COMMISSIONING OF THE EUROPEAN XFEL INJECTOR

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Abstract

The European XFEL Injector consists of an L-Band RF photoinjector, a TESLA type 1.3 GHz module, a 3rd harmonic RF section, a laser heater and an extensive diagnostic section to determine projected and slice properties of the beam. The commissioning of the complete system has been started in December 2015 after several years of construction. We will report on commissioning results and perspectives for the later XFEL operation.

THE EUROPEAN XFEL FACILITY

The European XFEL is under construction in the Hamburg region, Germany. It will provide FEL radiation in the range from 260 eV up to 24 keV out of three undulator sections that can be operated simultaneously with 600 µs long bunch trains with 2700 bunches each, which are produced with a repetition rate of 10 Hz. The FEL is driven by a 17.5 GeV linear accelerator based on TESLA-type superconducting accelerator modules.

The European XFEL is being realized as a joint effort of many partners. Eleven countries (Denmark, France, Germany, Hungary, Italy, Poland, Russia, Slovakia, Spain, Sweden, and Switzerland) agreed on the foundation of an independent research organization – the European XFEL GmbH which cooperates closely with the research centre DESY and other organizations worldwide.

The contributing partners are CNRS/IN2P3 (Orsay, France), CEA/IRFU (Saclay, France), DESY (Hamburg, Germany), INFN (Milano, Italy), NCBJ (Świerk, Poland), WUT (Wrocław, Poland), IFJ-PAN (Kraków, Poland), IHEP (Protvino, Russia), NIIEFA (St. Petersburg, Russia), BINP (Novosibirsk, Russia), INR (Moscow, Russia), CIEMAT (Madrid, Spain), UPM (Madrid, Spain), SU (Stockholm, Sweden), UU (Uppsala, Sweden), PSI (Villigen, Switzerland).

Construction of the European XFEL started in early 2009; the commissioning of the completed linear accelerator is planned to start at the end of 2016.

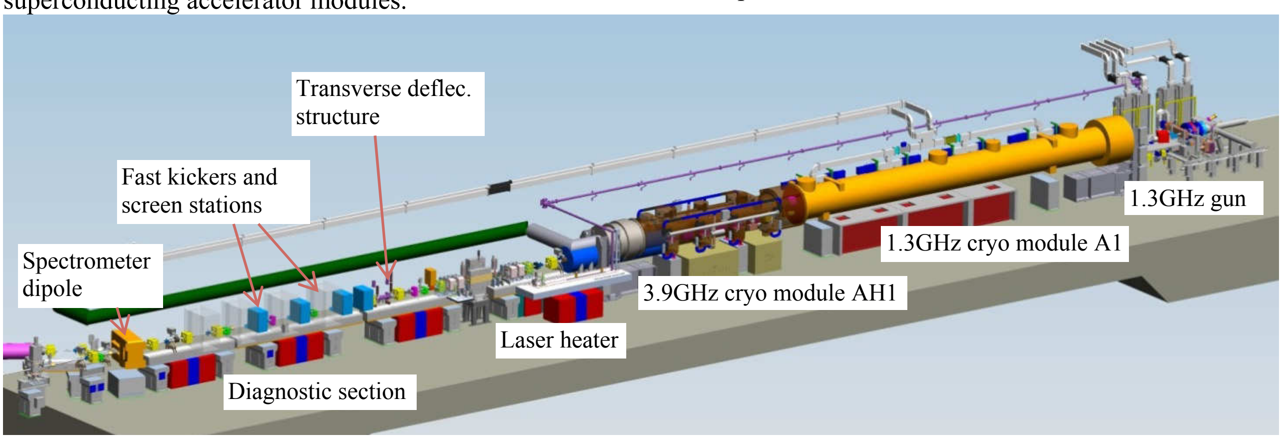

Figure 1: Model of the E-XFEL injector. The beam starts at the gun on the right and is presently stopped in the injector beam dump on the left.

THE INJECTOR

The XFEL Injector consists of a 43 m long beamline which will deliver the electron bunches for the European XFEL (see Fig. 1).

The starting point is a 1.5 cavity L-Band Photocathode RF-gun which is from the same type also serving as the electron source for the FLASH Linac at DESY [1]. The gun has been conditioned and characterized at PITZ [2,5]. The challenge is the combination of the high gradient of 50-60 MV/m and the long pulse length of 650 µs. First gun tests at E-XFEL already started during some weeks in 2014 and 2015 with the opportunity to begin the commissioning of a small but representative part of the system with the diagnostics, timing, high power and low level RF and the gun laser in the gun region. Presently the gun is continuously running with full bunch length and a gradient of 53 MV/m.

