ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI018

STATUS OF THE FABRICATION OF THE XFEL 3.9 GHz CAVITY SERIES

Cecilia Maiano, Michele Bertucci, Angelo Bosotti, Jin-Fang Chen, Paolo Michelato, Laura Monaco, Massimiliano Moretti, Carlo Pagani, Rocco Paparella, Paolo Pierini, Daniele Sertore, INFN/LASA, Segrate (MI), Italy

Abstract

The third harmonic system at 3.9 GHz of the European XFEL (E-XFEL) injector section will linearize the bunch RF curvature, induced by first accelerating module, before the first compression stage and it is a joint INFN and DESY contribution to the project. This paper presents the status of the fabrication of the 3.9 GHz cavity series in view of the XFEL injector commissioning in 2015.

INTRODUCTION

The E-XFEL injector foresees a third harmonic section after the RF photocathode gun and the first 1.3 GHz accelerating module [1-3], in order for the linac to deliver beams with sufficiently low emittances for the production of 1 Å FEL light to the experimental users. The high quality beam is generated in the injector complex, where the 3.9 GHz section performs the linearization of the RF-induced phase-space curvature, introduced by the first accelerating module after the RF gun.

The 3rd harmonic section consists of a single module with 8 SRF cavities at 3.9 GHz, provided by INFN and DESY as an in-kind contribution to the E-XFEL.

This paper reports on the status of the main ongoing activities related to the series components production of the 3.9 GHz section, which according to the European Pressure Equipment Directive (PED) 97/23/EC, under the supervision of the German TÜV-Nord acting as Notifying Body [4]. The experience achieved with the vertical testing of the first three prototypes [5, 6] defined in details the subcomponents and cavity fabrication and treatment procedures.

PED REQUIREMENT FOR THE CAVITY PRODUCTION

All superconducting components of the E-XFEL linac need to comply with the European PED norms [7], under the pressure conditions set by the Project of a Maximum Allowable Working Pressure (MAWP) of 4 bar in the 2 K circuits. As the cavity construction materials are not listed in the harmonised standards for the fabrication of pressure vessels, a Particular Material Appraisal has been issued by the Notifying Body, together with the design examination and the approval of fabrication drawings. Furthermore, traceability of all subcomponents and components needs to be provided at all stages, starting from the raw material to the final cavities.

All welds on pressure-bearing parts followed a weld qualification process with the Notifying Body and cavity fabrication is performed under its supervision, ending with a final pressure test of the helium tank space (up to 1.43 times the MAWP).

EXPERIENCE WITH THE CAVITY PROTOTYPES

Prior to the series production of 10 cavities three prototypes have been fabricated, processed and tested in order to set the cavity production parameters and define the cavity preparation steps. This activity provided the experimental direct confirmation of the cavity frequency sensitivity parameters, reported in Table 1, listed together with the main design parameters.

Table 1: Main cavity operational parameters and frequency (f) sensitivity coefficients

Design Parameters	Value	Unit
Nominal operating f	3900	MHz
Max tuner range	1	MHz
Tuner loading offset	+0.5	MHz
Frequency Sensitivity	**Value**	**Unit**
Longitudinal cavity sensitivity	~2.3	MHz/mm
Max f variation in elastic limit	~1.6	MHz
Air to vacuum f shift	-1.0	MHz
RT to 2 K f shift	6.0	MHz
BCP removal f effect	~-60	kHz/um

One important outcome of the cavity prototype experience is the strategy for reaching the correct frequency at the nominal cavity length. Table 2 outlines the frequency goals at the main steps of the cavity preparation cycle, during fabrication and in operating conditions.

Table 2: Frequency Preparation Goals

Fabrication steps	Frequency
Fabricated, in air at RT, before BCP	3903.8 MHz
After last BCP, in vacuum	3893.5 MHz
Operating Conditions	**Frequency**
At cold, in VT	3899.5 MHz
At cold, tuner preloaded	3900.0 MHz

In order to achieve these goals at the correct nominal length of the cavity a precise knowledge of the effects of the weld procedures (weld shrinkages, influence of weld seam perturbations …) is needed in order to prepare the subcomponents (half-cells, dumb-bells, end groups) with the proper over-metals for weld shrinkages compensation and sufficient material for the RF-based trimming operations.

All three cavities were fabricated, chemically treated; RF tested and in some case retreated, several times in the vertical test facility at the LASA laboratory in INFN Milano. A summary of the vertical experience is reported in a separate contribution to this Conference [5].

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI018

PRODUCTION OF THE 3.9 GHZ E-XFEL CAVITY SERIES

Weld Qualifications

In view of the PED qualification all welds in the pressure environment of the cavity (the boundary of the helium tank internal volume) had to follow a weld qualification, in order to fulfil the correct weld penetration and minimum weld depth as stated in the design certification. Representative test pieces have been prepared with the nominal weld parameters, the welds activities witnessed by the Notifying Body inspectors and subjected to destructive tests for micrographic analysis. Figure 1 shows the two test pieces containing the qualification welds.

