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ENHANCING THE SENSITIVITY OF THE ELECTRO-OPTICAL FAR-FIELD EXPERIMENT FOR MEASURING CSR AT KARA

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Abstract

At the KIT storage ring KARA (Karlsruhe Research Accelerator), a far-field electro-optical (EO) experimental setup to measure the temporal profile of the coherent synchrotron radiation (CSR) is implemented. Here, the EOSD (electro-optical spectral decoding) technique will be used to obtain single-shot measurements of the temporal CSR profile in the terahertz frequency domain. To keep the crucial high signal-to-noise ratio, a setup based on balanced detection is under commission. Therefore, simulations are performed for an optimized beam path and the setup is characterized. In this contribution, the upgraded setup and first measurements are presented.

INTRODUCTION

The Karlsruhe Research Accelerator (KARA), the storage ring of the accelerator test facility and synchrotron light source of Karlsruhe Institute of Technology (KIT), can be operated in a special short-bunch mode. Thereby, the momentum compaction factor is reduced leading to short bunch lengths of a few picoseconds at a beam energy of ≤ 1.3 GeV and beam currents of some milliamperes.

While we have shown sophisticated near-field electro-optical spectral decoding (EOSD) measurements [1], recently, a far-field EOSD setup is under commission aiming to measure the full temporal profile of the emitted coherent synchrotron radiation (CSR) with single-shot measurements to study the effects of the electron bunch dynamics. In single-bunch operation of KARA with a revolution frequency of 2.7 MHz, we aim to observe the bunch each turn. To measure pulses at MHz repetition rates, Karlsruhe linear array detector for MHz-repetition-rate spectroscopy (KALYPSO) [2,3], our KIT in-house developed ultra-fast line array detector, allows turn-by-turn detection.

While KALYPSO can cope with the MHz repetition rate in single bunch operation of KARA, there are more challenges for the far-field EOSD measurements of the CSR to overcome: Recently, we demonstrated [4] an enhancement of the sensitivity for electro-optical sampling (EOS) measurements in a demonstrator setup using a balanced detection scheme with two photodiodes, in particular using a telecom wavelength laser source. While these measurements are not single-shot measurements using a delay stage to scan the THz pulses, we have now started to design a balanced detection scheme for single-shot EOSD measurements. In this contribution, we provide an overview of our demonstrator setup, describe optics simulations for optimizing the configuration of the spectrometer setup using KALYPSO for balanced detection and show measurements to analyze the spectral distribution on the sensor as well as first test measurements with two spatially separated beam spots.

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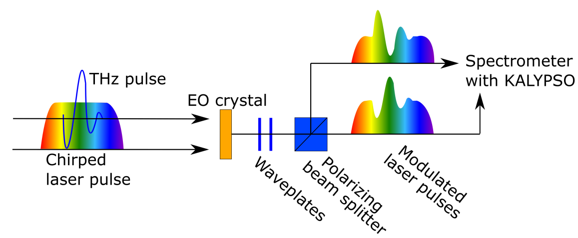

Figure 1: Schematic of the EOSD setup using balanced detection [4].

FAR-FIELD DEMONSTRATOR SETUP

While we aim to detect the CSR profile using EOSD, we first built a demonstrator setup using a commercial THz source to be independent of the accelerator operation for setting up and testing. Details of this setup can be found in ref. [4]. In short, linearly polarized, chirped laser pulses around 1560 nm central wavelength [5] are overlapped with THz pulses in an EO crystal (ZnTe) (Fig. 1), both created from the same laser system. The THz pulses introduce a change of the birefringence of the EO crystal, leading to a change of the polarization of the laser pulses. Using a nearly-crossed configuration of polarization optics, the modulation of the polarization is transferred into a spectral intensity modulation. We aim to detect this intensity modulation using a spectrometer setup with KALYPSO.

In ref. [4], we described EOS measurements using balanced detection to characterize and optimize the EO part of the setup. Now, we integrated a spectrometer consisting of a transmission grating and a cylindrical lens with KALYPSO as detector to perform single-shot EOSD [6] measurements of the temporal THz pulse profile.

