THIRD HARMONIC SUPERCONDUCTING CAVITY PROTOTYPES FOR THE XFEL

P. Pierini*, A. Bosotti, N. Panzeri, D. Sertore, INFN LASA
H. Edwards, M. Foley, E. Harms, D. Mitchell, FNAL
J. Iversen, W. Singer, E. Vogel, DESY

Abstract

The third harmonic cavities that will be used at the injector stage in the XFEL to linearize the bunch rf curvature distortions and minimize beam tails in the bunch compressor are based on the rf structures developed at FNAL for the DESY FLASH linac. The design and fabrication procedures have been modified in order to match the slightly different interfaces of XFEL linac modules and the procedures followed by the industrial production of the main (1.3 GHz) XFEL cavities. A revision of the helium vessel design has been required to match the layout of the cryomodule strings, and a lighter version of the tuner has been designed (derived from the 1.3 GHz ILC blade tuner activities). The main changes introduced in the design of the XFEL cavities and the preliminary experience of the fabrication of three industrially produced and processed third harmonic rf structures are described here.

INTRODUCTION

The RF cavity design for the 3.9 GHz structures [1] has been performed by FNAL for the design of the FLASH 3rd harmonic section (ACC39) [2,3]. Several cavities have been fabricated and tested [4] with accelerating gradients up to 24 MV/m, well above the design value of 14 MV/m needed for the FLASH operation.

The design of the European XFEL project [6] foresees a third harmonic section in the injector linac, at the beam energy of 500 MeV, before a bunch compression stage.

Three modules of 8 cavities are currently envisaged in the XFEL TDR to provide a sufficient linearization of the RF field seen by the bunch [3].

In the context of the XFEL activities the production of three prototypical cavities of the FNAL design has been tendered to one of the qualified producers of the main linac RF structures, including the responsibilities for the subsequent processing needed before the vertical testing (BCP chemical etching and high pressure rinsing stages). Fabrication is ongoing and, although no changes have been performed to the RF characteristics of the cavities as designed by FNAL, a few interfaces have been modified in order to either profit from existing components developed for the 1.3 GHz cavities (HOM pickup antennas, RF pickups, slim blade tuner design) or to reflect the different physical layout of the cross section of the XFEL cryomodules. In addition, the production process has been revised and adapted to the consolidated vendor experience based on the production of the 1.3 GHz cavities.

* paolo.pierini@mi.infn.it

XFEL CRYOMODULE LAYOUT

Type II and Type III Cryomodules vs XFEL

The FLASH linac, previously known as the TESLA Test Facility, TTF, is currently composed of cryomodules of two types, with different cryogenic piping locations within cross-sections of different sizes. The changes were performed in "generations" after successive iterations aimed at design simplification and cost reduction [7]. Currently Type II and Type III cryomodules are located in the linac tunnel. The first accelerating section of the FLASH linac (ACC1), after which ACC39 will be placed, is of Type II, meaning a large vacuum vessel (1.2 m diameter) and an internal piping distribution different than in the standardized 38" vessel of the Type III. Since ACC39 is cryogenically connected to the ACC1, the transverse cross section of the FNAL module has been designed to match that of a Type II.

However, the XFEL module design has been derived from the Type III, in particular concerning the relative location of the He Gas Return Pipe (HeGRP, acting as a structural backbone for the entire cold mass), the 2-phase He pipe and the cavity string.

The XFEL third harmonic cryomodules, which are in the early design stage, need to reflect this change in the cross-section and, in particular, the ACC39 design of the dressed cavity package (cavity+He tank and 2 phase pipe) needs to be revised to account for these different interfaces.

Main Couplers Orientation

Beam dynamics simulations of the entire XFEL linac suggests that, in order to obtain an on-axis cancellation of the RF coupler kicks, an alternating scheme for the coupler direction different from ACC39 needs to be used to limit emittance growth effects [8, 9]. This again has implications on the module design and requires the use of two types of dressed cavity assemblies, according to the coupler direction.

Slim Blade Tuner

The coaxial tuner used on the FNAL ACC39 module has been derived from the INFN blade tuner originally proposed for the TESLA collider [10], scaled to the smaller size of the 3.9 GHz RF structures. Recent progresses at INFN on the blade tuner concept for ILC led to the development of a simpler, lighter and cheaper device, that has been extensively characterized [11]. Slim tuners of this kind will be installed in the second FNAL ILCTA cryomodule currently under construction.