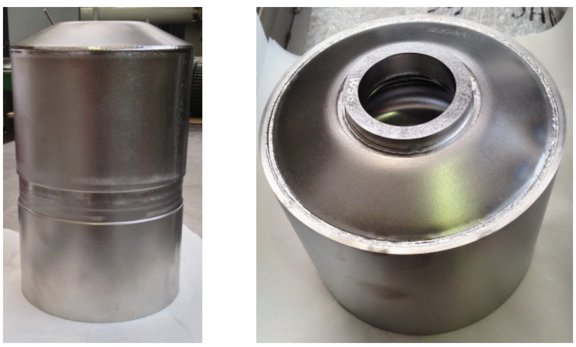

Figure 1: Weld qualification samples.

After the material approval, design qualification, approval of the fabrication drawings and weld qualifications by the Notifying Body, the work on the pressure bearing parts of the cavity could be started.

Status of XFEL 3.9 GHZ Component Prototypes

Half Cells

The RF frequencies of all half cells are measured after forming, initial machining (that provides the calibrated overmetal at the iris to compensate for the weld shrinkages and at the equator for later trimming and weld shrinkage compensation) and mechanical measurements. A frequency of 3684.6±1.5 MHz has been obtained, in line with the expected frequency computed with a purely 2D axisymmetric code of 3686.2 MHz and with the mechanical tolerances attainable in the machining stages. The overall spread of all measurement is limited to approximately 7 MHz. Given the large sensitivity of the structure frequency with respect to geometrical variations, the above value gives an indirect indication of a shape tolerance within acceptable limits.

Dumb Bells

Dumb Bells (DB) are subsequently formed pairing half cells and performing a fully penetrated iris weld in two steps from both sides. After welding all DBs are geometrically surveyed and the RF frequencies measured (see Figure 2). A π-mode frequency of 3808.8±1.0 MHz has been obtained, in line with an expected frequency of 3806.6 MHz computed from the average geometry of the measured parts, taking into account the weld shrinkages.

Figure 2: DB frequency measurement device.

Table 3 summarizes the RF measurements of the fabricated components.

Table 3: Summary of RF Measurements

	[Units in MHz]			
Component	**Freq.**	**Dev**	**Spread**	**Expected**
Half Cells	3684.6	1.5	7.2	3686.2
Dumb Bells	3808.8	1.0	4.9	3808.6

The combined RF and mechanical measurements of the DBs are used for issuing the trimming instructions in order to reach the frequency goal in Table 2.

End Groups

End groups (EG), shown in Figure 3, are still in fabrication stages, prior to the machining of the Nb Ti Helium vessel end cones and the weld of the ancillary ports for the main coupler, RF pickup and HOM antennas.

After completion of the mechanical fabrication RF measurements and mechanical surveys will provide the trimming instruction of the end groups.

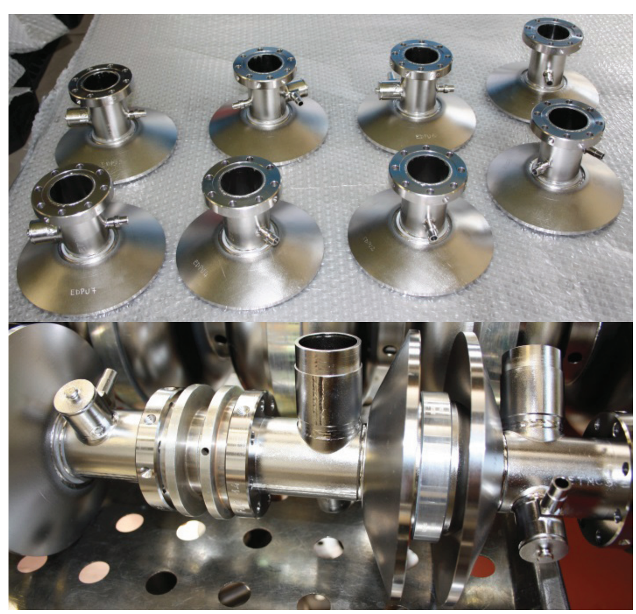

Figure 3:End groups at intermediate fabrication stages.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI018

After the trimming of the DBs and EGs, the cavity will be assembled by performing all equatorial welds on the structure.

CONCLUSIONS

After the setup of the fabrication procedure with the component prototypes, the cavity series for the European XFEL third harmonic injector module is currently under fabrication. As all equipment for the E-XFEL need to comply with the PED Directive, work on pressure-bearing components could only start after the fulfilment of the provision given by the norm, i.e. material approval by Particular Material Appraisal for the application, design certification, approval of fabrication drawings and quality control plan by the Notified Body, and design certification.

Fabrication is at an advanced stage, with the preparation and measurement of all components, and mechanical fabrication will end in mid July 2014. Cavities will be delivered to INFN after chemistry for vertical testing by September 2014.

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] M. Moretti, “Mechanical Analysis of the XFEL 3.9 GHz Cavities in support of PED Qualification”, these Proceedings, WEPRI020.

[5] J. Chen et al., “Status of the Vertical Testing of the XFEL 3.9 GHz Cavity Series”, these Proceedings, WEPRI016.

[6] P. Pierini et al., “European XFEL 3.9 GHz system”, SRF2013, Paris, France, 2013, MOP011, p. 100.

[7] A. Schmidt et al., “PED Requirements Applied To The Cavity And Helium Tank Manufacturing”, SRF2013, Paris, France, 2013, MOP048, p. 224.