EUROPEAN XFEL 3.9 GHz SYSTEM

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Abstract

The third harmonic system of the European XFEL (EXFEL) is a joint INFN and DESY contribution to the project. Achievements, status and activity plan for the cavity and cryomodule components are reviewed here.

INTRODUCTION

The European XFEL [1] linac will deliver beams with sufficiently low emittance to produce the 1 Å FEL radiation for the experimental users. The high quality beam is generated in the Injector complex, where the linearization of the RF induced curvature in phase space, introduced by the first accelerating module after the RF gun, is necessary to preserve the beam quality in the subsequent bunch compressors stages before entering the main linac. The RF curvature linearization is achieved by a 3rd harmonic section (consisting of a single module with 8 SRF cavities at 3.9 GHz), provided by INFN and DESY as in-kind contribution to the EXFEL.

As a preparatory phase to the production of the module, three cavity prototypes have been produced and tested several times, in different test conditions.

The experimental infrastructure at LASA is capable to test two cavities per cooldown during different fabrication and preparation stages for qualification (e.g. with and without Helium Tank integration, with or without HOM pickup antennas).

This paper presents the results so far achieved, the status of the facilities, and the status of the EXFEL 3.9 GHz module components.

EXPERIENCE WITH CAVITY PROTOTYPES

Three 3.9 GHz cavity prototypes were fabricated in Europe early in the EXFEL project stage [2] on the base of the structures developed by FNAL [3], now successfully operated in the FLASH ACC39 third harmonic system [4]. The EXFEL prototypes cavities have been extensively used to develop the fabrication/treatment tooling (for forming, welding, tuning, etching etc.) at the vendor and the cold RF testing infrastructure at INFN-LASA [5], that will be used for the production and qualification of the series components.

The cavities have been repeatedly tested and retreated in different conditions to qualify also the ancillary components (RF pickups, HOM antennas) and to train the INFN personnel for clean room operation.

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Setup of the Vertical Test Station

Currently the vertical test station is equipped with an insert (shown in Figure 1) capable to test two cavities in a single cooldown cycle, at different stages during their qualification (full RF CW characterization in all passband modes of the naked cavity, fundamental mode tests in pulsed conditions when the cavity is equipped with HOM antennas either with or without the helium tank). A common vacuum system connects the two cavities. Each cavity could be tested either with fixed or variable coupling at all stages of its qualification.

After upgrading the subcooling system to a cooling capacity of approximately 40 W [5] and after the commissioning experience with many tests, the test time was reduced from a full week to three days. He batch operation of the cryogenic infrastructure limits the test capabilities to a full cooldown cycle every three weeks, the bottlenecks being the He recovery/purification systems and clean room operation.

The prototype testing was also used to equip the test station with a quench detection system based on OST devices, to push this technique to the needed spatial resolution required by the small geometrical dimensions of the 3.9 GHz cavities. Moreover, a fast thermometry readout system has been developed to complement and cross check the second sound analysis [6].

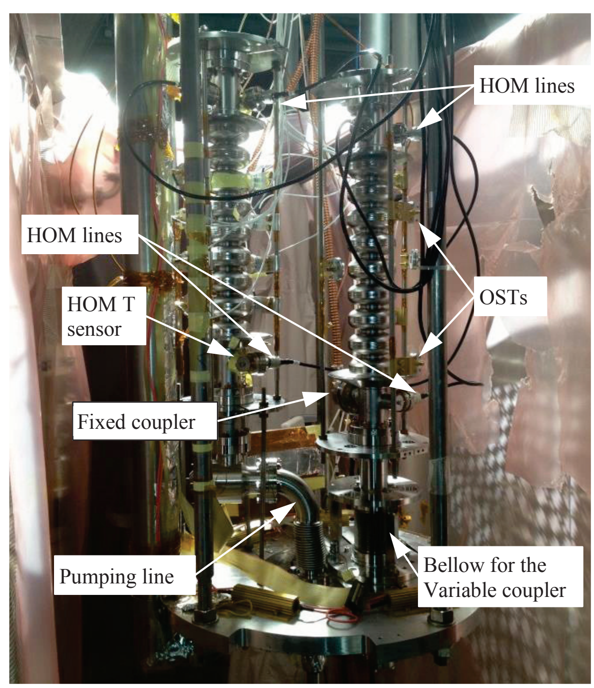

Figure 1: Vertical test insert with two prototypes.

