ELECTRON BEAM DIAGNOSTICS FOR THE EUROPEAN XFEL

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Abstract

The European XFEL is an X-ray free-electron-laser that is currently being built in Hamburg. It is organized as an international project and will be a large scale user facility [1,2]. Based on superconducting TESLA technology electron beams of high average power will be sent to several undulator lines simultaneously to produce hard X-rays with high average intensity and a peak brilliance by far superior to any 3rd generation light source. This paper will present the current status of the planning, the development and the prototyping process for the standard electron beam diagnostics of this facility. It will cover the main diagnostic systems, like the BPM system, beam size measurements, charge and beam loss measurements as well as the machine protection system.

INTRODUCTION

The European XFEL (E-XFEL) is a project to construct an international X-ray Free-Electron-Laser user facility close to DESY in Hamburg. The facility will be operated by a limited liability company with shareholders from the participating counties.

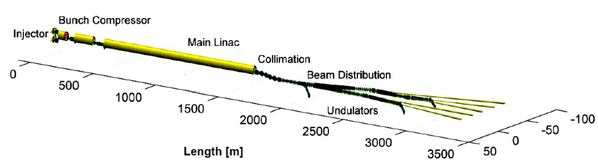

Figure 1: Sketch of the layout of the E-XFEL.

DESY will act as a host lab and leads the accelerator consortium, that is in charge for the construction of the accelerator. Like the FLASH facility [3] E-XFEL will also be based on superconducting TESLA RF technology. Therefore, this machine will provide much higher duty cycle as machines like SCCS and LCLS. An electron beam with a pulse length of 650 µs and a bunch rep rate up to 5 MHz will be accelerated up to 17.5 GeV at a repetition rate of 10 Hz. The shortest XFEL wavelength will be 0.1 nm or about 10 keV. To make optimum use of the high duty cycle, the long bunch trains can be distributed into 2 SASE undulator lines, which will be ramified into additional lines for “secondary undulators” that make use of the spent beam producing either FEL or spontaneous radiation. The time structure of the beam can be adjusted independently for both main SASE undulators (SASE I and SASE II) by means of a kicker septum scheme in the beam distribution system.

While the contracts between the founder states of the XFEL Company are still in the phase of final negotiation, and the signature of the conventions can be expected for summer, the construction phase of the facility has already started. The contracts for civil construction are placed and groundbreaking took place in winter 2008/2009. Also the procurement of main components will start this summer. The construction is scheduled to take about 5.5 years. According to this planning commissioning should start 2014. SASE is expected to follow about 1 year later.

STANDARD BEAM DIAGNOSTICS

This paper focuses on standard beam diagnostics like beam position, charge, beam size and beam loss. These systems are currently in the design phase. First prototypes are under construction or will be available soon. A description of the more specialized diagnostic systems can be found in Ref.[4].

BEAM POSITION MONITOR SYSTEM

Beam position monitors are the backbone of the diagnostic system. E-XFEL will distinguish between standard BPMs with moderate resolution and precision BPMs, where higher performance is required. For the standard BPMs mainly the button type will be used. About one third of the BPMs in the accelerator modules will be re-entrant cavity BPMs. About every third RF-Section of the LINAC, consisting of 4 accelerator modules, will be equipped with monitors of this type to provide a better resolution if required.

Cavity BPMs will be used mainly in and close to the undulator sections. One cavity BPM will be located in each undulator intersection. In addition before and behind the undulator sections there will be some of these cavity BPMs to allow for precise beam based alignment. Further high precision (cavity) monitors with a 40.5 mm beam pipe diameter will be used before the LINAC sections and in the collimation and distribution section. This type will also be used for the Intra Bunchtrain Feedback System (IBFB) developed by PSI [5].

Table 1: Numbers and types of the E-XFEL BPMs

BPM Type	Number	Diameter	Single Bunch Resolution
Standard Button BPM	228	40.5 mm	50 µm
“cold” BPM (Button, Re-entrant Cavity)	101	78 mm	50 µm
Precision BPM (Cavity)	117	10 mm	1 µm
Precision BPM (Cavity)	12	40 mm	1 µm

The BPM system for the E-XFEL will be provided by a collaboration of PSI, CEA and DESY. DESY will take over the mechanics for all BPMs, except the re-entrant cavity BPMs. These monitors will be supplied by CEA, including monitor and RF-front-end. The BPM electronics, the firmware and embedded software for all BPMs will be provided by PSI, except for the cold re-entrant cavity BPM, where the front-end is supplied by CEA.

Button BPM

Button BPMs will be used as standard BPM for all warm beamlines, except for the undulator sections. Furthermore, they will also be used in the XFEL cryo modules, rigidly connected to the quadrupoles at the end of an accelerator module string [6]. The button BPM electronics will be based on an analogue input stage that transforms the high-frequency broadband signals of the pickups into a low-frequency bandwidth-limited signal pulse of some 10ns length that is sampled directly by a fast ADC and post-processed by an FPGA. First prototypes are already under test at FLASH and PSI.

For the cold variant of this BPM type the development of the BPM body is almost finished. The custom made feedthroughs have passed the cryogenic tests successfully. Only minor changes of the overall design are expected with respect to the current prototype due to system integration issues in the cryo-module.

Re-entrant Cavity BPM

The re-entrant cavity BPM has the potential of better resolution compared to the standard button type [7]. About 30% of the cold BPMs will be of this type. From the mechanical point of view, the interfaces to the outside world of the cryo-module are identical. Also for this BPM the development is quite advanced. The feedthroughs are qualified for the operation in the cold. A prototype is currently mounted in the first E-XFEL cryo-module prototype. The RF front-end based on a down conversion scheme with IQ detection is under development at CEA. The electronics will be integrated into the modular BPM framework developed and supplied by PSI.

