

FABRICATION EXPERIENCE OF THE THIRD HARMONIC SUPERCONDUCTING CAVITY PROTOTYPES FOR THE XFEL

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Abstract

Three superconducting 3.9 GHz cavity prototypes have been fabricated for the XFEL linac injector, with minor modifications to the RF structures built by FNAL for the FLASH linac. This paper describes the production and preparation experience, the initial measurements, the plans for the XFEL series production and the cryogenic test infrastructure under preparation at INFN Milano.

INTRODUCTION

In order to achieve the high beam quality required for the FEL emission process, the European XFEL linac will include a third harmonic RF section in the injector, before the bunch compressor stages [1, 2], for the linearization of the voltage seen by the beam.

This concept will be tested in 2010 on the FLASH linac, where a cryomodule containing 4 3.9 GHz cavities have been engineered and fabricated by FNAL [2, 3].

The main components of the XFEL 3rd harmonic cryomodules will be procured as INFN and DESY in-kind contributions to the European XFEL Project, and, though based on the concept originally developed by FNAL, will have to reflect several design changes to match the different requirements and boundary conditions of the two installations. Several interfaces and subcomponents (as vessels, cryogenic piping, cavity feedthroughs and flanges, etc.) have been modified in order to: match the tighter requirements imposed by the XFEL beam dynamics, profit from existing components developed for the main linac cavities, reflect the different physical layout of the XFEL cryomodules and adapt the component fabrication to the consolidated experience available in Europe for the production of 1.3 GHz main linac components [4].

PROTOTYPE CAVITY FABRICATION

As the starting step, a small production of three RF structures implementing the interface changes described in Ref. 4 has been tendered (under the supervision of INFN personnel) to one of the companies qualified for the XFEL cavity production, which will be responsible for the cavities fabrication and processing, up to the preparation for the vertical qualification tests at INFN.

Cavity Mockups

For the development of the fabrication procedures and to assist in the commissioning of the necessary tooling for these new structures at the company (for fabrication, welding, field flatness tuning and surface processing) first a simplified copper RF mockup and later a complete

niobium mockup (using non RF-grade material, from discarded sheets after scanning) have been produced and tested. These mockups proved to be important for an iteration of the fabrication procedure on the basis of the experience determined in their production, and were also used for the development of the software procedures for the operation of the field flatness tuning device.

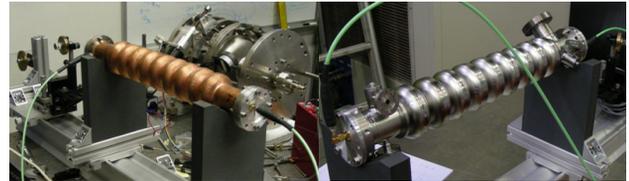


Figure 1: The copper (left) and non RF-grade niobium cavity mockups.

Fabrication Procedures

Following the standard fabrication procedures, all sub components (half-cell, dumbbells before and after trimming, end groups) are characterized, both with mechanical and RF measurements, during the production process, and all data is stored for the analysis of the production cycle. Figure 2 shows all production half-cells before the iris weld performed to create dumbbells.



Figure 2: Half cells before integration into dumbbells via iris welding.

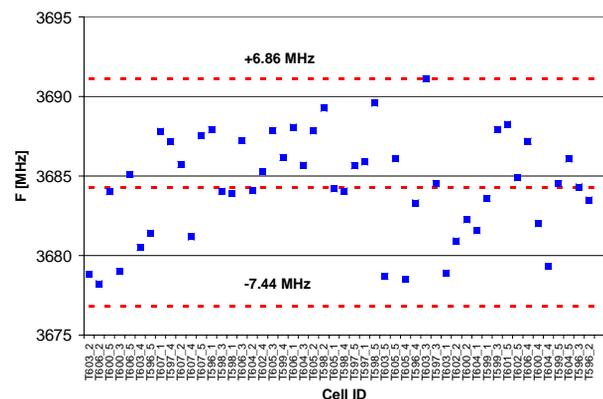


Figure 3: Frequencies of the untrimmed half-cells.