In order to validate the tests obtained at the INFN-LASA infrastructure one of the three cavities has been sent to FNAL for further independent measurements, which have shown similar RF performances [5].

Lessons Learned with Vertical Tests

As an outcome of the vertical testing of the cavity prototypes one cavity (3HZ03), which was repeatedly tested in different setups (variable coupling, fixed coupling, with and without HOM antennas), reached fully the EXFEL specifications in terms of needed gradient and quality factor. The other two show hard quenches at approximately 12 (3HZ01) and 16 MV/m (3HZ02) and Q_0 values lower by approximately a factor of 2 with respect to 3HZ03.

OST signal analysis [6] suggests that the quenches are located at the equatorial weld region, where a step-recess (lip) weld preparation [2] was attempted for the first time by the manufacturer, in order to simplify the weld tooling with respect to a head-to-head weld. The suspect is that foreign material could have contaminated a few equatorial welds. The same weld preparation is now used for the production of the 1.3 GHz main linac XFEL cavities and has been fully and systematically qualified by the cavity manufacturer, giving confidence of better results for the series production of the 3.9 GHz EXFEL cavities. Furthermore, the new cavity production infrastructure available at the manufacturer [7] has a higher degree of cleanliness and control with respect to the state at the time of the three 3.9 GHz prototypes.

Horizontal Tests and Cold Tuners

The prototype cavities will be soon integrated into their helium vessels and equipped with tuner prototypes of the INFN "blade" type [8] in order to be tested horizontally in a dedicated cryostat in the AMTF facility at DESY, designed and provided by BINP [9].

Helium vessels and blade tuners have been fabricated and are waiting for the final integration welds to the cavities. The subcomponents have been extensively characterized in warm conditions prior to their integration with the cavities [8], demonstrating the possibility to achieve the performances evaluated during the design phase. The tuner concept is derived from the ILC "slim" tuner design [10], successfully used in the S1-Global experiment [11] and in the CM2 module at FNAL.

PRODUCTION OF THE 3.9 GHz EXFEL CAVITY SERIES

The contract of a series of 10 cavities (8 for the module and 2 spare) has been awarded to the same manufacturer of the cavity prototypes.

The fabrication of an additional set of cavities for a spare 3.9 GHz module for the injector is foreseen in the next years and future upgrades of the EXFEL facility foresee the realization of a second injector system, for which the space in the injector building has already been reserved.

European Pressure Equipment Directive

According to the EXFEL Project specifications, the 3.9 GHz cavities - similarly to the main linac cavities [12] – are defined as subcomponents of pressure vessel, and need to comply with the provisions of the European Pressure Equipment Directive (PED/97/23/EC). This activity requires the involvement of a "notified body" both for the design examination and during the supervision of the cavity fabrication. TUEV-Nord, already involved for the main linac cavities process, has been appointed to the task.

Differently from the context of the large scale production of the 1.3 GHz cavities, where the approach of Module B+F was followed (EC type-examination performed with destructive tests on test pieces, followed by a simplified product verification on the series components), the small series of 3.9 GHz cavities are being fabricated following Module G provisions for Category IV pressure equipment (EC-unit verification, where each series component is examined) [13].

In the PED process non-standard materials for pressure vessel production (as Nb or NbTi) need to be approved by the notified body and procured by suppliers qualified for the procurement of pressure components. Therefore all the material for the 3.9 GHz cavity production was procured following the experience of the main linac cavities [12] and material traceability and Quality Control strategies are followed during the cavity production, as for the case of the main linac components. The complete set of technical documentation and fabrication instructions is in the hands of the notified body in order to start the cavity fabrication process under its supervision.

Workflow for the Cavity Series

The moderate gradient required for the 3.9 GHz cavities (40 MV of maximum voltage for the module, corresponding to approximately 15 MV/m of accelerating gradient), allows using a standard BCP treatment. The fabrication and treatment specifications were based on those used for the main EXFEL linac cavities. Figure 2 shows the sharing of work and responsibilities between the cavity manufacturer and the Institutions.

