Polish in-kind contribution to European X-ray Free Electron Laser (XFEL): Status in spring 2013

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Abstract In the years 2010-2011 Polish research institutes - members of the European-XFEL consortium, took responsibility for production and delivery of important components and test procedures for the superconducting linear electron accelerator (linac) of the X-ray free electron laser at DESY (Hamburg).. The paper briefly summarizes the progress of the work on cryogenic installation, test procedures for linac components and high order mode couplers and absorbers reached by WUT, IFJ-PAN and NCBJ groups with their subcontractors, respectively.

Keywords: superconducting linear electron accelerator, radio frequency (RF) field, high order mode (HOM) of RF field, RF cavity, cryogenic installation

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1. Introduction

The manufacturing of 103 accelerating modules for the linear electron accelerator of the European XFEL free electron laser is an international project organized in different work packages [1]. Each module contains among other things 8 superconducting (sc) nine-cell niobium cavities based on TESLA technology, placed in a liquid helium vessel and a single magnet package with a sc, super-ferric quadrupole magnet and two dipole magnets [2]. The magnet packages are also placed in a liquid helium bath. Every cavity is equipped with two high order mode (HOM) couplers. Parasitic high order modes in RF field are excited by the beam. They have to be coupled out by coaxial HOM couplers and transferred via cables to loads outside the module [3]. In addition a single beam line absorber (BLA) is installed in each of intermodule connections to absorb the travelling HOMs. Each cavity is equipped with a single pick-up (PU) antenna – a microwave field probe used by the RF control system to regulate the amplitude and phase of the accelerating field.

The following Polish institutions and their subcontractors contribute in-kind to the project with their capacity for facilities, work and with components:

- A group of NCBJ is responsible for design, production, testing and delivery of 1648 HOM couplers, 824 PU antennas and output lines and 110 HOM beam line absorbers (BLAs).
- A team of IFJ-PAN is in charge of preparation and performance of acceptance tests for XFEL-type cavities, complete accelerator modules, cold magnets and their current leads. During the preparation phase the team: takes part in development of the measuring software and hardware, tests prototype and pre-series units and elaborates test procedures. Then the IFJ PAN team starts to perform serial tests of 816 cavities, and 100 cryo-modules, 100 cold magnets and 100 magnets’ current leads. The serial tests in Accelerator Module Test Facility (AMTF) hall at the DESY site will be continued within next three years.

- WUT is responsible for design and WPT with its subcontractors are responsible for manufacturing and installation of a 165 m long XATL1 cryogenic transfer line for supercritical helium transport from the HERA refrigerator at DESY to the AMTF hall and of two vertical cryostats for low power acceptance tests of cavities.

The current status of implementation of the above listed tasks is reported in the following paragraphs.

2. Production and installation of the XATL1 cryogenic line and two vertical cryostats.

The cryogenic transfer line XATL1 is destined for the transport of cooling media at two temperature levels: 4.5 K and at 40/80 K. It is accomplished by the transport of streams of supercritical helium and cool gaseous helium in two different circuits which are placed in a cylindrical thermal radiation shield. The 40/80 K gas circuit is used to maintain a sufficiently low temperature of the shield, whereas the supercritical helium is further cooled and delivered to test stands inside the AMTF hall. XATL1 is a vacuum-isolated transfer line and all the processing tubes are installed inside an external vacuum envelope. The processing lines and radiation shield are covered with multilayer thermal isolation. The construction is based on design calculations, technical specification and hazard analysis prepared at WUT which was also involved in design of the two vertical test cryostats and two additional transfer lines connecting cryostats with a subcooler (liquid helium distribution system in AMTF).

