STANDARD E-BEAM DIAGNOSTICS FOR THE EUROPEAN-XFEL

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Abstract

The European XFEL is a 4th generation synchrotron radiation source, under construction in Hamburg [1,2]. Based on different Free-Electron Laser and spontaneous sources, driven by a 17.5 GeV superconducting accelerator, it will be able to provide several user stations with photons simultaneously. High average and high peak brilliance can be produced due to the superconducting technology. Flexible bunch pattern will allow for optimum tuning to the experiments demands. This paper will present the current planning of the electron beam diagnostics; give an overview of the entire system, as well as details of the main diagnostic systems.

INTRODUCTION

The European XFEL (E-XFEL) is an international X-ray FEL user facility close to DESY. It is constructed and will be operated by a limited liability company with shareholders from currently 12 counties. DESY acts as the host laboratory and leads the accelerator consortium, that is in charge for the construction of the accelerator.

Like FLASH [3], the E-XFEL will be based on superconducting TESLA RF technology. The beam parameters are summarized in Table 1. The shortest FEL wavelength will be 0.1 nm. 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”. The time structure of the beam can be adjusted independently for both main SASE undulators by means of a kicker/septum scheme in the beam distribution system.

Table 1: Design Beam Parameters of E-XFEL

Parameter	**Value**	**Unit**
Maximum energy	17.5	GeV
normalized emittance	1-2	mm mrad
bunch charge	0.1-1	nC
min. bunch spacing	222	ns
max. macro-pulse length	600	µs
bunches within macro-pulse	1 - 2700	
bunch pattern	arbitrary	
RF repetition rate	10	Hz

According to current planning commissioning should start in 2014. SASE is expected to follow about 1 year later.

STANDARD BEAM DIAGNOSTICS

This paper focuses on standard electron beam diagnostics. The systems are currently under design. First prototypes are available or under construction. Special diagnostic systems are described in Ref. [4].

BEAM POSITION MONITOR SYSTEM

The E-XFEL BPM system will be provided by a collaboration of PSI, CEA and DESY [5]. As listed in Table 2, there will be standard BPMs with moderate and precision BPMs with high resolution. The standard BPMs will be of the button type. Precision monitors will be different cavity BPM types. About one third of the BPMs in the accelerator modules will be re-entrant cavity BPMs. High precision cavity BPMs with a 10 mm beam pipe will be integrated in the undulator intersections. Further high precision (cavity) monitors with a 40.5 mm beam pipe diameter will be used for critical sections in the machine, like the vicinity of the bunch compressor chicanes, the collimation and distribution section, as well as after the undulators. They will also be used for the Intra Bunch-train Feedback System currently developed by PSI.

Table 2: BPM Resolution Requirements of E-XFEL

BPM Type	**#**	**Diameter**	**Single Bunch Res.**
Standard Button	228	40.5 mm	50 µm
“cold” BPMs	101	78 mm	≤ 50 µm
Cavity BPM	117	10 mm	1 µm
Cavity BPM	12	40.5 mm	1 µm

Button BPM

Button BPMs will be the standard BPMs in E-XFEL. In the superconducting part they are rigidly connected to the quadrupoles (see Fig. 1) at the end of each accelerator module string [6].

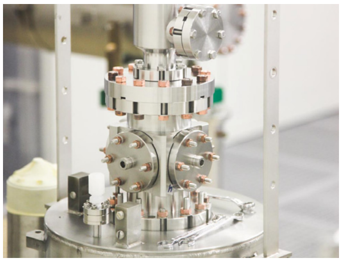

Figure 1: Button BPM for the cryo-modules, already assembled to the superconducting quadrupole package of the PXFEL3 prototype accelerator module.

The development of this BPM is almost finished. The custom made feedthroughs have passed the cryogenic tests successfully. The series production is planned to start this year.

The button BPM electronics will be based on an analogue front-end that transforms the pickups signal into a low-frequency bandwidth-limited signal of some 10ns length that are processed by a fast ADC followed by an FPGA. First prototypes are under test at FLASH and PSI.

Reentrant Cavity BPM

The re-entrant cavity BPM has the potential of better resolution compared to the standard button type [7]. From the mechanical point of view, the interfaces to the outside world of the cryo-module are identical. The feedthroughs are qualified for the operation in the cold. A prototype is installed in the PXFEL2 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. Beam tests are scheduled with a prototype installed at FLASH.

Cavity BPM

Two types of cavity BPMs based on the development of T. Shintake for SCSS will be used [8]. Both types with a beam pipe diameter of 10 mm and 40.5 mm, respectively, as shown in Fig. 2, consist of a reference and dipole resonator. The cross talk between the two resonators was measured to be very low (-43 dB). The two types have very similar RF parameters, which allow using the same electronics. The use of stainless steel results in rather low internal Q, preventing cross talk between consecutive bunches for all cavity modes even at the short bunch spacing of 220 ns. The design relies on precise fabrication without any tuning.

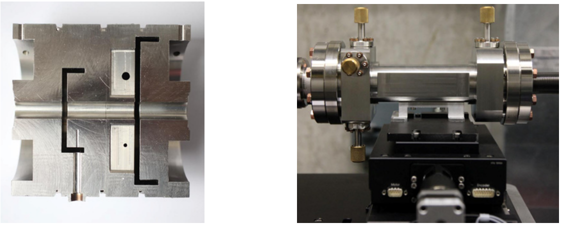

Figure 2: Both types of E-XFEL cavity BPMs; on the left a cut through the type for the undulator sections. The right picture shows the 40.5 mm type of the cavity BPM.

