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APPLICATION OF KALYPSO AS A DIAGNOSTIC TOOL FOR BEAM AND SPECTRAL ANALYSIS

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Abstract

KALYPSO is a novel detector capable of operating at frame rates up to 12 MHz developed and tested at the institute of data processing and electronics (IPE) and employed at Karlsruhe Research Accelerator (KARA) which is part of the Test Facility and Synchrotron Radiation Source at KIT [1]. This detector consists of a silicon, InGaAs, PbS, or PbSe line array sensor with spectral sensitivity from 350 nm to 5000 nm. The unprecedented frame rate of this detector is achieved by a custom-designed ASIC readout chip. The FPGA-readout architecture enables continuous data acquisition and real-time data processing. Such a detector has various applications in the fields of beam diagnostics and spectral analysis. KALYPSO is currently employed at various synchrotron facilities for electro-optical spectral decoding (EOSD) to study the longitudinal profile of the electron beam, to study the energy spread of the electron beam, tuning of free electron lasers (FELs) and also in characterizing laser spectra [2]. This contribution will present an overview of the results from the mentioned applications.

INTRODUCTION

The KIT storage ring KARA (Karlsruhe Research Accelerator) can be operated in different modes, one of which includes a short-bunch mode where the momentum compaction factor α_c is reduced. This results in shorter electron bunches which interact with their own coherent synchrotron radiation (CSR). This electron bunch self-interaction results in the formation of sub-structures in the longitudinal phase-space. This phenomenon is also called as the micro-bunching instability [3].

Ultra-fast single-shot beam diagnostic instrumentation is necessary to measure and analyse such beam dynamics of electron bunches in a storage ring or accelerator. Electro-optical spectral decoding (EOSD) is an experimental technique used to measure the longitudinal bunch profile of the electron bunch in a non-destructive method with high temporal resolution. EOSD technique allows encoding the longitudinal profile on to a frequency spectrum of an ultra-short laser pulse. A temporal resolution down to 200 fs (RMS) can be achieved by this technique [4]. Another experimental technique for beam analysis is to directly measure the emitted incoherent synchrotron radiation, for example to get the horizontal bunch size of the electron bunch. In a dispersive section, this is coupled to the energy spread of the electron bunch.

$$\sigma_\delta = \frac{1}{D}\sqrt{\sigma_x^2 - \beta_x \epsilon_x}. \quad (1)$$

In both above mentioned techniques a line array camera is equipped to detect the profile of the electron bunch. A very crucial necessity of this line camera is the capability to acquire data with MHz repetition rates for long acquisition times combined with a good spacial resolution. KALYPSO is one such line camera capable of streaming data with MHz repetition rates.

KALYPSO

KALYPSO (KArlsruhe Linear arraY detector for MHz-rePetition rate SpectrOscopy) is a line array detector, which currently operates at a maximum frame rate of 12 MHz. One of the main features of KALYPSO compared to other detectors is its data streaming mode wherein it acquires continuous data at MHz repetition rates and is processed with minimal latency. Figure 1 shows a photo of the latest KALYPSO detector card developed and produced at KIT.

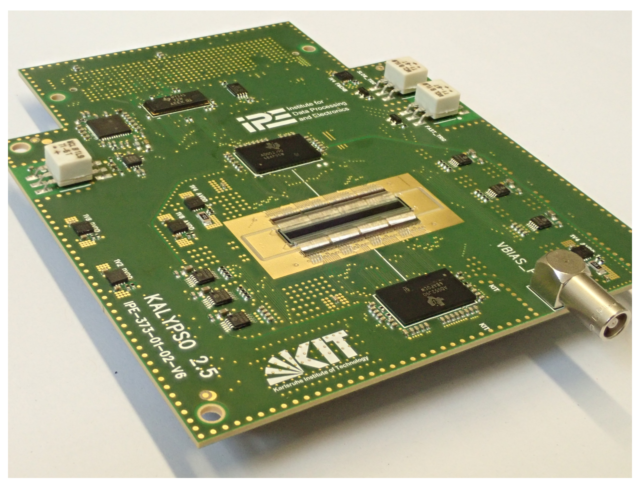

Figure 1: A fully assembled KALYPSO board with Si sensor and optimized sensitivity towards visible light.

The detector card consists of a semiconductor-based line-array sensor. For applications where a spectral sensitivity for 350 nm to 1 050 nm is required, a silicon (Si) sensor with an ARC coating is employed [5, 6]. For wavelengths beyond 1050 nm, line arrays based on indium gallium arsenide (InGaAs), lead sellenide (PbSe) or lead sulphide (PbS) can be mounted. The sensor has a read-out via a low noise and highly linear ASIC named Gotthard-KIT [7].

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The analog outputs of the ASIC are digitized by a high speed ADC-ADS52J90, with a datalink based on JESD204b subclass 2 interface standard [8]. In addition, the card is equipped with digital-to-analog converters (DACs) to provide voltage and current bias to the GOTTHARD ASIC and low jitter clock conditioners to provide on-board clock distribution [9].

