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POLISH IN-KIND CONTRIBUTION TO EUROPEAN XFEL: STATUS IN SUMMER 2017*

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Abstract

In the years 2010-2017 some of the Polish research institutes - members of the European-XFEL consortium, took responsibility for production and delivery of components, test infrastructure and procedures for the superconducting (sc) linear electron accelerator (LINAC) and PLC units of slow control system for the first experimental instruments of the European XFEL at DESY (Hamburg). The paper briefly summarizes the output of these works.

INTRODUCTION

European X-ray Free Electron Laser (Eu-XFEL) is dedicated to advanced studies of the structure of matter.It is based on a linear sc electron accelerator (LINAC) constructed by DESY (Deutsches Elektronen Synchrotron) and its partners of international XFEL consortium. The LINAC in its final version is composed of 97 modules. Each module contains 8 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 inside it [1]. The magnet packages are placed in liquid helium bath too. Every cavity is equipped with two high order mode (HOM) couplers. Parasitic high order modes (HOMs) in RF field are excited by e^- beam. They have to be coupled out by coaxial HOM couplers and sent via cables to loads outside the module [1]. In addition a single beam line absorber (BLA) is installed in interconnectors between the modules to absorb the travelling HOMs. Each cavity is equipped with a pick-up (PU) antenna – a field probe in RF control system to regulate the amplitude and phase of the accelerating field. The activities of Polish groups which contributed in-kind to the project are briefly described below.

Wroclaw University of Science and Technology (WUST) was in charge of design and Wroclaw Technology Park (WPT) with its subcontractors were 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 Accelerator Module Test Facilty (AMTF) hall and of two vertical cryostats for low power acceptance tests of cavities.

A group of National Centre for Nuclear Research (NCBJ) was in charge of design, production, testing and delivery of 1648 HOM couplers, 824 PU antennae with output lines and 108 HOM beam-line absorbers (BLAs).

A team of Institute of Nuclear Physics (IFJ-PAN, Krakow) was responsible for preparation and performance of acceptance tests for XFEL-type cavities, complete accelerator modules, sc magnets and their current leads.

Another group of NCBJ now contributes to the production of programmable logic controller (PLC) units for slow control system of the first experimental instruments to be installed at the ends of XFEL photon lines. The status of these tasks on the eve of XFEL facility startup is presented in the following sections.

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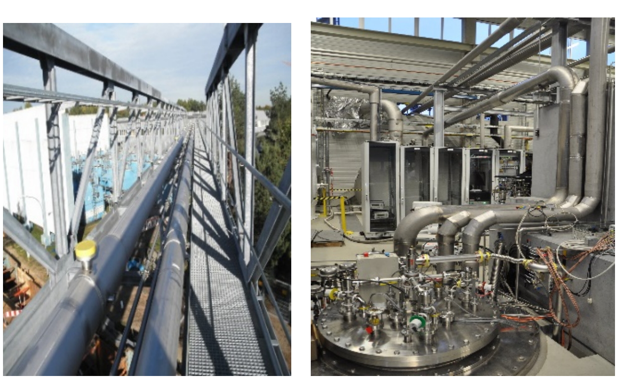
CRYOGENIC LINE AND TWO VERTICAL CRYOSTATES

A vacuum-isolated cryogenic transfer line XATL1 is composed of external vacuum envelope housing a thermal shield and four processing tubes [1]. It is destined for the transport of cooling media at two temperature levels in two different circuits: at 4.5 K (supercritical helium) and gaseous helium at 40/80 K. The latter 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. WUST was also engaged in design of the two vertical test cryostats.

A vertical cryostat consists of a liquid helium vessel with an "insert" structure to install four cavities to be tested and a thermal shield surrounding it . They are placed in a vacuum tank which contains valves and tubing for cold circuits, a recuperative heat exchanger and cold terminals for transfer lines connection. 4.7 K liquid helium from a redistribution system in ASTM (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 expansion on a Joule-Tomson (J-T) valve.

Before manufacturing all the cryogenic components were modelled to analyze thermal stresses and heat loads. In particular, a detailed analysis of design parameters of the transfer line [2], insert [3] and vertical cryostats [4] has been performed. Both, cryogenic line and the cryostats were certified by TUEV Nord company based in Germany. They were produced in the years 2010-2012 by WPT with its subcontractors: Kriosystem and KATES. The transfer line was mounted on a tube bridge (Fig.1a) and connected to the HERA cryoplant on the one end and to the subcooler on the other the cryostats were installed in the hall inside concrete radiation shields (Fig. 1b) and commissioned in 2013 (see Fig. 2). The installations have been functioning flawlessly for the next three years till the end of admission tests of the sc cavities and LINAC cryomodules.



a b

Figure 1: General views of XATL1 cryogenic line (a) and a vertical cryostat in AMTF hall (b), DESY in 2013.

Figure 2: Cooling curves of four cavities in a vertical cryostat. λ- transition to superfluid HeII is shown.