A vertical cryostat is composed of a liquid helium storage vessel equipped with an "insert" structure to facilitate installation of four cavities tested in a single run and a thermal shield surrounding the vessel . This structure is placed in a vacuum tank which contains also tubing and valves for cold circuits as well as a counter-flow heat exchanger and cold terminals for transfer lines connection. 4.7 K liquid helium from the subcooler is pre-cooled in the heat exchanger to 2.2 K and further cooled down to its working temperature of 2 K inside the vessel by iso-enthalpic expansion on a Joule-Thomson (J-T) valve. Each cryostat is equipped with necessary safety systems.

Both, cryogenic line and the cryostats had to comply with European norms and be certified by TÜV Nord company based in Germany.

Cryogenic transfer line and the cryostats were produced in the years 2010-2012 by WPT and its subcontractors: Kriosystem and KATES Poland and delivered to DESY. The transfer line was mounted on a tube bridge and connected to the HERA refrigerator on the one end and to the subcooler in the AMTF on the other (Fig. 1a). It underwent successfully high pressure and leak tests. One of the cryostats (Fig. 1b) was installed in the hall in February 2013 and is currently used for serial cavity tests. Installation of the other was completed in May 2013. The final commissioning of these devices is foreseen in 2013.

3. Test procedures and personnel training for the tests of 1.3 GHz superconducting cavities, complete accelerator modules and superconducting magnets.

The tests of 22 prototype cavities, 3 cryomodules, and 25 sc magnet packages were performed so far by the IFJ PAN team at DESY. Required documents were also written and delivered as a quality plan, risk assessment and test procedures. Elaboration of the test procedures included development of measuring hardware, software and local databases as well as their communication with user interfaces. The created procedures and documents were loaded to EDMS (Engineering Data Management System) – a central documentation and collaboration platform at DESY [4]. Efforts are taken to integrate and to test management and control system with other systems like DOOCS (Distributed Object Oriented Control System) and Oracle database.

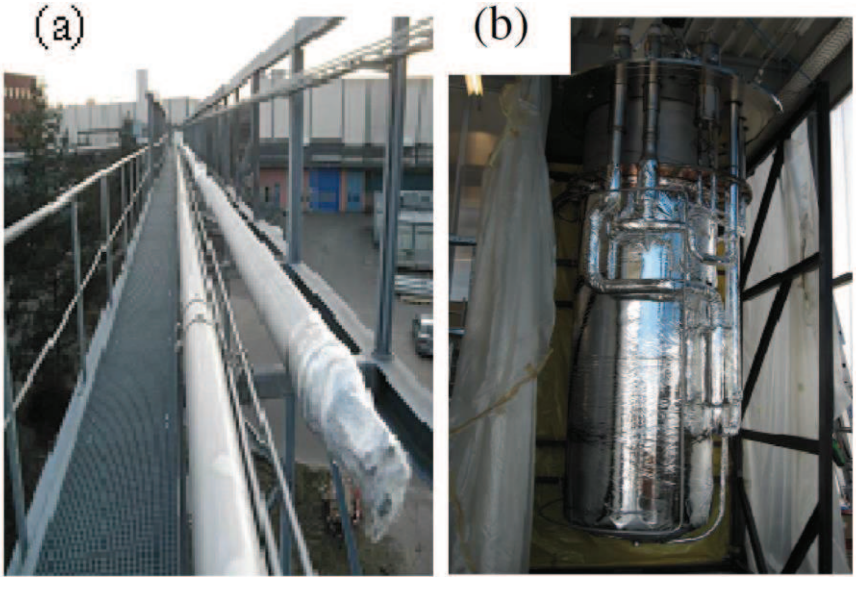

Figure 1. XATL1 cryogenic line under construction in April 2012 (a) and a view of one of the vertical cryostats during mounting of thermal insulation on the cryostat cold circuit and helium storage vessel (b).

A set of four TESLA-type cavities installed in a prototype insert of a vertical cryostat is shown in Fig. 2. In particular testing procedures for cavities included: cavity inspection and preparations for tests, cryogenic and vacuum operation and RF measurements like cavity spectrum measurement or quality factor measurement vs field gradient (see the plot in Fig. 2). The latter is connected with an important validation criterion for cavities: it is assumed that unloaded quality factor Q_0 of more that 10^{10} is reached for accelerating gradient up to 23.6 MV/m. It corresponds to 20 GeV maximum electron energy of the linac.