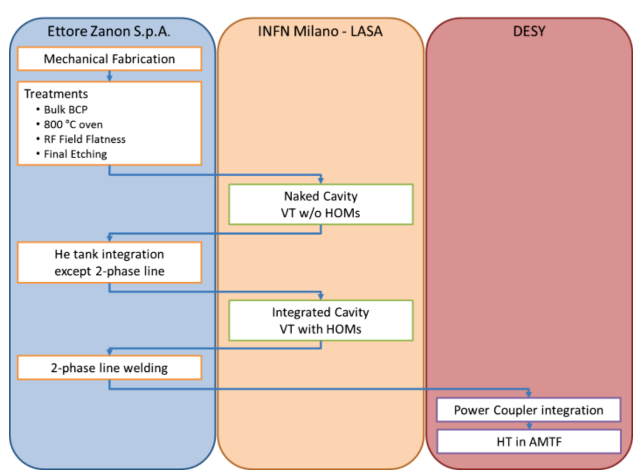

Figure 2: Cavity production and test workflow.

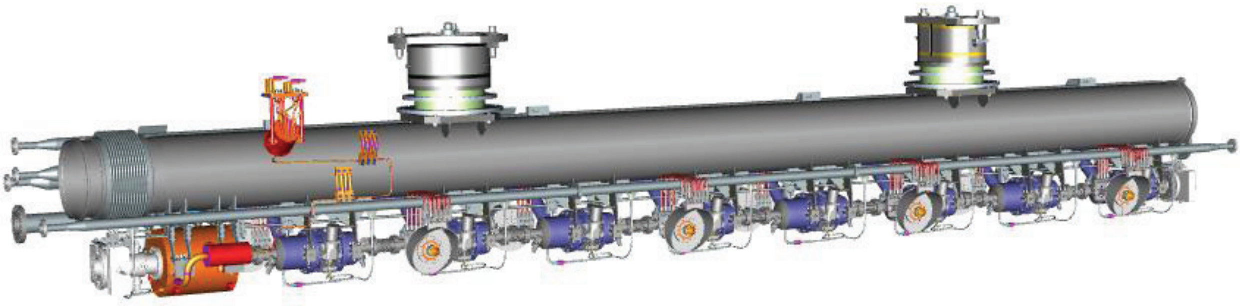

Figure 3: The string of beamline elements (8 cavities and a magnet package) supported by the Helium Gas Return Pipe of the cryomodule.

THE THIRD HARMONIC CRYOMODULE

The third harmonic cavity string is placed in a cryomodule which is directly connected to the first EXFEL accelerating module. The module design is thus constrained to follow the same concept and have the same transverse cross section as the main linac modules, especially concerning the distribution of the cryogenic lines in the transverse cross section.

The layout of the cavity string is shown in Figure 3, where only the supporting Helium Gas Return Pipe of the module is shown. Cavity packages are of two different types, with coupler ports facing opposite directions, since a configuration with alternating coupler ports has been selected in order to compensate coupler induced dipole kicks to the beam at the low energy of the injector section.

The transverse cross-section is depicted in Figure 4.

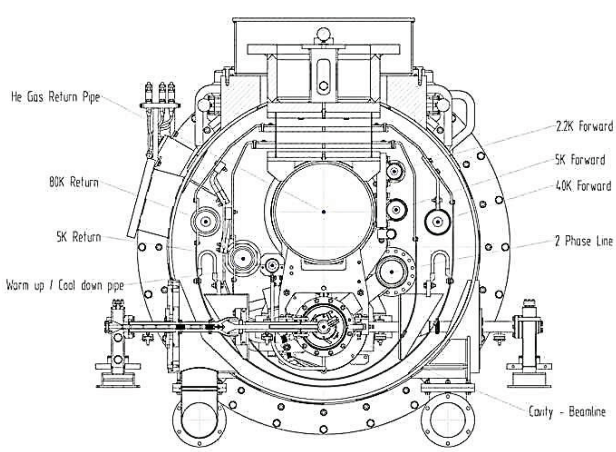

Figure 4: The cryomodule transverse cross-section.

A vessel of approximately 5 m hosts the beamline elements: 8 3.9 GHz cavities and a magnet package (quadrupole, steerers and BPM). Fabrication of the cold mass components is starting at Ettore Zanon SpA.

CONCLUSIONS

The main components for the third harmonic system of the EXFEL have been prototyped, tendered to qualified vendors and fabrication of all component and ancillaries is on the way. Cavities and cold mass are expected by summer 2014, for the technical commissioning of the injector before the end of the year.

ACKNOWLEDGMENT

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