The KALYPSO detector card is connected via VITA 57.1 FMC connector to the FPGA-based readout card 'Hi-Flex', an FPGA-based readout card developed at KIT, equipped with a Xilinx Virtex 7 device, with a 4 GB DDR3 memory and PCIe Gen3 interface [10]. The streamed data can be either processed within a CPU or GPU.

INSTALLATION AT KARA

Longitudinal Bunch Size Measurements

KALYPSO has been installed at the EOSD experimental setup at KARA to study the longitudinal bunch profile of the electron bunch. An ytterbium-doped fiber laser produces laser pulses with a wavelength around 1050 nm at a repetition rate of 2.7 MHz corresponding to the revolution frequency at KARA [11]. The laser pulses are sent to a gallium phosphide (GaP) crystal located inside the beam pipe of KARA and back to the experimental station for detection with KALYPSO. EOSD is based on the Pockels effect where the GaP crystal exhibits a proportional birefringence in the presence of an electric field. The polarization of the laser pulse is rotated by the birefringence and in a chirped laser pulse each spectral component corresponds to a certain part of the longitudinal electron bunch density. This modulation can be measured with the use of waveplates, polariser and a spectrometer. Figure 2 shows the current spectrometer setup at KARA for EOSD measurements using KALYPSO as the DAQ . The continuous data acquired from this experiment can also be used to reconstruct the 2D phase-space density of the electron bunches [12].

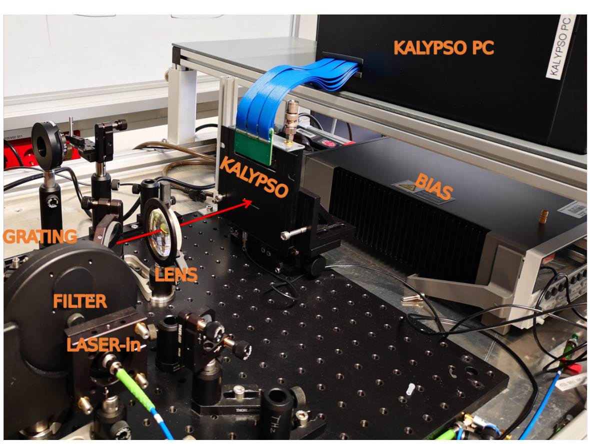

Figure 2: Grating spectrometer with DAQ of the EOSD setup.

Horizontal Bunch Size Measurements

The energy-spread measurement at KARA is performed at the visible light diagnostics (VLD) port by measuring the incoherent synchrotron radiation from a 5°-port of a dipole magnet. Figure 3 shows the optical setup used for the electron bunch energy spread measurements at KARA. The wavelength of the emitted radiation is in the range of 400 nm to 550 nm. Figures 4 and 5 shows preliminary raw data acquired at the VLD port, the later is a single-shot bunch profile of the incoherent synchrotron radiation acquired at the VLD port and, the former is its evolution in time or orbits. Each orbit is a sample of the incoherent synchrotron radia-tion with a sample step of 368 ns. The sinusoidal shift of the beam profile in the evolution corresponds to the synchrotron oscillation of the order of a few kHz. In principle, the the single-shot image obtained at the sensor is a convolution of the horizontal bunch size and the filament beam spread func-tion (FBSF). The FBSF is obtained by optical simulations. The current setup allows measurements of the horizontal bunch size with a single-turn precision [13].

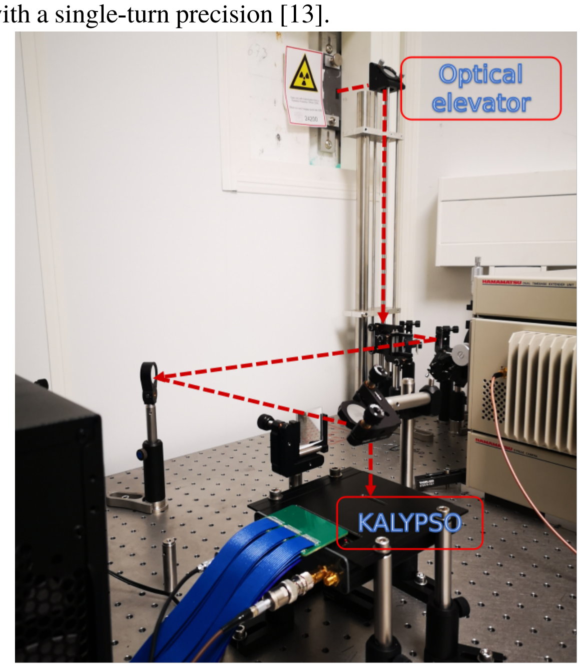

Figure 3: Optical setup for energy-spread measurement at the VLD port.