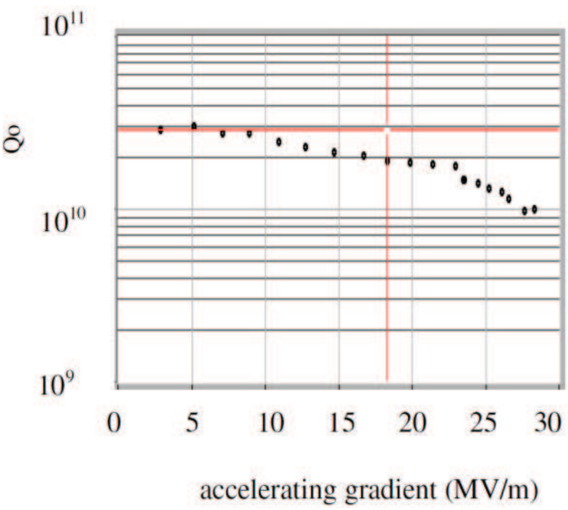

Figure 2. Four cavities installed in a prototype insert of a vertical cryostat (top) and a measured dependence of unloaded quality factor Q_0 on accelerating gradient for a cavity.

So far 18 procedures for cavity tests were prepared and at least 20 reference cavities, including the cavities dedicated for the pre-series cryomodules, were tested so far to verify these procedures.

A software for cavities: “Spectrum measurement” and “HOM tuning” created by the IFJ-PAN team was made available to the CEA Saclay group (France) which is responsible for the cryomodules assembly.

Works on cryomodules (Fig. 3): inspection and preparation for assembly, their cryogenic operation and the modules’ high- and low-power RF tests are included in 146 procedures. They were checked during tests of three prototype cryomodules performed so far at DESY and at Saclay with the participation of the IFJ-PAN team.

Sc magnets testing steps were described in 7 procedures. They comprise check procedures of feedthrough flanges and current leads and check of the magnets at 300 K and 2 K (e.g. harmonics and harmonic hysteresis measurement or stretched wire measurement). Magnets tests are aimed at measuring field quality, saturation effects, magnetic axis and roll angle. The magnets tests are performed in collaboration with another group of DESY.

This effort resulted in personnel training and fulfilling the criteria of the production readiness review which certifies the group’s ability to perform the in-series RF tests of cavities, cryomodules and superconducting magnets for the XFEL electron linac.

Figure 3. Prototype of XFEL cryomodule on a trolley in AMTF hall.

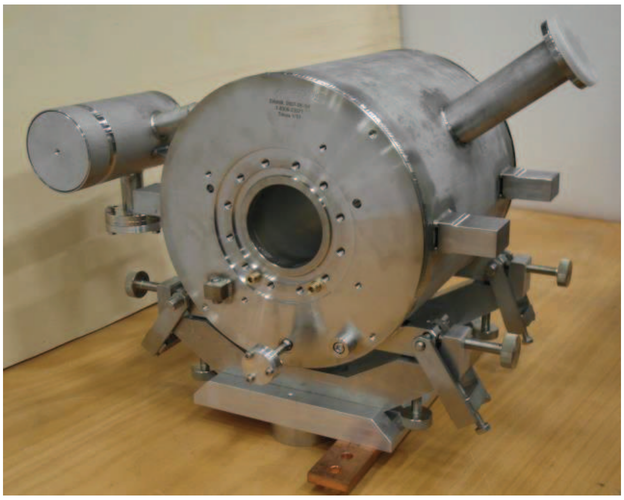

Figure 4. XFEL superconducting magnet.