Up to now all BPM prototypes have been reach its design resonance frequency of 3.3 GHz with in a tolerance of ±20 MHz. Beam measurements are in good agreement with the simulations [9]. The RF front-end, currently developed at PSI, will be based on down conversion and IQ detection. It will ensure high resolution and low drift.

XFEL CRATESYSTEM

E-XFEL will use the xTCA standards for physics purpose [10] as the crate standard. Accordingly double size AMC boards with rear transition modules (RTM) will be used. Two "standard" boards are currently under development, a commercial 16 bit 125 MHz ADC with 10 channels, and an in house developed versatile interface board with 4 fast serial links (DAMC02) [11]. Both boards supply a high amount of processing power by a VIRTEX 5 FPGA on board. The different applications will be adapted to these standard boards by means of special RTMs. The diagnostics uses this approach for toroids, wire-scanners and beam loss monitors.

BEAM SIZEMEASUREMENTS

An optimum emittance transport is essential for the FEL performance. E-XFEL will have special diagnostic sections behind the injector, within the two bunch compressors and in the collimation section to measure the projected and the slice emittance. These stations will combine 4 beam size measurements to determine the local twiss parameters and the emittance. This allows precise controlling and matching of the beam optics.

OTR screens will be used up to the second bunch compressor. These screens will include on axis and off axis OTR targets. The off axis targets will be used in combination with kicker magnets deflecting a single bunch out of the 600 µs long bunchtrain onto the screen. In addition this bunch can be streaked by a transverse mode structure to get access to slice parameters [4]. Depending on the location the resolution of the OTR stations has to be between 30 and 10 µm. Since LCLS has reported coherent effects in their OTR systems [12], the E-XFEL OTR chambers foresee ports for additional wire scanners.

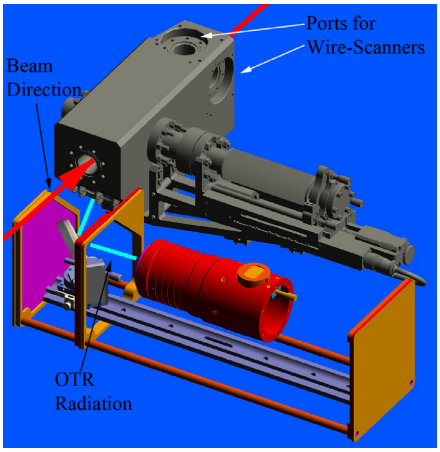

Figure 3: 3D view of an E-XFEL OTR station. Due to the angle with the beam the OTR is emitted under 45° in backward direction. Scheimpflugs´s principle is drafted by the tilted camera box. The blind flanges are the ports for the wire-scanners.

The on-axis, off-axis and streaked beam images require different focal spots and large field of view. Both aspects are tackled by the use of Scheimpflug's principle, known from large format cameras. An angle of 22.5° between beam axis and screen surface was chosen. 1:1 imaging is needed for the required resolution (see Fig. 3).

Due to the small beam size in the high energy sections wire scanners will be used there. They have to provide fast scans, i.e. the wire is driven through the beam during one RF-pulse with a speed of 1 m/s. The technical progress allows using linear motors. The trigger of a scan has to be precisely synchronized to the arrival of the beam. A prototype has shown a trigger jitter of less than 10 µs, corresponding to a position or bunch number jitter of less than 10 µm or 10 bunches. Of course, the scanner can be moved slowly through the beam adapting single bunch operation for commissioning.

CHARGE MEASURMENT

For high power beams transmission has to be close to 100%. Therefore the bunch charge has to be measured at various places along the LINAC. Furthermore, charge has to be well controlled for stable SASE operation. The current transformers (toroids) will be of the same type already in use at FLASH. The electronics will be based on the DAMC02 µTCA/RTM boards with fast sampling ADC and FPGA post-processing. Single toroids will be linked to their neighbours by fast optical links to release alarms to the machine protection system with few µs latency in case of imperfect transmission. A fast link to the LLRF will provide charge information for beam loading compensation.

DARK CURRENT

The long RF pulse trains of the superconducting LINACs requires dark current suppression, which is mainly generated by the RF gun. The dark current monitors are based on a 1.3 GHz stainless steel cavity [13]. A picture of such a monitor is shown in Fig. 4. First measurements have been performed at FLASH. These sensitive monitors are also suited for charge measurements in case of very low charge operation of FLASH or E-XFEL.

Figure 4: 1.3 GHz cavity dark current monitor with one coupling antenna in front.

BEAM LOSS AND MACHINE PROTECTION

Since the beam power of the superconducting E-XFEL LINAC is up to 600 kW CW, a machine protection system (MPS) is essential to prevent the machine from mechanical damage, to minimize activation and radiation damage. The MPS will be an upgraded version of the FLASH system [14].

The beam loss monitors will be based on photomultipliers, enabling bunch-by-bunch loss determination. The readout will base on the DAMC02 hardware. The signals from 8 monitors will be processed by one readout unit. The shaped data from the BLM is digitized by 14 bit 50 MHz ADCs located on a RTM, integration of losses and alarm generation is done in the FPGA of the DAMC02 board.

The latency of the system is about 300 ns plus cable delay. A second µTCA board produces the test signals to drive the LED implemented in the BLM.

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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