

BUNCH ARRIVAL-TIME MONITORING FOR LASER PARTICLE ACCELERATORS AND THOMSON SCATTERING X-RAY SOURCES

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Abstract

The ELBE center of high power radiation sources at Helmholtz-Zentrum Dresden-Rossendorf combines a superconducting CW linear accelerator with Terawatt- and Petawatt- level laser sources. Figure 1 shows a layout of the facility and an overview of the secondary sources. Key experiments rely on precise timing and synchronization between the different radiation pulses. An online single shot monitoring system has been set up in order to measure the timing between the high-power Ti:Sa laser DRACO and electron bunches generated by the conventional SRF accelerator. This turnkey monitoring system is suitable for timing control of Thomson scattering x-ray sources and external injection of electron bunches into a laser wakefield accelerator.

INTRODUCTION

ELBE Accelerator and High-Power Lasers

The ELBE accelerator produces electron bunches up to an energy of 40 MeV in continuous wave (CW) operation [1]. The nominal repetition rate is 13 MHz while various pulse patterns can be generated by the two injectors. The first injector is a thermionic DC-gun operating at 235 kV followed by two normal conducting buncher cavities. It provides electron pulses with a charge of up to 100 pC. The second injector is a superconducting photo gun (SRF-Gun) that will provide electron bunches with a charge of up to 1 nC [2]. The main accelerator consists of two cryo modules, each equipped with two 9-cell TESLA-type cavities [3].

Adjacent to the conventional accelerator, two high power lasers have been set up, enable new experiments with high electric fields and ultra-fast time scales. The chirped pulse amplification Ti:sapphire system DRACO (Dresden laser acceleration source) produces laser pulses up to 6 J at a repetition rate of 10 Hz or 45 J at 1 Hz [4]

A fully diode-pumped laser system - PEnELOPE (Petawatt, Energy-Efficient Laser for Optical Plasma Experiments) is being constructed in the same area. A five stage amplifier system relying on Yb:CaF₂ as gain medium is designed for pulse energies of 150 J and a pulse duration of <150 fs at a repetition rate of 1 Hz [5].

Main fields of research are the development of novel compact and brilliant sources of energetic particle beams and potential applications, e.g., in the field of radiation oncology [6].

Thomson X-ray Source

The combination of high power lasers and the ELBE accelerator offers the opportunity to explore the physics of high-intensity laser-electron interaction. One application is the operation of a picosecond narrow-bandwidth Laser-Thomson-backscattering X-ray source. Here both beams are interacting in a dedicated target chamber. The generated narrowband X-rays are highly collimated and can be reliably adjusted from 12 keV to 20 keV by tuning the electron energy (24–30 MeV) [7].

In order to provide a constant photon flux the spatial as well as the temporal overlap between both pulses have to be ensured. Both beams are transported up to 100 meters so that temperature drifts and mechanical vibrations affect the pointing and arrival-time stability at target position.

