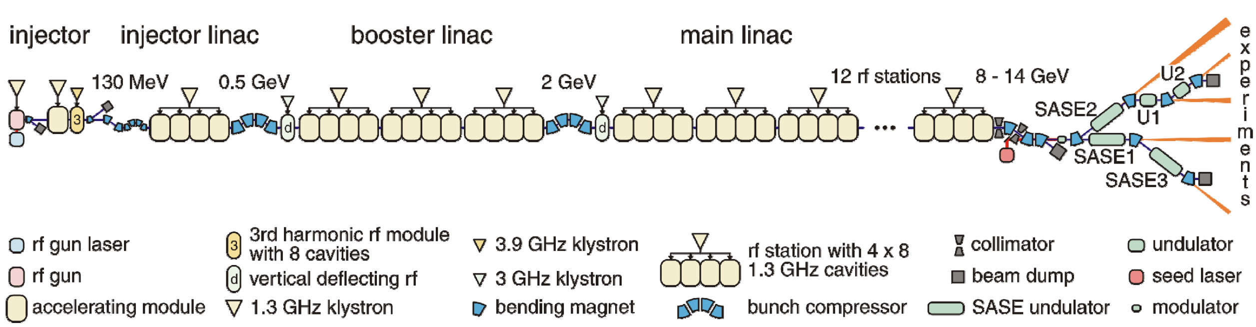

Figure 1: Schematic layout of the European XFEL complex, the third harmonic system is at the injector stage.

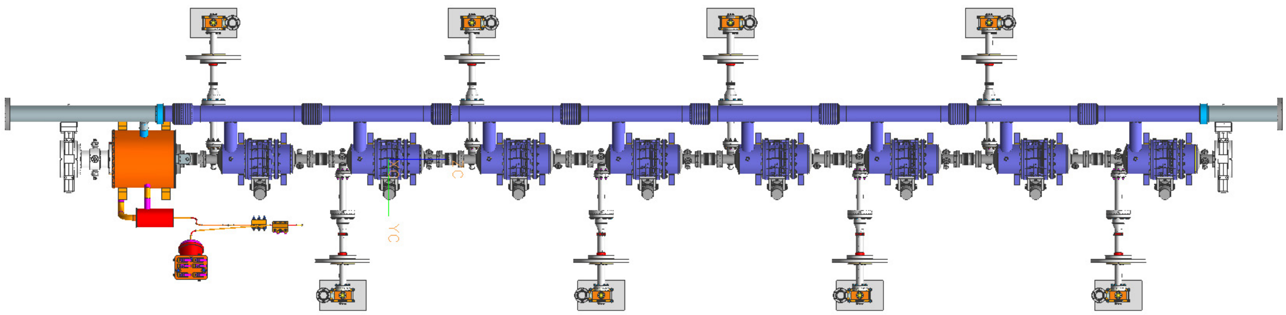

Figure 2: Cavity String layout with alternating coupler configurations and magnet package at the upstream end (beam direction is from left to right). The flange-to-flange cavity string length is 5504 mm.

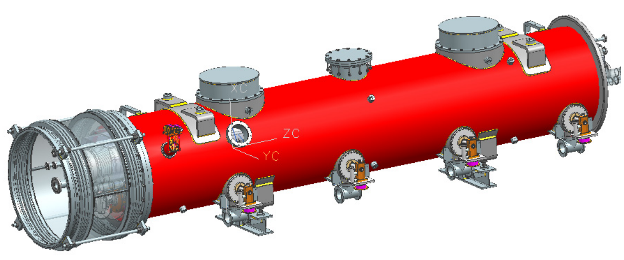

Figure 3: The third harmonic eight cavity module for the EU XFEL.

CAVITY PROTOTYPES

In order to prepare for the realization of the XFEL third harmonic system and to set up the necessary treatment and testing facilities a small pre-series of three cavities has been tendered to industry, to be characterized at the vertical test stand at INFN LASA. Cavity mechanical fabrication and surface treatments up to the vertical tests are under the vendor responsibility.