Here, a major difference between the current demonstrator setup and the far-field setup using KARA in single bunch operation plays an important role: While the laser system and thus also the THz emitter [5] are operated at 62.5 MHz, single bunch operation provides THz pulses at 2.7 MHz repetition rate. A reduction of the repetition rate using a pulse picker is under investigation, but currently hampered by the low efficiency of available pulse pickers with the required repetition rates leading to low laser pulse power. Neverthe-

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less, the beam path is further optimized for future use in balanced detection with KALYPSO.

The prerequisite parameters are given by the laser beam after the polarising beam splitter (PBS) in Fig. 1, a transmissive grating with 600 grooves/mm as well as the size of the sensor. We use an InGaAs sensor (see ref. [2] and inset of Fig. 2) with a frame rate of 2.7 Mfps, 256 microstrips with a strip pitch of 50 µm. This leads to a total width of the sensor of 12.8 mm with a height of 0.5 mm. Thus, for balanced detection with two beam spots, each beam spot needs to be smaller than 6.4 mm.

SPECTROMETER SETUP FOR BALANCED DETECTION

Simulations

The optical beams and elements were simulated using VirtualLab Fusion Software [7] applying ray tracing as a first approach and field tracing for the final analysis. The beam path was optimized between the PBS and KALYPSO consisting of a transmission grating with 600 grooves/mm and a cylindrical lens (Fig. 2). Lenses with focal lengths between 40 mm and 70 mm were analyzed. Besides a variation in the focal length of the lens, the distance between the grating and the lens was optimized. Optimum settings were determined with a focal length of 60 mm for the lens and a distance of 59 mm between the grating and the lens.

Measurements

The integration of the spectrometer for balanced detection using KALYPSO as detector was done in two steps: First, one beam path of the spectrometer was set up according to the optimized parameters from the simulation to characterize and analyze the spectral distribution of the laser beam in the plane of the detector. Second, both beam paths were integrated and the profiles were detected with KALYPSO.

For the analysis of the spectral distribution, a commercial fiber-coupled spectrometer was used [8]. The laser beam was coupled into a polarization maintaining single mode fiber with a fiber collimator. A slit (width 100 µm) was attached to the fiber collimator to cut out a small part of the laser beam for spectral analysis corresponding to the width of two strips of the sensor. With this setup, the spectral profile was scanned. The result is shown in Fig. 3. Three spectra detected at three different slit positions are shown. At each position, a narrow spectrum in the range of 2 nm width (full width at half maximum) is achieved as required. The detected intensity maxima is illustrated for each measured spectra at the different wavelengths. The obtained spectrum has a distribution similar to the laser spectrum given by the manufacturer showing the same features. The measurement range of the commercial spectrometer is limited to 1600 nm.

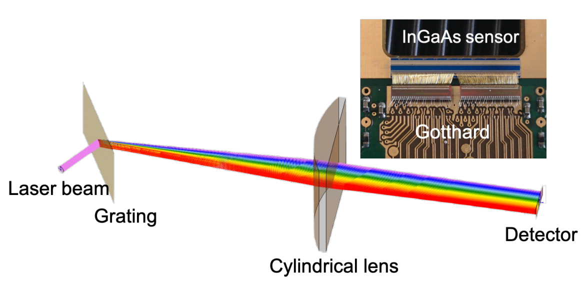

Figure 2: Illustrated is the simulated beam path including the optics (grating and cylindrical lens) as well as a photo of the sensor part or KALYPSO (InGaAs sensor) with the Gotthard chips.

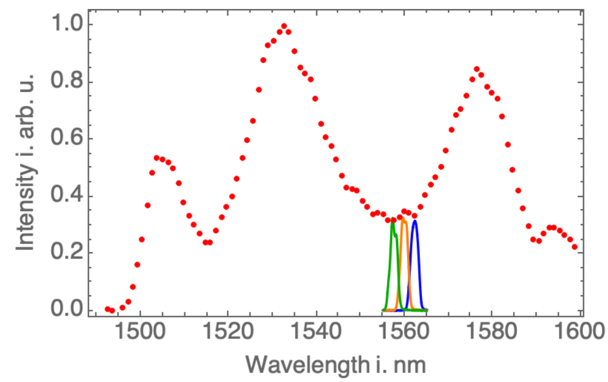

Figure 3: Shown is a graph with single measurements (green, yellow, blue) using the described setup using a slit and a collimator and the maxima of fits to all single measurements plotted with red dots reproducing the spectral shape.

