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Installation management for the European XFEL main accelerator

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Installation management for the European XFEL main accelerator

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Abstract. By end of 2016, the main accelerator of the European XFEL was completed. To build this complex machine in a minimum of time, certain management methods were introduced in mid 2015, which accelerated the installation process substantially. In the following 64 weeks additional 84 % of the main accelerator were set up. This was possible due to an improved planning, the reinforcement of two teams as well as a permanent controlling and optimizing of the installation process. In this paper, the installation process from July 2015 to end 2016 and the measures, which speeded up the workflow, are described.

1. Introduction

In the 2 km tunnel of the European XFEL, 96 superconducting accelerator modules were installed. Typically, 12 accelerator modules form a so-called cryo-string (CS), which was identical to one installation section. It is particular that no supply tunnel exists. Therefore, the accelerator modules hang from the ceiling while the RF stations, electronic racks, power and cooling water supply etc. are located below them on the ground (Figure 1, details in [1]).

The installation of all these components in one single tunnel was a complex undertaking, which was done by several expert groups of DESY and some external companies. The main tasks were split into 13 work packages (WPs):

- WP 01 – RF System
- WP 02 – LLRF System
- WP 03 – Accelerator Modules
- WP 05 – Power Couplers
- WP 08 – Cold Vacuum
- WP 13 – Cryogenics
- WP 28 – Accelerator Controls
- WP 32 – Survey & Alignment
- WP 33 – Tunnel Installation
- WP 34 – Utilities
- WP 36 – General Safety
- MDI – Cabling for some WPs
- IT – Fibre Optics and Ethernet

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At the beginning of 2015, the interaction between these WPs was not ideal. For this reason, the installation speed was not sufficient to ensure the completion in 2016. So a new installation management approach was introduced in mid 2015.

