ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEIB04

CHALLENGES OF THE XFEL CRYOMODULE INTEGRATION AND INDUSTRY TRANSFER

F. Chastel, P. Pluvy, H. Rocipon, ALSYOM, Saclay, France

Abstract

The construction of the European XFEL Accelerator is based on in-kind contributions shared by several institutes throughout Europe and Russia. Within the French contribution, CEA is responsible for the assembly, in a dedicated facility located in Saclay, of the up to 100 cryomodules constituting the Linac. Since 2012, ALSYOM has been selected as the industrial partner for such assembly works. This presentation will detail the organization set up for this partnership and the related challenges of this transfer to Industry.

INTRODUCTION

For many years, the CEA Institute of Research into the Fundamental Laws of the Universe (IRFU) has been working, in close collaboration with DESY, on the XFEL Project, including on assembly of two prototype cryomodules.

The assembly of the up to 100 series cryomodules, with a delivery rate of one module per week, needs a dedicated workforce and hence, CEA issued, late 2011, a call for tender in order to share this task with an industrial partner.

ALSYOM, specialized in design, manufacturing and assembly of large scientific components and systems, has been selected in July 2012, and the members of the dedicated team arrived in Saclay a couple of months later. Since June 2014, the final team of approximately 29 people is operational.

A comprehensive overview of the overall cryomodules production is given in [1].

PROJECT STRUCTURE

In addition to the up to 100 cryomodules to be produced for the Linac, three more modules have already been assembled as a pre-series production for training purposes. One of these modules will also be used in the injector system. While the previous prototypes were slightly different from the series modules, these three ones were very similar to the series ones.

The first cryomodule, named XM-3, was assembled by CEA employees only. The ALSYOM team was invited to attend every single step of the assembly process without taking part in the actual assembly works.

The overall assembly of this first pre-series module was completed in 7 months, which is roughly four times the target assembly time for series production.

The next module, XM-2, was assembled by CEA engineers and technicians from CEA together with a few operators from ALSYOM who joined the team at that time. This preliminary ALSYOM team followed this module all along the assembly line, from the first steps in clean room, through the different workstations, until the final shipment. This module was completed in 4 months and a half, close to the target (during this period, the module was supposed to stay two weeks on each of the seven different workstations, instead of one week per workstation as required for series production).

The assembly of the next – and last – pre-series module, XM-1, began in late June 2013 while the previous one was being completed. This module was also assembled by both CEA and ALSYOM with a major involvement of ALSYOM operators while CEA employees completed training and backed them.

Series production started early September 2013, just one year after ALSYOM arrived in Saclay, with assembly of the cold coupler parts on cavities.

As discussed above, the pace allowed for pre-series modules was twice the series one, namely two weeks per workstation instead of one. During the beginning of the series production, the first modules, XM1 to XM7, have to be done according to a given ramp-up scenario, with an acceleration and a shift from a two weeks rate to a one week rate, starting from the last workstations up to the first ones located inside the clean room. According to this scheme, XM8 should be the first module to be produced at the nominal pace.

This Project structure, which is made of four different phases, has been chosen to allow for a long training period and a progressive increase of the production. It can be summarized as follow:

- A pre-series production:
  - XM-3 : for observation only
  - XM-2 and XM-1 for training
- A series production with
  - Ramp-up period, from XM1 to XM7
  - Nominal production rate from XM8 up to XM100

PROGRESS STATUS

In June 2014, the fifth serial cryomodule, XM5, is on the way to be delivered, and on the other end of the assembly line, XM11 has just entered the clean room. Figure 1 gives the different assembly times for the cryomodules which have been already delivered and those foreseen for the next ones.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEIB04

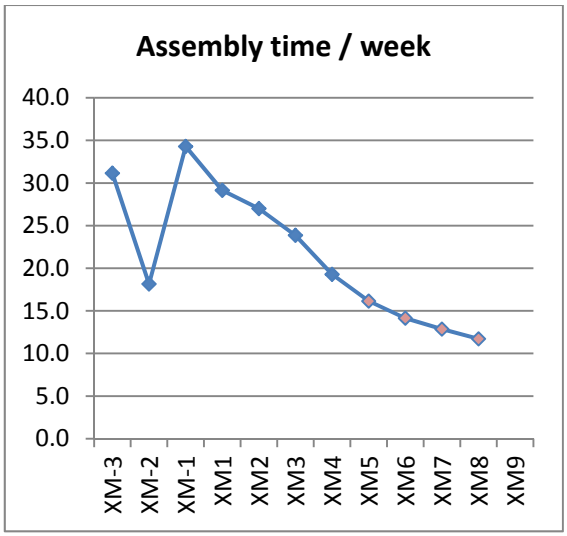

Figure 1: Assembly times for the first cryomodules.

