VERY FIRST EXPERIENCE WITH THE STANDARD DIAGNOSTICS AT THE EUROPEAN XFEL

D. Lipka* on behalf of the European XFEL Diagnostics team, DESY, Hamburg, Germany

Abstract

The whole European XFEL becomes in operation this year. Dedicated standard diagnostics systems are installed and almost all types are tested at the injector before. Now the standard diagnostics are used to commission the facility. In this contribution the very first results and the operation experiences of the standard electron beam diagnostics of the entire European XFEL are reported.

INTRODUCTION

The European X-ray Free-Electron Laser (EU-XFEL) [1, 2] is the 3.4 km long international facility, running from DESY in Hamburg to the town of Schenefeld (Schleswig-Holstein) in Germany, see Fig. 1. To construct and operate the EU-XFEL, international partners agreed on the foundation of an independent research organization – a non-profit limited liability company under German law named the European XFEL GmbH. DESY is leading the accelerator construction consortium and will be in charge of the accelerator operation.

The accelerator is based on superconducting TESLA Radio-Frequency (RF) technology. Within one RF pulse of up to 600 μs length, a train with up to 2700 bunches can be generated. This results in a bunch minimal spacing of 222 ns. The repetition rate of the RF pulses is 10 Hz, so that a maximum number of 27000 X-ray pulses per second can be produced. The beam charge varies from 20 pC to 1 nC to provide different characteristics of the output radiation, i. e. the average power or the bunch length, as requested by the users. Therefore diagnostics components have to monitor the beam properties within this dynamic range.

Beam operation of the photocathode gun started already in February 2015, the complete injector became operable in December 2015 and beam characterization with optimization take place until July 2016 [3]. A description of the injector operation with the standard diagnostics is presented in [4]. The cooldown of the main accelerator was finished end of 2016. In January 2017 beam operation after the injector started: the transmission was established step by step to each dump in the two successively bunch compressors and in the following up to the first main dump at Osdorf site (about 2100 m behind the electron source) in January and February 2017, compare with Fig. 1. End of April the beam was transmitted through two SASE sections, these sections installed serially after another. First lasing was performed beginning of May. Along the complete electron beamline several diagnostics systems are installed, commissioned and have been optimized for the measurement of the electron beam properties. This paper focuses on standard electron beam diagnostics for the EU-XFEL. Special and higher-order mode diagnostics systems are described in [5–12].

* dirk.lipka@desy.de

STANDARD DIAGNOSTICS FOR THE EUROPEAN XFEL

The standard diagnostics contains a variety of charge, position, loss monitors and screen stations. It is also planned to use wire scanners at positions with high electron energies. The list of monitoring systems is given in Table 1. A description of the different systems with results of their laboratory and beam tests can be found in [13–27].

Charge Monitors

Toroid are used consisting of a ferrite core with windings around a ceramic gap in the pipe and are distributed along the beamlines [13]. During beam commissioning these monitors started in a self-trigger mode to detect the beam independently from the timing system; this feature is useful to detect the first beam and measure the delay between beam and trigger signal. In the following the trigger mode is enabled to improve the performance. The beam position monitors (BPM) are providing the charge signals too. In the Figure 2 the transmission is shown with the Toroids and BPMs from the injector to the dump after two SASE sections; a beamline length of about 3.1 km. The Toroid charge values differ only by max. 3% therefore the laboratory calibration has this relative accuracy. The charge calibration from the BPMs are used from the experience during the injector operation, still some discrepancies are seen; these will be corrected. In addition the Toroids generate a history of the beam arrival time in sub-nanosecond range to verify that the photocathode-laser hits the correct RF-bucket. This was used to correct the timing of the laser after maintenance. Faraday cups and dark current monitors [14] are used to measure the charge as well. The later is able to detect even charge values below pC.

Table 1: Diagnostics system numbers for the complete EU-XFEL and for the gun with injector

System	Total number	Gun and injector
Charge monitors	~50	10
BPMs	~460	14
Screens	~70	11
Wire scanners	12	0
Loss monitors	~490	20

