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ELECTRO-OPTICAL SPECTRAL DECODING OF THZ PULSES AT MHZ REPETITION RATES

M. M. Patil*, E. Bründermann, M. Caselle, S. Funkner, L. L. Grimm, G. Niehues, M. Reißig, J. L. Steinmann, C. Widmann, A.-S. Müller,
Karlsruhe Institute of Technology, Karlsruhe, Germany

Abstract

A far-field electro-optical (EO) setup based on a balanced detection scheme has been set up to measure the coherent synchrotron radiation (CSR) at the Karlsruhe Research Accelerator (KARA). To enable the readout with a electro-optical spectrally decoded scheme (EOSD), a KALYPSO-based line array camera, sensitive to NIR operating at a readout rate of 2.7 MHz, has been included in the set-up. In this contribution, measurement results with the KIT-developed ultra fast line array camera KALYPSO-based spectrometer in combination with a commercial THz emitter are presented.

INTRODUCTION

The Karlsruhe Research Accelerator (KARA) serves as both, synchrotron light source and accelerator test facility. One distinctive operational mode of KARA is the low-α_c mode, wherein the longitudinal bunch size of electron bunches is reduced to a few picoseconds. This mode leads to the emergence of microstructures within the longitudinal phase space of the electron bunch, a phenomenon commonly referred to as the microbunching instability [1].

Concurrently, this results in the emission of intense and short bursts of coherent synchrotron radiation (CSR) within the THz region. Investigating this radiation is pivotal for understanding the microbunching instability.

Observing the rapidly changing beam dynamics requires both single-shot and turn-by-turn measurements. This capability has been successfully demonstrated using the near-field electro-optic spectral decoding (EOSD) setup at KARA [2]. This setup is capable of measuring the Coulomb field of the electron bunch with the in-house developed KALYPSO (Karlsruhe linear array detector for MHz-repetition-rate spectroscopy). KALYPSO enables single-shot turn-by-turn measurements at a frame rate of 2.7 MHz, the frequency also being the revolution frequency of KARA [3,4].

Currently a far-field EOSD setup is in commissioning, which aims at measuring the temporal profile of the CSR by far-field EOSD to combine it with simultaneous single-shot near-field measurements by EOSD at KARA.

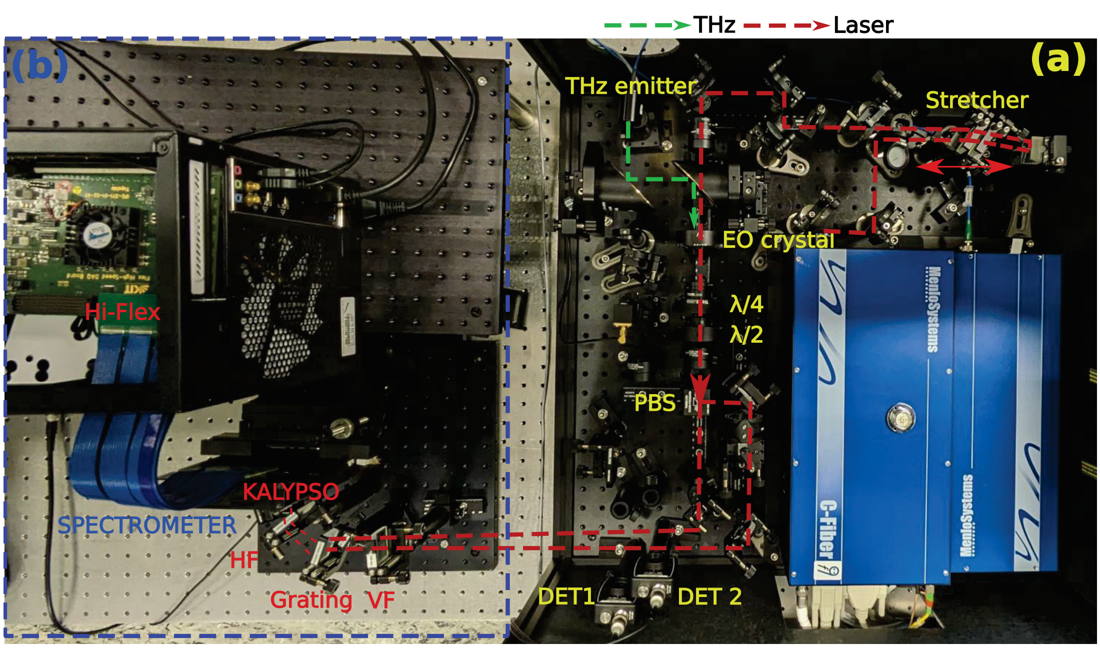

Figure 1: The far-field EOSD setup for measuring THz pulses. The right section (a) of the image consists of the free-space port of the commercial laser, fiber port for the THz emitter, the pulse stretching with two transmission gratings, GaAs crystal, polarization optics, a polarized beam splitter (PBS) to transmit vertically and horizontally polarized laser to the two photodetectors (DET1, DET2) for balanced EOS. On the left section (b) of the image, the transmission grating based spectrometer is shown, along with horizontal and vertical focussing lenses, InGaAs based KALYPSO with its DAQ card Hi-Flex.

