STATUS OF THE STANDARD DIAGNOSTIC SYSTEMS OF THE EUROPEAN XFEL

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Abstract

The European XFEL, an X-ray free-electron-laser user facility based on a 17.5 GeV superconducting linac, is currently under construction close to the DESY site at Hamburg. DESY is in charge of the construction of the accelerator. This contribution will report the status of the standard diagnostic systems of this facility. The design phase has finished for all main systems; most of the components are in production or are already produced. This paper will show details of the main systems, their installation issues and will report on the further time schedule. Furthermore, the preparation of the commissioning of the RF gun with beam will be presented.

INTRODUCTION

The European XFEL facility (E-XFEL) is currently under construction in Hamburg [1]. The facility is organized and will be operated as an international company with shares hold by the countries participating in the construction, either with cash or in-kind contributions. DESY acting for the German Ministry of Science and Education is the biggest shareholder of this company, and is taking the leadership of the Accelerator Construction Consortium, that is in charge to build and operate the accelerator.

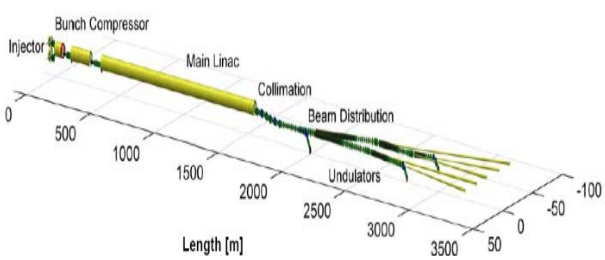


Figure 1: Layout of E-XFEL.

The core of the facility is the 17.5 GeV superconducting accelerator, able to supply up to 5 undulator systems with electrons simultaneously. The corresponding 5 photon beamlines transport the radiation into an experimental hall, with a distance of about 3.3 km to the gun (Fig.1). The overall facility will be installed in a tunnel system at an underground level between 28 and 7 m. Due to superconducting RF the machine is able to run long RF pulses at a repetition rate of 10 Hz each containing up to 2700 bunches. The beam distribution within the bunch train is enabled by a fast kicker septum system, capable to split the long bunch train into two sub-trains. Arbitrary bunch patterns out of this sub-trains are possible using a beam dump kicker to kick out bunches not requested by the users. This scheme was very recently successfully demonstrated at the FLASH facility with the first lasing of the FLASH2 beamline, simultaneously while FLASH was continuing to provide long bunch SASE delivery for users [2]. The electron beams are then send to X-ray SASE Undulator systems of up to 200 m length to produce intense photon pulses down to 0.5 Å at mJ level. One of the two main beamlines provides 2 SASE undulators for hard and soft X-ray production in a sequence, the other starts with only a hard X-ray system and has the option to be upgraded either with spontaneous radiation sources for hard X-rays or with soft X-ray laser sources. Due to the installation in a tunnel, all the electronics has to be installed close to the machine. Racks shielded by about 20 cm of heavy concrete will be used.

The project is now entering the installation phase [3]. All underground buildings are completed and the technical infrastructure is almost finished. The first of the 101 accelerator modules is installed in the tunnel. About 10 more are currently under test at the Accelerator Module Test Facility (AMTF) at DESY. Newly assembled modules are coming almost every week from the assembly facility at CEA, Saclay. Concerning the installation of the warm beamline, the assembly of the girder systems for the injector and bunch compressor sections has started.

The project time schedule foresees, to continue commissioning of the RF gun system this fall, to complete the injector and start commissioning in late spring 2015, the main accelerator should be completed about 1 year later, so that commissioning can start in summer 2016. The goal to get first photons is set to the end of 2016 and first lasing to spring 2017. First user operation with some relaxed operation parameters should be possible about 1 year after the start of the commissioning.

