LLRF COMMISSIONING OF THE EUROPEAN XFEL RF GUN AND ITS FIRST LINAC RF STATION

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Abstract

The European X-ray free electron laser (XFEL) at the Deutsches Elektronen-Synchrotron (DESY), Hamburg Germany is in its construction phase. Approximately a third of the super-conductive cryomodules have been produced and tested. The RF gun is installed since 2013; periods of commissioning are regularly scheduled between installation phases of the rest of the injector. The first linac, L1, consisting of 4 cryomodules powered by one 10 MW klystron is installed and being commissioned. This contribution reports on the installation and preparation work of the low-level radio frequency system (LLRF) to perform the commissioning of the XFEL first components. The commissioning plans, schedule and first results are presented.

INTRODUCTION

An overview of the low level radio frequency (LLRF) system for the European XFEL is given in [1], with a description of the system architecture and the functionality of its main components. Details about the Micro Telecommunication Architecture (MicroTCA.4)-based LLRF system are found in [2] while performance results evaluated in the FLASH accelerator at DESY are given in [3]. Last year, the first component of the XFEL accelerator, the RF gun, was installed in the injector building. A description of its LLRF and the first results of its commissioning are reported in [4]. This contribution reports on the next XFEL milestone, namely, the installation and commissioning of the first linac, corresponding to the first 4 cryomodules installed into the XFEL tunnel (XTL). Results observed with the first beam produced at the XFEL injector are also presented. Figure 1 gives a schematic layout of the accelerator sections of the XFEL (Ax), grouped into injector, linac 1, 2 and 3.

INSTALLATION

Tunnel Installation

All XFEL cryomodules first undergo a series of tests [5,6] performed in the accelerating module test facility (AMTF). The next step consists of installing the waveguide distribution

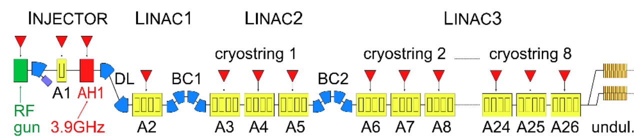

Figure 1: Layout of the XFEL linacs, separated by the dog leg (DL) and the two bunch compressors (BCs).

system, tailored according to each cavity's gradient performance [7]. The complete system (cryomodule + waveguide) is then mounted inside the tunnel, suspended to the ceiling, after which the string connection work can start. The intermodule welding connections are performed and the cryogenic feed- and end-cap at each end of the cryostring are installed. Vacuum connections are performed; the racks containing all electronics can then be placed underneath the modules.

Figure 2: Cryomodule transport into the XFEL tunnel.

The racks require individual water connection for their cooling units, connection to the mains and installation of the concrete radiation shielding, to the side and above the racks. The cabling work can then start (RF, Ethernet, interlock, vacuum, piezo, tuners, optical fiber etc...), from rack to rack and also between racks and cryomodule patch panels. The cabling work requires careful planning and sequential timing;

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numerous patch panels are required and the working space inside the tunnel is limited.

Pre-Commissioning

To minimize the working time in the tunnel and optimize the installation time, as much pre-commissioning work as possible is performed on the LLRF system before its tunnel installation. First, the LLRF components are tested individually, as part of the quality control process described in [4]. This includes random checks of the manufacturer tests, and advanced tests performed in dedicated test stands for selected devices such as the down converters or the digitizers. The MicroTCA.4 crate, Fig. 3 is then assembled with all its components (power modules, CPU, controller hub, digitizers, down converters, as well as other modules responsible for timing, radiation monitoring and machine protection). Many crucial steps are checked during this phase: the versions of all low-level hardware programs are checked and updated if needed: bios, operating system, device drivers, micro-controllers and FPGAs firmware. The front-end servers are installed and configured: watchdog, timing, LLRF controller, machine protection and diagnostics. To ensure a certain level of reproducibility and robustness, check lists were established. Although the first installation was performed fully manually, clearly some setup and configuration tasks need to be automated. Simple scripts (shell, matlab, python) will be written to ensure all parameters are properly and systematically initialized. Since individual modules are all labeled during the incoming inspection phase, the complete crate occupation, including the correct module identification numbers, is documented and saved in the database (i.e. which CPU, which down-converters are installed where, etc...)

