

THE CHALLENGES TO ASSEMBLE 100 CRYOMODULES FOR E-XFEL

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Abstract

As In-Kind contributor to the E-XFEL project, CEA is committed to the integration on the Saclay site of the 101 cryomodules (CM) of the superconducting linac as well as to the procurement of the magnetic shieldings, superinsulation blankets and 31 cold beam position monitors (BPM) of the re-entrant type. The assembly infrastructure has been renovated from the previous Saturne Synchrotron Laboratory facility: it includes a 200 m² clean room complex with 112 m² under ISO4, 1325 m² of assembly platforms and 400 m² of storage area. In parallel, CEA has conducted industrial studies and three cryomodule assembly prototyping both aiming at preparing the industrial file, the quality management system and the commissioning of the assembly plant, tooling and control equipment. In 2012, the contract of the integration has been awarded to ALSYOM. The paper will summarize the outputs of the preparation and prototyping phases and the status of the start of the industrial phase.

INTRODUCTION

The 17.5 GeV superconducting RF linac of the E-XFEL project [1] will comprise 101 cryomodules (see Fig.1) including the injector module. These twelve-meter long cryomodules, deriving from the FLASH technology, include a string of eight 1.3 GHz RF cavities with an average gradient of 24 MV/m, followed by a BPM and a superconducting quadrupole.

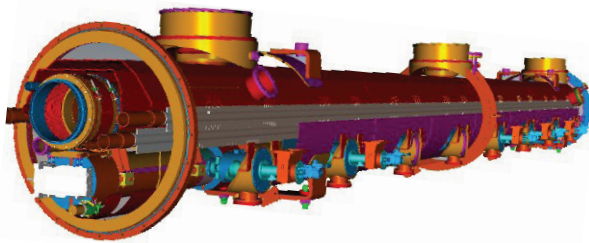


Figure 1: XFEL Cryomodule 3D-model.

This string is closed by two gate valves at both ends. Within the Accelerator Consortium (AC), CEA is committed to the assembly of 103 cryomodules over 2013 to mid-2015 with the goal to deliver one cryomodule per week to DESY for RF acceptance. Strategic decisions, shared by the AC, were taken in 2008 first to host the assembly plant on CEA premises at Saclay, using the former Saturne Synchrotron Laboratory accelerator and experimental halls, second to subcontract the 103 modules assembly work, including 3 pre-series modules, to an industrial company. The layout of the assembly

plant (see Fig. 2), was optimized by breaking down the assembly work in seven successive blocks of one-week procedures, leading to one clean room complex for coupler and string assembly, and five cryostating workstations for the remaining module assembly work, including alignment and control operations. To allow for a fluid circulation of the cryomodules along the assembly chain even when a repair is needed at one workstation, each workstation, but the vacuum vessel cantilever (see Fig. 3), has been doubled to offer module parking possibilities.

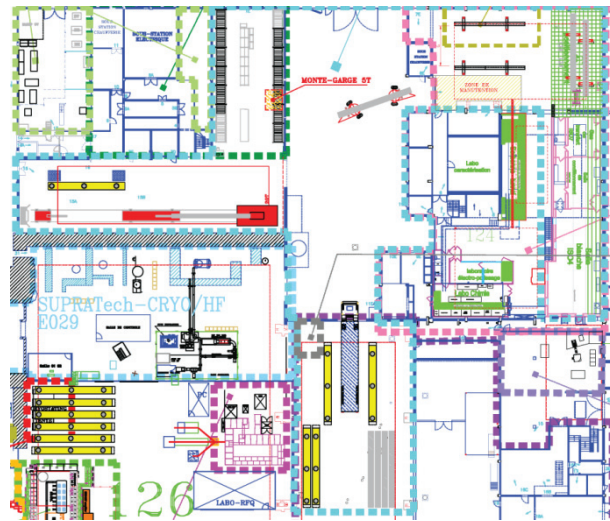


Figure 2: XFEL village layout (the village is delimited by dashed blue line).



Figure 3: Cold mass on cantilever system.

OUTPUTS FROM THE PREPARATION PHASE

To ensure the integration of 103 CM at the rate of one cryomodule per week, CEA has set up a program to form

an expert team and to commission the facility. This program includes a training phase, a prototyping phase and the industrial phase.