The bunches are extracted from a Cs_2Te [3] cathode by UV-laser pulses of several µJ at 257 nm. The laser system, build by MBI, Berlin, is running very reliable. Several diagnostic systems enable the online measurement and stabilization of the pulse energy along the pulse train and the position of the laser on the cathode.

The normal conducting gun is driven by an RF-station identical to the ones used for the SC-1.3 GHz RF-modules. The momentum of the electrons reaches up to 6 MeV/c within the gun before they enter the first SC-module, which is of the standard XFEL type and increases the momentum to about 130 MeV/c. In addition there is

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the superconducting 3rd harmonic module to manipulate the longitudinal phase space of the bunches [7,20]. The main purpose is to linearize the energy profile and to improve the bunch compression in order to reach the bunch length and high peak current necessary to start the SASE process.

The second half of the injector allows the measurement of all relevant beam parameters, namely the charge, the trajectory and the timing of the beam. In addition different screen stations have been added which allow the investigation of the optics and the beam emittance[4].

A transverse deflecting structure and a laser heater [6] are installed and will be commissioned soon.

At the end a 30° dipole is used to send the beam into a local dump, which allows the stand alone operation of the injector over the full parameter range while the installation of the main linac proceeds.

THE INJECTOR COMMISSIONING

Table 1: Main Parameters of the Injector

	goal	unit
charge p.bunch	0.02 – 1.0	nC
train length	1 - 2700	bunches
RF flat top	600	µs
momentum	130	MeV/c
pulse length	20	ps
slice emittance	<1	mm mrad

The complete injector beamline was closed for the first time end of November 2016. On Dec. 9th the cool down of the injector started. On Dec 14th the injector modules were stable at 2 Kelvin and the tuning of cold cavities started. On the Dec. 18th the SC-1.3 GHz module (A1) accelerated beam for the first time and within about one hour the first bunches with 0.5 nC charge reached the dump. The charge and position diagnostics worked very well right from the beginning. We clearly could profit from component tests at FLASH and the previous beam commissioning of the components during the stand alone operation of the gun in 2014 and 2015.

The Cold Modules

Once the beam operation was established both cold modules were commissioned with beam. The RF signals from the directional couplers were calibrated and the loaded quality factor was adjusted to 4.6E6 for all 8 cavities of A1. Simultaneously the cavities were phased to the beam with the LLRF system[16].

Shortly after the A1 also the 3.9 GHz module was commissioned. Due to delays in the delivery there was no time to test this module in the cold state in advance. Therefore it was even more important to see that also this module is working as expected. The achieved cavity gradient of 17 MV/m is well above the needed amplitude of 7-10 MV/m [8].

The purpose of this module is to linearize the longitudinal phase space. The effect can be seen on a screen in the dispersive dump beamline (see Fig. 2)

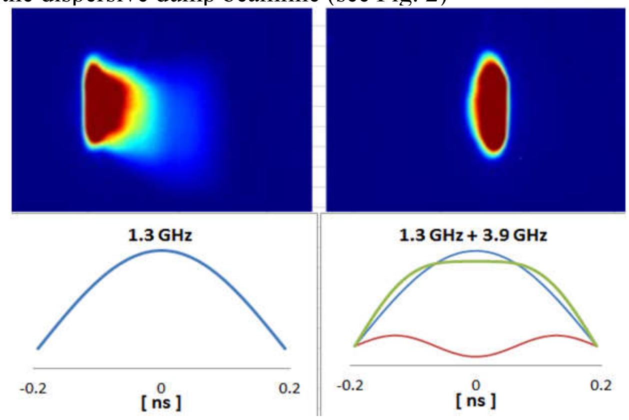

Figure 2: Picture of the beam in the dump beam line showing the reduction in energy spread. On the left the 3.9 GHz module is off – on the right it is set to 16 MV and 180° in phase w.r.t. the A1 module.

Standard Diagnostics

A challenge for the position and charge measurements (see Fig. 3) is the large range of bunch charges from 20-1000 pC [9]. It could be shown that this was very successful. The reached resolutions are summarized in the following table, they are measured for each bunch in the bunch train:

Table 2: Resolution of the Diagnostics

	at 20 pC	at 500 pC
button BPM	10 µm	5 µm
cavity BPM	10 µm	2 µm
re-entrant BPM	50 µm	5 µm
Toroid	0.3 pC	0.3 pC

