A FAST WIRE SCANNER SYSTEM FOR THE EUROPEAN XFEL

T. Lensch*, T. Wamsat, B. Beutner, Deutsches Elektronen Synchrotron, Hamburg, Germany

Abstract

The European-XFEL is an X-ray Free Electron Laser facility located in Hamburg (Germany). The 17.5 GeV superconducting accelerator will provide photons simultaneously to several user stations. Currently 14 Wire Scanner stations are used to image transverse beam profiles in the high energy sections. These scanners provide a slow scan mode for beam halo studies and beam optics matching. When operating with long bunch trains (>100 bunches) fast scans will be used to measure beam sizes in an almost non-destructive manner. This paper briefly describes the wire scanner setup and focusses on the fast scan concept and first measurements.

INTRODUCTION

The E-XFEL is a superconducting accelerator with an energy of up to 17.5 GeV. Within one RF pulse of 600 µs up to 2.700 bunches can be accelerated. With a repetition rate of 10 Hz this corresponds to up to 27.000 X-ray pulses per second that can be distributed to the different undulator lines to allow for simultaneous operation of experiments [1]. Since spring 2019 the E-XFEL is operated with up to 600 bunches.

At the E-XFEL there are 14 wire scanner units installed. Each wire scanner unit consists of two motorized forks (horizontal and vertical plane). Each fork is driven by a separate linear servo motor. This 90 ° configuration of motors helps to avoid vibration influences. The wire position is measured with a linear ruler (Heidenhain) which has a resolution of 0.5 µm. The motion unit is integrated by a custom front end electronic into the MTCA.4 [2] environment. A set of three 90 ° tungsten wires (50, 30 and 20 µm) and two crossed 60 ° wires (10 µm) is mounted on each titanium fork (see Fig. 1). This wire setup enables the users to make a 30 ° angled beam tomography with six scans at one location.

Wire scanner units are installed in groups of three upstream of the collimation section and upstream the undulator systems. Two locations in the post linac measurement section are equipped with an additional wire scanner unit each since summer 2019 to reduce the RMS error of the emmittance measurement [3].

Several dedicated photo multiplier based detectors are installed downstream each set of wire scanner units. These fast 6-stage tubes are installed connected to a scintillating fiber wrapped around the beam pipe or connected to a scintillating paddel. Additionally regular beam loss monitors (BLM) can be used for loss detection [4] [5].

While slow scans with single bunches are a tool already used at the E-XFEL to measure beam halo distribution [6] and beam optics matching fast scans will allow to measure beam sizes in a non-destructive manner during user operation with long bunch trains.

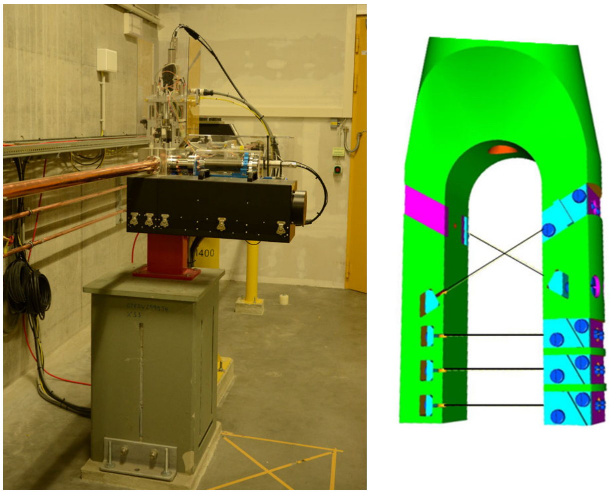


Figure 1: Left: wire scanner unit with horizontal and vertical plane installed in the E-XFEL with a screen station in the foreground. Right: 3D drawing of the fork with the different wires. Wire thicknesses from bottom to top: 50, 30 and 20 µm) and two crossed 60 ° wires (10 µm).

FAST SCAN

At the E-XFEL wire scanners had been developed to measure beam sizes within one long bunch train (bunch repetition rate up to 4.5 MHz) without interruption of user operation.

Technical Issues

To be able to hit bunches in fast scan mode the motor which drives the fork needs to be triggered with the general timing system. Using a custom trigger interface the motor controller is able to provide an adequate repetitive accuracy. Figure 2 shows the measured motor jitter of a fully assembled test setup.

The acceleration phase of the fork to the desired speed of 1 m/s takes about 20 ms. Depending on the z-position of the wire scanner unit and a region of bunches to be hit inside a bunch train an additional individual delay needs to be added to the timing trigger. Selection of the desired wire is also done by increasing this delay. Figure 3 shows complete strokes with different selection of wires. The area where the up to 600 µs long electron beam is, is highlighted red.