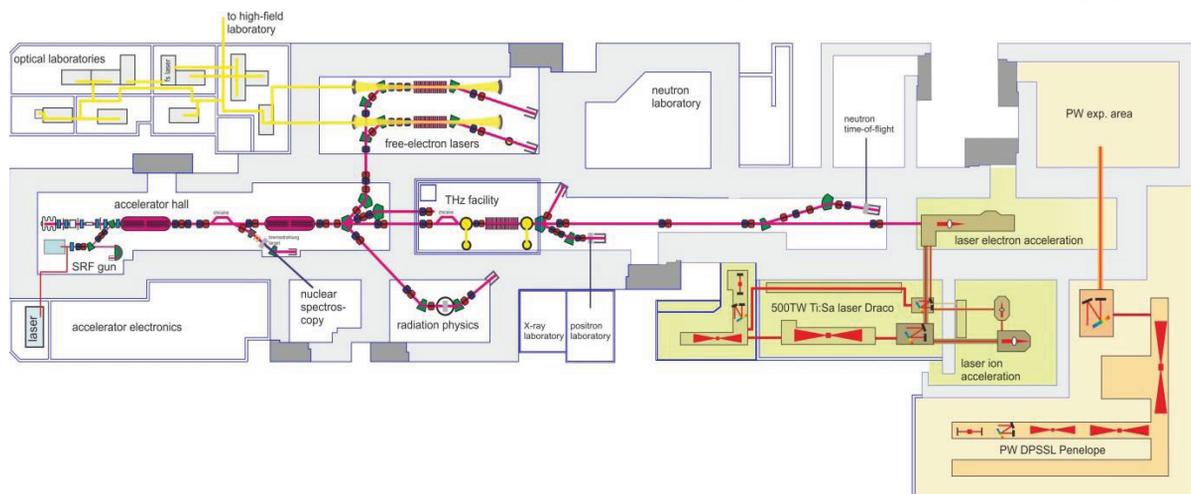


Figure 1: Layout of the ELBE - Center for high power radiation sources.

ARRIVAL-TIME MONITOR

Measurement Setup

The implemented bunch arrival-time monitor (BAM) directly measures the temporal relation between the laser pulse and the electron bunch next to the target for every single shot. Accordingly, no further external timing reference is needed. A broadband RF pickup acquires a probe of the particle bunch's electric field and modulates a fraction of the high power laser pulse in a fast electro-optical modulator (EOM). The amplitude modulation gives a direct measure for the timing between both beams. Figure 2 schematically shows the interaction point of both beams and the implemented BAM diagnostic.

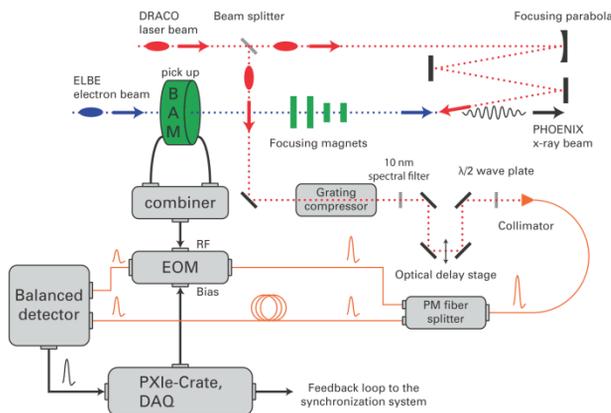


Figure 2: Thomson scattering X-ray source with implemented arrival-time online diagnostic.

The reference signal from the electron bunch is generated by a FLASH-type button pickup, developed by DESY [8]. It has an RF bandwidth of 12 GHz and was used before for the ELBE-BAM system operating at 1550 nm.

A beam splitter takes out a fraction of the main DRACO laser pulse serving as the optical reference signal. It is sent through a grating compressor to compensate for the chromatic dispersion in the following optical fiber. A spectral filter can be applied to adapt for the spectral bandwidth of the EOM. Limiting the optical bandwidth improves the extinction ratio of the used EOM (Photline NIR-MX800-LN-20) which gives a higher dynamic range and better resolution of the setup [9]. The EOM has a RF bandwidth of about 25 GHz.

An optical delay line allows adjusting the optical path length of the laser reference signal in order to match to working point of the BAM to the temporal overlap of the laser and electron beam of the Thomson source. Furthermore, calibrating the BAM is possible during operation without affecting the X-ray production.

After coupling the laser into an optical fiber, the laser signal is divided in a reference path and a measurement path using a polarization maintaining (PM) fiber splitter. The coupling ratio is chosen that the insertion loss of the EOM is compensated and both signals have the same amplitude on the detector at the working point.

The reference signal is used to normalize intensity fluctuations of the high power laser, which would appear as an arrival-time shift.

It has been found that a static splitting ratio gives not enough flexibility to adjust the power levels on the detector. The next iteration of the BAM will use a free space power divider based on a polarizing beam cube (PBC) and half lambda wave plates.

The balanced detector amplifies the amplitude difference between reference and measurement signal with a selected gain. The used model provides also the single detector responses so that signal conditioning can be done in the digital domain in order to minimize the noise floor of the measurement.

For the digital data processing a National Instruments PXIe-Crate is used. It is equipped with a fast ADC operating at 250 MHz to acquire the detector signals and a FPGA to calculate the relative arrival-time and to generate time stamps for each individual pair of pulses.

