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A FAST WIRE SCANNER SYSTEM FOR THE EUROPEAN XFEL AND ITS IMPACT ON SAFETY SYSTEMS

T. Lensch*, T. Wamsat, 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 12 Wire Scanner stations are used to image transverse beam profiles in the high energy sections. These scanners provide a slow scan mode for single bunch operation. When operating with long bunch trains (>100 bunches) fast scans are used to measure beam sizes in an almost nondestructive manner. To operate fast scans multiple impacts on the beam loss system (BLM) and the charge transmission interlock (TIS) have to be taken into account. This paper focusses on the interaction between these systems and first experiences performing 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].

Wire Scanners at E-XFEL

Wire Scanners are widely used for beam profile measurements. A fork equipped with thin wires passes through the electron beam. The wire interaction with the beam produces scattered electrons and showered particles downstream the wire scanner unit which are detected by photomultipliers. The signal plotted over the wire position represents the beam profile (see Fig. 1).

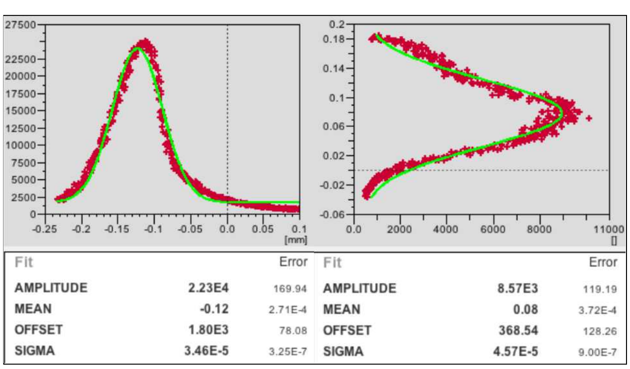

Figure 1: Profiles measured by wire scanners with 20 µm wire at 250 pC per bunch. Left the horizontal plane (x-axis: wire position, y-axis: photmultiplier signal) and right the vertical plane (axes swapped) is shown. A Gauss fit is displayed in green.

At the E-XFEL there are 14 wire scanner units installed. Each wire scanner unit consists of two motorized forks (horizontal and vertical plane) driven by a linear servo motor. This 90 ° configuration of motors helps to avoid vibration influences. 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. 2). The wire position is measured with an optical linear ruler. [3]

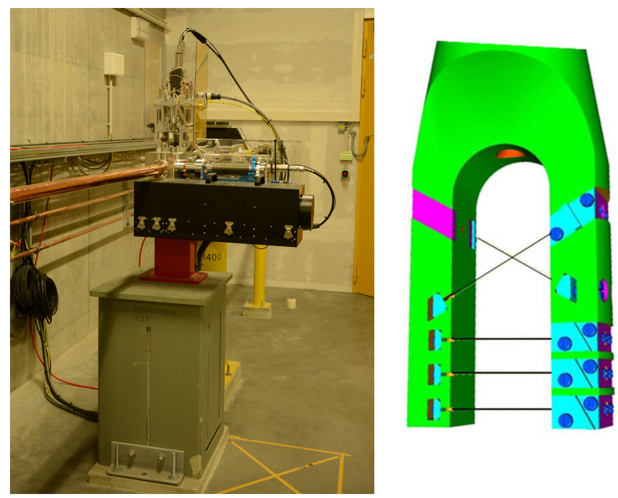

Figure 2: Left: wire scanner unit with horizontal and vertical plane installed in the E-XFEL with a screen station in the foreground. Right: 3D drawing of the fork with the different wires. Wire thicknesses from bottom to top: 50, 30 and 20 µm) and two crossed 60 ° wires (10 µm).

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. Scattered electrons and showers are detected by several dedicated photo multipliers installed downstream each set of wire scanner units. Figure 3 shows the distribution of wire scanner units in the E-XFEL.

SCAN MODES

The wire scanner system developed for the E-XFEL supports *Slow* and *Fast Scans* for different measurement purposes.

