CHALLENGES IN SRF MODULE PRODUCTION FOR THE EUROPEAN XFEL

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Abstract

The internationally organized European XFEL free-electron laser is under construction at the Deutsches Elektronen-Synchrotron (DESY). With an electron beam energy of 17.5 GeV the possible wavelength will be down to below 0.05 nm. The project is the first large scale application of the TESLA technology developed over the last 15 years. The main linac will consist of 100 accelerator modules, i.e. 800 superconducting accelerator cavities, operated at a gradient of 23.6 MV/m. The talk describes the activities with respect to the module production within the international collaboration. The challenges and the status of final prototyping, industrialization and commissioning of new infrastructure will be presented.

INTRODUCTION

The European XFEL [1] is based on a superconducting linac comprising of 100 accelerator modules housing eight TESLA type cavities each (Fig. 1). In order to operate at its design energy of 17.5 GeV, confirmed recently by the XFEL Council, the design gradient of the cavities is 23.6 MV/m. The construction of the cold linac is a common effort of many institutes sharing the responsibility for this superconducting linac. The overall coordination is with DESY leading the XFEL Accelerator Consortium. Table 1 summarizes the major contributions [2].

Table 1: Contributions to the XFEL Cold Linac

Institute	Component / Task
CEA Saclay / IRFU, France	cavity string and module assembly; cold beam position monitors
CNRS / LAL Orsay, France	RF main input coupler incl. RF conditioning
DESY, Germany	Cavities & cryostats; contributions to string & module assembly; coupler interlock; frequency tuner; cold vacuum system; integration of superconducting magnets; cold beam position monitors
INFN Milano, Italy	Cavities & cryostats
Soltan Inst., Poland	Higher Order Mode coupler & absorber
CIEMAT, Spain	Superconducting magnets

CHALLENGES

Key challenge of the accelerator module production is the knowledge transfer to industry and between the collaboration partners. This includes the experience with infrastructure, procedures, handling of critical components as well as dedicated tools. In all of these fields the knowledge established on prototypes and small batches has to be adapted to the series production of cavities, couplers and modules.

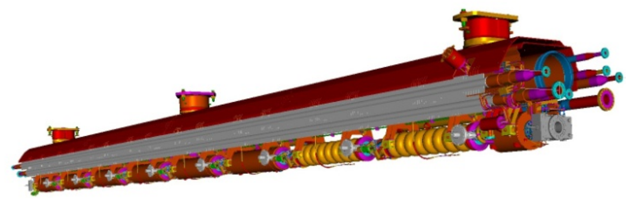

Figure 1: Cold mass with cavity string of European XFEL module.

In contrast to the previous cavity fabrication the cavities for the European XFEL have to be fabricated according to the Pressure Equipment Directive (PED 97/23/EC). This requires a guaranteed "Transfer of Identification" from the material to the final cavity, i.e. a tracking of all relevant parts. The necessary procedures of the PED process are done together with a "Notified Body" (here: German TÜV Nord). After the identification of the classification of the pressure equipment, the "conformity assessment procedure", which defines the adequate PED procedure, was worked out. The so-called modules B and F of PED 97/23/EC have to be applied. Module B includes the EC "type examination" of all relevant documents, vendors, procedures and the fabrication of test pieces for weld qualification (Fig. 2). Module F, the "product verification" for series production, is based on Module B and requires e.g. the pressure test of each individual cavity.

Figure 2: Test piece for weld qualification (Courtesy of RI).

CAVITIES

The European XFEL call for tender [3] was published in July, 2009. Production and surface preparation will be done in industry. After negotiations with the possible

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vendors the contract was allocated by DESY, the supervision of the cavity production will be done in shared responsibility of DESY and INFN Milano. Details of the cavity specifications are available to the SRF community on request.

Research Instruments (RI) and E. Zanon (EZ) were contracted to produce each 4+4 pre-series cavities followed by 280 XFEL type series cavities and 12 so-called HiGrade cavities, first used for quality assurance, later available for further investigations & treatments (high gradient R&D towards ILC). Nb / NbTi will be supplied by DESY. The remaining cavities will be ordered in 2012.

The production will precisely follow the specifications which also include the exact definition of infrastructure to be used. The final treatment after bulk electro-polishing (EP) will be different for the two selected vendors: EP for RI / so-called BCP Flash for EZ.

In order to optimize the overall cost, no performance guaranty is given by the vendors, i.e. the risk of unexpected low gradient or field emission is with the contractor DESY (responsibility for re-treatment). The gradient goal is an average usable XFEL gradient of 23.6 MV/m at an unloaded quality factor of $1 \cdot 10^{10}$.

