STANDARD ELECTRON BEAM DIAGNOSTICS FOR THE EUROPEAN XFEL

D. Lipka*, DESY, Hamburg, Germany, for the XFEL diagnostics team

Abstract

The European XFEL under construction in Hamburg needs to control the electron beam parameters for reliable machine and FEL operation. Due to the flexible bunch pattern, a minimum bunch spacing of 222 ns and large variation of the beam charge a high dynamic range of the monitors is necessary. This paper presents an overview of the planned standard electron beam diagnostics. The status of the main systems is presented, as well as the results from prototype tests with beam at FLASH and PITZ.

INTRODUCTION

The European Free-Electron Laser (E-XFEL) is an international X-ray FEL [1]. The injector is located at the DESY site and the experimental hall is located at the village Schenefeld, with a distance of about 3.5 km. The E-XFEL is constructed and will be operated by a limited liability company with shareholders from different countries. DESY is the host laboratory and leads the accelerator consortium which is in charge for the construction and operation of the accelerator.

The acceleration of the electron bunches is based on superconducting TESLA RF technology. To maximize the duty cycle up to 2700 bunches within one bunch train of length up to 600 μs will be generated. This results in a bunch spacing of 222 ns. Charges between 20 pC and 1 nC can provide different characteristics of the output radiation, average power or bunch length, as requested by the users. Therefore diagnostic components have to monitor the beam properties within these dynamic range.

This paper focuses on standard electron beam diagnostics. Special diagnostics systems are described in Ref. [2].

BEAM POSITION MONITOR SYSTEM

The BPM system will be provided by a collaboration of PSI, CEA and DESY [3]. Button BPMs (2/3) and reentrant cavity BPMs (1/3) will be installed in the cold modules. The warm beamlines will be equipped with warm button BPMs. Between the undulators and at special positions where a higher resolution than buttons is requested cavity BPMs will be installed. The signals of the BPMs will be processed by modular BPM electronics called modular BPM unit (MBU) including front-end electronics, ADCs and FPGAs provided by PSI [3]. The entire BPM system will be capable for single bunch measurements, so that data for every bunch in the train at all BPM location are available for every RF pulse.

Button BPM

The button BPMs are divided in cold and warm types and will be provided by DESY. In Fig. 1 a picture of a cold button is shown. The tube diameter in the cold modules is 78 mm and in the standard beamline 40.5 mm. Therefore the button diameter at the cold is larger (20 mm) compared to the warm buttons (16 mm). A relatively large gap[1] between button and holder provides high signal intensity [4]. Intensive tests are performed on cold test buttons to verify the tightness at cryogenic temperatures with temperature cycles down to 4 K which was successfully [4]. The button BPM front-end electronics will transform the signals into a low-frequency bandwidth-limited signal of some 10 ns length.

Figure 1: Picture of a cold button.

Reentrant Cavity BPM

This type of BPM will be provided by CEA Saclay. The monitor is based on a cavity; the separation of the position sensitive signal from the monopole mode is done by hybrids [5]. The mechanical interface of this BPM is identically to the cold button BPM. The feedthroughs are tested successfully for the cold application. The front-end is based on down conversion with IQ detection which will be integrated in the MBUs.

Cavity BPM

Cavity BPMs with waveguides to separate the dipole from the monopole modes are provided by DESY, see Fig. 2 on a teststand at FLASH. It consists of dipole and reference resonators based on the design provided by T. Shintake [6]. The undulator intersection has a tube diameter of 10 mm compared to the standard beamline diameter

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* dirk.lipka@desy.de

[1] A small gap is necessary for ring accelerator to not disturb the beam properties. This is not necessary for linear accelerators.

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Figure 2: Picture of the cavity BPM teststand at FLASH. The beam enters from right to left. First 3 BPMs are for the undulator intersection, the last one is for the standard beamline.

of 40.5 mm. Therefore the design of cavity BPMs for the undulator intersection and standard beamline differs by this diameter. The performance is expected to be equally (resonance frequency, loaded quality factor and sensitivity) to be able to be used with the same electronics. To decouple the reference to dipole signal the distance between dipole and reference resonator for the beamline cavity BPM is larger (19 cm). The design relies on precise fabrication without any tuning. The measured resonance frequencies and the quality factors are within the requirements. The resolution measured with an oscilloscope during prototype tests was already below 2 μm for the undulator type and below 6 μm for the beamline type [7]. Later one already fulfills the requirement. The front-end electronics provided by PSI is expected to reach a better resolution. It is based on down conversion and IQ detection with beam charge sensitive attenuator switches to increase the dynamic range.

TRANSVERSE BEAM SIZE MEASUREMENT

The emittance of the electron beam will be measured using 4 transverse beam sizes at 4 station after another. These stations will be located behind the injector, within the two bunch compressors and in the collimation section.