Cavity BPM

The requirements on BPM resolution is at most places of the machine rather loose, tight requirements are mainly valid in and around the undulator sections, as well as for few places to steer the beam after the LINAC sections and in beam distribution system. In the collimation section they are also required for the IBFB that is using special low latency electronics. Two types of cavity BPMs will be used. Both types consist of a reference and dipole resonator. Special care is taken for the dipole cavity to optimize the coupling of the dipole mode to the coupling slots [8]. The version for the undulator sections has a 10 mm beam pipe, while the other will be for the standard 40.5 mm beam pipe diameter. From RF point of view both types have the same frequency (3.3 GHz) and Q (70). Therefore, the can be read out with the same type of electronics. The cavity BPM RF front-end, currently developed at PSI, will be based on down conversion and IQ detection. It will ensure high resolution and low drift.

BPM Electronics

The overall BPM electronics system concept developed by PSI follows a modular design approach that maximizes the amount of common hard- and software for the different BPM types in the machine. The BPM electronics will consist of analogue RF front-end (RFFE) modules that are specific for each pickup type, and a generic FPGA-based digital back-end carrier board with two ADC mezzanine modules that is used for all BPMs in the machine. The RFFEs and the digital back-end board with its ADC mezzanine modules are plugged into a common customized crate that contains one generic digital back-end as well as either four button BPM RFFEs or two cavity or re-entrant BPM RFFEs. This generic modular hardware approach that is also employed for the IBFB-specific low-latency BPM and signal processing hardware [9] allows minimizing the overall development and maintenance effort and provides a unified control and timing system interface for all BPMs in the machine.

BEAM SIZE MEASUREMENTS

Like for all other SASE machines emittance control is an important task for the diagnostics, since the optimisation of the emittance transport is essential for the FEL performance. Therefore, E-XFEL will have special sections after the injector, the two bunch compressors and in the collimation section to measure the projected and if possible also the slice emittance. These stations will combine 4 beam size measurements to determine the local twiss parameters as well as the emittance. This allows also controlling the optics and correcting its match to the following sections.

Below 2 GeV (up to the second bunch compressor) the beam size measurements will be done by means of OTR screens. These screens will include on axis and off axis OTR targets. The off axis targets will be used in combination with kicker magnets that deflect a single bunch out of the 650 µs long bunch train onto the screen. In addition this bunch can also be streaked by a transverse mode structure to get access to slice parameters [4]. Resolution of the OTR stations has to be between 30 and 10 µm depending on their location. Since LCLS has reported problems with coherent effects with their OTR systems due to the strongly compressed beam, the E-XFEL OTR chambers provide ports for installation of additional wire scanners in case of such problems in a later stage.

In the high energy sections the beam size is getting to small for OTR diagnostics, and wire scanners will be used for measurements. They have to provide fast scans, i.e. the wire is driven through the beam during one RF-pulse. Nevertheless, OTR systems will also be installed for commissioning purpose and single bunch operation.

On-axis and off-axis operation of the screens requires two different focal spots. In addition imaging of a streaked beam requires large field of view. For both aspects it would be appropriate to focus onto the entire plane. The Scheimpflug's principle, known from large format cameras, allows extending the depth of field by choosing appropriate angles between the object, the image and the lens plane. If these planes have a common intersection line, the entire screen plane is imaged well focused onto the image plane. Therefore an angle of 67.5° between beam axis and screen surface was chosen. A magnification close to 1:1 has to be used to achieve the required resolution. With large view fields large CCD chip cameras will be required.

CHARGE MEASUREMENT

To ensure proper beam transport the transmission has to be close to 100%. Therefore the charge of the bunches has to be measured at various places along the LINAC. Furthermore, charge has to be well controlled for stable SASE operation. The charge monitors will be on the same toroid (current transformer) type that is already in use at FLASH. Significant change will be done for the electronics. Fast sampling ADCs using either numerical integration or data fitting schemes will be used for improved read-out. The electronics of a single toroid will be linked to their neighbours, so that the transmission between two monitors can be checked, and fast alarms can be released in case of problems. The system will be based on digital electronics implemented on µTCA technology. The processing of the alarms will be done by an on-board FPGA of the ADC board.

BEAM LOSS AND MACHINE PROTECTION

Superconducting LINACs are able to transport a large amount of charge and energy due to the high duty cycle. The maximum beam power of E-XFEL is about 600 kW cw at 17.5 GeV. This number indicates that a machine protection system is required to prevent the machine from damage. In this context damage does not only mean mechanical damage of components but also their activation and degradation. Electronics will suffer from high radiation levels in the machine and the undulators will degrade in performance.

Therefore a machine protection system will be installed. The system will process signals from all over the machine. Slow signals from magnets, RF, vacuum and screens will be used to check for the correct machine state and will block beam operation or allow for only single or few bunches depending on the status of the machine. Fast signals from e.g. beam loss monitors or transmission measurements will cause an interrupt of charge production or beam abortion by means of the dump kicker in case of imperfect transmission of the long bunch trains.

The system will be an upgraded version of the FLASH system [10], using similar principles with updated technologies. The logic units collecting and evaluating the input channels and creating the alarms will be based on modern digital processing units. The beam loss monitors will still be based on photomultipliers, but with a readout using fast ADCs and digital signal processing. Both units will be implemented as AMC boards for the µTCA standard.

SUMMARY

The developments for the standard beam diagnostics for E-XFEL are in an advanced state. The design of the main systems is clear, and partners within E-XFEL collaboration are fixed. First prototypes are already under test at FLASH.

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