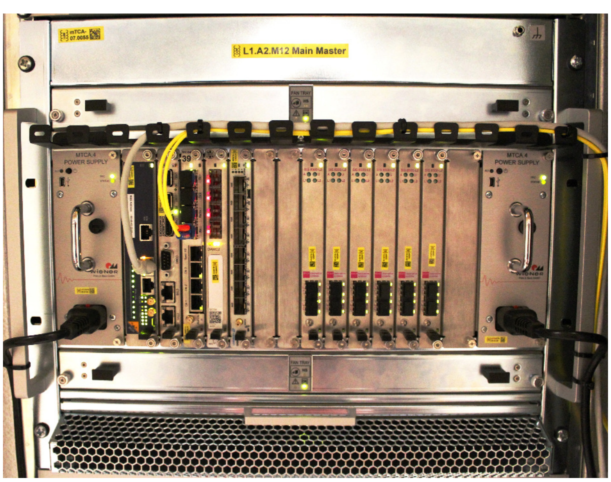

Figure 3: Linac 1, accelerating station 2, (L1.A2) LLRF master MicroTCA.4 crate, powered up and in complete configuration.

At this stage of the installation, the core of the LLRF system, the fully equipped MicroTCA.4 crate, is verified. The down-converters are getting local oscillator signals, the FPGAs are clocked, one can check the proper functionality of the vector modulator by monitoring the LLRF drive signal. A reference signal is distributed to each down-converter to verify the integrity of the RF signal path. A sign-off sheet is then released when the MicroTCA.4 installation is complete and ready for the next installation step.

The LLRF racks are prepared before the electronics can be assembled. Custom-made top patch panels, brackets for power strips, cable ducts for RF and for AC cabling are mounted, lighting, supporting rails and guides for clamping the RF cables are assembled. The electronic components can then be mounted and fixed into the LLRF racks. This includes the external power supply module (PSM), the piezo driver (PZ16M), the local oscillator and clock generation module (LOGM), the reference distribution module (REFM) and the drift compensation module (DCM). The next step consists of performing the inner-rack cabling. This crucial step is outsourced to an external company. To ensure proper cooling of the racks, blank panels are mounted in the unoccupied slots. The racks can be temporarily powered to perform an integral test. A reference signal is injected in place of the cavity forward, reflected and transmitted signals, at the patch panel at the top of the rack and the corresponding signal is monitored on the user graphical interface. This step guarantees the integrity of the complete signal chain, from rack patch panel to the corresponding digitized channel. After this final system validation, the racks are ready to be transported and installed into the tunnel.

COMMISSIONING

Before the commissioning can start, the permission to safely operate an accelerating station has to be granted by the official authority, namely the German *Technischer Überwachungsverein* (TÜV). During this validation phase, the emergency shutdown, personnel and technical interlock are demonstrated in front of TÜV inspectors. The coupler processing interlock module (CPIM), which is part of the LLRF system needs to be approved during this step. The CPIM is a narrow bandwidth (300 kHz) bandpass filter, centered around 1.3 GHz and placed at the output of the LLRF system, before the high-power RF chain. This device ensures that the RF cavities cannot be accidentally excited at their room temperature resonance frequencies during the coupler warm conditioning phase. Both the filter characteristics and the interlock mechanism preventing RF operation if the filter is bypassed are checked.