Training Phase

In 2007, CEA and DESY have started the transfer of the knowledge by a period of observation by CEA personnel at DESY (M3 CM for FLASH) followed by a “hands-on” assembly period where CEA personnel participated in the assembly of the FLASH M8-PXFEL1 CM with the DESY team.

Pre-industrial Studies

Meanwhile, CEA has conducted industrialization studies aiming at defining industrial equipment and methods for the cryomodule assembly. The first study has determined the workflow from the storage to the shipment, with cavity reception, clean room assembly, roll-out, alignment, vessel roll-over and coupler assembly (see Figs.2-7). The areas have been dimensioned accordingly and matched to the infrastructure which was renovated from the previous Saturne Synchrotron Laboratory facility: the 200 m² clean room complex with 112 m² under ISO4 allows assembling the couplers to the cavity and two cavity strings in parallel; the *cryostating* will be held on the 1325 m² of assembly platforms and 400 m² are dedicated to storage.



Figure 4: PXFEL2_2 in the ISO4 clean room facility.

The first fabrication file included assembly procedures with task description, duration and definition of manpower skills. It included also the big tools drawing updates, task schedules and risk analysis. The cost of the 103CM integration has been estimated. The outputs of this first study led CEA to launch the big tools fabrication, speed-up the infrastructure set-up, establish the quality insurance plan and start the prototyping phase when CEA team is training in house by assembling 3 CM using its infrastructure and tools.

The second more detailed study finalized the tools such as the clean room tools specific to CEA infrastructure, the detailed assembly procedures with tools in use, duration of the tasks, incoming and outgoing parts; the parts flow has been consolidated, the stock needs have been

evaluated. This study has defined the product breakdown structure, updated the risk analysis and detailed the schedule in tasks. The outputs of this study were used to place the call for tender for the 103 CM integration.

Prototyping Phase

The prototyping phase consisted of the assembly of 3 CM (namely PXFEL2_1, PXFEL3_1 and PXFEL2_2) at Saclay by both CEA and DESY staff allowing commissioning the tools and the infrastructure. The infrastructure was equipped with the services and fluids for the CM assembly. Big tools such as girders and pillars (cf Fig 5) have been manufactured ahead of time and used during the prototyping phase.



Figure 5: PXFEL2_2 cold mass hooked to the girder in the Roll-Out area.

Small tools, especially those dedicated to clean room assembly (see Fig.6), were manufactured and commissioned during the prototype phase. Ionized gun and particle counters for clean room assembly were ordered and used to insure the required low level of particles on the part to be assembled (less than 10 particles per minute of 0.3 microns on the part to be assembled).



Figure 6: coupler to cavity connection in the clean room with tools (elevator table and coupler holding).

Vacuum groups, equipped with RGA and slow pumping-venting system, have been installed on the clean room wall and in the warm-coupler hall. Those groups, provided by DESY, are designed to reduce the particles

migration when pumping or venting a cavity or a coupler. CEA has designed specific vacuum groups with a turbomolecular pump and a gauge attached to the cavity in the clean room and the primary pumps outside the clean room. Those groups are dedicated to the leak detection and venting of the cavity during the string assembly. They have been received at the start of the XFEL CM assembly. The tests and controls have been detailed (RF, mechanical, vacuum, electrical), implemented and validated. To ease measurements and systematic recordings, software and automation have been developed for the RF, alignment and tuner test benches and for particle counters. They have been tested on the prototypes.

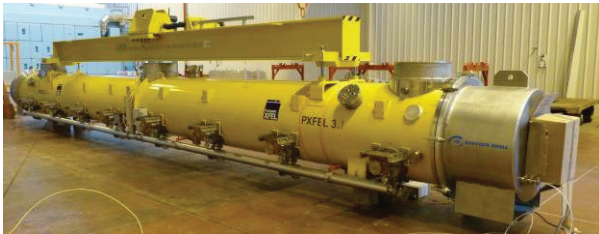


Figure 7: PXFEL3_1 CM before shipping to DESY.

The assembly procedures have been tested during a first assembly, then modified according to CEA's infrastructure and tools and rechecked on a last assembly for repetitive tasks. The part workflow from the reception to the assembly halls has been validated. Improvements on a few workstations are under evaluation, aiming at saving assembly time.