Screen stations will be used up to the second bunch compressor, see Fig. 3. These screens will include on and off axis targets. The off axis targets will be used in combination with kicker magnets deflecting a single bunch out of the 600 μs long bunch train onto the screen. In addition this bunch can be streaked by a transverse mode structure to get access to slice parameters [8].

Since LCLS has reported coherent effects on their OTR screens [9] an investigation on the screen is ongoing; for material investigation see [10]. OTR screens could be replaced by scintillating screens and fast gated cameras to catch the decaying scintillator light. An other method could be a geometric filter: due to a different emission angles between OTR and the scintillating light.

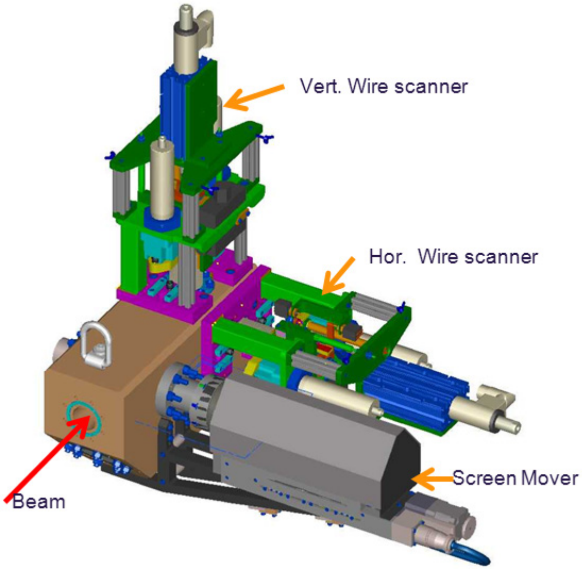

Figure 3: 3D-model of a transverse beam size measurement station. It includes a screen station and two wire scanners for vertical and horizontal scans.

To measure the transverse beam profile at high electron energies wire scanners will be used in combination of the screen stations, see Fig. 3 and 4. The wire scanners include horizontal and vertical wire scanners installed on the vacuum chamber. After pumping down to 10^{-7} mbar scans with nominal 1 m/s has been successfully performed. 50000 scanning cycles were accomplished for every scanner to test the bellow and vacuum parts performance. Vacuum pressure during the cycles has been monitored with periodic fine (He) leak tests. Reproducibility of the wire position, velocity and acceleration was recorded as well. The scanners triggering accuracy tests were carried out in order to check the mechanical performance. The main mechanical and performance characteristics of the wire scanner system are listed in table 1.

Table 1: Wire Scanner Specifications

units to install	24
number of wires per fork	3 + 2 (3x90° ± 60°)
Wire material	tungsten
fork gap	15 mm
wire-wire distance (0°)	5 mm
stroke	53 mm
scanning modes	fast (1 m/s), slow
measurement duration	5 s (per emittance measurement stations with 4 scanners)
position accuracy in a cycle	2 μm (rms)
width accuracy per cycle	2 % (rms)
wire positioning error	1 μm

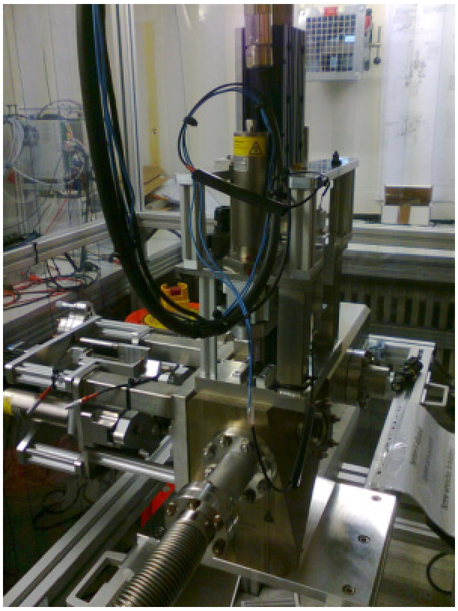

Figure 4: Picture of a vacuum chamber with mounted wire scanner.

CHARGE MEASUREMENT

For high power beams transmission has to be close to 100 %. Therefore the bunch charge has to be measured at various places along the accelerator. Furthermore, charge has to be well controlled for stable SASE operation. The current transformers (toroids) are tested at FLASH, a cross section of a 3D-model is shown in Fig. 5. The ceramics divides the tube such that the mirror charge will induce voltages in the windings around the core. A test setup in the laboratory is shown in Fig. 6. The differential signal processing are done by two different amplifiers to provide a large dynamic range. So far resolutions down to 0.6 pC are verified [11]. Single toroids will be linked to their neighbors by fast optical links to release alarms to the machine protection system with few μs latency in case of imperfect transmission.