Fast scans are only performed with a stroke out. After this motion the fork is directly moved back to the home position without hitting electron bunches again.

Correction of Bunch Position Offsets

During data acquisition the beam position at the wire might vary. Without correction the emittance could be over- or underestimated depending on the direction of the drift and the direction of wire motion. Figure 4 shows an orbit

---

* timmy.lensch@desy.de

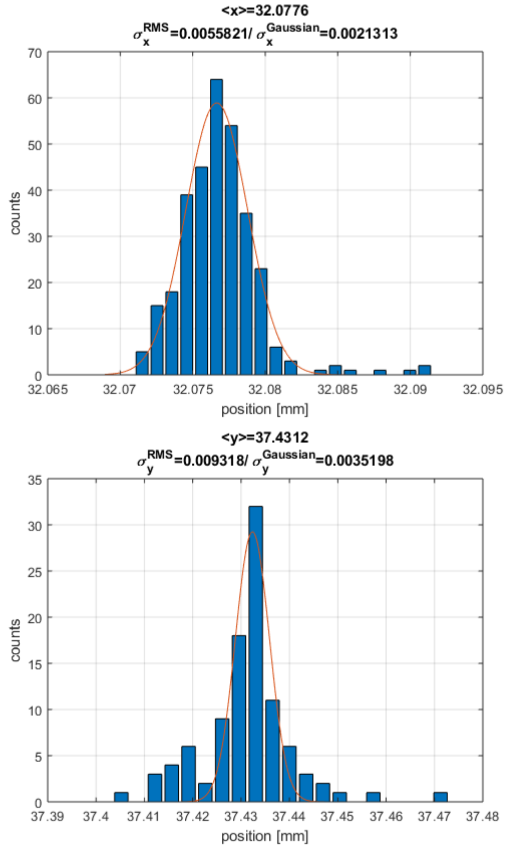


Figure 2: Motor jitter at fully assembled test setup: Horizontal (top) RMS 5.6 µm, Gaussian 2.1 µm and vertical (bottom) RMS 9.3 µm, Gaussian 3.5 µm.

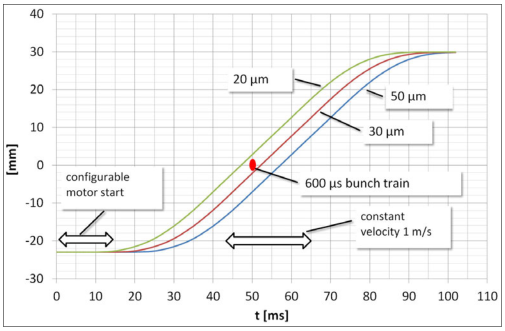


Figure 3: After a timing system event at 0 ms the servo motor starts after a configurable delay which includes z-position of the wire, bunch position inside the bunch train and wire selection (crossed wires not shown). The bunches typically appears in the center of the beam pipe at a position near 0 mm and 50 ms after the trigger event. The home position of the wire is at −23 mm (horizontal plane) respectively 23 mm (vertical plane).

drift of ca. 100 µm at the wire position during a bunch train with about 500 bunches.

The effective wire position relative to the beam is used instead of only the wire position. This can not directly be calculated since no BPM is installed at the wire scanner station. However data of two adjacent BPMs can be used to calculate a *virtual* beam position at the wire.

Let N be the transfer matrix from BPM 1 to BPM 2 and M the matrix from BPM 1 to the wire station. We restrict ourselves to the horizontal plane but the vertical can be obtained in the same way. The angle x_1' at the first BPM is calculated as

$$x_1' = \frac{x_2 - N_{11}x_1}{N_{12}} \tag{1}$$

with x_n being the position obtained from BPM n. With x_1 and x_1' the position at the wire is determined by

$$x_{\text{wire}} = M_{11}x_1 + M_{12}x_1' = M_{11}x_1 + M_{12}\left(\frac{x_2 - N_{11}x_1}{N_{12}}\right). \tag{2}$$