Although the cryomodules are still at room temperature, many parameters can be checked to identify problems as early as possible and to minimize the LLRF system commissioning time after cool-down. The following settings and system features need to be checked: the RF power level distributed from the master oscillator into the RF station is measured and compared against the estimated cable attenuation; the optical communication between master and slave LLRF subsystems is established; the piezo sensor connectivity is checked; the RF gating and the interlock mechanism from the machine protection system are verified; the $8\pi/9$ filter

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parameters (center frequency and bandwidth) are configured according to the data acquired during cryomodule tests in AMTF. A first power calibration is performed, based on a power meter measurement at the output of the klystron arms and the measured attenuation of the waveguide distribution. The LLRF can then be calibrated to display power signals to scale with a precision of 10-15%. This rough calibration is useful for coupler reconditioning. The final calibration can only take place with beam, during cold conditioning.

OUTLOOK

Schedule

The first RF station, L1.A2, is now undergoing its commissioning. In parallel, the cryogenic and vacuum connections for the first 12 modules of the third linac, L3.A6, A7 and A8 are performed. In the current schedule, the commissioning of this cryostring will take place in early summer 2015. Valuable experience was acquired during the installation and commissioning of L1; the tasks are now largely optimized and one should expect an increased pace for the next modules. The current plan is to continue with the installation and commissioning of RF stations in L3 until the last quarter of 2015. Then, the second linac L2 will be completed and the bunch compressor sections connected. The rest of L3 will then be installed up to the tunnel closure, scheduled for June 2016. In parallel, the focus will shift to the injector, with the installation of the first accelerating module A1 in June 2015, followed by the third harmonic module AH1 in August-September 2015. The injector cool down and cold commissioning is then planned to start before the end of this year.

Installation During Commissioning

Due to the nature of the project and the time constraints, commissioning of RF stations needs to take place at the same time as installation work is performed. This implies numerous complications and interruptions of the work flow which are really becoming obvious at this phase of the tunnel installation. The circulation inside the tunnel is regulated by means of traffic light and schedule coordination. Green/red lights indicate if a given RF station is being conditioned; cryomodule transport and work in the close vicinity is not allowed during these times. When possible, the automated coupler reconditioning is also scheduled after regular working hours. As can be seen in Fig. 2, the available space next to the installed modules and racks is very limited. During component transport (beamline, girders, modules, scaffoldings, etc...), the path must be kept clear of instruments, tool boxes and other equipment typically required for in-situ installation or troubleshooting work.

The third linac L3 stretches from 500m until 1.5km into the tunnel. Due to the long distances, the use of bicycles with trailers becomes a necessity. Furthermore, due to fire hazards and the large distance between emergency exits (2km), it is now required to carry a personal oxygen pack to access the tunnel. As a consequence, access to the racks and electronics during commissioning must be kept to a minimum and carefully planned.

As a preliminary and encouraging commissioning result, the first accelerated beam in the XFEL injector is shown in Fig. 4. The beam corresponds to 20 bunches, 2 nC charge, at a repetition rate of 10 Hz. More results are to be reported during injector commissioning, in late 2015.

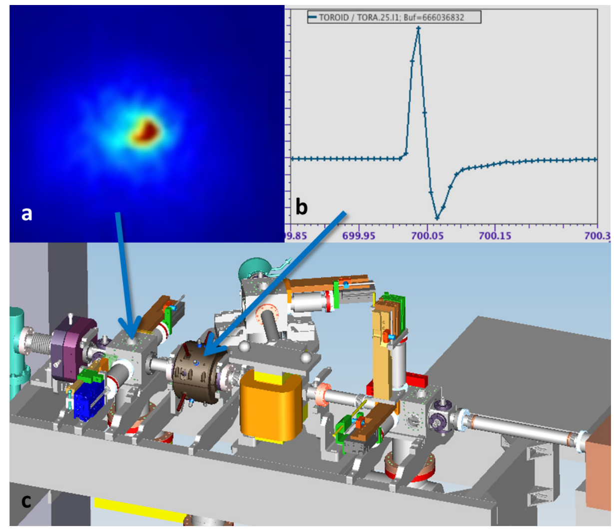

Figure 4: First accelerated photo electrons in the European XFEL (a), detected charge measurement at the toroid (b), as shown in the beam line (c).

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