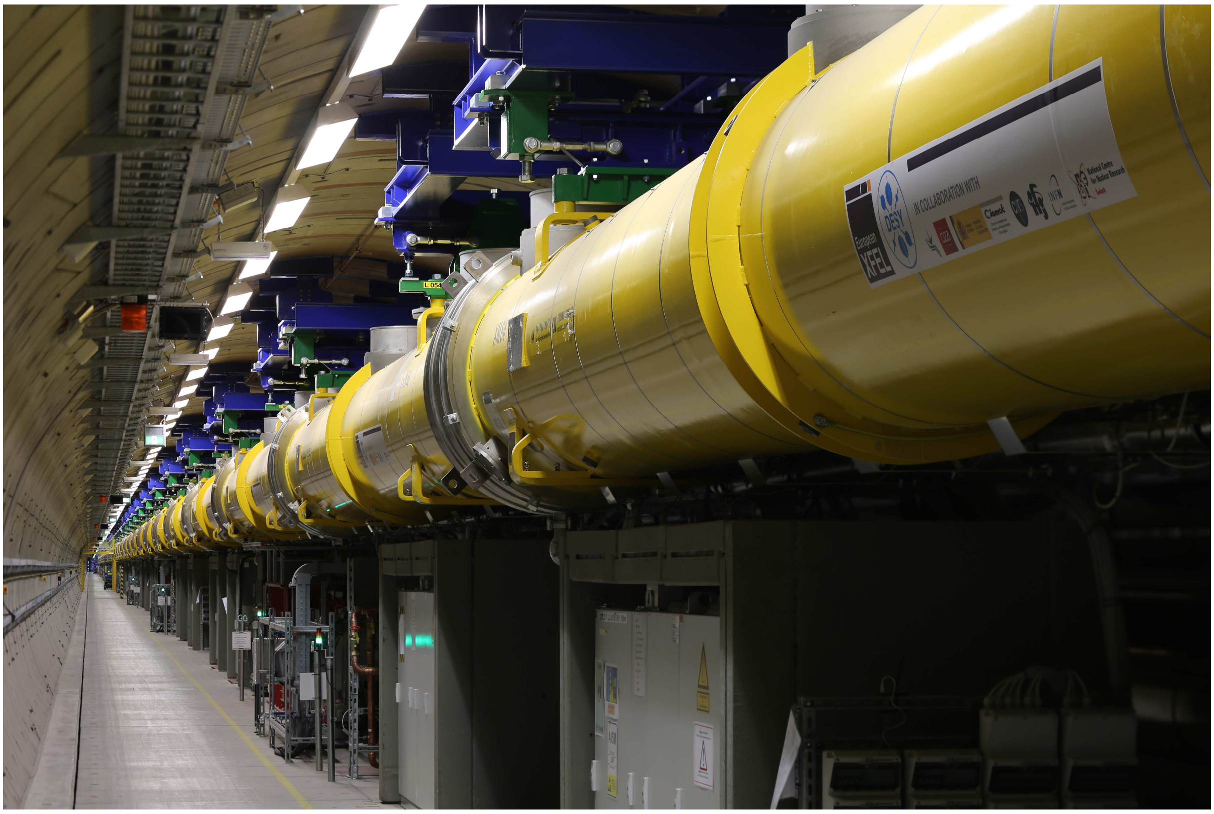

Figure 1. Completed main accelerator in one single tunnel. On top accelerator modules and cable trays. Below RF stations, electronic racks, power and water supply etc.

2. Installation Management

The installation management methods used were based on [2, 3] and included three key elements: planning, controlling, and continual improvement.

2.1. Planning

A new process plan was worked out in cooperation with all involved WP leaders in order to optimise the interaction of the WPs (scheme described in [4]). In broad outline the installation was effected as follows. First of all, 12 modules were fixed to the tunnel ceiling and their cryogenic pipes as well as the beam pipe were interconnected (Figure 2 Block „Installation of 12 Modules“). Apart from a few exceptions (e.g. positioning of klystrons and pulse transformers), all other process steps, which had to be carried out underneath the modules, were not allowed to start until the connection of the pipes and their final checks were completed. This was necessary to enable the fastest possible welding of the cryogenic pipes, which was essential for completing the whole installation process in time.

After the module installation was done, the electronic racks were brought into position and the installation of waveguides, power and water supplies started (Figure 2 „RF Stations“). Simultaneously, the “Optical Fibres” were laid. The installation of cable trays started a few days later and afterwards, cables for most of the WPs were laid (“Cable”). The “Ethernet” cable laying started three weeks later because some of the waveguides had to be installed before. After the electronic racks had been supplied with power, cooling water, Ethernet etc., some subsystems, which are necessary to operate the RF stations, were commissioned („Preparation Personnel Interlock“). Afterwards, the functionality of the personnel interlock was tested ("TÜV"). Subsequently, the remaining process steps were done and the conditioning of the RF couplers could start afterwards.

In order to meet the overall deadline in 2016, it was necessary to complete one "Installation of 12 Modules" every 8 weeks. The process analysis showed, however, that this would not be possible with the welders available at that time. Therefore it was decided to commission a second welding team. Plan # 1 came into force in July 2015.