The matrices N and M are determined for the beam-line: BPM 1 $\xrightarrow{1}$ quadrupole $\xrightarrow{2}$ wire-station $\xrightarrow{3}$ quadrupole $\xrightarrow{4}$ BPM 2. In thin lens approximation the result is:

$$\begin{aligned}
M_{11} &= 1 + k_1 l_1 L_1 && (3)\\
M_{12} &= L_1 + (1 + k_1 l_1 L_1)\, L_2 && (4)\\
N_{11} &= 1 + k_1 l_1 L_1 + \\
&\quad + k_2 l_2 \left[L_1 + (1 + k_1 l_1 L_1)\, L_2 + \right.\\
&\quad \left. + (1 + k_1 l_1 L_1)\, L_3\right] && (5)\\
N_{12} &= L_1 + (1 + k_1 l_1 L_1) L_2 + (1 + k_1 l_1 L_1) L_3 + \\
&\quad + \Big[1 + k_1 l_1 L_1 + k_2 l_2 \left[L_1 + (1 + k_1 l_1 L_1) L_2 + \right.\\
&\quad \left. + (1 + k_1 l_1 L_1) L_3\right]\Big] L_4, && (6)
\end{aligned}$$

with k_n, l_n being the strength and length of quad n and L_n the drift length between these elements. This equation covers all wire scanner configurations at the E-XFEL since selected quad strength and drift length can be set to zero if required.

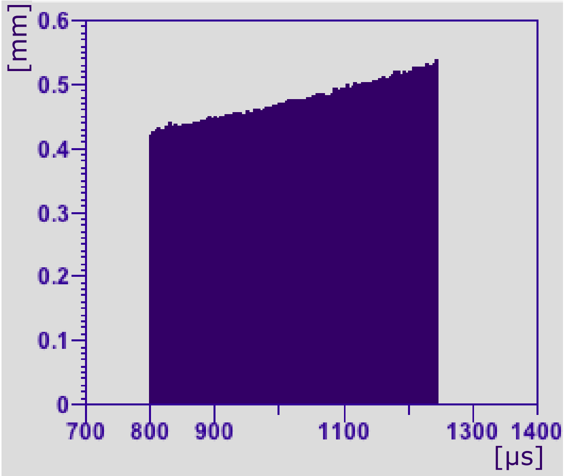


Figure 4: *Virtual* BPM at wire scanner z-position showing orbit drift of a bunch train with about 500 bunches.

First Fast Scans at the E-XFEL

A fast scan measurement is started by transmitting a special bunch pattern via the general timing system to all sub

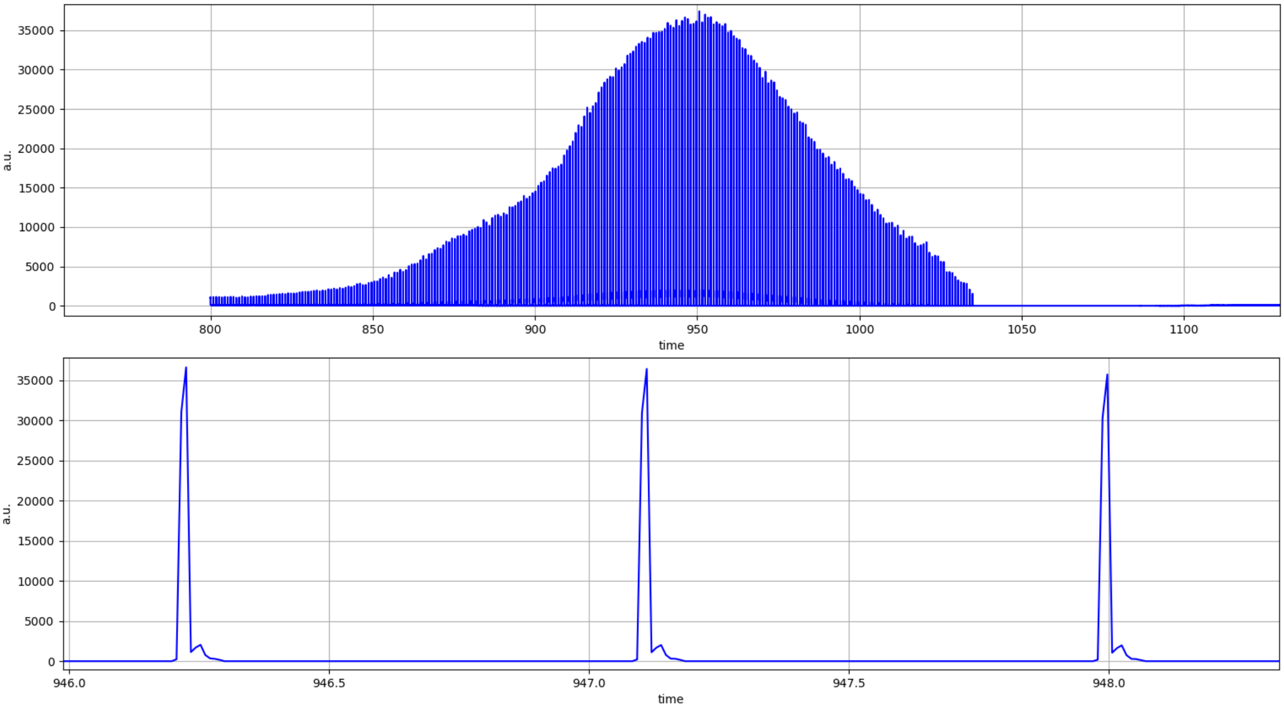
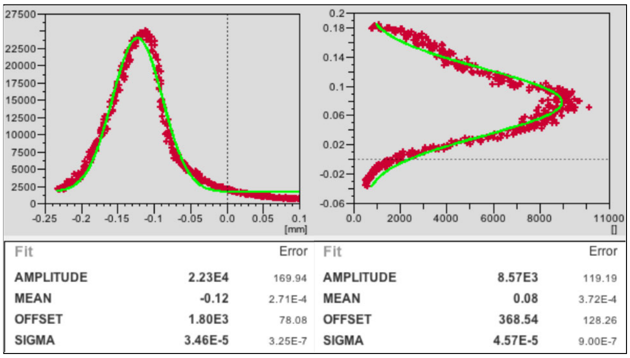