The additional cavities are ordered as an option to be placed after the evaluation of the successful start of the series production. First series cavities are scheduled for mid of 2012; all cavities to be delivered within two years. He-vessels for Research Industry's cavities will be supplied by DESY. Both contracts have a volume of approximately 25 M€ each.

Material

As all Nb / NbTi semi-finished products (Fig. 3) will be supplied [4], the responsibility for quality assurance and logistics is with DESY. The material is contracted to four companies (Ningxia OTIC, Plansee Metal GmbH, Tokyo Denkai and W.C. Heraeus).

The in-house infrastructure was extended in order to handle about 19.500 pieces (for 680 cavities) within the cavity production time. The quality assurance includes acceptance at the contractor, visual incoming components inspection, dimension checks, material parameters (RRR, interstitial and metallic impurities analysis, metallography, tensile test, hardness HV), definition of numbering system, marking and documentation using the DESY EDMS system. All sheets are scanned by eddy-current technique (Fig.4). As described above, all semi-finished products for pressure bearing components of cavities have to be fabricated according to PED requirements and their traceability has to be guaranteed.

The first batch of 3.500 pieces was already delivered to RI and EZ.

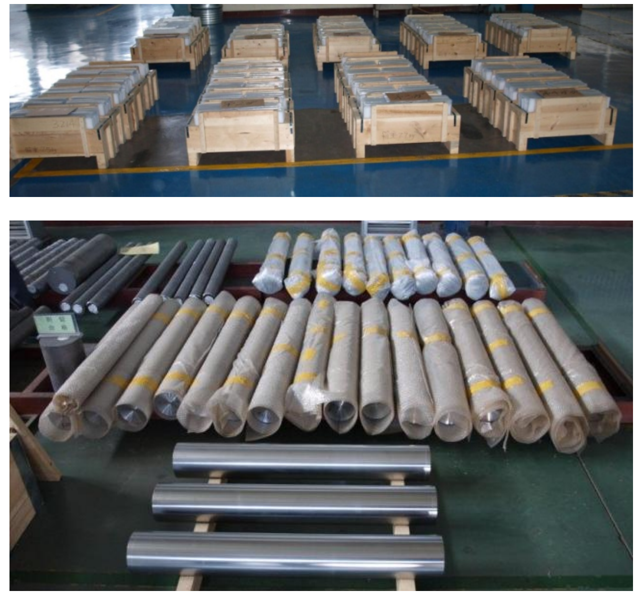

Figure 3: Semi-finished Nb and NbTi products.

Figure 4: Eddy current scanning of XFEL niobium sheets at DESY.

RF Measurements

One important step during cavity fabrication is the RF frequency tuning of half cells as well as dumb-bells (pairs of half cells). In order to considerably shorten the tuning time and thus the costs, a dedicated apparatus was developed. The prototype was successfully used for the FLASH cavity production. Two more machines were fabricated with only minor changes. Key issue for the industrial use are automation and documentation [5].

The finished cavities need to undergo a frequency and field flatness tuning. Also here two dedicated machines for the series cavity production were built and commissioned [6]. While the mechanical parts were contributed by DESY, the development of software and electronic devices was done at FNAL. CE certification of the entire machine according to European rules and laws is necessary. The finished machines can be operated by Non-RF-experts.

Surface Preparation

Two schemes of final surface treatment – electro polishing (Final EP) and a final buffered chemical polishing (BCP Flash) – were studied together with the strategy to weld the cavities in its helium vessel after the final surface treatment intensively prior to the call for tender [7, 8, 9].

