EO-SAMPLING-BASED TEMPORAL OVERLAP CONTROL SYSTEM FOR AN HH SEEDED FEL

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Abstract

FELs have been greatly interested as intense light source in short-wavelength region. However, their temporal profile and frequency spectra have shot-to-shot fluctuation originated from a SASE process. One of the promising approached to the problems is a seeded FEL scheme by introducing full-coherent light pulses. It is important for the high order harmonics (HH) seeded FEL scheme to synchronize the seeding laser pulses to the electron bunches. The difference of their arrival timing is drifting at the meeting point in the first undulator. On the other hand, the spatial pointing of the seed laser must be smaller than transverse overlapping between HH-pulse and electron bunch. Therefore, an arrival time feedback system and non-destructive monitor are necessary to achieve seeded FEL operation continuously. We have constructed the arrival timing monitor based on Electro-Optic (EO) sampling which measures the arrival time difference of the seeded laser pulses with respect to the electron bunches simultaneously while the seeded FEL operation, in which the probe laser pulses for the EO-sampling is from the same laser source using as FEL-seeding. The EO-sampling system has been used for the arrival time feedback with less than 500 fs adjustability for continual operation of the HH-seeded FEL. The continual operation of the seeded FEL is feasible for day-long user experiments.

INTRODUCTION

SCSS test accelerator in SPring-8 Center has been operated as the HH-seeded FEL several times for the extreme ultraviolet (EUV) wavelength region [1]. The HH-seeded FEL is very powerful method to generate intense full-coherent and narrow-band pulses in short wavelength region. The HH-seeded FEL operation has been performed by synchronizing and spatial overlapping between the seeding laser pulse, which is generated from an ultra-short pulsed Ti:Sapphire laser pulses, and the electron bunches.

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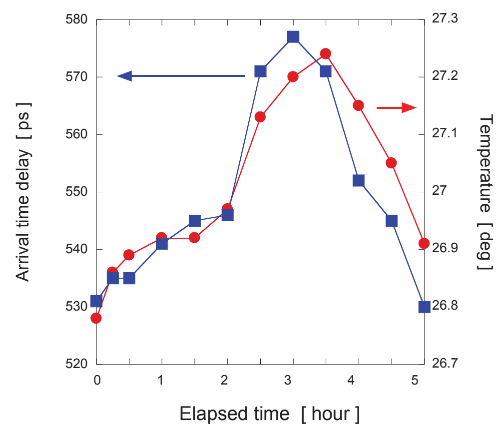

Figure 1: Drift of the arrival timing between the electron bunch and the laser pulse and the temperature in the facility for elapsed time.

We found that our seeding laser source has large drift of the arrival-time about 50 ps for a day as shown in Fig. 1. The drift was measured by the EO-sampling system and temporal delay control system described following section. The arrival timing drift was correlated with a variation in the environmental temperature at the accelerator facility as shown in Fig. 1. The electron bunch length (~600 fs) and seeding laser pulse length (~50 fs) are less than 1 ps. Therefore, it is necessary to achieve the temporal overlap between them within ~500 fs accuracy for the continual operation of the seeded FEL. The temporal overlap is indispensable for the arrival time monitor in real time without disturbing seeded FEL operation. EO-sampling measurement is one of the best methods to monitor the arrival time difference between the seeding laser pulses and the electron bunches [2, 3].

We built the temporal control system based on the EO-sampling technique employing the same external laser source for seeding.