Figure 5: Raw data plot of detector data of one of the first fast scans. x-axes is in micro seconds, y-axes are arbitrary units from detector ADC. The upper plot shows a bunch train with about 300 bunches (repetition rate of 1.1 MHz) with 250 pC per bunch hitting a 20 µm tungsten wire moving with 1 m/s. At 800 µs the bunch train starts, the wire hits the beam core at ca. 950 µs.The lower plot is zoomed to three bunches near the core.

systems. If a prepared wire scanner unit receives such bits it arms the motor and starts with a following timing system pre-trigger event. Additionally this timing pattern masks all relevant beam loss monitors and transmission interlocks in the beamline section for this bunch train so that losses forced by the wire do not stop the beam and disturb both, the measurement and machine operation. Figure 5 shows a detector raw data plot of one of the first fast scans.

Within the DOOCS control system data sets of detector data and the corrected wire position is sampled. Figure 6 shows a horizontal and vertical fast scan.



Fit		Error
AMPLITUDE	2.23E4	169.94
MEAN	-0.12	2.71E-4
OFFSET	1.80E3	78.08
SIGMA	3.46E-5	3.25E-7

Fit		Error
AMPLITUDE	8.57E3	119.19
MEAN	0.08	3.72E-4
OFFSET	368.54	128.26
SIGMA	4.57E-5	9.00E-7

Figure 6: Two fast wire scans with 20 µm wire at 250 pC per bunch. Left the horizontal plane and right the vertical plane ist shown. A gauss fit is displayed in green.

CONCLUSION

Precise triggering of the wire scanner motor is essential to hit bunches reliable and repeatable. Furthermore simultaneously masking of BLMs and transmission interlocks through the general timing system is important to allow measurements without blocking these systems longer than necessary (max. one bunch train).

We have shown, that the developed system is able to measure beam emittances in a fast manner within a single long bunch train without interruption of user operation. While slow scans are meanwhile a standard tool for automated halo measurements and beam optics matching the fast scans are currently under final implementation for operation.

ACKNOWLEDGEMENTS

We thank A. Delfs, V. Gharibyan, I. Krouptchenkov, D. Lipka, D. Noelle, M. Pelzer, P. Smirnov, H. Tiessen, M. Werner, K. Wittenburg, A. Ziegler for wire scanner design and installation and O. Hensler for software development.

REFERENCES

[1] D. Nölle, "The Diagnostic System at the European XFEL; Commissioning and First User Operation", in *Proc. IBIC'18*, Shanghai, China, Sep. 2018, pp. 162–168. `doi:10.18429/JACoW-IBIC2018-TUOA01`

[2] MicroTCA, `https://www.picmg.org/openstandards/microtca`

[3] Nina Golubeva, "XFEL post-linac measurement sections: Upgrade of optics and screen / wire locations", DESY internal note, July 2018.

[4] T. Lensch, S. Liu, and M. Scholz, "The European XFEL Wire Scanner System", in *Proc. IBIC'18*, Shanghai, China, Sep. 2018, pp. 498–500. `doi:10.18429/JACoW-IBIC2018-WEPC05`

[5] T. Wamsat and T. Lensch, "The European XFEL Beam Loss Monitor System", in *Proc. IBIC'18*, Shanghai, China, Sep. 2018, pp. 357–360. `doi:10.18429/JACoW-IBIC2018-WEOB03`

[6] S. Liu *et al.*, "First Beam Halo Measurements Using Wire Scanners at the European XFEL", in *Proc. FEL'17*, Santa Fe, NM, USA, Aug. 2017, pp. 255–258. `doi:10.18429/JACoW-FEL2017-TUP003`