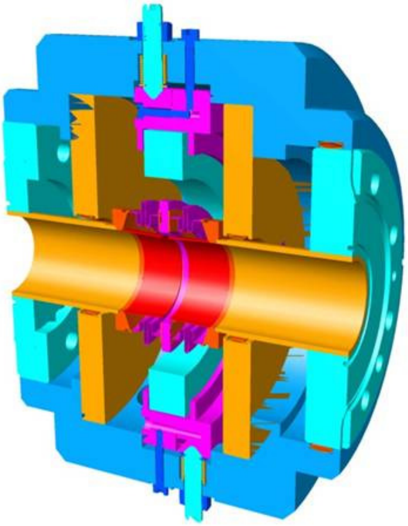

Figure 5: Cross section of a Toroid.

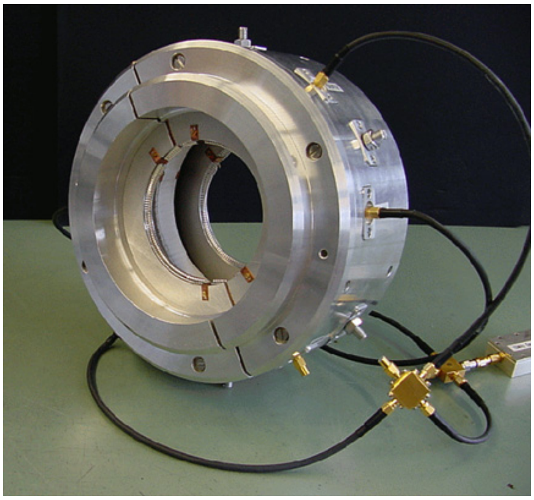

Figure 6: Picture of a Toroid in the laboratory.

In addition a dark current monitor (DaMon) will be used. Dark current is produced due to field emission in the accelerator. To reduce the dark current collimators and kickers are used. The efficiency has to be measured by using the non-destructive dark current monitor. This devise consists of a passive resonator with the first monopole at the acceleration frequency. This provides pile up of the induced dark current voltage to a measurable level. In Fig. 7 a dark current monitor is shown. It was confirmed at FLASH and PITZ that the observation limit of the DaMon is 40 nA [12]. Since the first monopole mode amplitude is proportional to the beam charge this monitor can be used to detect the charge too. The resolution measured at FLASH is below

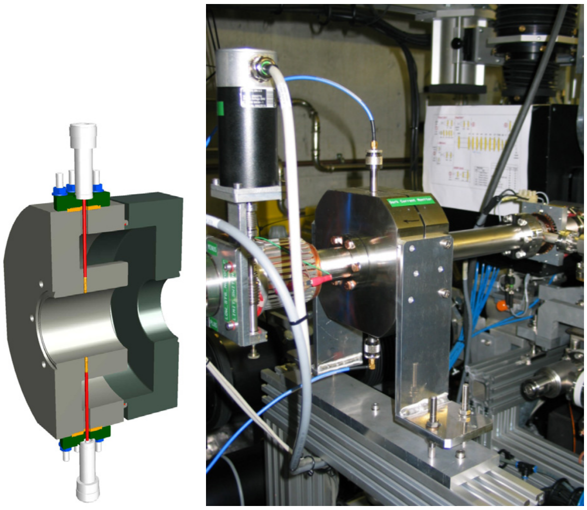

Figure 7: Dark current monitor. Left: cross section. Right: in the beamline at PITZ.

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0.6 pC, which is delivered by an additional electronics, beside the dark current electronics. The dark current signals are affected by the beam charge too, this can be used for very low beam charges with better resolution. In addition this device has the potential to measure the bunch length with a resolution of about 2 ps before the bunch compressor[2].

BEAM LOSS MEASUREMENT

The beam loss monitors (BLM) will be based on scintillators processed by photomultipliers, enabling bunch-by-bunch loss determination, see Fig. 8. The readout will base on the μTCA electronics [13]. A multipurpose digital carrier board DAMC02, developed at DESY, will be used. A so called rear transition module connected to this board will be used to shape the signals from the BLMs, it will sample them with a 50 MHz ADC. Data processing and alarm generation will be done by a powerful Virtex 5 FPGA onboard the DAMC02. The signals from 8 monitors will be processed by one readout unit. The latency of the system is about 300 ns plus cable delay. Furthermore, a test generator will be provided to drive the LED implemented in the BLM [14].

Figure 8: Picture of a scintillator with photomultiplier.

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. The program to investigate luminescent screens to deal with the COTR problem affecting the screen stations has been started. Prototypes of all main systems are already under tests at FLASH.

ACKNOWLEDGEMENT

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[2] This resolution is sufficient after the injector of the accelerator. Behind the bunch compressor the bunch length is already shorter.