The work package of standard diagnostics is taking care of all systems needed as standard tools in bigger quantities, as described in Table 1. More special monitors, usually for longitudinal diagnostics are within the scope of the special diagnostics work package. In the standard diagnostics work package, the systems are either provided by DESY as the main contributor or as projects with in-kind contributions from PSI, CEA or IHEP Protvino. PSI, CEA and DESY are providing the BPM system as a collaborative effort [4], and IHEP has delivered the mechanical components of the BLM system [5]. In general the status of the different systems is advanced and within the current global time schedule. Therefore, also the diagnostics have entered the installation phase, details

ISBN 978-3-95450-141-0

on each system and on the different machine sections will be given in the following chapters.

DIAGNOSTIC SUB-SYSTEMS

Since the E-XFEL is based on a superconducting linac, all vacuum systems close to the cavities have to fulfil Class 100 or ISO 5 cleanliness requirements. Therefore, cleaning and assembly of all parts in general takes place in clean rooms. Components used inside the cryo-modules have even to be cleaned to Class 10 or ISO 4 specifications (Fig.2).

Figure 2: Assembly of button BPMs in cleanroom environment.

The control system standard of E-XFEL is µTCA.4. Therefore, most of the electronic developments are based on MTCA.4[6].

Table 1: Overview on Diagnostic Devices

Device	Injector	Main Linac	SASE Lines
Cold BPMs*	2	100	
Button BPMs	11	104	111
Cavity BPMs 10 mm			103
Cavity BPMs 40.5 mm	3	18	5
Toroids	4	17	15
Dark Current Monitors	2	7	
Faraday Cups	3		
Simple Screens (45°)	6	4	4
Screens	1	26	16
Off Axis Screens	4	8	
Wire Scanners		3	9
Beam Loss Monitors	8	92	250
Dosimetry Sensors	10	200	500

* 31 Reentrant Cavity BPMs, 71 Cold Button BPMs

BPM System

The BPM system for E-XFEL is an in-kind contribution of the BPM collaboration by PSI, CEA and DESY. DESY is in charge of the BPM RF-pickups, except the re-entrant cavity BPM. CEA provides the re-entrant cavity BPMs together with the corresponding RF front end electronics[7]. PSI takes care of the entire electronics - RF front ends and digital back ends - except the re-entrant cavity BPMs [4].

The button BPM is the working horse of the E-XFEL. Two different types of buttons are used. One with a button diameter of 20 mm has a very robust design and was designed for applications in the cryogenic environment [8]. Extensive tests at liquid helium temperature have proven the robustness of this feedthrough design. Flat flanges for diamond edge aluminium gaskets are used to be compatible with the flange system of the E-XFEL cryo-modules. The BPM body with 78 mm diameter and 170 mm length (Fig.3) has the same external interfaces to the module as the re-entrant cavity BPM, so that both fit to the module design. Alignment of the cold BPMs to the vessel of the module´s superconducting quadrupole is done by means of dowel pins. BPMs of both types are routinely assembled to “BPM quadrupole units” About 20 of them are already delivered to CEA for module production.

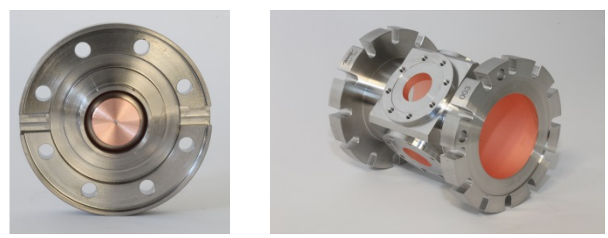


Figure 3: Cold button BPM: Feedthrough and body.

The second feedthrough type with 16 mm buttons was optimized to provide high signal levels, in order to face the challenge of low charge operation [9]. It is used in all warm button BPMs with different beam pipe diameters from the standard 40.5 mm beam pipe to the dump lines with a diameter of 200 mm (Fig. 4). The BPMs are rotated by 45° around the beam axis, so that no synchrotron radiation should hit the buttons. All feedthroughs are delivered. The production of the bodies of all warm button BPMs was done in-house. Cleaning, assembly and final vacuum checks are done on demand. Several BPMs are already installed in the tunnel.