* meghana.patil@kit.edu

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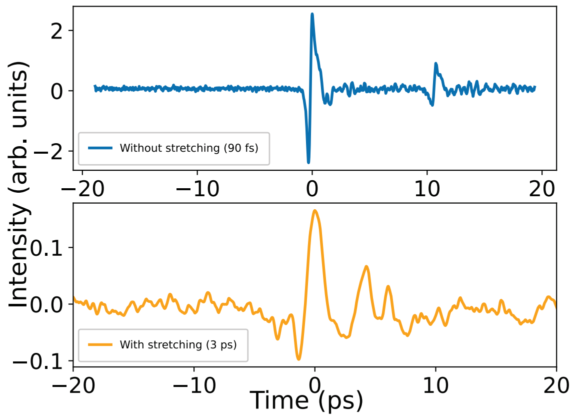

Figure 2: EOS scans of the laser pulses before and after stretching. The blue plot corresponds to the EOS signal measured without stretching (laser pulse length at 90 fs) and the yellow plot corresponds to the EOS signal with stretching (laser pulse length at 3 ps).

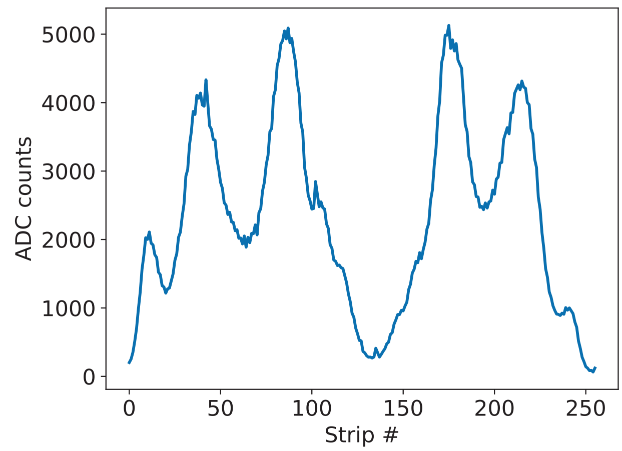

Figure 3: Balanced spectrum as measured by KALYPSO. Strips 0-127 show the laser spectrum with horizontal polarization while the strips 128-256 show the laser spectrum with vertical polarization.

EXPERIMENTAL SETUP

The experimental setup employed for the characterization of the coherent synchrotron radiation (CSR) temporal profiles has been extensively described in prior work [5]. Presently, a commercially available THz emitter [6] is used for system validation and optimization.

In brief, the far-field EOSD experimental setup (see Fig. 1) at first involves precise measurement of the temporal characteristics, which is also known as electro-optic sampling (EOS). This is achieved by using linearly polarized laser pulses with a central wavelength of 1560 nm. These pulses are stretched to a few picoseconds and the chirped pulses then pass through a gallium arsenide (GaAs) electro-optic (EO) crystal. THz pulses are simultaneously transmitted through the crystal and temporally overlapped with the laser pulses. During the temporal overlap, the THz pulses cause the birefringence of the crystal to change resulting in a change in the polarization. This change in polarization leads to a change in the laser intensity, which can be achieved by using a combination of $\lambda/4$ and $\lambda/2$ waveplates in a near crossed configuration. A balanced detection technique consisting of a polarising beam splitter and two photo detectors is used to detect the intensity modulation. The two photodetectors are readout by a lock-in amplifier. The temporal difference between the THz signal and the laser pulse is changed by moving the mechanical delay stage for the THz emitter included in the laser system.

Figure 2 shows two EOS scans performed with and without stretching the laser pulses. The laser pulses are stretched in order to encode the CSR profile on the temporal profile of the laser pulse and in turn on the spectral components. A combination of two transmission gratings (600 grooves per millimeter) are used to stretch and thereby also chirp the laser pulses. The amount of stretching can be adjusted by changing the distance between the two gratings. While the laser pulse length without stretcher is 90 fs, using the stretcher, it can be varied from 3 ps to 16 ps in the current setup. Several EO scans have been performed at different grating distances and have been reported in [7].

In Fig. 2 the gratings are set to a distance to achieve a pulse length of around 3 ps. The modulation of the laser pulse can be clearly seen in the non-stretched setting, however when stretched, the intensity decreases substantially. The reason for the reduced EO signal is that when chirped, the laser peak intensity gets distributed over a longer period. And consequently, within the sampling window of the photodetectors, intensity measured at any given time is lower than that of a non-chirped pulse, where the laser intensity is concentrated over a short duration. Once the temporal overlap position is identified, the vertically and horizontally polarized laser pulses are decoupled from the two photodetectors and transmitted towards a single shot spectrometer setup consisting of a vertically focusing (VF) cylindrical lens, two horizontally focusing (HF) cylindrical lenses, a transmission grating and a line camera KALYPSO based on indium gallium arsenide (InGaAs) [8]. The InGaAs sensor consists 256 microstrips with a pitch of 50 µm. The framerate of KALYPSO is 2.7 MHz while the laser system has a repetition rate of 62.5 MHz. Hence, currently only one in every 23 laser pulses is measured, however, it is possible to perform turn-by-turn measurements while the repetition rate of KARA is 2.7 MHz. The spectrometer setup has been optimized and the resulting spectrum is comparable with that measured using a commercial spectrometer [9]. However, performing single-shot balanced detection on the same KALYPSO is tricky due to the limitations posed by the total area of the InGaAs sensor as well as the bulky optics currently used to accommodate the two laser spots on the sensor. A measurement of the optimized spectrometer setup is shown in Fig. 3. It can be seen that the two spectra are not

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completely equal. The spectrum on the right is horizontally flipped due to a mirror used for lateral movement of the spectrum on the sensor of KALYPSO. Spectral measurements were also performed with and without the laser intensity modulation (with and without enabling the THz emitter). We expect that with further improvement of the currently low EO signal and by equalizing the spectra the modulation can be measured.

SUMMARY AND OUTLOOK

This paper describes the current status of the far-field EOSD setup at KARA. The optics have now been adapted to easily switch from EOS to EOSD. The spectrometer setup has been improved. The effort to make the balanced detection on KALYPSO to work is in progress.

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