PREPARATION PHASE FOR 1.3 GHZ CAVITY PRODUCTION OF THE EUROPEAN XFEL

W. Singer#, S. Aderhold, A. Brinkmann, R. Brinkmann, J. Dammann, J. Iversen, G. Kreps, L. Lilje, A. Matheisen, W.-D. Moeller, D. Reschke, J. Schaffran, A. Schmidt, J. Sekutowicz, X. Singer, H. Weise. DESY, Hamburg, Germany
P. Michelato. INFN, Milano, Italy.

Abstract

The preparation phase of cavity production for the European XFEL [1] includes a number of issues: material, mechanical fabrication, treatment, transport and RF measurement, documentation and data transfer.

About 50 prototype cavities are produced at industry, treated (partially at industry and partially at DESY) and RF-tested at DESY. The XFEL requirements are fulfilled with a yield of approx. 90%.

INTRODUCTION

The activities of the XFEL Work Package SC Cavities (WP4) are very comprehensive and cannot be described in detail in this paper. More information can be found in the references [2-9]. The main task of WP4 during the preparation phase was working out and verifying the strategy for the large scale mechanical fabrication and treatment of the cavities at the factory, transport to DESY and RF testing. The work was based on development and experience gained during FLASH construction, and in the context of the TESLA collaboration.

The following aims were pursued.

Material issues: qualification of new high purity niobium vendors, verification of large grain material as a possible option for XFEL.

Mechanical fabrication issues: accommodation of the TESLA cavity design to the XFEL demands, establishing manufacture in conformity to the PED (pressure equipment directive) requirements, development of a strategy for ramping up the fabrication, find the optimum and safe way of integration of the helium tank into the fabrication sequence.

Treatment, transport and RF measurement issues: establishing the XFEL treatment recipe, in particular the final surface treatment (final 40μm EP Electropolishing or short 10 μm Flash BCP Buffered Chemical Polishing), and the cavity preparation strategy (with, or without a helium tank welded, with or without assembly of HOM antennas). Check the achievability of the XFEL performance requirements, check the accessible yield especially for the first treatment cycle, and check the possibility of the RF test of the cavity welded into a helium tank.

Documentation and data issues: work out of the XFEL specifications, data transfer and data storage.

More than 50 prototype cavities have been produced at two European companies ACCEL (recently RI) and E.ZANON under supervision of DESY. Some sophisticated equipment developed in the frame of TESLA collaboration's R&D has been built and will be available for XFEL cavity producers: equipment for RF measurement of half cells, dumb bells and end groups, equipment for cavity tuning at room temperature and possibly equipment for eddy current scanning of niobium sheets. Equipment for optical control of the inside surface developed in collaboration between Kyoto University and KEK is installed at DESY and is being upgraded in order to automated inspection of the cavity integrated into the helium tank [2].

#waldemar.singer@desy.de

MATERIAL ISSUES

Two main material issues have been considered in the preparation phase: qualification of the potential material vendors and large grain LG material.

In addition to three established Nb suppliers, Wah Chang (USA), Tokyo Denkai (Japan) and HERAEUS (Germany), several companies are anticipated to be qualified. Three steps of qualification for the XFEL have been defined: Step 1. Material testing (RRR, Microstructure, Eddy current scanning, Tensile test, Hardness, Impurity content). Step 2. Single cell cavity fabrication and treatment at DESY followed by RF tests. Step.3. Nine-cell cavity fabrication, treatment at DESY and RF tests. Only two companies SE Plansee (Austria) and Ningxia Orient Tantalum Industry Co. (China) sucessfully passed all three steps and were therefore included into the list of qualified material suppliers for the XFEL.

The manufacturing approach of slicing discs from the melted ingot and producing cavities by deep drawing and electron beam welding (large grain LG) as a cost effective option was taken into consideration for XFEL [3]. Several single cell and eleven 9-cell cavities have been produced from LG material. The tested cavities demonstrated adequacy for XFEL performance even using a simplified treatment procedure (BCP only). Unfortunately, it turned out that there could be a shortage on the market of the amount of LG material required for XFEL fabrication. In order to minimise the risk for the project it was decided to use conventional fine grain material for the XFEL.

PROTOTYPE FABRICATION

Small changes with respect to the original TESLA design have been done for the XFEL to reduce costs and to simplify fabrication. Removal of coupler port stiffener, reduction of flange machining on cavity's short side, removal of outside recess of the cells in the equator area, reducing the number of holes and thinning of the stiffener ring, in particular, have been done.

Material and helium tanks for prototypes have been purchased by DESY, the cavity mechanical fabrication was done by the factory, preparation and RF tests were done mainly at DESY.