Figure 4: “Warm” button BPM components.

Beam tests at FLASH and the PSI test accelerator using the BPM electronics from PSI have demonstrated a

ISBN 978-3-95450-141-0

resolution of 30 µm for the cold button and 11 µm for the standard 40.5 mm BPM at 20 pC. Within the nominal charge range of E-XFEL (0.1-1 nC) the resolution is 5 µm (cold) and 3 µm for the warm button BPMs [10].

For the warm beamlines also 2 types of cavity BPMs have been designed and built [11]. Both types work at a frequency of 3.3 GHz. The material is stainless steel resulting in a rather low Q of about 70. This design was chosen to be able to cleanly separate the signals at bunch repetition frequencies up to 4.5 MHz. Both types will use the same electronics provided by PSI. The 40.5 mm cavity BPMs type shown on a injector girder in Fig. 5, will also be part of the fast transverse intra bunchtrain feedback of the E-XFEL, which will be provided by PSI as an in-kind contribution [12].

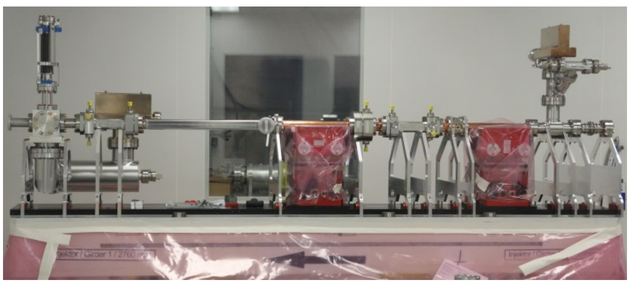


Figure 5: XFEL girder with two 40.5 mm cavity BPMs during assembly in the clean room.

The BPM for the 10 mm beam pipe, designed for the Undulator sections, is much more compact, since crosstalk between reference and dipole cavity is much smaller. A part of the production of the 140 BPMs is installed in the FLASH2 beamline (Fig.6), and has already been commissioned there [13, 14].

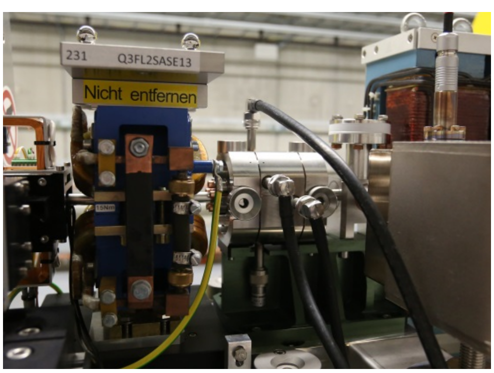


Figure 6: XFEL cavity BPM of the Undulator type installed in an Undulator intersection of the FLASH2 beamline.

Close collaboration with industry and QA actions including RF measurements at the manufacturers´ site resulted in a series production of 140 BPMs of the 10 mm type and 30 BPMs with a beam pipe diameter of 40.5 mm, all within the specification [11].

Measurements at FLASH, FLASH2 and the PSI test injector showed that the resolution of the 10 mm type is about 0.5 µm and for the 40.5 mm type about 1 µm in the standard operational range of 0.1 to 1nC of the E-XFEL. Even at a charge as low as 2 pC a resolution of 11 µm was measured for the undulator type BPM [15].

Charge Measurements

Apart from of faraday cups in gun region, the E-XFEL will use standard DESY toroids and dark current monitors [16] for charge measurements.

The main charge monitor system of E-XFEL is based on the so called toroids, DESY´s standard AC current transformers used in all transfer lines and also at the FLASH facility. Beside the refinement of the front-end electronics like development of a new amplifier and adding a test pulse generator, the main development step was to go to µTCA. The design includes online bunch by bunch data processing in an FPGA and fast digital data links. The fast communication links allow to use two toroid stations for low latency transmission validation, and can also be used for communication to other customers like laser controls or low level RF system. Furthermore bunch pattern validation and detection of too high charge is provided by bunch by bunch FPGA processing. Interlocks detected by the toroids are reported by a special low latency interface to the machine protection system [17].