TESTS RESULTS

The module PXFEL2_1 was undressed, rolled in the clean room with no string disassembly and then re-dressed. Its RF test shows no degradation of its performance with respect to its previous test.

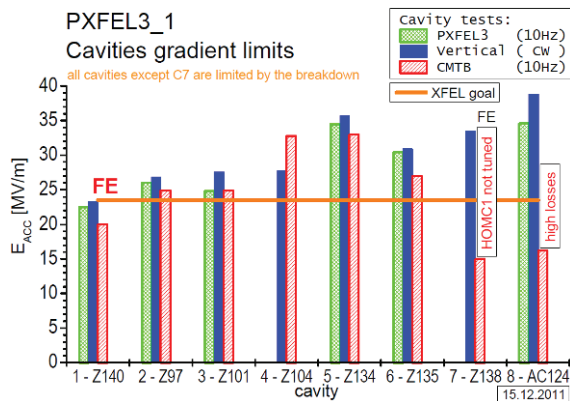


Figure 8: PXFEL3_1 RF test results.

Module PXFEL3_1 tests results (see Fig. 8) show some degradation of cavity performance: cavities 1 and 8 are under the XFEL specifications and the HOM coupler of cavity 7 was not tuned thus the RF power was limited. The HOM tuning procedure has been revised while its

specifications have been finalized. Module PXFEL2_2 average accelerating gradient is according to the specifications even though individual cavity performances were degraded, but for one cavity. All cavities but one have suffered from one (seldom two) non-conformity during the coupler or string assembly. PXFEL3_1 and PXFEL2_2 had shown also assembly deviation leading to possible misalignment of the string within the module. Increasing the checks has prevented those deviations for the following XFEL modules.

QUALITY INSURANCE AND QUALITY CONTROLS

During the prototype phase, CEA and DESY established the Manufacturing Bill Of Material (MBOM [2]) which is collecting, recording, and archiving the complete mandatory fabrication information. It is focused on the parts that are needed to integrate a CM at CEA. The MBOM also includes information about how the parts relate to each other, the inspection to be performed, the tests to be recorded, the assembly procedures, the documentation etc... The XFEL cryomodule MBOM contains roughly 500 lines i.e. 500 elements are assembled on a CM at CEA. A Bill of Material (BOM) is then created for each CM containing the physical parts integrated in the module as well as the assembly reports, control reports, and configuration. DESY Engineering Data Management system (EDMS) manages the MBOM and the BOM.

An Acceptance Data Package (ADP) based on quality assurance and quality control by CEA and its industrial partner will support the first step of CM acceptance by CEA after assembly. It includes the certificate of conformity, the "as-built" configuration, the traveler, and the control and non-conformities reports. The second CM acceptance stage will be based on the cryogenic and RF tests in AMTF at DESY.

PROCUREMENTS

CEA is in charge of the procurement of the 800 cavity magnetic shields. The awarded company proposed some closing improvements as well as a new Cryophy™ material which was qualified on the CM prototypes. Precut and assembled multilayer blankets for the 2K and 70K superinsulation have been ordered: they facilitate the assembly and reduce its duration. Cryogenic loss measurements on the prototype modules qualified them for the series. CEA is also in charge of 31 cold re-entrant BPM (cf. figure 9). These BPM have been studied and prototyped at CEA [3], and tested on FLASH. The integration with the cold quadrupole is done at DESY. The electronics developed by CEA in collaboration with PSI will be implemented in the modular BPM unit [4].

CEA is also in charge of providing clean studs, screws, nuts, washers for the coupler and string assembly. The orders have been placed for the material and a process developed in house to clean the hardware and transfer it to the work stations.

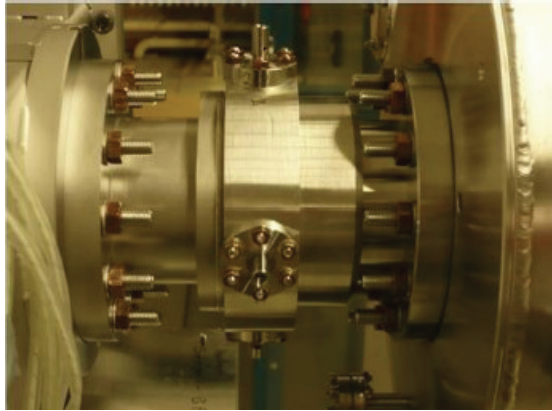


Figure 9: BPM installed in a cryomodule.