For the XFEL third harmonic activities the "slim" tuner design has been scaled to the 3.9 GHz cavity dimensions.

Due to the much stiffer mechanical behaviour of the 3.9 GHz structures and the moderate accelerating gradients needed for their operation, no fast compensating tuning action is needed to handle Lorentz Force Detuning effects under pulsed operation.

Figure 1 shows a cavity, dressed with tank and tuner, located within the main boundaries of an XFEL main linac module cross-section.

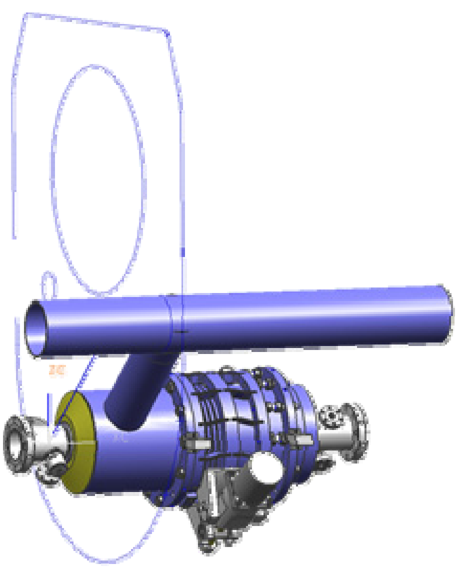

Figure 1: The XFEL third harmonic cavity dressed with the revised "slim" tuner, shown in the transverse cross section of the XFEL cryomodule (indicating HeGRP, 2 phase line and inner 4 K shield).

Work on the definition of a possible layout of the XFEL third harmonic cryomodules has just been started, along the guidelines expressed before. The final XFEL design will benefit from the many years experience gathered during the operation of the FLASH modules and from the ongoing FNAL ACC39 development.

The current XFEL third harmonic module foresees a string of eight cavities, a quadrupole/bpm package and an HOM beamline absorber, for a total module slot length of approximately 6 meter.

PROTOTYPE XFEL CAVITY FABRICATION

Mechanical Design Changes

Three nine cell cavities using the single-leg HOM coupler developed by FNAL [12] are currently under fabrication in Europe for the XFEL. A few variations have been made to the fabrication drawings or production steps in order to conform either to ancillaries developed for the XFEL (like HOM antennas and RF pickups) or to the consolidated expertise of a qualified vendor of the main linac structures:

- All the Conflat flanges in the original design of the cavity for the HOM antennas and RF pickups have been replaced with the same flanging system of the main linac (based on Al "diamond seals"). The same standard feedthrough components of the main XFEL linac for the HOM antenna pickup assemblies or the RF pickup will be used.
- In order to perform the last 9 equatorial welds in a single load of the Electron Beam Weld (EBW) machine, the end cones inclination of the tank has been changed, allowing access from the fixed electron beam gun to the end cells equatorial region. Weld lips have been machined at the equatorial plane of the cells, in order to ease the assembly process and to avoid the use of a temporary tooling to tack the assembly before performing the final EBW equatorial seams. Weld lips should also decrease the chance of niobium droplets from the EBW seam deposited on the RF surface.
- Similarly to what is being done for the XFEL 1.3 GHz cavities, alignment boreholes were placed on the cavity flanges to transfer the cavity alignment reference. A reference ring and plane are also machined at the cone transition in the end groups to assist mechanical survey.