Slow Scan

Slow scans are performed with single bunches (one bunch every 100 ms) at the E-XFEL. Thereby the wire is driven slow (i.e. 0.2 mm/s) for a distance of a few millimeters

* timmy.lensch@desy.de

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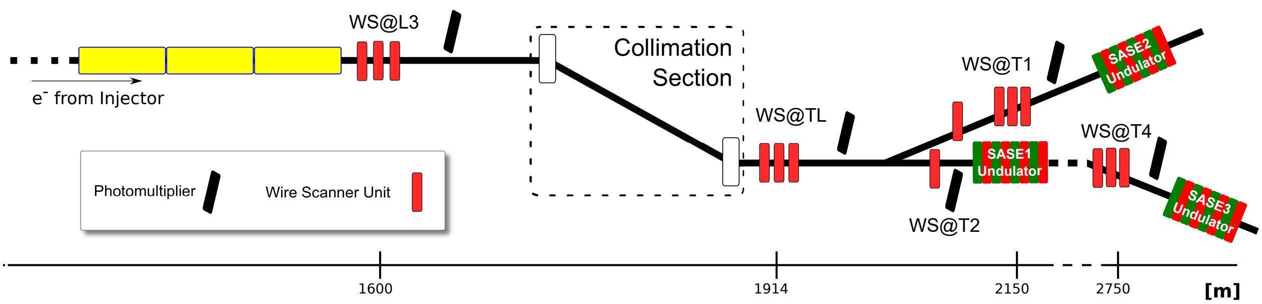

Figure 3: Simplified overview of 14 wire scanner units and detectors. Dedicated wire scanner detectors are installed about 15-60 m downstream of the last wire scanner unit respectively. Regular BLMs are installed all over the machine at certain positions.

through the beam. A profile measured in slow scan mode takes several seconds per plane (horizontal or vertical) and is typically used during machine studies to measure beam halo distribution [4].

Fast Scan

When operating with long bunch trains (>100 bunches) fast scans are used to measure beam sizes in an almost non-destructive manner. This scan mode offers a beam profile measurement within a single bunch train (600 µs) during user operation. Therefore a tungsten wire is driven with a speed of 1 m/s through the electron beam hitting several hundreds of bunches.

Figure 4 shows a photomultiplier raw signal of scattered electrons. Plotting this signal over wire position represents again the beam profile (see Fig. 1).

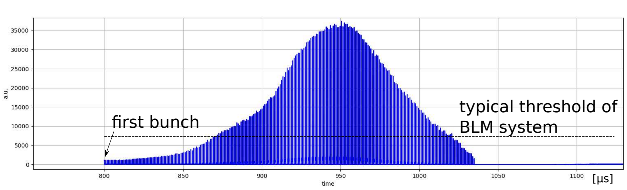

Figure 4: Raw data plot of a photomultiplier signal of a fast scan. X-axis is in micro seconds, y-axis is in arbitrary units from detector ADC. At 800 µs the bunch train starts, the wire hits the beam core at ca. 950 µs. This fast scan measurement gives a profile within one bunch train. Several BLMs and TIS monitors downstream the wire would stop following bunches as thresholds are exceeded (dashed line).

IMPACTS ON INTERLOCK SYSTEMS

During wire scans scattered electrons which are used for the measurement are also detected by several Beam Loss Monitors (BLM) [5] and the Transmission Interlock System (TIS) based on Beam Charge Monitors [6] downstream the wire scanner unit.

An important restriction in *slow scan mode* is the limitation to single bunch operation which is done by a hard wired connection to the Machine Protection System (MPS) [7] which sets the beam mode to single bunch operation. Successive losses by BLMs or TIS monitors will raise an alarm to the MPS which then permanently stops beam operation until an operator resets the system. In *slow scan mode* no special action is necessary as the allowed number of successive losses is larger than the duration of a typical measurement (i.e. allowed number of successive loss overrun: 3.000 bunches, long taking halo measurement: 800 bunches).

In *fast scan mode* the wire hits several hundreds of bunches within a single bunch train. When losses detected by the BLMs or TIS monitors exceed certain thresholds the bunch train is stopped with a latency in the order of 10 µs which disturbs both, the measurement and machine operation. To prevent the BLM and TIS from cutting the bunch train the general timing system [8] distributes the trigger for the wire scanner and tags bunches (called special bunches) as *'used for wire scan'* which should not trigger an alarm.