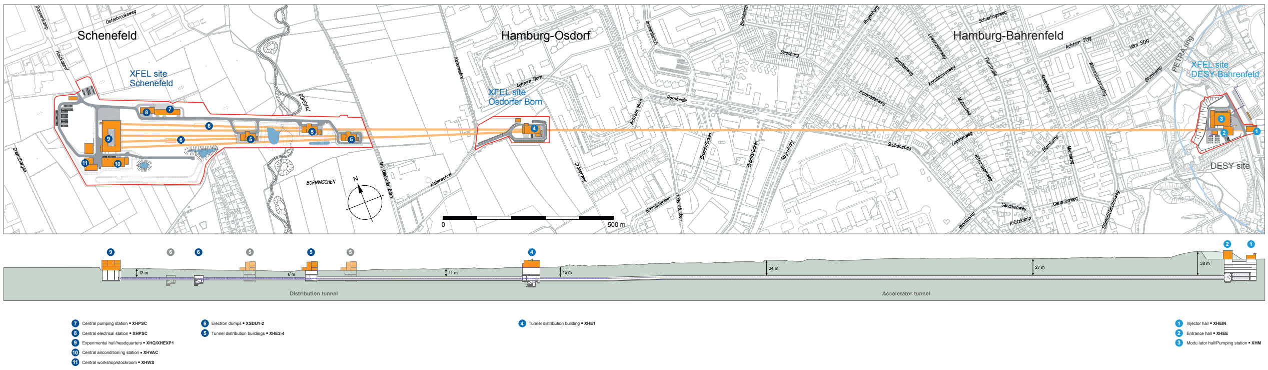

Figure 1: Map of the EU-XFEL tunnel. The beam starts at the DESY site on the right and is stopped at the Schenefeld site on the left. The lower picture shows the cross section of the tunnel with distances to the earth surface. Total distance between the electron source and the experimental hall is 3.4 km.

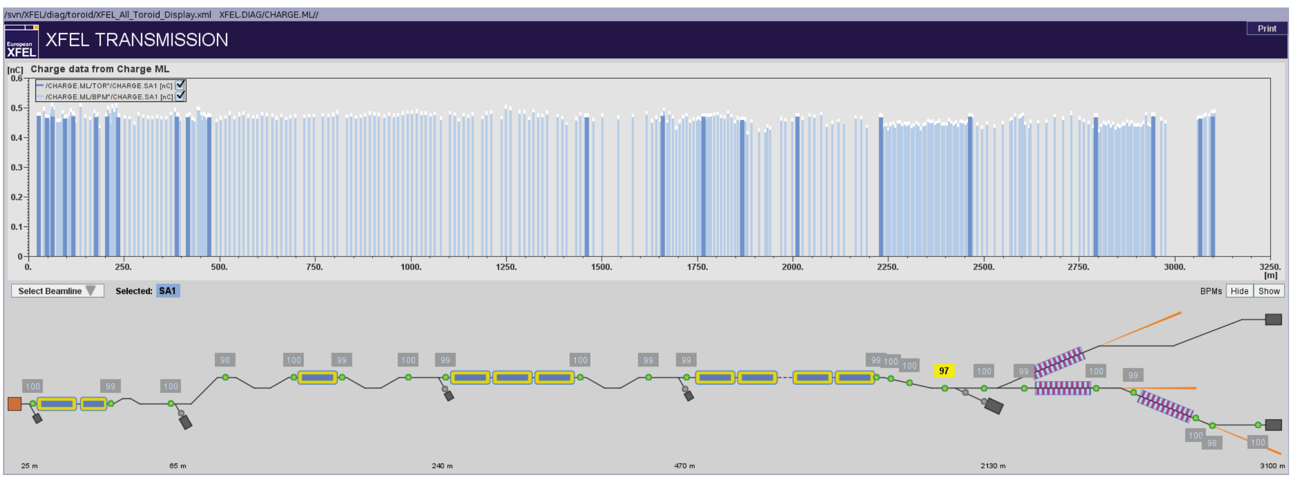

Figure 2: Display of the beam charge values along the beamline during beam commissioning up to the main dump at Schenefeld after two SASE section, beam starts on the left to right. The dark blue bars are the Toroids, the bright blue bars are from beam position monitors. Below a sketch of the beamline with transmission values in percent.

Beam Position Monitors

Button and cavity BPMs [15–20] with single-bunch detection are used, such that each bunch with 222 ns spacing can be measured. The complete BPM system including electronics is an in-kind contribution of CEA Saclay, DESY and PSI [28]. The pickups are developed at DESY (buttons and cavities) and CEA (reentrant cavities); the electronics, firmware and software for all BPMs is developed at PSI, except for the reentrant front-end electronics provided by CEA. These monitors are used in self-triggered mode during beam commission like the Toroids. After the delay between beam signal and timing is found these monitors switched to triggered mode to improve the performance. A resolution measurement of the BPMs is shown in Fig. 3. The best resolutions are observed for the cavity BPMs, followed by the reentrant and button BPMs like expected. At the dumps larger beampipe diameters are used therefore this results in larger resolution values. The BPMs are functional from the first day of beam operation and therefore are a main diagnostics device to detect the beam, especially into the accelerator section between 480 m and 1430 m where only these vacuum diagnostics are able to measure the beam charge transmission, compare with Fig. 2.

Screens

The scintillating screens with 200 μm thick LYSO:Ce targets are oriented such that coherent optical transition radiation generated at the screen boundaries will geometrically be suppressed by an observation angle of 45°. A grid for calibration is mounted on the screen mover too. Depending on the requirements, different optical systems are used for the screen stations. One provides 1:1 imaging, the other one reduces the screen image by a factor of two. Basler Aviator cameras are installed for good image resolution. The main system with 1:1 imaging reaches a resolution $\leq$10 μm [21]. An example of an transverse beam image is shown in Fig. 4.

