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Abstract

The production of the 103 superconducting accelerating modules for the European XFEL is an international effort. Institutes and companies from seven different countries (China, France, Germany, Italy, Poland, Russia and Spain), organized in 12 different work packages contribute with parts, capacity for work and facilities to the production of the modules. Currently the series production of the individual parts started or is approaching. Personnel is trained for the assembly and testing of parts and as well for the complete modules. Here we present an overview and the status of all these activities.

INTRODUCTION

In the early 1990s the Tera Electronvolt Superconducting Linear Accelerator (TESLA) collaboration started working on the development of a pioneering superconducting accelerator technology [1]. The concept has proved so successful that it was also chosen for the European XFEL [2].

Each superconducting accelerating module for the European XFEL consists of several parts provided by different work packages (WPs). The core parts are the superconducting 1.3 GHz nine-cell cavities provided by WP04. They are used for beam acceleration. For beam focusing and steering each module contains a superconducting quadruple magnet from WP-11. A beam position monitor produced by WP-17 is attached to the magnet. The rf power is fed into the cavities via power couplers delivered by WP-05. The frequency tuners from WP-07 are used for keeping the cavities on resonance. Bellows connecting the individual cavities are part of the WP-08, the 'cold vacuum', likewise the coupler vacuum system. WP-06 organizes the Higher Order Mode (HOM) and pick up (PU) antennas. All these parts are installed inside the cryostat. The cryostat is also called 'cold mass' and part of the WP-03.

The final assembly is done in the responsibility of WP-09 (string assembly) and WP-03 (module assembly) at CEA, Saclay and the final module operation test is performed by WP-10 at the Accelerator Module Test Facility (AMTF) at DESY, Hamburg. Proper rf control in the later accelerator will base on properties measured during the modules tests. This item is the task of WP-02. Before transportation into the XFEL tunnel for installation, each module receives a waveguide system tailored by WP-01 to the cavity performances.

Providing infrastructure and support needed for parts tracking, quality control and nonconformity handling for all these activities is the task of the WP-40.

SUPERCONDUCTING CAVITIES

More than 800 superconducting TESLA type cavities [3] will be used for the European XFEL. They are mechanically manufactured and surface treated [4] by the two companies Ettore Zanon (EZ) and Research Instruments (RI) and delivered to DESY ready for vertical testing in the AMTF by a Polish team from IFJ-PAN, Krakow. Always eight cavities with similar performance will be put together and shipped to CEA for the string and module assembly.

Both companies manufactured reference cavities which have been surface treated at DESY and vertically tested. These cavities showed promising maximum gradients above 28 MV/m. They are used for the qualification of the companies' infrastructure created for the cavity treatment (clean room, degreasing and ultrasonic cleaning, HPR, (electro) chemical surface treatment, annealing furnaces, slow venting slow pumping systems etc.). The commissioning of the infrastructure is ongoing. The series delivery to DESY will start in November (RI) and in December (EZ).

COLD MAGNETS

The accelerating modules of the XFEL linac will be equipped with one combined superconducting magnet [5] per module, which consists of a main superferric quadrupole for focusing and two nested corrector dipoles for beam steering. The magnet series production is being done under the supervision of CIEMAT in Spain: ANTEC produces the magnets while Trinos Vacuum Projects takes care of the helium vessel, assembly and tests (electrical, pressure and vacuum). The magnetic measurements are done at DESY as a common German and Polish in-kind contribution. The conduction cooled current leads are produced at CECOM in Italy under DESY supervision while the copper coating of the beam pipe is being done by Galvano-T in Germany.

The three pre-series units have been successfully produced and tested. Green light has been given to series production in June, 2012.

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POWER COUPLERS

LAL Orsay contributes to the XFEL project with the delivery of 800 power couplers [6, 7] to CEA for the assembly of 100 accelerator modules. The tasks consist of the industrial monitoring and coupler quality control at the production sites and the rf conditioning and testing at the LAL campus [8].

A 70 m^2 clean room used for the coupler preparation at LAL is under construction. The 5 MW power rf station has been installed for the conditioning of 8 couplers simultaneously. The industrial production by Thales and RI is in the last process validation phase and the mass production start is scheduled for the end of the year.

FREQUENCY TUNERS

The goal of the XFEL cold tuning system [2] is the adjustment of the cavity frequencies to the accelerator rf frequeny with a resolution better than 1 Hz. The XFEL slow tuner is based on the TTF/SACLAY tuner [9]. This tuner design is working in the TTF Linac since 1997 with high reliability. In addition, the tuning system will also compensate Lorentz Force De-tuning (static and dynamic) using piezoelectric actuators [3].

All the orders for the tuner parts have been made and the fabrication is in good progress. The drive units and piezo systems will be checked by industry prior to delivery. The first full tuner systems are available at CEA. An automatic system has been developed to verify the correct tuner installation during the string and module assembly.

BEAM POSITION MONITORS

Beam steering through the linac requires proper information on the beam position. It is provided by one beam position monitor (BPM) per module. Two different types are used, 1/3 will be re-entrant and 2/3 button BPMs [10]. Both types have different advantages and disadvantages.

The ramp up of the BPM series production is in time with the magnets arriving DESY and the last one will be produced and available mid-2013. The individual production rates of both BPM types are under investigation.