Tagging of Bunches and Trigger a Wire Scan

Slow scans using single bunches produce tolerable losses during a typical measurement. Therefore no special tagging of bunches is needed.

To start a *fast scan* several steps are necessary. A software sets up a plane (horizontal or vertical) of a wire scanner unit. Subsequently the timing system is configured to tag certain bunches inside a bunch train and to trigger a wire scan. This information is distributed to all subsystems. The prepared wire scanner unit starts the wire motion and downstream BLMs and TIS monitors, which are configured accordingly, do not stop the beam if thresholds are exceeded in the associated bunch train. In the following bunch train (100 ms later) all BLMs and TIS monitors are not masked anymore.

Nevertheless, in case of losses outside tagged bunches the interlock systems generates an alarm and cuts the beam. Although if the wire motion is slower than 1 m/s the beam is stopped to prevent the wire from melting. These technical interlock relevant functionalities are realized by hard wire connections to the MPS system.

After wire motion and data taking the wire is driven to the home position during two following bunch trains without hitting the electron beam again.

The distribution of bunch tagging and triggers is done in real time between timing system and involved systems (BLMs, TIS, Wire Scanner Units). Inside these systems the

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information is processed by FPGA logic to be able to trigger the wire motion in the order of microseconds and to mask detected losses bunch synchronously in sub-microseconds.

Figure 5 shows a sequence diagram of systems involved to wire scans.

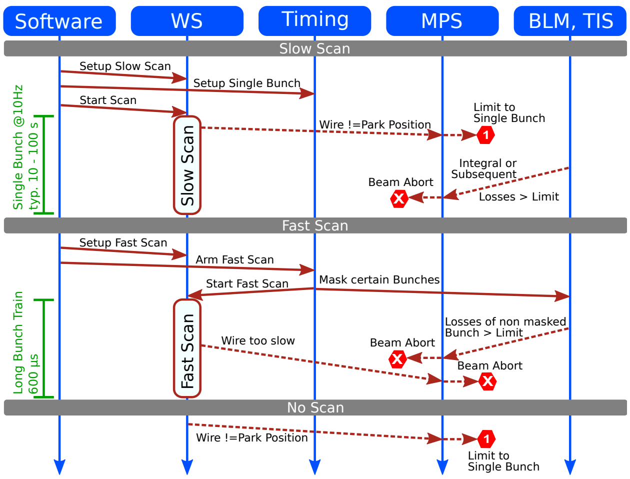

Figure 5: Sequence diagram of different scan modes. To perform a slow scan the timing system needs to be configured for single bunch operation. As a fallback the wire scanner system limits the bunch number through the MPS to single bunch operation. For fast scans the timing systems is essential to start synchronized action in distributed systems. Dashed lines are hard wired interlock connections between systems.

BLM and TIS Based Interlocks

In the E-XFEL there are about 400 photomultiplier based BLMs at certain positions. Additionally there are 36 charge monitors distributed over the whole machine. Consecutive charge monitors are able to detect poor transmission without blind spots along the machine. Scattered electrons and showered particles are detected by several BLMs downstream the wire and often by a charge monitor as well. Both systems raise different types of alarms to the MPS and though cut the bunch train (see Table 1).

Table 1: Alarm Conditions and Typical Thresholds

Alarm	BLM	TIS
Single	arbitrary unit / bunch	20 pC / bunch
Multi	a.u. / 30 bunches	500 pC / 30 bunches
Integral	a.u. / bunch train	10 nC / bunch train

A single alarm is masked completely if tagged bunches have been arrived from the timing system. Multi and Integral counters are not accumulated with losses tagged to be wire scan caused.

CONCLUSION AND OUTLOOK

The wire scanner system of the E-XFEL offers slow and fast scan modes. The software and firmware integration is widely grown. While slow scans are already being used for halo measurements and automated quad scans, fast scans are being introduced for coming applications.

Simultaneously masking of BLMs and TIS monitors and triggering the wire motion through the general timing system is essential to allow measurements without blocking these systems longer than necessary (max. one bunch train). Measurements are a trade off between tolerable and necessary losses during scans. Therefore it was helpful to implement trigger and masking schemes iterative into these systems.

In the future, wire scanners usage will be more automated in an emittance software environment and will be moved from expert-only usage to operators and scientists in daily use.

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