The manufacturing sequence of the structures was defined performing test welds and with the realization of mockups [7], then the structures have been manufactured, the inner surface has been etched by approximately 150 µm, followed by a standard 800°C heat treatment (at DESY) for dehydrogenation and field flatness tuning. The cavities have been tuned to >95% field flatness at a length within ±0.4 mm from the nominal.

Qualification of the RF Testing System at LASA

The vertical testing area at LASA [8], originally conceived for 500 MHz cavities, has undergone extensive refurbished both in the cryogenic and RF facilities.

The facility operates with dewars in batch mode, supported by a He liquefier providing 40 l/h and by a helium gas recovery, cleaning and storage system. Pumping units have been equipped to provide subcooling capabilities, with a cryogenic capacity for operation at 18 W of power dissipation at 2 K (and approximately 10 W at 1.8 K). The test cryostat itself has a very good thermal performance and has a static consumption under stationary condition of less than 1 W. The cryostat insert has been adapted for the smaller dimensions of higher frequency cavities.

New RF hardware has been acquired to provide 100 W at 1.3 GHz and 200 W at 3.9 GHz of RF power.

The existing HPR system and UPW plants have been refurbished and adapted as well, increasing the water production capabilities and redesigning the HPR nozzle and wand systems for the tight dimensions of the 3.9 GHz multicell structures. A small (9 m^2) clean room hosts the HPR system and provides the space for the final installation of the RF antennas and pick ups necessary for the cold tests. A pump stand for slow pumping/venting of the cavities and leak checking has been developed using commercial components.

To decouple the qualification of the cryogenic/RF operation of the upgraded test facility from that of the 3.9 GHz prototype cavities, the LASA infrastructure has been qualified using a monocell 1.3 GHz cavity of known performance. The cavity has been prepared and tested at DESY with a fixed coupling antenna setup. After its shipment to Milano under vacuum conditions, it has been retested without breaking vacuum, thus allowing to control the calibration, RF and cryogenic operation of the facility. The cavity has then been opened in the clean room at LASA and all antennas completely dismounted. A full HPR rinse has been performed at the cavity and all parts have been reassembled for further testing, in order to qualify the cleanliness of the infrastructure and the training of the clean room personnel. The Q vs. E_{acc} for the three tests is shown in Figure 4.

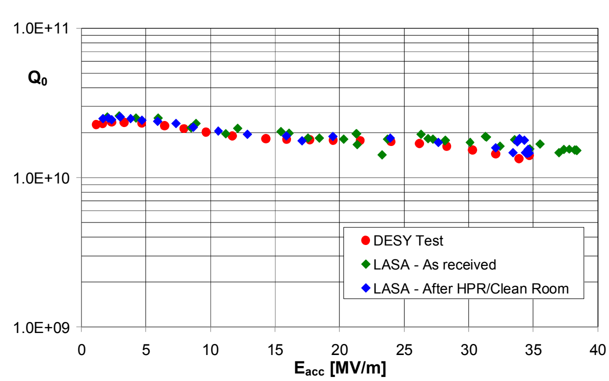

Figure 4: Test history for the qualification of the LASA vertical test area. The 1-cell 1.3 GHz cavity was tested first at DESY and two times at LASA afterwards, as received and after clean room operations and HPR.

Qualification of the 3H Cavity Production

After achieving the successful qualification and operation of the RF/cryogenic facility at INFN, a final surface etch of 35-40 um has been performed on one of the pre-series cavities. The resonator has then entered the assembly clean room in LASA, to be prepared for the measurements in June 2011. Figure 5 shows a picture of the cavity before insertion in the vertical test dewar.