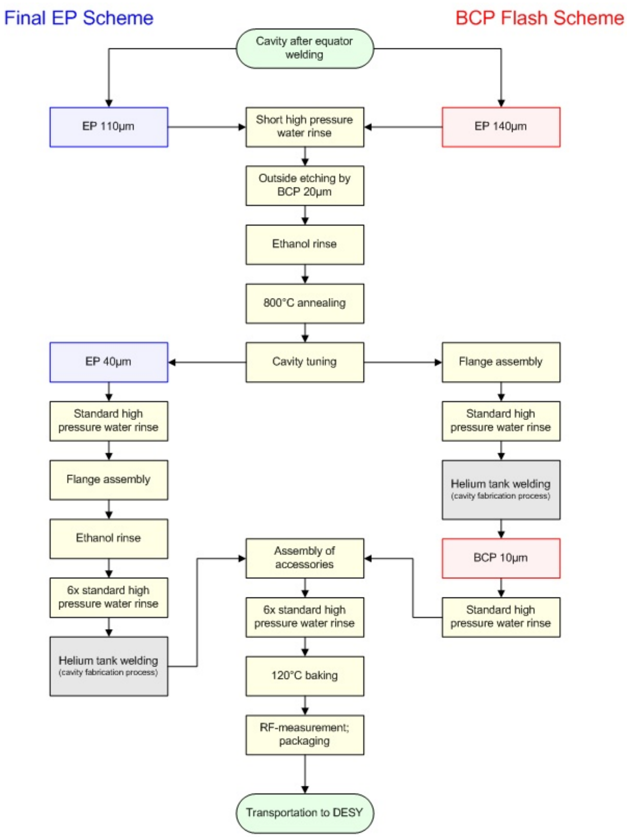

Figure 5: Schematic work flow of surface treatment.

Figure 5 shows the applied scheme for surface treatment of the completed XFEL cavities. RI will apply a final EP of about 40 µm, which requires the welding of the Helium vessel after the surface treatment. EZ will apply BCP Flash (10 µm removal) on the cavities already equipped with their He-vessels, which results in a reduced number of preparation and handling steps. Both vendors will produce 4 pre-series cavities each for the set-up of the new company's preparation infrastructure. Additional 4 pre-series cavities ("reference cavities") each will be used for commissioning and qualification of the new preparation infrastructure after an initial preparation and RF-test at DESY.

Transportation

After the final surface preparation in industry the cavities will be transported to DESY for their vertical acceptance test. The installation of the cavities to the test insert and the acceptance test itself is in the responsibility of DESY. After the successful acceptance test the cavities have to be shipped to CEA Saclay / France for the module assembly. The transport of each individual cavity will take place horizontally in a commercially available box adapted to this special purpose (Fig. 6). The loaded box has been successfully tested with respect to the impact of mechanical vibrations and shocks ("transport tests") [10] under various conditions (Fig. 6). The subsequent RF tests showed neither a change of the cavity frequency nor any degradation of the cavity performance.

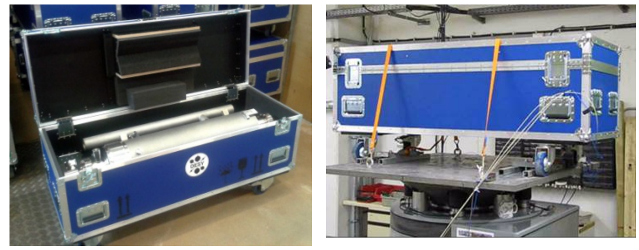

Figure 6: Cavity transport box (left) and set-up for transport test (right).

RF MAIN INPUT COUPLER

The responsibility for the XFEL RF power coupler production has been taken over by LAL Orsay / France. The contract for production was placed at a consortium of THALES (France) and RI. The preparation for conditioning of the couplers will take place at Orsay in a new cleanroom infrastructure. For RF conditioning a new dedicated 5 MW RF station will be set up at Orsay. In order to fulfil the required conditioning rate of approximately eight couplers per week, the common conditioning of four couplers is under investigation. The conditioned couplers will be provided directly to CEA Saclay being the module assembly site. The coupler interlock system needed after the installation in the XFEL tunnel is developed and will be contributed by DESY [11].

CRYOSTATS AND MODULES

Cryostats and Prototype Modules

In preparation of the series production one prototype cryostat each was supplied to DESY by IHEP Bejing (China), THALES and Duro Felguera s.a. (Spain). All three cryostats, consisting of the so-called cold mass, i.e. the supporting structure with all cryogenic process lines and temperature shields, and the outer vacuum vessel were meanwhile assembled at DESY and CEA Saclay.

Equipped with a string of eight cavities and the quadrupole / BPM package all three cryostats named as module PXFEL1 - PXFEL3 were tested on the Cryomodule Test Bench (CMTB) at DESY. While module PXFEL1 showed excellent results with an average maximum gradient of 32.5 MV/m, some individual cavities of the second and third module suffered in performance compared to their vertical acceptance test [12, 13, 14]. Until mid of 2012 the modules PXFEL2 and PXFEL3 will be used in order to offer assembly training and guarantee the transfer of knowledge.

Based on the positive mechanical and cryogenic experiences with the prototype cryostats the contract for 83 cryostats was placed to two vendors. Additional 20 cryostats required for the final 17.5 GeV energy will be ordered in 2012.

Cavity String and Module Assembly

The cavity string and module assembly at CEA Saclay (Fig. 7) required a complete new infrastructure. Construction started in 2009 and since 2010 the infrastructure is under commissioning using the prototype modules. For the series production the main input coupler, cavity string and module assembly will be contracted to industry by CEA Saclay around end of 2011.