HOM COUPLERS AND BLAs

The HOM couplers and PU antennae were developed for TESLA-type cavities in the previous decade (see eg. [5]). Specific choice of the coupler type for XFEL was agreed on between NCBJ, DESY and Kyocera company (NCBJ subcontractor). NCBJ team performed RF matching of external circuits and resistive loads [1]. BLAs design completion at NCBJ required, certain structure modifications based on computation of fatigue resistance of compensation bellows and precise materials selection. In particular, the choice of the material of ceramic rings for travelling HOM absorption was based on measurements of high order modes attenuation (at 300 K and at 70 K) and dc resistivity. The obtained results led to the choice of AlN-based lossy ceramic rings produced by Sienna Technologies Inc. (USA). The quantities of HOM couplers (1700) and PU antennae (850) delivered to DESY till May 2015 exceeded the contractual obligations of NCBJ. Of the 110 beam-line absorbers (BLAs) delivered together with auxiliaries till the end of 2016, 97 were installed in XFEL LINAC after admission tests at DESY comprising leak check, residual gas analysis and magnetic permeability of their walls. One of the BLAs that have successfully passed the tests is shown in Fig. 3.

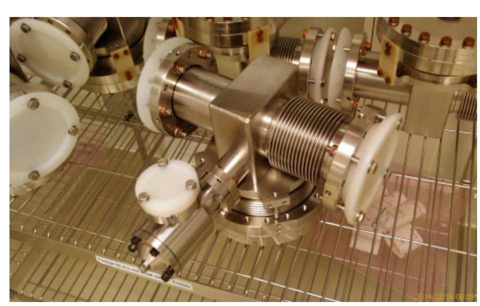


Figure 3: BLA after admission tests at DESY.

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TESTS OF SC MAGNETS, CAVITIES AND LINAC CRYOMODULES

Before performing the tests the IFJ PAN team at DESY elaborated the documents: quality plans, risk assessment and nearly 200 detailed test procedures. The latter included development of measuring software, hardware and local databases as well as their communication with user interfaces. The written procedures and documents were loaded to Engineering Data Management System – a central documentation and collaboration platform at DESY [1]. The test procedures are characterized in some detail in [6] including eg the rules of input and output inspection or vacuum and cryogenic systems operation.

In brief: tests of sc magnets are aimed at measuring field quality, magnetic axis, roll angle, or saturation effects [1, 6-8]. They comprise check procedures of feedthrough flanges and current leads and measurements of the magnets at 300 K and 2 K (see Fig. 4). Tests include harmonics and harmonic hysteresis measured with rotating coil or stretched-wire measurements used to determine the field angle and offset between magnetic and mechanical axes. Those tests were performed in collaboration with a German group of DESY.

Cavities tests in a vertical cryostat (Fig. 5a) are aimed at determining their performance, maximum available electric field (accelerating gradient) and its dependence of radiation level, cavity quality factor Q_0 on the gradient. An important validation demand for the cavities assumes that Q_0 of more than 10^{10} is obtained for the field gradient up to 23.6 MV/m. The contracted number of tested and approved cavities (816) was reached in March 2016.

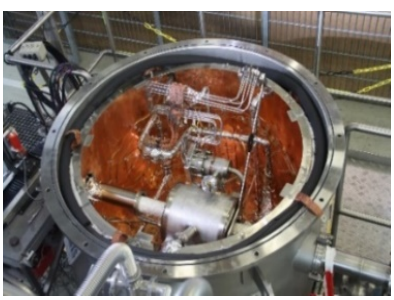
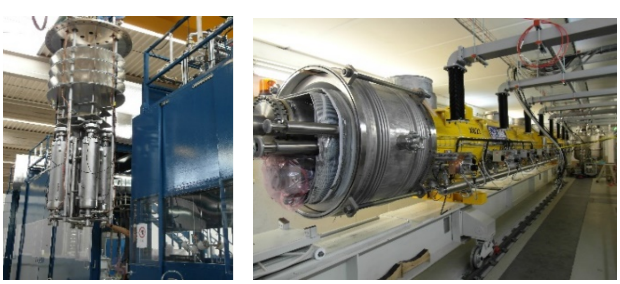


Figure 4: Sc magnet with current leads in a test cryostat.



(a) (b)

Figure 5: Four cavities in a transportation frame (insert) on their way to a cryostat (a) and a complete LINAC module prepared for high power RF tests (b).

Low- and high power RF measurements of cavities installed inside a module were performed with Vector Network Analyzer and a klystron as power sources, respectively (Fig. 5b). This final check of the LINAC components results in cavities tuning and determination of external quality factors of input RF couplers, HOM couplers and pick-up antennae. HOM spectra are measured to verify if the parasitic higher modes are attenuated. Maximum and usable field gradients are measured for a single cavity. Finally heat load measurement is done to calculate cavity Q_0 [6]. All the planned tests of 100 LINAC modules were finished and documented till Aug. 2016.

MANUFACTURING OF PLC UNITS

The newest NCBJ engagement into Eu-XFEL facility refers to manufacturing of Beckhoff programmable logic control units for slow-control systems of the first six experimental instruments in XFEL facility. For each of these instruments rough estimates of the equipment to be controlled include 300 motors and 60 valves and pumps which call for 200 PLC units in total. Out of this number, 187 units have been manufactured till July 2017 (Fig. 6). The remaining quantity should be completed till the end of August 2017.

Figure 6: Assembly of a PLC module at NCBJ.

SUMMARY

Implementation of the cryogenic installation by the end of 2012 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 assembly of the modules and the entire LINAC. Continuous research and upgrading of the test procedures in many aspects (see [9-19]) allowed testing of long cavities and modules series in a tight time schedule since 2014 (on average: 8 cavities and one module per week). The cryogenic installations and the beam line absorbers were positively assessed and certified in the light of design criteria.

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