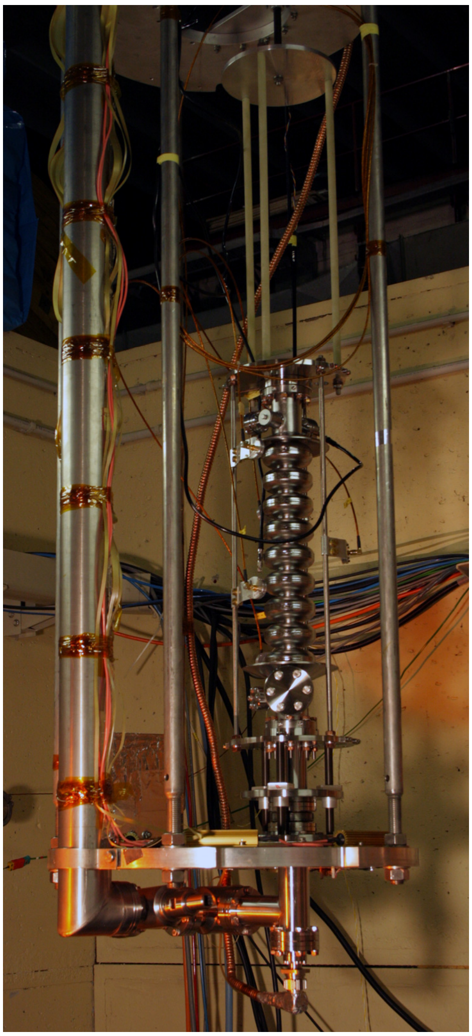

Figure 5: The 3.9 GHz cavity prepared for the test on the variable coupling insert.

In the test the cavity showed a low field Q_0 of 10^8 at 2 K. Large losses forbid to reach accelerating fields greater than 8.5 MV/m, with a low RF duty cycle to allow cryogenic operation by reducing the RF losses. No signs of field emission or clear signals from the second sound detectors (provided by FNAL) around the cavity could be observed. Under excitation in individual modes of the lowest passband, single cells were excited up to 20 MV/m with reduced power deposition, in support of the indication of a bad status of the whole surface.

The dewar cooldown was performed with an initial stage of nitrogen precooling, in order to reduce the liquid He inventory needed to perform the tests, somewhat simplifying the batch operations.

From the test results we therefore suspect to have driven the cavity into "Q-disease" conditions, since it was kept in the region from 77 K to 150 K for several hours. Future tests will be soon performed with a fast cooldown procedure, without the use of nitrogen precooling to validate our assumption.

THE XFEL SYSTEM

The 3.9 GHz cryomodule is a special one-of-a-kind component. It is not in the workflow of the main XFEL facilities in order to reduce possible interferences with the "industrial" assembly operations foreseen for the main linac cryomodules. Once vertically tested at INFN and integrated with the helium tanks, the cavities will be equipped with power couplers in the DESY clean room and individually tested horizontally in CHECHIA. String and module assembly will be performed in the DESY areas where all FLASH modules are assembled, and the whole module will be tested at the CMTB, which is not used for the testing of the XFEL modules. Tendering for the main 3.9 GHz cavities and cryomodule components is foreseen to start in 2012, or earlier.

SUMMARY

A substantial effort is undergoing at INFN, with the strong collaboration with DESY and assistance from FNAL, for the realization of most of the components for the third harmonic system of the EU XFEL linac. Cavities and the cryomodule will be provided as an Italian in-kind contribution to the project. All cavities will be characterized at the INFN facilities at LASA and the component production is to be launched in 2012.

ACKNOWLEDGEMENTS

We acknowledge the contribution from many people at DESY, in particular: R. Bandelmann, H.D. Brueck, W. Decking, M. Dohlus, C. Engling, K. Jensch, W.D. Moeller. A particular thank to E. Harms and H. Edwards from FNAL for sharing their experience with the successful ACC39 program at FLASH.

REFERENCES

[1] For a description of the beam dynamics layout of the EU XFEL: http://www.desy.de/xfel-beam/index.html

[2] H. Edwards, C. Behrens, E. Harms, in *Proceedings of LINAC10*, Tsukuba, Japan, p. 41, and E. Harms et al., *ibidem*, p. 422.

[3] R. Paparella et al., *these Proceedings*, contribution MOPC090.

[4] P. Pierini et al., in *Proceedings of LINAC08*, Victoria, BC, Canada, p. 808.

[5] E. Vogel et al. in *Proceedings of SRF2007*, Beijing, China, p. 481.

[6] C. Pagani, et al., *TESLA Report* 2001-36.

[7] P. Pierini et al., in *Proceedings of SRF2009*, Berlin, Germany, p. 844.

[8] D. Barni et al., in Proceedings of SRF1999, Santa Fe, USA, p.422.