Figure 7: String and module assembly at new CEA Saclay infrastructure.

As the main input coupler assembly as well as the cavity string assembly is crucial for the later module performance, the thorough qualification of all critical infrastructure components as well as the staff training is especially emphasized. Therefore, the assemblies, transportation and RF tests of the prototype modules will go on until the series production will start 2012.

Module Transportation

All 83 (+20) assembled modules must be transported on the road from CEA Saclay to DESY about a distance of approximately 1000 km without any damage or performance degradation. Therefore, the allowed maximum impact to the modules during transportation was defined as 1.5 g. A dedicated transport frame (Fig. 8) equipped with electronic shock loggers and GPS is used. Up to now 5 transports between Saclay and Hamburg took place. Before the series production will start 4 - 5 more transports are foreseen, which will include additional checks of the module alignment after the arrival at DESY.

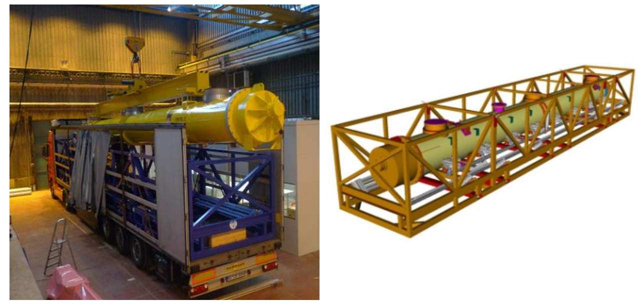

Figure 8: Module transport (left) and 3D sketch of the module transport frame (right).

CAVITY AND MODULE ACCEPTANCE TEST

At DESY the so-called Accelerator Module Test Facility (AMTF) is under construction in which both the vertical cavity acceptance test after delivery from the two vendors and the at Saclay completed accelerator modules will be tested. The vertical acceptance test will be done in 4-cavity units with a rate of at least 2 units per week. The modules will be tested with a rate of 1 module per week. Figure 9 shows the overall layout of the AMTF. Two vertical test cryostats, three accelerator module test stands, and one waveguide assembly and test facility are part of the installation. AMTF will be operational mid of 2012.

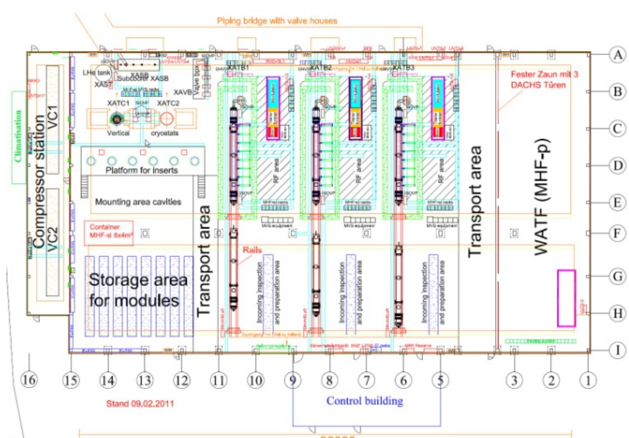

Figure 9: Layout of AMTF.

Cavities not passing the accelerating gradient requirements will be sorted out and not send to CEA Saclay. Re-treatment will be done in the responsibility of DESY either in the existing in-house infrastructure or contracted to the cavity vendors.

For both vertical acceptance test and horizontal module test new software is required and under commissioning or development, respectively. The extension and modification of the DESY cavity data base was already started.

REFURBISHED DESY CLEANROOM

The cleanroom for the processing and assembly of accelerating cavities at DESY was set-up in the early 1990ies. In preparation of the requirements for the XFEL cavities and modules like assembly training, routine assembly of quadrupole / BPM package and future re-treatment of cavities, the cleanroom was completely updated [15]. The air distribution and condition was replaced to a state-of-the-art system. The assembly areas of cleanroom class ISO 4 were enlarged significantly. The chemistry and cleaning facilities are now located in a class ISO 5 and ISO 4 instead of ISO 7. For reduction of the ultrapure water consumption a recirculation system at one High Pressure Ultrapure Water Rinsing stand was installed and is under commissioning.

SUMMARY

The module production for the European XFEL has started. Contracts for key components are placed and several components already available. The necessary new infrastructure at CEA Saclay is under commissioning, while the cavity and module test facility at DESY is under construction.

ACKNOWLEDGEMENT

The European XFEL module production is a collaborative work of several institutes. Thus the author likes to thank the complete team of all involved colleagues from the different institutes.

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