TEAM STRUCTURE

The dedicated ALSYOM team counts 29 people, including management, support activities and production staff, including:

- vacuum technicians: leak detection, residual gas analysis, pumping units management.
- technicians specialized in all the alignment operations performed with a laser tracker.
- RF experts: cavity incoming inspection and HOM tuning.
- welders for all welding operations, including orbital welds for helium circuitry and aluminium welds for thermal shields assembly.
- controllers for all incoming inspection activities.
- clean room activity operators
- operators for all other assembly works taking place outside the clean room.

Figure 2 shows the recruitment effort performed by Alsyom to reach the project target.

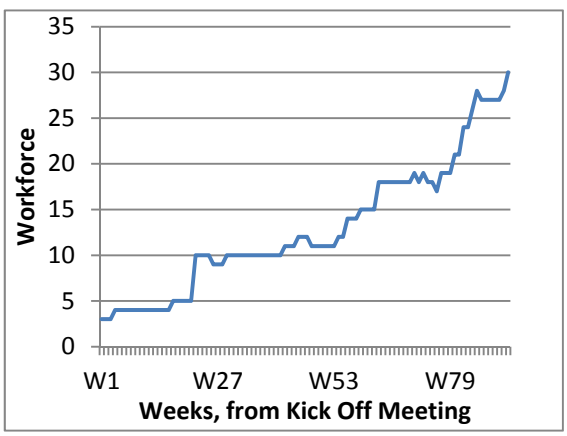

Figure 2: Workforce evolution.

WORKSHOP LAYOUT

The production line is split in seven workstations:

- WS1-CC: coupler cold part assembly on the cavities, inside the ISO4 clean room
- WS2-SA: string assembly, inside clean room
- WS3-RO: roll-out area, for string equipment and cold mass + string assembly
- WS4-AL: cavities alignment
- WS5-CA: equipped with a cantilever tool for the introduction of the cold mass and string assembly inside the vacuum vessel
- WS6-CO: warm coupler parts assembly
- WS7-SH: last operations before shipment.

All the operations to be done on a single workstation must be completed within one week, so that the module can leave and pass on the next workstation. This is a condition for a delivery rate of one module per week.

All the workstations located outside the clean room, have been doubled, excepted the cantilever which is a very large equipment (more than 25 meters long).

With such a double-line layout, the production would not be entirely stopped even if a module must stay more than one week on a workstation to solve possible problems.

TECHNICAL ISSUES

Up to now, seven cryomodules have already been delivered, and additional experience has been gained about how to handle some specific technical issues.

The XM-1 string assembly was completed in clean room by end of August 2013 and the first operations on the roll-out area started in early september 2013 with the orbital welding of the Titanium pipes of the 2-phase line. In order to fullfill all the PED requirements, these welds were X-rayed. This NDT operation showed numerous pores in the welds, some of them being unacceptable to pass PED certification. A joint analysis was carried out by DESY, CEA and ALSYOM, and the main outcomes were :

- to pay attention to the cleanliness during every step of the preparation before welding
- replacement of the longitudinal welded Titanium pipes by seamless pipes
- introduction of a different shield gas device
- changes in the welding parameters

Thanks to these changes, the welding activities has resumed successfully.

One lesson learned from this experience is that all commissioning activities, in particular NDT testings and the related requirements (in that case those linked to PED certification), have to be carefully taken into account since the beginning of the project. The X-Ray controls are carried out by a specialized company contracted by CEA. Since they have been introduced with XM-1, these X-ray tests are now mandatory for all the Titanium welds of

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEIB04

every cryomodule and it is expected to be a requirement for all the production until the last module. The results of these tests, as well as all tests related to PED certification (visual tests, penetrant tests, leak tests, configuration reports) must be verified by an Inspector from the Notified Body which is in charge of the PED certification. All these activities, which must be planned carefully, are an additional challenge for the production management of the roll-out area which is definitely the most busy workstation.

A second relevant technical issue was the improvement of the bearings assembly between the cold mass and the cavity string, in order to reinforce its reliability and the subsequent quality of the cavity string alignment.

Another technical issue of interest may be the overheating of some couplers reported from the last RF and cryogenic tests performed with XM-1 and XM1. This illustrates that, despite the numerous tests performed at Saclay all along the assembly process, the only relevant and comprehensive test with cryogenic conditions and RF power is made at DESY, a few weeks after the module has left Saclay. This is a risk at the beginning of the project when some experience is being gained from the first test results while some other modules have already been delivered.