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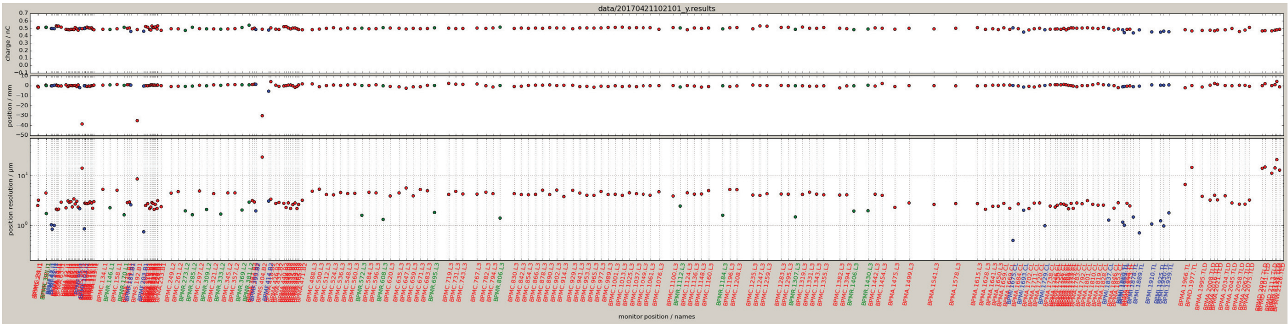

Figure 3: Resolution measurement result of the BPMs from the injector on the left to the first main dump before the SASE sections on the right. Upper plot: charge reading; middle plot: vertical position data; lower plot: vertical resolution. Different kind of BPMs deliver different resolution. Colors: red - buttons, green - reentrant, blue - cavities.

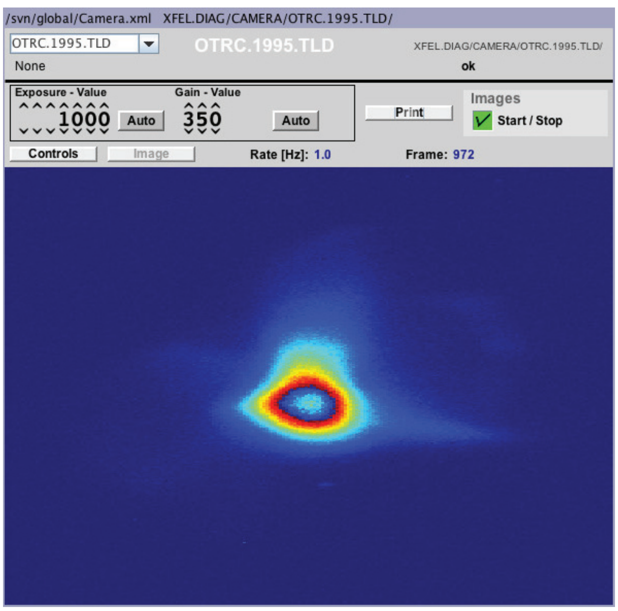

Figure 4: Display of the transverse beam distribution with a screen station at 1995 m behind the electron source during the first beam commissioning.

Note: half filled screens (off-axis screens) are available as well at the diagnostics stations of the injector and bunch compressors to measure the transverse beam distribution of kicked bunches. This is useful to characterize the beam properties during long bunch train operations where only one bunch is kicked. This was done successfully during the beam characterization.

Beam Loss and Halo Monitors

The beam loss monitors (BLM) are based on scintillators read out by photomultipliers [25]. The 490 BLMs are distributed along the electron beamline of the EU-XFEL. They generate alarms to stop the beam operations based on dark current or single bunch losses when a threshold is exceeded. During operation these monitors was intensively used to prevent losses. Beam Halo monitors (BHM) are installed in front around the dump vacuum chambers and consist of four diamond and four sapphire sensors operating as solid-state ionization chambers [26]. They are capable to detect both beam losses on a bunch-by-bunch basis and dark current. Diamond sensors provide higher sensitivity, whereas sapphire sensors remain operational at higher intensities of impinging particles. Both kind of sensors showed the halo of charged particles accordingly to her sensitivities and used to prevent high losses before the dump to provide safe beam operation.

Dosimetry

To protect the electronics and undulators the γ radiation is measured due to RadFets with rack-internal and external sensors [27]. During the operation these sensors became operational and measured the radiation which was correlated with the number of bunches in the train because higher number of bunches caused a higher accumulated dose.

SUMMARY

The standard diagnostics of the EU-XFEL has been ready for beam property measurements since the first day of beam operation. BPMs and Toroids can be used in self-trigger as well as in externally-triggered mode, the measured resolution fulfill the requirements. The dark current monitors are useful to measure both, dark current and beam charge. Online monitors of beam loss, halos and radiation dose are installed and operational. Screen stations are used with on- and off-axis screens. The latter one is useful during long bunch train operation to prove the beam properties during user operations by observing one bunch out of the whole train.

OUTLOOK

The diagnostics for the third SASE section will be installed in the next months and becomes in operation in autumn this year.

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