ISBN 978-3-95450-119-9

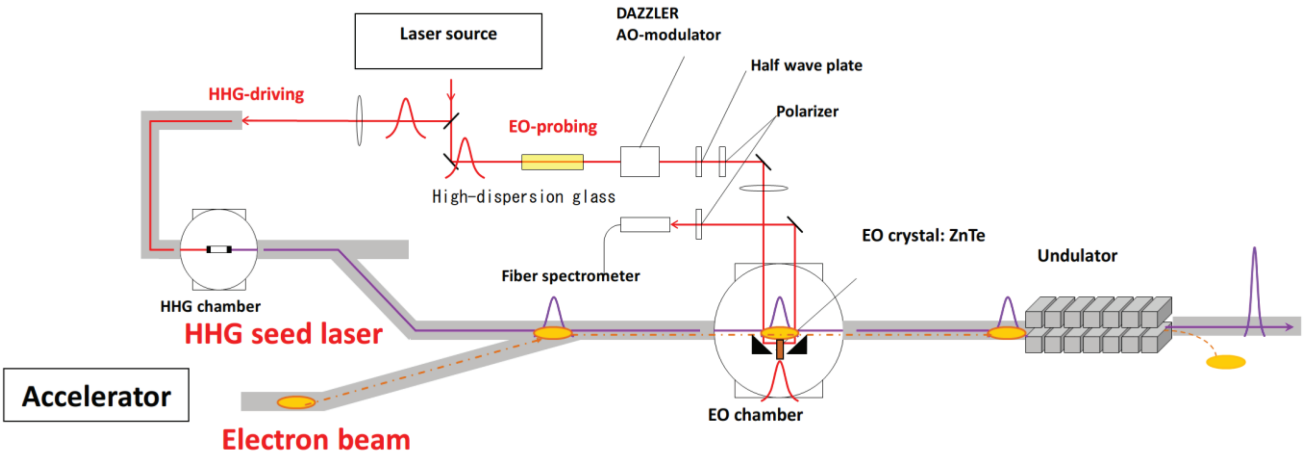

Figure 2: Layout of EO-sampling apparatus with seeded FEL setup at SCSS test accelerator.

EXPERIMENTAL SET-UP

The temporal-overlap keeping system with the EO-sampling scheme was built on the seeded FEL at SCSS test accelerator. The system set-up is shown in Fig. 2. The seeded FEL pulses were generated by interaction between the electron bunches and the HH seeding laser pulses at the entrance of the first undulator. We used the home-made ultrashort-pulsed Ti:Sapphire laser system, which generated 50 mJ pulse energy and 150 fs (FWHM) pulse duration. The laser pulses were focused in a Xe gas cell using a lens with f =4 m focal length and the pressure of the gas cell was optimized to obtain the maximum intensity of the 13th harmonic at 61.5 nm. The pulse energy of the HH pulses for the seeding source was estimated to be 2 nJ, and the HH pulses was focused at the entrance of the first in-vacuum undulators. The beam size of the HH pulses at the entrance of the first undulator was about 0.8 mm and 0.5 mm in the horizontal and vertical directions, respectively. The acceleration energy and the current of the electron beam were 250 MeV and 0.22 nC, respectively. Especially for the seeded FEL operation, the electron bunch length was stretched to 600 fs, which is longer bunch length than a normal user-operation condition of about 200 fs, so as to be easy to overlap the electron bunch and the seeding laser pulse in time. Moreover, longer bunch length is possible to reduce SASE output while seeded FEL operation. However, the external laser pulses have a large arrival time drift over 10 ps at the entrance of the first undulator (Fig.1.). Therefore, the temporal overlapping system is necessary to keep FEL-seeding. It is also necessary to keep maximum spatial overlap (in transverse) within sub-millimetres for the seeded operation.

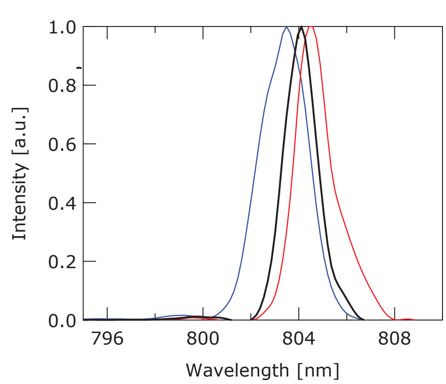

Figure 3: The normalized spectra of decoded probe pulse for the EO-sampling. The spectrum with central wavelength of 803 nm (blue line) showed the probe laser pulses arrived 1 ps earlier than the electron bunches. In the spectrum with central wavelength of 804 nm (black line), overlap between the probe laser pulses and electron bunches was in the best seeding condition. The spectrum with center wavelength of 805 nm (red line) showed the probe laser pulses arrived 1 ps later than the electron bunches.

For the temporal overlapping system using the EO-sampling scheme, the external laser pulse was split about 5 µJ for the probe pulse from 50 mJ by taking leakage from one of HR mirrors before the focusing lens for the HH generation. Then, the probe laser pulses were stretched to ~5 ps (FWHM) with the spectrum bandwidth of 5 nm (FWHM) by passing through high-dispersive glasses and a DAZZLER-AOPDF (FASTLITE Inc.). The AOPDF is a programmable acousto-optic modulator and was used to obtain linear chirp for the probe pulses. In addition, it was used to adjust the arrival timing of the probe laser pulses with respect to the HH seeding source at the EO-sampling chamber placed just before the first undulator. Therefore, the arrival timing drift of the HH seeding pulses and the probe laser pulses were negligible since both pulses passed in the same environmental condition. The arrival time of two pulses with respect to the electron bunches were controlled simultaneously by means of the temporal delay control system by means of synchronization electric circuits with <500 fs adjustability.

The stretched probe laser pulses had the chirp rate of 1 ps/nm. The EO crystal made from ZnTe has the thickness of 1 mm and the cross section of 3 x 4 mm. It was used for the EO sampling. The crystal was placed about 2 mm away from the electron beam axis. When the electron

ISBN 978-3-95450-119-9

bunches pass the side of the EO crystal, the polarization of the probe laser pulses is changed in the EO crystal by the electro-optic effect. For the EO-sampling scheme of spectral decoding, the timing difference is possible to measure shift of the corresponding peak wavelength of the decoded laser pulses.