INDUSTRIAL PRODUCTION

The contract for 103 CM integration has been awarded to ALSYOM in July 2012. The 103 CM are named XM-3 to XM-1 for 3 pre-series modules, these modules can be considered as spares and could go in the injector and the LINAC if they perform according to the specifications. The series cryomodules XM1 to XM100 will be installed on the LINAC. The industrial production splits into three phases.

The first phase consists of the assembly by CEA of the first pre-series cryomodule (XM-3) and the observation by ALSYOM as well as the deployment of their industrial method based. XM-3 has been assembled with parts from the XFEL production lines, except the large grain cavities and the couplers (TTF3) provided by DESY. The quality of the parts issued from the different Work-Packages (WP) has been validated on this module. 43 Non-Conformance Report (NCR) were issued to the WP in charge; about 13 NCR are under the responsibility of CEA. The NCR are the main reason for the 7-month assembly time (initially scheduled from Sept. 2012 to Dec. 2012). Nonetheless, the performance of the CM (see Fig. 10) reaches 32 MV/m in average for individual cavity useable gradients and 29 MV/m when powered by pairs, higher than the 23.6 MV/m XFEL specification.

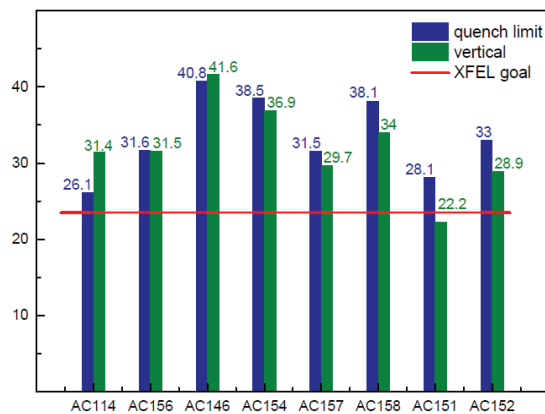


Figure 10: XM-3 RF test results (blue bars).

Seven cavities are reproducing or overcoming their individual test gradient while cavity 1 is degraded from 31 MV/m down to 23 MV/m useable gradient. Three cavities reached gradients above 38 MV/m. This successful test is qualifying CEA team and procedures and partially CEA infrastructure and industrial feasibility. The partial qualification lays in the fact that cavities and couplers are pre-industrial and the clean room vacuum system was not complete. Weldings certification would have to be reworked in order to install this module in the injector for 2014. The first phase also includes the set-up of the storage area, the ERP (entreprise resource planning) parameterization and the consumable parts ordering.

The second phase is the training of the company team attended by the CEA team on the assembly of the second and third pre-series modules (XM-2 and XM-1). XM-2 has been assembled in 18 weeks, delivered to DESY on August 8th, 2013 and is being prepared for the tests in AMTF. It is the first module being assembled with XFEL production cavities. The clean room vacuum groups were operated for the first time and CEA and Alysom team worked together. The test results will qualify 100% of the clean room tool.

XM-1 assembly by Alysom with the assistance of CEA (see Fig. 11) has started in July 2013: it is the first module being assembled with all XFEL production components.



Figure 11: CEA and Alysom team in front of XM-1 string.

The third phase covers the assembly of the 100 series CM from XM1 to XM100 by Alysom. The assembly of XM1 (see Fig. 11) started on September 2, 2013 using the last batch of TTF3 couplers. A ramp-up period of four months is foreseen to reach the production rate of 1 CM per week by January 2014. Alysom is fully in charge of the assembly whereas CEA is the expert team as well as the inspector team insuring the quality of the assembly.

The challenge to start this phase is to have a continuous supply and flow of components to feed the integration chain and to achieve continuous assembly without interruption days.

CONCLUSIONS

After tune-up and commissioning with prototype cryomodules, the XFEL village is ready for the industrial production phase and its hand-over to CEA industrial partner Alsym. The pre-series XM-3 cryomodule successful RF test provides a solid basis for the assembly transfer. The industrial production ramp-up phase has started with the assembly of the first series cryomodule XM1. The complete industrial production should span the entire 2014-2015 years unless an accelerated production scheme can be set up.

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