AN ELECTRO-OPTICAL SYSTEM FOR MAX-LAB TEST-FEL FACILITY*

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Abstract

To get information about arrival of the electron bunch relative to the laser pulse; electro-optic detection scheme in near-crossed polarizer configuration was set up and tested. Electron bunch induced birefringence in ZnTe crystal leaves a polarization footprint in a chirped infrared pulse. The IR pulse is sampled before third harmonic generation from the amplifier, stretched and synchronized to the ultraviolet beam that is used for seeding. We report details of this setup and preliminary jitter measurements.

INTRODUCTION

To seed a free electron laser good information about the electron bunch arrival time relative to the seed laser pulse is needed. Electro-optic effect (in which birefringence is induced by the electric field of electron bunch which is passing by a crystal) is often used for either timing measurements or for longitudinal bunch profile measurements. [1] The crystals that are used are those of zincblende structure, most often ZnTe and GaP (ZnTe usually gives better signal, but GaP has resonances on higher frequencies than ZnTe which makes it useful for bunch profile measurements). Those crystals are not birefringent in the absence of electric field. Technique (called spectral decoding) that is used at MAX-lab is using chirped infrared pulse to pass through the crystal. When electron bunch is passing by the crystal, the crystal becomes birefringent and the polarization of corresponding part of the infrared pulse is changed. The infrared pulse is then sent through polarizer which gives intensity modulation from change of polarization. After the polarizer, IR pulse is then spectrally decomposed to determine which part of spectrum experienced change in polarization. The wavelength corresponds to time (ideally, with certain limitations [2]), and information about timing of electron pulse, relative to the electron bunch, is determined.

EXPERIMENTAL SETUP

The EO-chamber

The test-FEL at MAX-lab uses two Ti:Sapphire lasers (Thales Alpha 10) with a common oscillator (Femtolasers Synergy, 93.7 MHz, locked to 3 GHz RF clock). One of

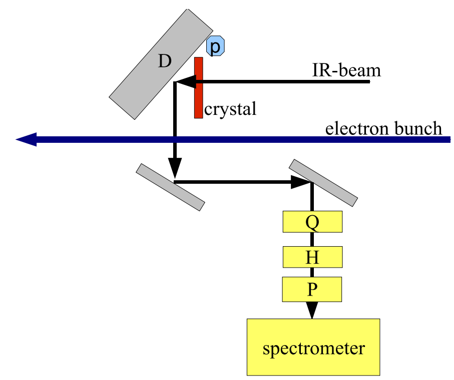

Figure 1: Position of the crystal relative to the electron bunch path. Infrared beam passes through crystal, is reflected of the D-mirror (D) and leaves the vacuum chamber. It is directed with two mirrors onto the quarter-wave plate (Q), half-wave plate (H), Glan-Thompson polarizer (P) and finally spectrometer. The reverse biased photo diode is on the same mount as the crystal (p).

them (263 nm, 10 ps, 10 Hz, 500 μJ) is used for photocathode operation and the other one (263 nm, 10 Hz, 300 fs, 150 μJ) is used for seeding the FEL. A part of the beam (about 10%) from the second laser is sampled before tripling to 263 and used for this electro-optical scheme. [3]

IR and UV Beam

The IR beam is sent to a stretcher (two 1200 l/mm gratings with changeable separation currently giving 10 ps/nm stretch), focusing lenses (effective focal length 6.5 m) and a delay stage. After the delay stage, it is combined with the UV beam (which passed its own focusing lenses) and they both go through a motorized delay stage (Thorlabs 150 mm) which controls the effective delay between electrons and the laser beams. Beams are then guided to the vacuum system and the seed laser insertion mirror.

Synchronization of IR and UV Beam

The goal for a seeded FEL is to overlap the UV laser pulse with the electron pulse. Here we use the stretched IR as a common reference and separately center both the UV and electrons on the IR profile. In the setup for UV-IR overlap both pulses are focused on a glass plate. The high intensity UV pulse generates a change in refractive index in the glass, affecting part of IR. Using a spectrometer it is

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then possible to position the UV pulse with an accuracy of 2 ps.

EO Chamber

The chamber in which the crystals are placed is positioned 30 cm in front of the modulator-undulator and after the first screen. Figure 1 shows the important part of timing setup. The crystals are mounted next to each other on a translatable stage (the distance to electron beam can be controlled). The stage carries both crystals (ZnTe and GaP), a D-mirror and a reverse biased photo-diode (which is used with an oscilloscope for rough time synchronization). The crystals are mounted next to each other in front of the D-mirror. D-mirror is rotated for 45° so that it sends the IR-laser beam out of the chamber under right angle. The translation stage is inserted by the amount so that the crystal is just about to start scraping off the alignment beam, and thus the electron beam and the UV-beam since they are all made to coincide (by use of two YAG-screens, before and after the modulator). The distance from the electron bunch to the point at the crystal through which the IR-laser is passing is approximately 4 mm.