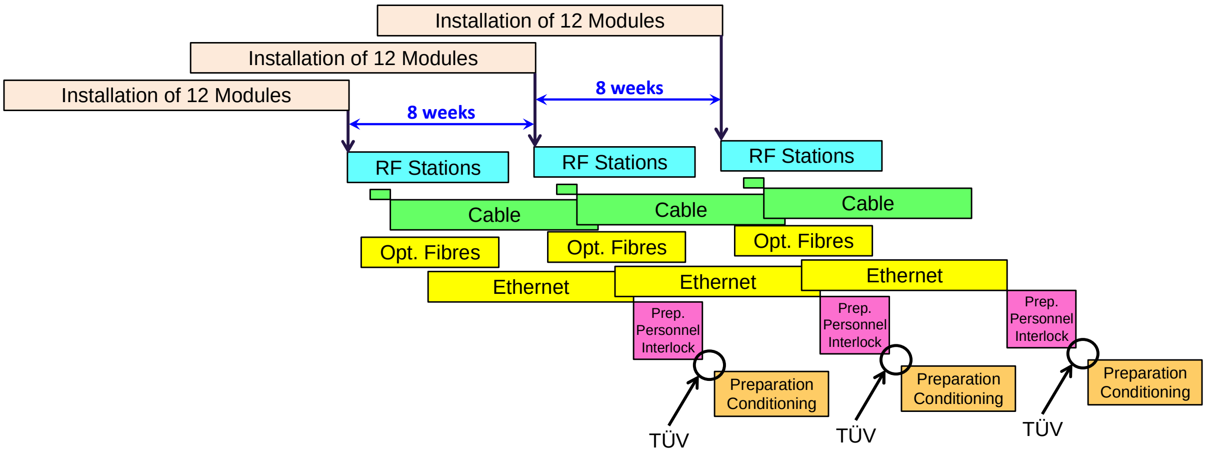

Figure 2. Original planning in mid 2015, each block represents 4 to 24 process steps.

2.2. Controlling

To control the installation process, the following four tools were used [4]:

- *Timetables* – four weeks in advance, each WP leader got a timetable when to start which process step
- *Weekly tunnel meeting* (Figure 3)
- *Daily tunnel inspections*
- *Monitoring* of the installation status

The installation status was recorded once a week. It included all installation steps with three possible states: not started, started or finished. The total number of process steps started and finished per week was used as figure of merit to indicate the installation activity and was displayed in a graph (Figure 4). The fluctuations are due to the fact that sometimes many process steps were started in the same week, e.g. after the installation of modules in one cryo-string was finished. For that reason, the trend line is a better indicator. It is correlated to the actual installation speed.

2.3. Continual Improvement

In contrast to other approaches it was assumed that the process could be speeded up permanently because of the growth of experience in the interaction of the WPs. So in the on-going installation each opportunity was caught which allowed to start a process step earlier than originally planned. In addition, the initial plan # 1 was optimized three times, from one cryo-string installation to the next.

Figure 3. Weekly meeting in the accelerator tunnel at the site of installation.

3. Actual Installation Process

On 28 July 2015, plan # 1 came into force with CS 3 (Figure 4). Despite certain deviations, plan # 1 worked well and due to the continual improvement, the personnel interlock test (Figure 4 “TÜV”) was brought forward by 15 days. So the installation management prove to be effective for CS 3. The problem at this time was that the interval between completion of “Installation of 12 Modules” in CS 3 and CS 4 was 12 instead of 8 weeks because the second welding team was not trained enough at this time for their difficult task. On the basis of the processing time measured for “RF stations + Utilities”, a decision was made to assign a second waveguide installation team in order to reduce this processing time. The success of this action can be seen in the further process. Before the “Installation of 12 Modules” in CS 4 was finished, the optimised plan # 2 became effective, which lead to a precision landing of the CS 4 personnel interlock test. However, now the duration of the cabling (“Cable”) became time-critical. As countermeasure, some cables were preassembled outside the tunnel and the work on different cryo-strings could be partly parallelized. A drawback was the increasing gap between the finalization of “Installation of 12 Modules” in CS 4 and CS 5 from 12 to 13 weeks, but afterwards it shortened to 6 weeks between CS 5 and CS 6. This lead to the breakthrough in speeding up the installation process because now it was possible to work on up to four cryo-strings at the same time.

As a result of all these measures the installation speed was increased by a factor of 10 (graph in Figure 4) and 84 % of the main accelerator were built in the period from July 2015 to October 2016.

On 11 October 2016, a pressure test of the Helium exhaust line was carried out. During this test, the line fell down on a length of 200 m and damaged the installation of CS 8 and 9. Despite the necessary repair work, the main accelerator was completed on 6 December 2016. The cool down of the superconducting accelerator modules started at 10 December 2016 and the first beam through the complete electron accelerator was reported on 23 February 2017 [5].