EXPERIMENTAL RESULTS

The decoded spectra of EO-sampling measurements are shown in Fig. 3. In Fig. 3, the spectrum peaks at 803 nm, 804 nm, and 805 nm are corresponding to +1 ps delay, 0 ps, and –1 ps delay of probe laser pulses with respect to the electron bunch, respectively.

The EO-sampling system was used to monitor the temporal overlap between the probe laser pulses and the electron bunches. The arrival time drift was then calculated from the monitored peak position of the EO-measurement, and feedback to the synchronization system. At first we tried the closed-loop feedback, in which the trigger delay time for the compensation of the arrival time drift was calculated automatically in the computer program in terms of the peak position of the decoded EO-signal pulse. However, the closed-loop feedback was found to be difficult for long time operation due to shot-by-shot EO-signal fluctuation and arrival time jitter originated from the laser source. The external laser source has some fluctuations in the pulse energy, spectral intensity distribution, and timing jitter with ~1 ps. Then, the trigger delay was adjusted manually in a few-seconds cycle by monitoring the variation of the decoded EO-signal.

The output energies for the seeded FEL operation were shown in Fig. 4 for 90 minutes with keeping the arrival timing. The seeded FEL pulses were continuously obtained longer than seven hours, and pulse energy was achieved up to 20 μJ in the EUV region at 61.7 nm.

SUMMARY

We have constructed the EO-sampling based temporal overlap control system for the continual seeded FEL operation. By using the EO-sampling system, the seeded operation was continued over several hours with reaching 20 μJ pulse energy at the 61.7 nm wavelength.

The temporal resolution of the EO-sampling system is ~1 ps and the accuracy depends on the synchronization of external laser source using as seeding pulse and EO-probe pulse. In present study, the time resolution of the EO-sampling system was about 0.7-0.8 ps, and was not better than the bunch length of 0.6 ps. Moreover, the chirped probe laser pulse is conjectured having some high-order dispersion that causes degradation of time resolution. In order to achieve the closed-loop feedback control for the temporal overlap, the resolution of the EO-sampling system must be improved.

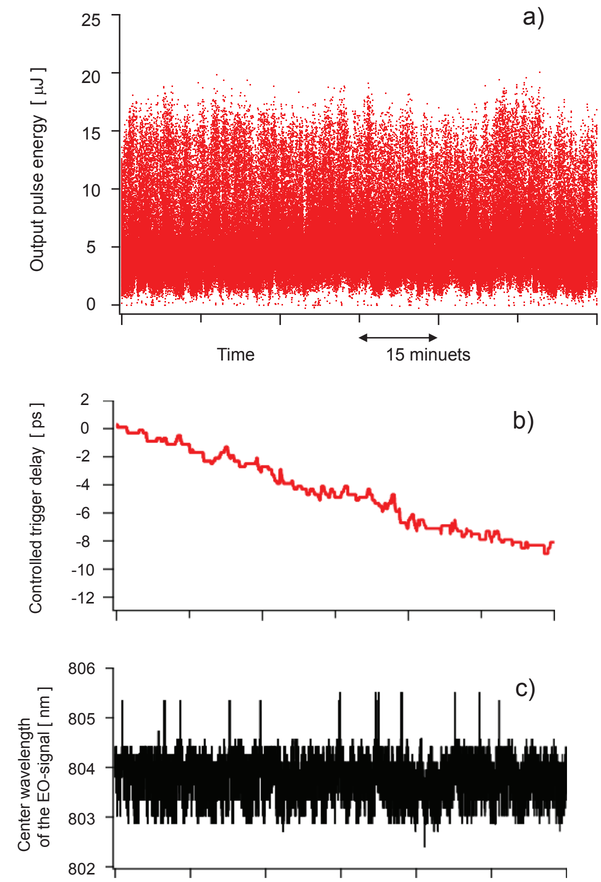

Figure 4: Experimental data for the seeded FEL lasing condition with timing feedback using the EO-sampling. a) Output pulse energy of the seeded FEL for 90 minutes operation. b) The time delay of the synchronization system that was changed to keep the temporal overlap for the seeded FEL operation. c) Central wavelength of the decoded EO-signal while the continuous seeded FEL operation.

In the near future, we are preparing the spectral broadband laser source over 300 nm for the EO-sampling system. In this experiment the spectral bandwidth of the EO-probe pulse was 5 nm with the chirp rate of 1 pn/nm. The chirp rate will be improved as 100 fs/nm. Then, the temporal overlapping control will be possible to perform with closed-loop feedback automatically. In our father project, we are planning to realize the 3D-EO-sampling for overlapping in all dimensions.

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