Laser Beam Analysis

The IR-beam is coming from the EO-chamber and after passing one of the crystals it hits the D-mirror positioned behind the crystals, so that electrons pass next to it and the laser beam is reflected by it. The IR-beam then continues onto two silver mirrors, a quarter-wave plate, a half-wave plate, a Glan-Thompson polarizer, and finally a slit which is the entrance point to the spectrometer (consisting of a lens, a grating (1200 mm/l), and a CCD camera). The polarizer is set so that its trans-polarization plane is s-polarization for the grating of spectrometer. The quarter-wave-plate is then rotated so that the signal passing through to the camera (without the electron beam) is minimal. It is possible to stop anything noticeable to go through (due to high polarization ratio, and low residual polarization rotation when there are no electrons). This is done in order to minimize any polarization that builds up in the crystals and the whole system when there are no electrons. Then, the half-wave plate is inserted. If it is left in minimum-signal position that would be similar to crossed polarizer setup; instead, it is a bit rotated off so that it is possible to measure change in sign of THz polarization flip. The half-wave plate is rotated so that the signal of electrons will still not saturate the camera and that opposite polarization will not change sign. This rotation is about two degrees. The background on the camera when there are no electrons needs to be recorded and subtracted later in analysis of the data.

MEASUREMENT AND RESULTS

IR laser beam that is used for EO was stretched to 50 ps (FWHM) and focused on the crystal. The wave plates were positioned and rotated as previously described. The electron bunch with energy of 400 MeV and estimated charge of 50 pC that is planned for running of the FEL was used to induce birefringence in the 1 mm thick ZnTe crystal. A thick crystal and highly chirped pulse were selected in order to get higher signal and be sure that something will be observed in initial measurements. The CCD camera in the spectrometer was triggered on the repetition of the injector (in this case 2 Hz).

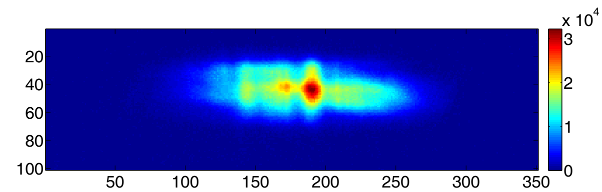

Figure 2: Colored signal on the spectrometer (x and y axis both in pixels). Although horizontally the wavelength span of 5 nm is changing linearly, the corresponding time is due to non-linear chirp of the IR laser pulse.

Figure 2 shows the signal on the spectrometer. The horizontal scale is actually frequency (5 nm of bandwidth mapped). From this image the background still needs to be subtracted. The image is summed vertically into bins (corresponding to one pixel).

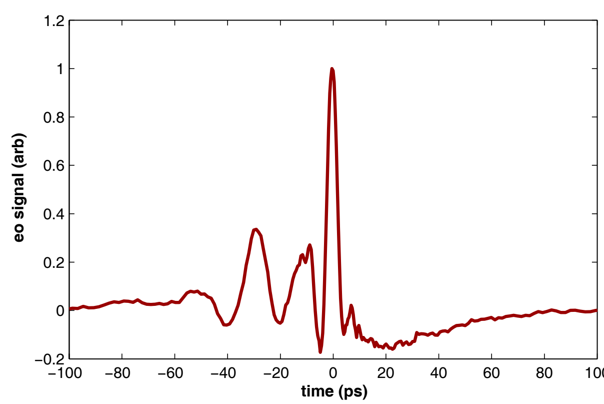

Figure 3: Measured signal obtained from one shot, after background subtraction. The horizontal axis is chirp-adjusted and translated to the maximum. The origin of the oscillations with 20ps period is to be investigated. The dip in signal between 10 and 40 ps is because of spectral instabilities of the oscillator.

The actual timing on the horizontal axis was measured by shifting the laser in time with delay stage and observing the electron signal characteristics. Using changes in time resolution (number of ps per pixel) the non-linearity of the laser chirp was modeled by a polynome of second order. The horizontal axis was adjusted to proper time scale. Figure 3 shows the signal obtained in such a way with adjusted horizontal scale.

Measurement of the relative jitter between the laser pulse and the electron bunch was done by acquiring data from the EO system without changing anything else. The preliminary results show a root mean square jitter of 2 ps which would be too high for normal operation of the FEL. Further measurements are needed to confirm this initial one, get more statistics and to test what might be the dominant underlying cause of this significant jitter.

CONCLUSION

First signals from the electro-optical system at the test-FEL at MAX-lab were obtained using spectral decoding in near-crossed polarizer setup. Initial measurements show stable and reproducible operation of the setup but also indicate high jitter between electron bunch and seed-laser beam. Improvements in resolution are planed in the EO system by use of the time decoding. The resolution of the system is enough to be used while searching the temporal overlap between the seed laser and the electron pulses. Thus a major obstacle for the continued commissioning of the Harmonic Generation at the test-FEL has been removed.

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