In the future the timing signal can be used for a slow feedback on the synchronization system between laser and electron accelerator. By adjusting the phase of the laser oscillator with an electronic phase shifter the arrival-time on the target position can be kept constant.

FIRST RESULTS

The setup has recently been commissioned and characterized during a Thomson beam time. Therefore a calibration measurement has been performed, meaning a temporal shift of the laser pulse with respect to the electron pulses. Figure 3 shows the calibration curve after optimization and the used working point. The rising edge has been linearized by fitting an appropriate function response to the inverse of the response function. The system gives a resolution of 167 fs RMS at a bunch charge of 47 pC. The dynamic range allows linear measurements within 27 ps before it comes to over-modulation in the EOM which gives ambiguous measurement results.

The resolution is mainly limited by high losses of the RF cabling (3.5 meters) due to spatial restriction and the imbalance of signal path and reference path.

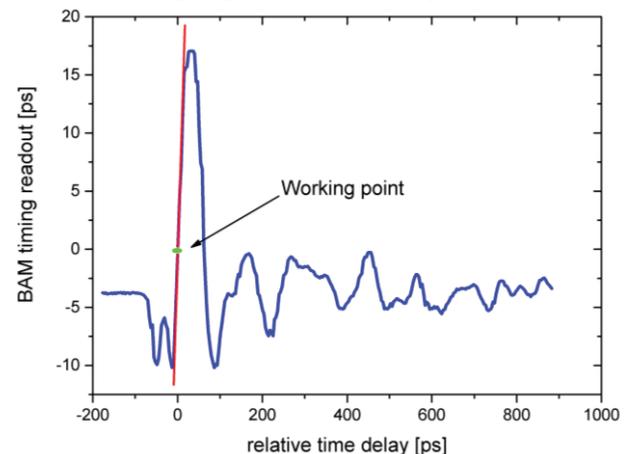


Figure 3: Calibration plot of the BAM setup.

The BAM has been used to monitor the arrival-time during the operation of the X-ray source. Figure 4 shows the relative arrival-time jitter of 3000 consecutive shots at 10 Hz repetition rate. A drift of 15 ps peak-to-peak between both sources could be observed while the fast jitter is on the order of 2 ps peak-to-peak.

This corresponds to measurements that have been taken earlier with BAMs installed at the ELBE beamline [10].

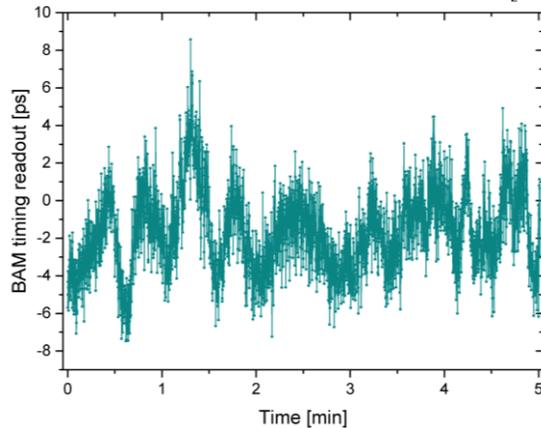


Figure 4: Measured arrival-time jitter between laser pulses and electron bunches on a time scale of 5 minutes.

CONCLUSION

An online timing diagnostic has been set up which enables non-invasive and single shot timing measurements with high accuracy. In the first commissioning run, a resolution of 167 fs RMS at a bunch charge of 47 pC was demonstrated.

The system has been used to monitor the arrival-time between high power laser pulses and relativistic electron bunches. A fluctuation of more than 15 ps could be observed on a five minute time scale.

OUTLOOK

The diagnostic system can be used for systematic jitter studies in order to improve the machine stability. The recovered signal can furthermore be used for a slow feedback to stabilize the arrival-time on target.

The resolution of the online monitor can be improved by using an RF-pickup providing a signal with higher spectral content. At ELBE two EuXFEL-type pickups are in use offering a spectral bandwidth of up to 40 GHz [11]. This pickup is foreseen as a future upgrade of the described setup.

As a next step the PM fiber splitter will be replaced by a free-space power divider based on a polarizing beam cube. By adjusting the preceding lambda half wave plate the power level can be perfectly balanced on the photo diodes.

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