During the fabrication of 1.3 GHz prototype cavities a prototype of a semiautomatic RF measurement machine for RF measuring the half cells, dumb-bells and end groups (HAZEMEMA) was designed and built [4]. This machine performs an easy load of the parts and automated RF measurements. Two similar machines will be used for the XFEL cavity fabrication.

The helium tank welding process was developed and implemented [5]. During tank welding a control of the cavity RF characteristics and, if required, a tuning at room temperature takes place. A special field profile measurement system (FMS) was developed for that. The system allows protection of the inner cavity surface from particle contamination. The installation of the FMS has to be done in an ISO 4 clean room. It was proven that welding of the helium tank on to the cavity keeps the resonant frequency.

TREATMENT AND RF TEST RESULTS

During treatment of prototype cavities the main issue pursued was establishing the XFEL recipe, in particular the final surface treatment [6]. The prior (rough EP) treatment consists of EP removal of a 110-140 µm surface layer, followed by an ethanol rinse, an outside etch using BCP and an 800°C annealing under UHV conditions. Two options of final treatment have been investigated. Final EP of 40-50 µm with subsequent ethanol rinse followed by ultra pure high pressure water rinsing (HPR) and 120°C bake or alternatively a final Flash BCP of 10 µm, HPR and 120°C bake. The major treatment steps can be seen in the work flow diagram of Fig. 1.

An industrialization of the main EP treatment was successfully done. Two equipments for EP have been set up at companies ACCEL and HENKEL under DESY supervision. EP is carried out horizontally similar to the DESY installation. The first step of EP (rough EP) on approx. 30 prototype cavities (removal by EP of approx. 110-140 µm) was successfully done at these factories.
The remaining preparation steps and RF tests were performed at DESY.

For the XFEL cavity production it is foreseen that the industry will carry out the mechanical fabrication, welding of the cavities into the helium tanks, cavity treatment according to DESY recommendations and assembly of High Order Mode HOM – antennas, pick-up antennas, high Q fix antennas in the required clean conditions for the RF test. Vertical RF test will be done at DESY.

Two aspects have to be emphasized in terms of the RF testing of cavities with integrated helium tanks and HOM output lines. Firstly, the T-mapping is not possible when helium tank is welded. This restricts the diagnostic. Secondly, all TESLA cavities for FLASH were vertically tested in cw (continuous wave) mode without output lines of the HOM couplers i.e. without HOM feedthroughs. The HOM couplers output lines were attached later during the assembling process. The CW acceptance test for XFEL cavities with assembled HOM feedthroughs is foreseen to lower the production cost. In the cw test, heat load of the HOM couplers increases by factor of 100, comparing to the XFEL nominal operation. In order to avoid the overheating, a pulse acceptance test with ca. 5 s long pulses and off time of ca. 50 s has been proposed and successfully implemented [8]. Cavities in the pulse test demonstrate similar or sometimes even higher Eacc compared to the cw RF test without HOM feedthroughs.

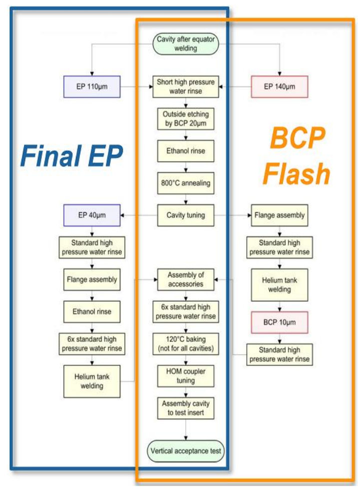

Figure 1: Work flow diagram of the alternative final treatment strategy with integrated helium tank.

Generally, the strategy is: welding the He-tank to the cavity before the vertical RF acceptance test.

Analysis of the first and last vertical RF acceptance test on prototype cavities [9] shows two main limitations for the XFEL design gradient of 23.6 MV/m. About 25% of the first tests are limited by field emission for both types of the final surface treatment (final EP or final Flash BCP). In most cases the field emission limitation can be cured sufficiently by an additional application of high pressure water rinsing HPR only. Gradients of several cavities of one vendor were limited by quench at 15-17 MV/m. In order to understand the reason of reduced performance, samples have been extracted from two cavities and investigated. Detected defects that caused quenches can be separated in two categories: defects of topographical nature and defects showing foreign elements (iron, areas with increased content of carbon).
Both effects – field emission and early quenches – limit the yield to 70% - 80% of the design gradient. With an additional HPR and re-test the yield is close to 90%.

DOCUMENTATION

The specification for the XFEL cavity production that defines the requirements for mechanical fabrication, treatment and quality management was worked out. In addition, the specification contains the detailed practical recommendations based on DESY experiences. The required inspection data and documentations are listed.

The DESY EDMS (Engineering Data Management) product will be used for XFEL as a central repository of all engineering information. This includes all documentation of the manufacturing process from niobium sheets to the completed cavity. The external manufacturers are being connected to the EDMS, enabling DESY to perform quality control activities and to access process documentation even during early stages of the production process.