Although the demonstrator setup is currently running at a repetition rate of 62.5 MHz not fitting the frame rate of KALYPSO, first measurements with two beams for the balanced detection scheme were performed. Thus, every 23rd pulse was detected. Figure 4 shows the part of the setup, which is labelled in Fig. 1 as "spectrometer". The two beams after the PBS are led through one grating and each beam through a cylindrical lens before reaching the InGaAs sensor. The distances of the grating, lens, and detector are roughly fitting the values given by the optimization during the simulations. However, due to partly rather bulky mounts and limited sizes of the grating and the lenses, restrictions are given. For further optimization, smaller mounts and optics with different sizes or an integrated optical system are necessary.

Figure 5 shows the results of the first measurements with two beam spots from the far-field demonstrator setup and the spectrometer (Fig. 4) described above. It is clearly visible that there are two beams hitting the sensor. While there is some overlap in the middle part of the sensor, each side gives a profile of one of the beams. Both beams differ in width and intensity which can be ascribed to the non-optimized beam path. Due to the space constraints, it was not possible to move the detector closer, which results in larger beam spots than calculated in the simulations. Thus, we cannot see strips on the sides without a beam to account for the two slightly differently performing readout chips (two Gotthard chips, for details see [9]) and to perform a shot-by-shot pulse calibration of the baseline.

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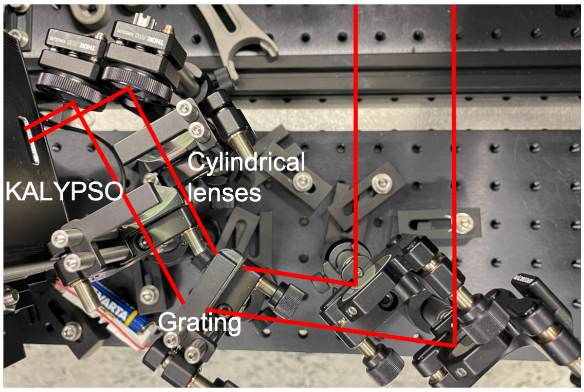

Figure 4: Shown is a photo of the spectrometer setup with an illustration of the two beam paths and the optical elements (grating, two cylindrical lenses and KALYPSO).

The two arms of the spectrometer differ in resolution compared to each other due to the different path length after the gratings. Here, compact, integrated optics are necessary for an accurate and symmetrical alignment. Compared to the measurement in the beginning of the beam path with the commercial spectrometer in Fig. 3, multiple optical components are added which influence the spectral shape. Furthermore, introducing an iris or slit in front of the spectrometer setup will help to optimize the beam profile.

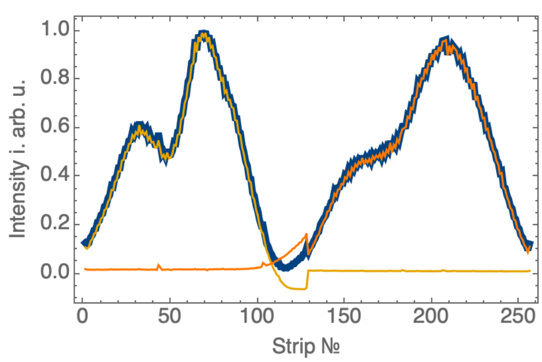

Figure 5: Shown are the intensities detected with KALYPSO plotted against the strip number. The measurement with two beam spots (thick blue line) is overlaid with two further measurements (yellow, orange) where one beam path was blocked.

SUMMARY AND OUTLOOK

This contribution describes efforts towards a balanced, single-shot EOSD detection for a far-field setup at KARA aiming to enhance the sensitivity of the setup. For the spectrometer, part of the demonstrator setup, beam path simulations were performed to find an optimized configuration for two beam spots onto an InGaAs sensor. First measurements were conducted to measure the wavelength separation onto the strips of the sensor and to detect two beam spots. Nevertheless, further steps are needed for EOSD single shot measurements. More compact optics and mounts are essential for an accurate alignment and a pulse picker will enable matching repetition rate of the laser and the detector. Furthermore, detailed characterization measurements to achieve sufficient sensitivity for the EOSD far-field measurements are required.

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