X-FEL uses 36 of these devices, always located at the beginning and end of a logical section of the machine and at all the branches. The vacuum hardware ready for installation, the front-end is being built while the back-end is in the final development phase.

The dark current monitors are based on 1.3 GHz stainless steel cavities. They use the pile up resulting from summing up the signals coming from the low charged dark current buckets coming in phase at the RF repetition rate of 1.3 GHz. This scheme allows the detection of dark currents in the nA range. In addition, also the signal of the regular bunches can be seen, so that charge measurements with some fC resolution are possible. 9 of these monitors will be installed, the resonators are available; the series production of the electronics will finish in fall this year.

Beam Size Measurements

Due to the compressed bunches X-ray FELs very easily run into the problem of coherent radiation emission from screens, the so called COTR. Furthermore, the E-XFEL will use long bunch trains with up to 2700 bunches per train. These two requirements together with the need of 10 µm resolution for the screens was the driver for the beam size measurement system, using scintillating screens and (fast) wire scanners.

The high resolution screens have the LYSO:Ce target oriented perpendicular to the beam axis, so that COTR will be reflected back into the beam pipe [18]. The camera is looking to the scintillating light from the screen under an angle of 45°. Using the Scheimpflug principle the field of depth is extended almost over the entire screen. 1:1 magnification together with a large chip CCD camera gives a field of view of 12.9 mm x 9.6 mm. The

ISBN 978-3-95450-141-0

screen holder allows to place up to 2 targets and a calibration screen, one of the screens can be an off axis screen, allowing to kick single bunches out of the long train to this target. The system was successfully tested at FLASH, and is now also in use at the FLASH2 beamline (Fig.7).

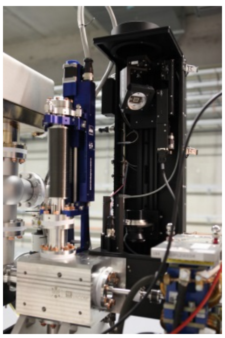
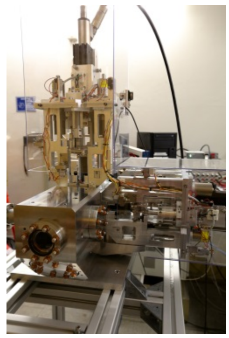
a)  b) 

Figure 7: E-XFEL screen station and wire scanner.

a) Screen station installed in FLASH2 with the optics box opened. One can see the lens and the camera in Scheimpflug configuration.
b) Wire scanner with horizontal and vertical scanner in the vacuum chamber. The ports in front of the scanner are used to install a screen system like the one shown in part a) of the figure

In addition E-XFEL will have 4 wire-scanner systems, each consisting of 3 stations, so that emittance and twiss parameters can be measured without touching the magnets. Each station consists of one fast scanner for the horizontal and one for the vertical plane. The scanners are driven by linear motors and move on trigger within 800 µs and 1 m/s speed through the beam (slow scans are also possible). The wire should withstand 100 bunches at 1 nC, so that fast scans are always possible The mechanics of the scanners is in production, and the µTCA based electronics is in the final development phase [19].

Figure 8: Pair of type X-FEL type BLMs installed in the FLASH2 beamline.

Beam Loss Monitoring and Dosimetry

With an average beam power of up to 600 kW CW, E-XFEL has to have an effective protection against beam loss, in order to avoid damage and to keep activation to reasonable low limits. Therefore about 350 beam loss monitors [5] and a network of about 700 dosimetry sensors will be installed [20].