TRAINING CHALLENGES

Team building, with recruitment of all the operators and their successive training, is the key factor for a successful transfer of knowledge to Industry on such a large scale.

As shown above, the recruitment effort was maintained since the beginning of the series production.

All the specifications for the tests and the assembly procedures must be as detailed as possible. But it is also very important to have an efficient and reliable process for recording and management of all non conformities and successive design changes. A comprehensive data management system is provided by a dedicated team from the XFEL Project. This software, namely EDMS, has been tailored to suit the needs of the different workpackages who have to share information. It is close to an industrial ERP software and it ensures a full traceability of all production and tests activities of the project, including design upgrade. More information on this topic can be found in [2].

PRODUCTION MANAGEMENT CHALLENGES

The overall assembly process is made of many different steps. Obviously, the management of so many activities is a big challenge. A correct coordination is essential to ensure a shift of the modules on the different workstations every week. In particular, all test activities as well as hold points must be performed on time to allow for a smooth progress of the module along the assembly process.

A traveler is used to record the tasks once they are finished as well as all related information, such as name of the operators, date, test report reference and comments if any. This is also usefull for training of new operators who have to understand and remember the correct sequence of all the differents tasks.

Some tasks must only be done according a well established sequence while some other operations can be done in parallel on in several different orders.

Another challenge for the workload management comes from operations that require to stop all other activities. This is true for welding operations and for laser tracker measurements. During these operations, the people who are dedicated to standard mechanical operations must shift on other activities on a different module until the welding or the laser tracker measurements are finished. Sometimes, it means that they will join other people who have already started their own operations and they will leave even if these operations are not completed. In that case, it is also very important to fill the traveler properly to ensure a correct traceability of what has been really done. This could be misleading for people who still need to be trained.

There are a few places in the process where the workload can be slightly balanced. For instance, some aluminium thermal shields can be welded either on the alignment workstation or on the cantilever workstation depending on the progress of the previous module. Another example, is the transfer of the stepping motors assembly on the couplers, from the warm coupler part workstation to the shipment workstation. This may help to complete the warm coupler parts assembly within one week while the current shipment activities can be done easily in far less than one week.

While there was nearly no overlap between the different pre-series cryomodules operations, the ramp-up period, at the beginning of the series production, has shown that all the handling and lifting operations needed for moving several modules from one workstation to the next one are time demanding and must not be underestimated.

A well-known constraint also exists between the roll-out workstation and the string assembly workstation inside the clean room as both activities share a common tool.

In the clean room, once the cold coupler part has been assembled on the cavity, the cavity is moved into the string assembly area. On this line, the cavities lay on big stands mounted on bearings rolling on a track. This system is used to make the string exit the clean room. This means that the string will lay on the same stands until it has been assembled on the cold mass and moved to the alignment area. There are two parallel tracks in the clean room. Within the nominal scenario, on week 1, module XMn is on the roll-out area on track A while the cavity string of XMn+1 is being assembled in clean room on track B. The week after, XMn+1 will go out on the roll-out area while the posts which have been used for XMn will go back in clean room for XMn+2 string assembly.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEIB04

If XMn must stay on its posts on roll-out area a few more days, there will be no posts available for XMn+2 string assembly in clean room and all the clean room activity will be blocked.

Some improvements are foreseen to help make the assembly process as smooth as possible.

For instance, a different method for string assembly has been proposed. It would consist in leaving the cavity at atmospheric pressure just after cold coupler part assembly and residual gas analysis. For the string assembly, nitrogen flushing would be made by means of a simple flexible pipe to be plugged on the cavity instead of connecting a pumping unit for venting. This topic is discussed in [3].

ACKNOWLEDGMENT

Series production of up to 100 cryomodules, with a delivery rate of one per week, is definitely a challenge. The team building and its subsequent training are critical phases for the Project and the tranfer of knowledge from research institutes to Industry needs a close collaboration between the two partners. The author would like to thank all DESY and CEA colleagues for their outstanding commitment and support.

REFERENCES

[1] H. Weise, “How to produce 100 Superconducting Modules for the European XFEL in Collaboration with Industry”, WEIB03, IPAC2014, to be published.

[2] L. Hagge et al., “Configuration Management in the Series Production of the XFEL Accelerator Modules”, THPRO006, IPAC2014, to be published.

[3] S. Berry et al., “Clean Room Integration of the European XFEL Cavity Strings”, WEPRI001, IPAC2014, to be published.