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COMPACT ELECTRO-OPTICAL BUNCH LENGTH DETECTOR: FROM AN EXPERT DEVICE TO AN OPERATOR TOOL

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Abstract

Laser-based electro-optic detection (EOD) has been a valuable tool to measure the longitudinal electron bunch shape with sub-ps resolution for more than a decade, but it has always been a tool for expert use. Recently, the server and the user interface have been updated, allowing automated laser locking, time calibration, and measurements to prepare for general operator use at the EuXFEL. It is currently prepared for EO Spectral Decoding measurements, but the implementation of advanced reconstruction algorithms (Diversity Enhanced EO Spectral Decoding) is ongoing. The paper presents details of the setup and user interface, as well as recent measurements.

INTRODUCTION

Short electron bunches with a high peak current are needed to drive the SASE process in free electron lasers (FELs) like FLASH or the European-XFEL [1, 2]. To reach these short bunches, the initially long electron bunches created at the photocathode guns are compressed in several magnetic bunch compressor chicanes at different electron bunch energies of hundreds of MeV in between accelerating sections.

Electro-optical bunch length detection (EOD) [3] offers the possibility of measuring the longitudinal bunch profile and arrival time in a non-destructive manner with single bunch resolution for every bunch in the bunch train.

The compact EOD setup at Eu-XFEL is in operation since 2016 and at FLASH a copy of the system has been installed in 2024 as part of the enhancement of longitudinal diagnostic capabilities within the recent FLASH2020+ upgrade [4]. However, until recently, the EOD measurements required expert knowledge, python or Matlab programs and a significant amount of manual interaction to the accelerator control system.

EOD SETUP

Electro-optically active crystals like gallium phosphide (GaP) become birefringent in the presence of an electric field. The electro-optical detection techniques use this effect to transfer the temporal profile of fast changing electric fields by sampling the change in birefringence with laser pulses. Afterwards, the modulated temporal profile of the laser pulse can be analysed with classical laser techniques. A schematic drawing of the setup for spectrally encoded electro-optical detection (EOSD) can be found in Fig. 1.

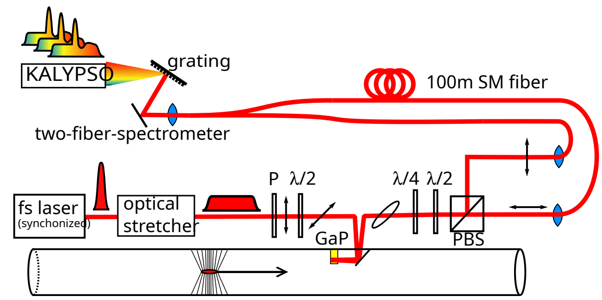

Figure 1: Schematic drawing of a spectrally encoded electro-optical detection setup. P: polariser; PBS: polarizing beam splitter.

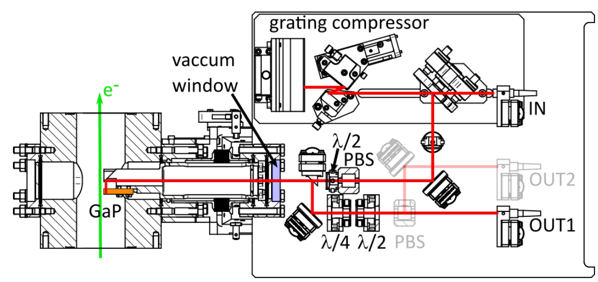

Figure 2: Assembly drawing of the optics set-up at the electron beam line including the vacuum chamber (left). PBS: polarizing beam splitter.

The EOD setup at the European-XFEL is installed at the exit of the 2nd bunch compressor, where the electron bunches have an energy of 700 MeV and usually a bunch length of 250 fs to 1 ps. The crystal is inserted from the side to avoid it being hit by the synchrotron radiation from the bunch compressor magnets (vertical dispersion). The edge of the crystal in the normal measuring position has a distance of about 5 mm from the electron beam path, which is sufficient to avoid particles from the beam halo in normal operation.

The required laser optics (see Fig. 2) are placed above the electron beamline, directly connected to the crystal holder for best alignment stability, while the laser and all electronics are placed in a radiation shielded rack underneath the beamline. For an extensive description of the setup, see Ref. [5].

The setup at FLASH is placed at the entrance of the 2nd bunch compressor at 550 MeV with similar electron bunch conditions, but the laser and electronics can be placed outside the accelerator shielding and can be accessed during accelerator operation and it is equipped with a two-channel

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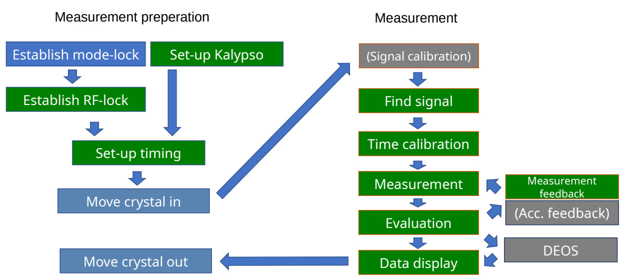

Figure 3: Flow diagram of the high-level functionality of the EOD-server. Completed automatisation in green, manual action required in blue, future tasks in gray.

version of the spectrometer to enable DEOS [6] measurements.