BEAM AND COUPLER VACUUM

The cavities are connected via Copper coated bellows without RF-shields. A novel sealing system has been developed [11]. It consists of rigid Nb-Ti flanges EB welded to the Niobium cavities and massive aluminum rings as gaskets. The bellows are being fabricated by BINP, Novosibirsk and delivered to CEA after particle cleaning at DESY [12].

The production of these units has been started. The first components have been delivered for the installation into the pre-series modules.

The rf power input coupler has two ceramic windows [6]. This design enables the complete closure of the cavity in the clean-room by mounting the coupler up to the first window, thus preventing any contamination during further assembly of the module. Between the two windows a common vacuum for all eight couplers is established by a sputter ion pump and a Titanium sublimation pump (TSP).

The coupler pump line systems are fabricated at BINP. After particle-cleaning at DESY, the items are delivered to CEA. The TSP and the sputter ion pumps are purchased by DESY and delivered to CEA. The delivery of the components started.

HOM AND PU ANTENNAS

HOMs are excited by beam and can spoil the beam quality [13]. Therefore, every cavity contains two HOM couplers, one at each end, to filter these modes and couple them out via coaxial antennas and cables transferring them to loads, located outside the module [14]. In addition, each cavity is equipped with a PU antenna taking a small portion of the rf power for the rf control electronics regulating amplitude and phase of the accelerating rf mode.

NCBJ (former INS-Swierk) provides, as in-kind contribution, 1616 HOM and 808 PU antennas and all cables and feed-throughs for their output lines. More than 200 sets are already on stock. They will be followed by 105 sets delivered every 3 months.

CRYOSTATS

The TESLA cryostat technology [15] incorporates the string of accelerating cavities and a cold focusing magnet together with all cryogenic process lines avoiding separate cryo-lines. Cryogenic boxes at the beginning and the end of a chain of several modules are used for the helium supply. This leads to a compact arrangement of the accelerating cavities and comparatively low cryogenic losses and is well suited for longer linacs like the XFEL.

The cryostats for the XFEL [16] are provided by IHEP, Beijing and EZ. The cryostat delivery from EZ to CEA already started with a rate of two per month. The IHEP cryostats will first arrive at DESY before being transported to CEA. IHEP starts the cryostat delivery in October.

STRING AND MODULE ASSEMBLY

An assembly infrastructure, called the 'XFEL Village', has been set up at CEA and is used by an industrial operator for the integration of the accelerator modules under CEA supervision. Two lines of seven workstations, designed to produce one module per week, will gradually integrate the different components of the module over seven weeks. Work will begin in the 112 m^2 ISO4 clean room with the assembly of the cold coupler parts to the cavities, and then the cavities and quadrupole package in a string. After string roll-out, five workstations are designed for cryostat integration, cavity alignment, ISO5 assembly of power coupler parts [17] and final inspection and shipment.

The industrial operator contract has been awarded to the company ALSYOM. The transfer of knowledge will occur through the assembly of three pre-series modules until March 2013 when ramping up the assembly rate will start with the series modules.

MODULE OPERATION TESTS

After transportation [18], the accelerator modules will be received at the AMTF by the Polish team from IFJ-PAN, Kraków. The team performs the complete test cycle starting with the entrance inspection and installation of each module at one of the three module test stands operating in parallel. The functional test includes the cool down to 2 K, the measurements of the cryogenic losses and the rf operation of all cavities to determine all required parameters like the maximum cavity gradients and the levels where field emission starts [19, 20]. After warm up the modules are handover to the next work package for wave guide installation.

The training of IFJ-PAN personnel for the assembly and testing of the modules is actually done at DESY's Cryomodule Test Bench (CMTB) and is well advanced, likewise the software and testing procedures developed by the team.

RF CONTROL TESTS

Stable rf field provided by the digital rf control is essential for the XFEL electron beam quality. Good knowledge of parameters permits the adjustment of the rf control for optimal performance. At the AMTF the subsequent parameters will be determined: the individual cavity quench voltage, the range and characteristic of the cavity slow tuning motors, the performance of the piezo actuators and sensors, the sensitivity to microphonics, the identification of other fundamental modes, the performance and characteristics of the cavity loaded Q versus the coupler motor position and the Lorentz force detuning compensation. Finally, nominal module operation will be established. A full description of the LLRF tests is given in [21].

WAVE GUIDE INSTALLATION

The variation of the cavity performance of each module will be accommodated by tailoring the rf power distribution via the wave guide system [22]. By doing so, the average accelerating voltage provided by each module is optimized. The wave guide systems will be assembled and tested in a separate infrastructure in the AMTF hall and also attached in the AMTF to the modules before the installation in the XFEL tunnel.

INFORMATION AND PROCESS SUPPORT

Module integration needs reliable procedures for gathering, processing and archiving the complete mandatory fabrication information. A solution has been established based on the concepts of tracking and tracing [23] and with the help of a central collaboration and documentation platform, the DESY Engineering Data Management System [24].

SUMMARY AND OUTLOOK

The work on the XFEL accelerating modules enters now the phase when all the series productions of the different components need to start to supply the final assembly at CEA with sufficient parts. Deviations of some components and infrastructure installations from the original schedule are addressed together with corrective measures. Furthermore, the preparation phase for the module series assembly started and the training of the personnel performing the module operation tests is well advanced. In all, quite some international machinery starts working for the production of the XFEL accelerating modules.

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