The BLM system is based on the classical scheme using scintillators read out by PMTs (Fig.8). Two types, plastic scintillators and quartz rods, detecting Cherenkov light are used. The signals from 8 BLMs are digitized on a µTCA rear transition module and are then processed in a FPGA on the AMC backend on a bunch by bunch time scale. If different interlock conditions are violated, a signal is issued to the machine protection system. Beside of the single bunch, few bunch and integral loss alarms processed in the FPGA, a fast single bunch alarm based on an analogue comparator is also included. The latency of the BLMs is few ns for the analogue channels and some 100 ns for the alarms processed in the FPGA.

The dosimetry system [20] will be based on RadFet sensors. It consists of internal sensors, positioned on a special FMC carrier board on other electronics, like the µTCA AMC boards of the machine protection system or in the BPM crates of EXFEL. These sensors will be at the same position like “other” electronics, and therefore will deliver a dose map of the electronic racks. The FMC carrier has a field bus interface to the outside. It allows to connect outside sensors via the so called “Dosibox”. Several of these boxes can be connected to a bus line, each connecting to up to 4 sensors. Cable lengths up to 20 m are possible. These external sensors will be place at critical devices like the undulators. From the point of sensitivity two ranges will be covered, for low dose regions inside the shielding of the electronic racks the sensitivity will be in the mGy range, while the external sensors will work with some Gy resolution. For a future upgrade, the possibility to include neutron sensors is foreseen in the design.

ACCELERATOR INSTALLATION

Currently the installation of the technical infrastructure is almost finished, but the injector and the main accelerator tunnel are ready for the installation of accelerator components. Fig. 9 shows the first accelerator module, which was recently installed in the tunnel.

Figure 9: First E-XFEL accelerator module installed in the tunnel.

ISBN 978-3-95450-141-0

In the injector building, the RF gun with the warm beamline between the gun and the first module is installed and the commissioning has started in September 2014. This first about 1.5 m long beamline, shown in Fig. 10, contains BPMs, screens, charge and dark current monitors.

The remaining warm beamline in the injector is currently being installed. The next step will be the assembly of the girder system for the bunch compressors.

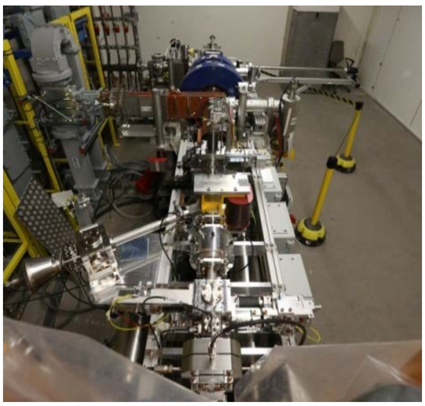


Figure 10: RF gun with first about 1.5 m long beamline installed in the injector building.

TIME SCHEDULE

After completion of the cryogenic infrastructure of the injector and the availability of the 3.9 GHz third harmonic structure the injector will start operation in late spring 2015. There will be about one year time for intensive commissioning of the injector. The goal is, to have the full range of operation parameters from the injector available after this time. Since almost all devices are used in the injector this intense commissioning process covers also most of the diagnostics. In mid-2016 the installation of the entire facility will be finished, and cool down of the linac will start. First photons should be possible by the end of 2016, and lasing in the X-ray regime is scheduled for spring 2016.

CONCLUSION

The diagnostic system for E-XFEL is well on track. The vacuum hardware is produced and ready for installation. The electronics systems are close to production. Even if the start-up of the complete facility is still two years ahead the commissioning work already has started, since cavity BPMs, screens, BLMs and toroids of the E-XFEL type are part of the FLASH2 beamline and have been commissioned there [13,14]. Furthermore, the E-XFEL injector has started the operation of the RF gun. After studies with RF only, production of photoelectrons will follow within the next weeks.

ACKNOWLEDGMENT

This paper gives an overview over the work done within the standard diagnostic work package. Therefore it represents the contributions of many people of the project team. The author would like to thank all contributors to this work package as well as all people in the E-XFEL project helping to get the entire machine ready for installation and commissioning.

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ISBN 978-3-95450-141-0