Fig. 2 shows the manufacturing structure of a cavity in the helium tank with associated inspection sheets for quality control as a base for the EDMS documentation.

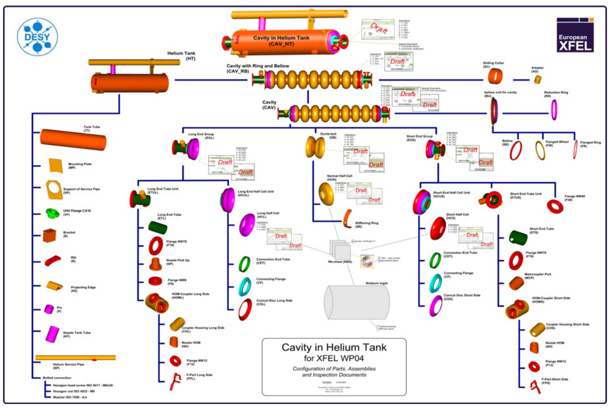

Figure 2: Manufacturing view of a cavity with helium tank in the EDMS, showing the subassembly breakdown structure with the linked inspection sheets.

For statistical evaluation the cavity data bank created for FLASH at DESY will be reconsidered and extended for XFEL tasks.

SUMMARY AND OUTLOOK

In order to check some ideas a special single cell program for XFEL [10] was created at DESY. The single cell cavities have been build at DESY and treated mostly at the industry (at companies ACCEL and HENKEL). The program was very helpful particularly for the qualification of new suppliers of high purity niobium, for the work on niobium specifications (e.g. optimization of tantalum content), the work on specifications for cavity mechanical fabrication (e.g. check requirements for welding preparation of parts), the development of LG cavities, verification of the high pressure water quality in the HPR equipments etc.

As mentioned above, a cavity with helium tank has to be built for XFEL cryomodules as a pressure device according PED/97/23/EC (Pressure Equipment Directive). Requirements of PED include examination of cavity design, FEM calculation, testing of material, creation of the particular material appraisal (PMA), examination of material suppliers, examination of purchased semi products, examination of the fabrication procedure (deep drawing, coning, annealing etc.), analysis of welding connection realizations, examination of the welding procedure and welder qualification, destructive and non-destructive tests of welding connections, pressure test on each cavity with a helium tank etc.. The electron beam welded connections have been investigated on one of the cavities destructively. At the moment not all connections fulfil completely the PED requirements. The required correction will be established in the pre-serial and serial cavity fabrication.

ACKNOWLEDGEMENTS

We would like to thank all participating colleagues whose enthusiastic effort allows us to push forward the work on cavities for XFEL project.

REFERENCES

[1] H. Weise. The European XFEL Based on Superconducting Technology. Proceedings of the 14th International Workshop on RF Superconductivity, Berlin, Germany, September 20-25, 2009

[2] S. Aderhold. Optical Inspection of SRF cavities at DESY. Proceedings of the 14th International Workshop on RF Superconductivity, Berlin, Germany, September 20-25, 2009

[3] W. Singer et al. Development of Large Grain Superconducting Resonators for the European XFEL. PAC'09, Vancouver, Canada, May, 4-8, 2009. http://www.JACoW.org

[4] J. Iversen et al. Development and Design of a RF Measurement Machine for the European XFEL Cavity fabrication. Proceedings of the 14th International Workshop on RF Superconductivity, Berlin, Germany, September 20-25, 2009

[5] A. Schmidt et al. Update on 1.3GHz Cavity Weld to Helium Vessel and Application of the FMS. Proceedings of the 14th International Workshop on RF Superconductivity, Berlin, Germany, September 20-25, 2009

[6] B. van der Horst et al. Experiences on Improved Cavity Preparation Cycles with a Vision on Industrialization of the Cavity Preparation, Proceedings of the 14th International Workshop on RF Superconductivity, Berlin, Germany, September 20-25, 2009

[7] J.-H. Thie et al. Mechanical Design of Automatic Cavity Tuning machines. Proceedings of the 14th International Workshop on RF Superconductivity, Berlin, Germany, September 20-25, 2009

[8] J. Sekutowicz. Pulse Acceptance Test for XFEL Cavities. TTC Meeting, Chicago, USA, April 19-22, 2010

[9] D. Reschke et al. Analysis of RF Results of Recent Nine-Cell cavities at DESY. Proceedings of the 14th International Workshop on RF Superconductivity, Berlin, Germany, September 20-25, 2009

[10] A. Brinkmann et al. Progress of the Test Cavity Program for the European XFEL. Proceedings of the 13th International Workshop on RF Super-conductivity, Beijing, China, October 15-19, 2007