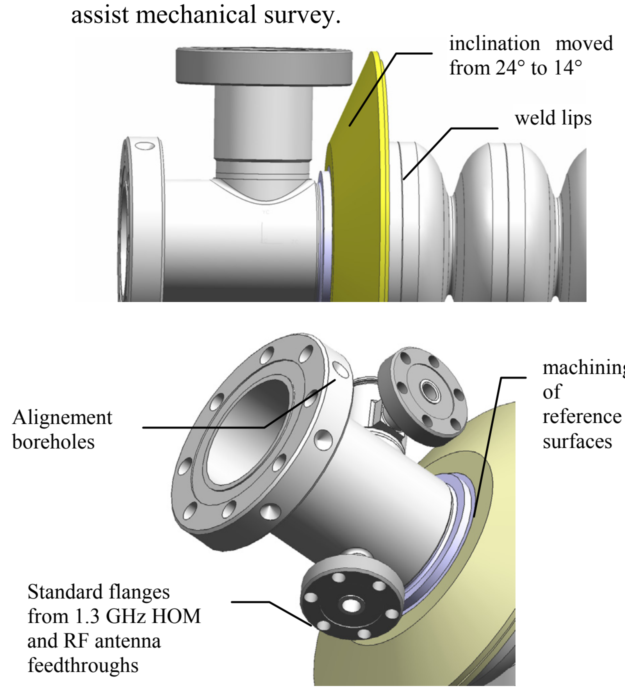

Figure 2: End group of the XFEL 3rd harmonic cavities (coupler side), showing some of the modifications.

EBW Parameters

Batches of non RF-grade high RRR Nb provided by DESY, discarded after the sheet scanning QA process, have been used to fabricate an initial series of halfcells, then dumbbells, double dumbbells and end groups in order to determine the correct EBW parameters and toolings needed, and to experimentally determine the weld shrinkages to be taken into account in the fabrication drawings.

Figure 3 shows some of these parts during RF characterization. Halfcells and dumbells thus obtained were used to determine the experimental frequency coefficients for the trimming operations that need to be performed at the dumbbell stage and the effect of weld seams. This information is used to develop a consistent procedure, following closely that of the 1.3 GHz cavity fabrication, in order to meet the correct physical length and nominal frequency of the cavities. A field flatness tuning device to axially stretch or compress the individual cells is also being developed.

Figure 3: Equatorial weld lip preparation of the dumbells (left) and samples (right) for equatorial EBW parameters.

RF Characterization of Subcomponents

During the realization of the test parts using non RF grade Nb all the machining and welding tooling were debugged and improved when necessary. Frequency sensitivity coefficients were experimentally determined and compared with RF simulations. As an example Figure 4 shows the trimming sensitivity of the first series of 6 dumbbells produced. In the first 4 weld operation the spring load of the weld tooling caused excessive weld shrinkage of the structure, resulting in a global frequency offset. Nonetheless, the average longitudinal trimming sensitivity of -25.7 MHz/mm closely matches the value compute from SuperFish simulations (-24.7 MHz/mm).

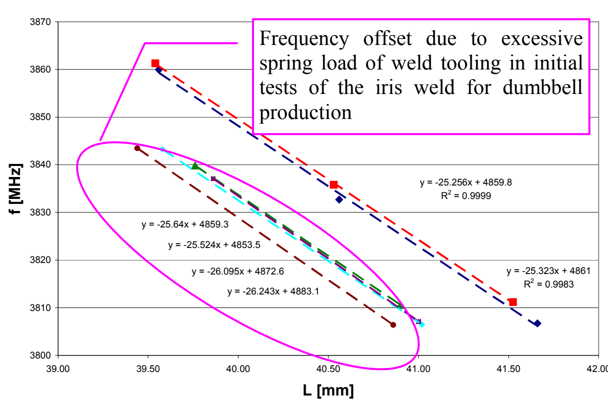

Figure 4: Frequency sensitivity for dumbbell trimming.

Status of the Prototype Fabrication

After the weld tests performed to determine all weld parameters the three RF structures are now being fabricated. All main subcomponents have been prepared. All the production halfcells have been formed and their frequency spread is consistent with the achievable tolerances of the production process. Dumbbells and the main end group subassemblies are in the preparation stage. After the final trimming of the dumbbells to achieve the correct cavity length and frequency the final equatorial welds will be performed.

A copper RF mockup of the nine cell structure is under fabrication to test the field flatness measurement device under realization, and to provide a mechanical mockup for the test of the vertical inserts designed at INFN for the RF measurement of the cavities.

CONCLUSIONS

The development of the main components of the superconducting 3.9 GHz system for the XFEL linac has started at INFN and DESY, and is relying on the extensive experience in the production of the main linac cavities and cryomodules and on the activities carried by FNAL for the FLASH ACC39 construction.

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