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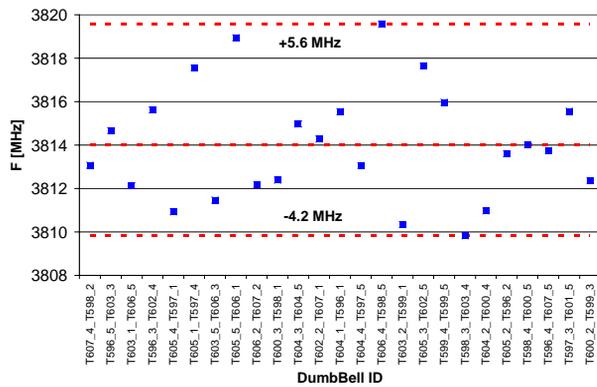


Figure 4: Frequencies of the untrimmed dumbbells.

Figure 3 shows the frequency distribution of the half-cells after forming and the first machining operation. At this stage the half-cells are prepared with the additional overlength of metal to account for the weld shrinkages and precision-trimming procedures that occur later in the fabrication stage. No tolerance is imposed during this machining stage, and the observed frequency spread in Figure 3 is due to the resulting variation in the equatorial over length (the half-cell nominal sensitivity is approximately -50 MHz/mm for length increase). Subtracting this correlation the remaining frequency spread due to difference in the cell shapes has a standard deviation of 1.2 MHz, indicating a good reproducibility in the inner shape. Independent 3 D measurements were performed on sample cells and confirmed this analysis.

The half-cells were then welded at the iris in order to form dumbbells and Figure 4 shows the resulting frequencies of the dumbbell production. Again, the observed frequency spread is mainly due to the spread in the over length metal provided at the equatorial planes.

We followed the procedure described in Ref. 5 in order to meet the design cavity frequency at a geometrical cavity length within a few mm from its nominal value.

After the dumb bell mechanical and RF characterization, each dumb bell is tolerance-trimmed at both equator sides for its integration into the cavity structure. For the evaluation of the needed trimming [5] we used the sensitivity coefficients that were experimentally derived from the production of the mockup structures.

Currently, the first of the prototype structures (3HZ01) has been completed in April 2009, and is being inspected in order to qualify the process before completing the production of the remaining two structures, for which all components are ready - missing only the last trimming and equatorial electron beam welds.

Field Flatness Tuning

Figure 5 shows the device, which has been developed to tune the frequency and field flatness of the cavity. Each cavity cell can be stretched or compressed in order to perturb its frequency and achieve the required 90% field flatness level.

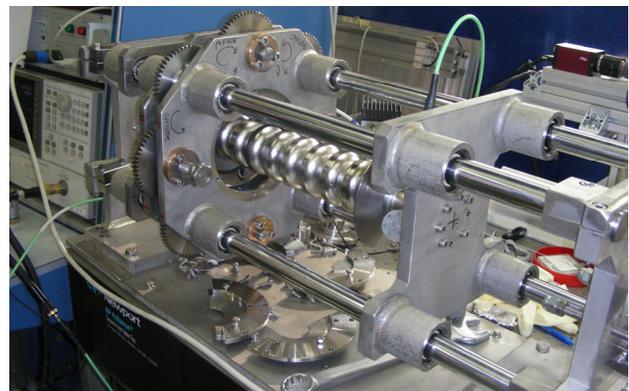
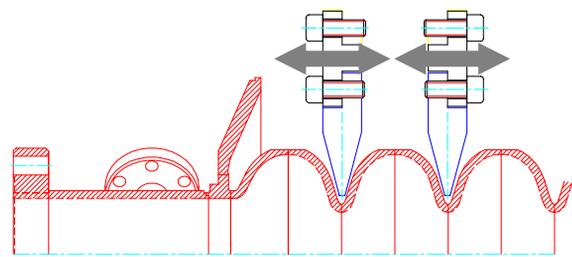


Figure 5: The cavity field flatness tuning device.

The 3HZ01 cavity, as fabricated, shown a frequency 6 MHz above expected, with a +1.2 mm deviation from the expected length, indicating the possibility of a further slight adjustment in the procedure coefficients. It is to be noted, however, that the setting of the goal frequency in our procedure is still affected by an uncertainty of the sensitivity coefficients to chemical etching. Data from the FNAL experience has been assumed until now and will be confirmed after the commissioning of the chemical facility at the vendor, due in the following months.

Figure 6 shows the field profile of the 3HZ01 cavity before (blue line) and after (red line) the field flatness tuning. The cavity frequency has been lowered by 3 MHz, in order to meet the correct geometrical length and test the accuracy of the software procedures developed at INFN for the supervision of the tuning process, and that will be used in the production of the XFEL 3.9 GHz cavity series. A field flatness of 94% has been achieved in four repeated iterations of cell deformations.