SERVER AND OPERATOR INTERFACE

The EOD setup is integrated in the doocs-based [7] FLASH and EuXFEL control system via the new EOD-server, which directly controls the KALYPSO line camera [8] and accesses and monitors other servers, necessary to operate the EOD, e.g. the servers for laser synchronisation [9], timing or motor control. The server programming is based on the ChimeraToolKit [10].

The server includes basic fault status detection, e.g. to warn the operator in case of laser synchronisation problems, takes care of background subtraction and signal normalisation and offers semi-automated ('single button') operation point search and time calibration. Bunch length, arrival-time and signal amplitude ($\propto$ bunch charge) are calculated for all bunches in a train with up to 1 MHz repetition rate, as well as a moving average for individual bunches in the train. The bunch properties are calculated by a Gaussian fit for on selected bunch from the bunch train and, for increased calculation speed, by numerical integration of moments for all bunches. A signal-based timing feedback keeps the signal centred in the measurement time window.

The server is also prepared for further extensions to include the DEOS reconstruction algorithm [6].

A flow diagram of the high-level functionality of the EOD-server is shown in Fig. 3. Some tasks still require manual action, like the timing setup after hardware changes or, for safety reasons, the insertion and extraction of the EO-crystal, but many tasks are now automatised or require only few, simple interactions by the operators. Figure 4 shows some examples of user-interface panels.

MEASUREMENTS

The new server allows easy online measurements of the bunch shape of full bunch trains at 1 MHz. Figure 5 shows, as an example, a moving average over nine consecutive bunches at a selectable position within the bunch train. For the given example, the measured rms bunch length is 1.15 ps (note that the bunch length displayed in the panel is 2σ).

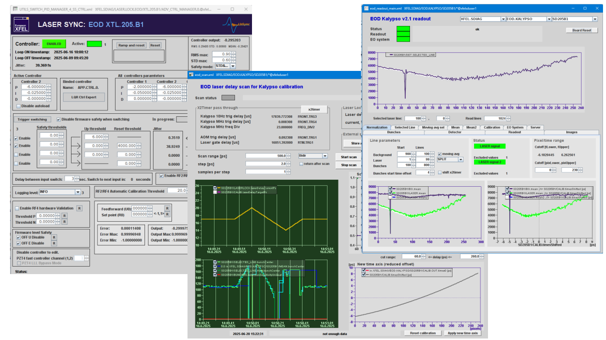

Figure 4: Some examples of the user interface panels (from left to right) for laser synchronisation, timing scans and normalisation settings.

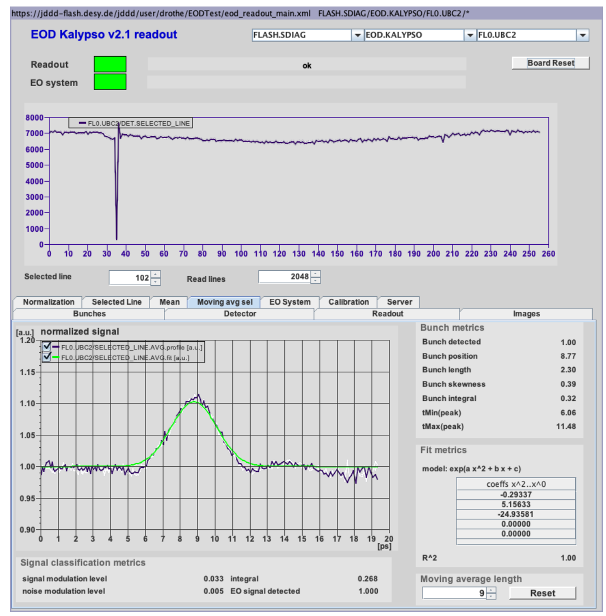

Figure 5: Online EOSD measurement at FLASH (note that the given bunch length is 2σ in ps).

CONCLUSION AND OUTLOOK

The compact electro-optical bunch length detector has been used at the EuXFEL since more than a decade, but has always been a tool for expert use. The improved server infrastructure adds a significant degree of automatisation and increases availability, enabling operators to use the system with ease. The integration of complete measurement and signal evaluation into the control system allows for long-term measurements and easy correlation with other accelerator parameters.

The server is prepared to implement advanced signal reconstruction algorithms in the near future.

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