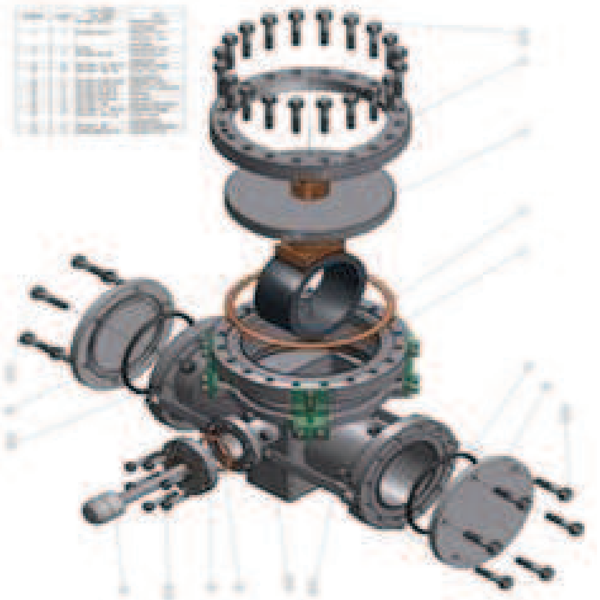

Figure 5. A scheme of the beam line absorber.

4. Design, production, testing and delivery of HOM couplers, PU output lines and HOM beam line absorbers (BLAs).

The types of HOM couplers and PU antennas were agreed on between NCBJ, DESY and Kyocera company (NCBJ subcontractor). The choice of cables for HOM damping which connect the couplers and 50 Ω external loads was based on calculation of RF match between these components and on cable attenuation measurements.

BLAs design completion (Fig. 5) required certain structure modifications based on computation of fatigue resistance of compensation bellows (used for thermal stress release) and precise materials selection. In particular the choice of the material of the ceramic ring for HOM absorption was based on measurements of high order modes attenuation and dc resistivity. The measurements were performed on samples of different ceramic materials at 300 K and 70 K. The obtained results led to the choice of AlN-based CA137 composite produced by Ceradyne, Inc. (USA).

Delivery to DESY of 300 HOM couplers with 150 PU antennas plus auxiliaries and two BLA prototypes (for testing) as well as contracting most of the materials allowed beginning of the serial production.

Until now all the components for HOM couplers and PU antennas have been contracted or purchased and most of them are delivered or in stock. A system for HOM couplers quality check was installed at NCBJ. Manufacturing of 103 BLAs is contracted together with its components. According to the time schedule, installation of the above elements and the final commissioning should be reached in June 2014.

5. Significance of the Polish in-kind contributions.

The key role of the tasks of Polish groups involved in construction of European XFEL superconducting linac is obvious. Completing within the last 12 months of the cryogenic installation and reaching the readiness for serial tests and serial production of HOM couplers and absorbers enabled other teams of DESY and CEA Saclay to start cryomodules assembly. The first pre-series cryomodule was delivered to the AMTF hall in June 2013.

The elaborated test procedures for RF cavities and the modules combine previous experience gained by many IFJ PAN groups which worked at DESY within Tesla Test Facility project (in the two previous decades) with recent modifications connected with the prospect of testing in a tight time schedule of long series (on average: 8 cavities and one module per one week!).

The cryogenic installations (produced by WPT, Kriosystem and KATES Poland) and the beam line absorbers (Lamina state enterprise) were positively assessed and certified in the light of design criteria.

6. Future prospects for the European XFEL.

Apart from the underground electron linac facility of nominal electron energy equal 17,5 GeV (maximum design energy 20 GeV) the European XFEL will comprise a collimating and a beam distribution systems, a set of undulators including three which make use of self-amplified simulated emission (SASE-type), five X-ray optical lines placed in underground tunnels and an experimental hall. The 17.5 GeV electron energy corresponds to 0.1 nm photon wavelength which can be reached in two of the planned SASE undulators.

According to the XFEL directorate generating the first X-ray photon beam is expected in 2016.

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