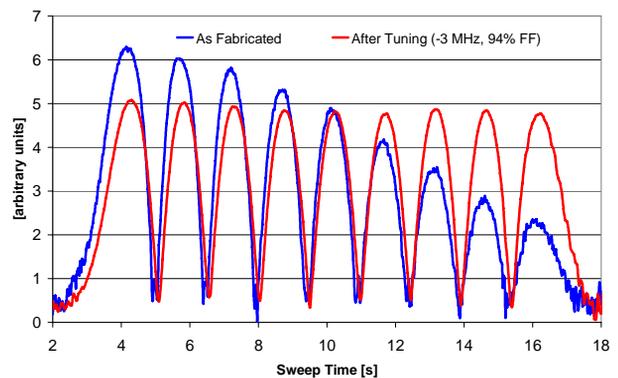


Figure 6: Field flatness profile after cavity fabrication (blue line) and after field flatness tuning (red curve). A field flatness of 94% was achieved.

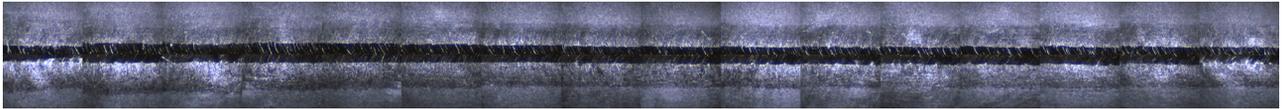


Figure 7: Typical pattern of the optical inspection at the cavity equator (all 360° folded in the picture).

Optical Inspection

For the supervision of the cavity fabrication process an optical inspection system based on a commercial boroscope system, with a home-made diffused LED lighting, was developed at INFN, for the inspection of the cavity welds before and after the main chemical etch for the damage layer removal. Figures 7 and 8 show the pattern of an equator weld and the inspection device.



Figure 8: Optical system developed for the inspection of the cavity welds.

INFRASTRUCTURE FOR VERTICAL TESTS AT INFN

The LASA laboratory is equipped with a vertical test stand, originally designed for 5-cell 500 MHz cavities. The existing vertical insert has been redesigned in order to host the cold test of the smaller 3.9 GHz cavities. A variable coupling scheme has been chosen to allow an optimal RF coupling during the qualification measurements.

A room temperature linear actuator, installed externally to the cryostat top flange, moves the cavity - in its titanium constraining frame - to adjust the penetration length of the antenna, which is fixed to the bottom plate of the insert. Figure 9 shows the cavity in its frame in the insert. The system was designed for a total antenna range of 50 mm, with a sensitivity of 8 μm /half motor step.

The existing cryogenic facility (LHe filling and recovery, vacuum system for subcooling, etc.) is already capable of performing the cavity measurements at a rate of few tests per year. About 13 W of cryogenic heat removal capabilities at 2 K are available for RF measurements with the present setup.

Installation at LASA of the modified vertical insert is scheduled by Summer 2009. In order to increase the testing rate and to better cope with the XFEL 3rd harmonic section installation schedule a few upgrades are also foreseen to the existing LASA infrastructure for the management, transfer and recovery of the helium fluids.

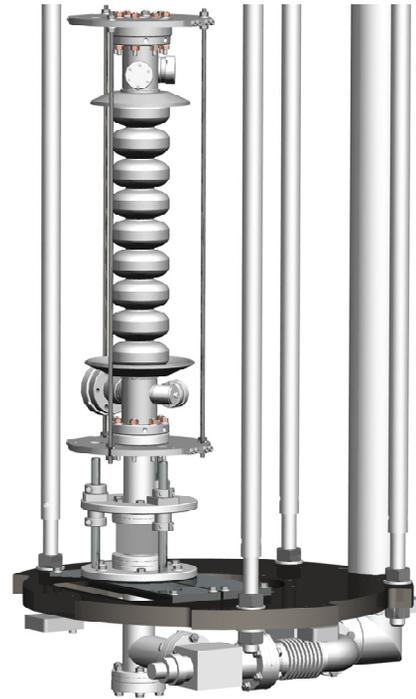


Figure 9: Adaptation of the cryostat vertical insert with the variable coupling antenna.

ACKNOWLEDGEMENTS

We would like to acknowledge here the contribution of many colleagues at INFN and DESY involved in the Workpackage 46 “3.9 GHz System” of the European XFEL Project, and of G. Corniani and M. Festa from Ettore Zanon S.p.A.

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