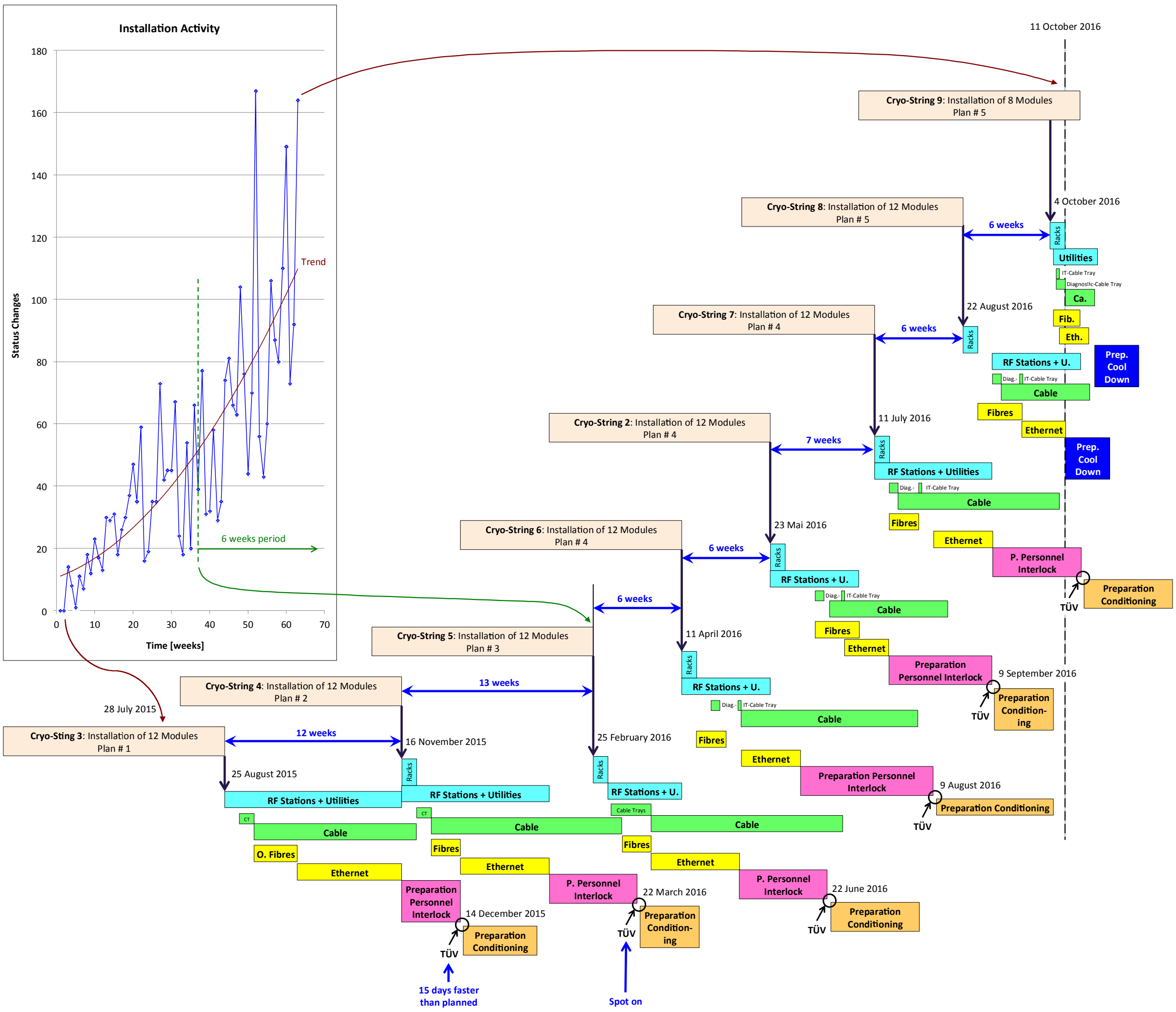

Figure 4. Installation process from July 2015, when the installation management took effect, to October 2016. In this period of just over 15 months, 84 % of the main accelerator was installed. The trend line indicates the increase of installation speed.

4. Summary

The implementation of the installation management led to an increase of the installation speed by a factor of 10. Thus the main accelerator of the European XFEL could be completed in 2016. In relation to future projects, it is fair to say that with adequate process management, the installation of such a machine can take place in 2 years.

Acknowledgments

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