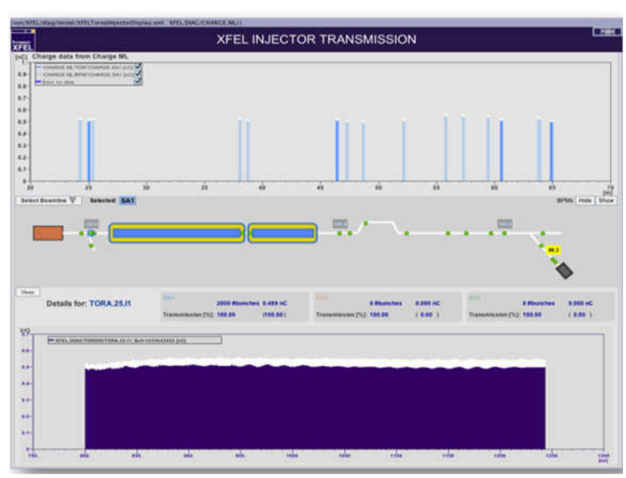

Figure 3: Display of the transmission along the injector and the charge along the bunch train of 2000 bunches.

Cryo Plant

Part of the commissioning was also the first operation of the XFEL cryo plant which is using parts of the former HERA plant which were overhauled and completed with

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cold compressors to reach the needed 2 K Helium. Since December the injector modules are at the 2 K level with only short disturbances, which are caused mainly by the cold compressors which are a newly developed system and where the reliability still has to be improved.

Control System

The working horse of the front end electronics is the new developed MTCA.4 standard. [10]

The operation of the XFEL is based on an heterogeneous controls infrastructure [14, 18]. The underlying control systems are DOOCS [11] and TINE [12] plus EPICS for the cryogenics and Karabo[22] for the photon diagnostics. In addition, a high level controls layer makes sure that as many machine parameters as possible are set in physically meaningful units, hiding the underlying technical implementation [13].

The operation of the machine relies heavily on a set of configurable multi-purpose tools. JDDD, the Java DOOCS Data Display [19], allows the deployment of powerful graphical control interfaces with a minimum of effort. Other tools have been commissioned for the automatization of data recording, scans, correlation studies, system checks, and arbitrary command sequences such as starting up and shutting down the injector with all its subsystems.

More specialized high-level applications are needed for certain measurements and have been commissioned with beam for RF phasing, trajectory control and dispersion correction.

Emittance Measurements

A big part of the injector commissioning is focused on emittance studies and optimization. For this purpose 4 screen stations have been installed within a regular FODO section. The beam shapes allow to match the optics [15] and to measure the transverse beam emittance. In combination with the TDS also the longitudinal bunch profile and slice emittances are accessible. Three measurement methods have been implemented in separate tools:

- 4-screen on-axis: The four screens are successively moved in and out of the beam path. This method takes about 3 min. and is restricted to trains of a few bunches only (Fig. 4).
- 4-screen off-axis: Single bunches are deflected onto four off-axis screens with fast kicker magnets. This measurement takes about 5-10 seconds and can be performed for each bunch out of the bunch train, making an emittance scan over the bunch train possible for the first time.
- Quadrupole scan: This third method, implemented by colleagues from FERMI, varies the strength of a single quadrupole while measuring the beam size on a single on-axis screen.

The measurements are in good agreement to about 10-15 % in terms of emittance.

The best projected emittances so far at the standard bunch charge of 0.5 nC measured are about 1.2 mm mrad. The influence of the RF-amplitudes of the modules is one of the topics presently under investigation as well as the development of the emittances along the bunch train.

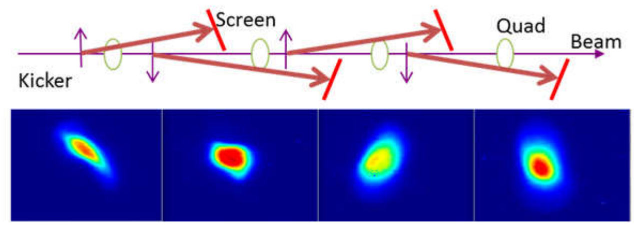

Figure 4: Scheme of the off axis emittance measurement with pictures of a sample measurement.

Outlook

Presently the last two critical devices are under commissioning. The transverse deflecting system consists of a 550 mm long 3 GHz RF structure, able to streak individual bunches out of the train vertically. These bunches will be kicked to the off axis screens to examine the longitudinal profile and slice emittance of the bunch. This will be a most valuable device for a better understanding of the dynamics within the bunches.

The laser heater uses an IR-laser which overlaps with the beam inside a wiggler to moderately increase the energy width to avoid possible micro bunch instabilities [6, 21].

The injector commissioning will proceed until end of July, when the cryogenic system will be completed for the cool down of the complete linac at the end of September 2016.

ACKNOWLEDGEMENTS

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