Laser Stability Measurements

Laser systems are a key component for beam diagnostics, its stability is a crucial necessity. Since KALYPSO allows for a fairly high repetition rate, it can be used as a tool to analyse the laser stability of individual laser pulses and assist in better error corrections in future experiments. This experiment can be performed fairly easily with the help of simple optics. Figure 6 shows a single snapshot of a 1560 nm commercial laser and its deviation from the averaged spectra. Detailed analysis and online diagnostics of the laser stability using KALYPSO can help to improve the signal-to-noise (SNR) ratio.

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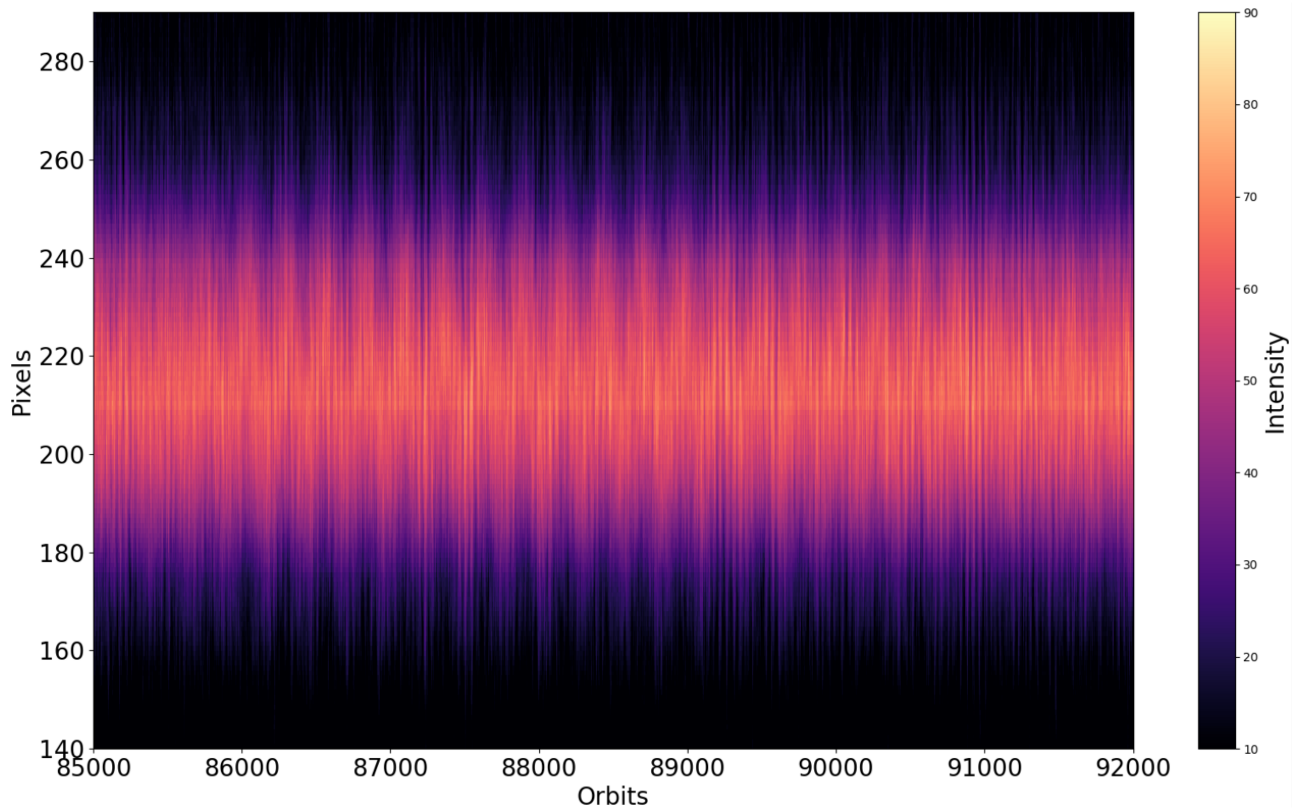

Figure 4: Evolution of the profile measured by KALYPSO: the total orbits recorded were 10^5 and cut short for better visualization.

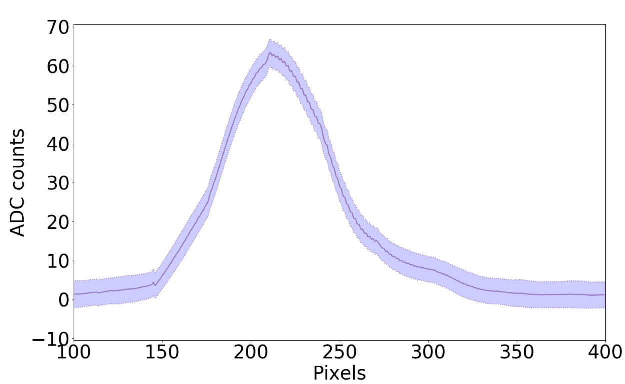

Figure 5: Single-turn profile of the incoherent synchrotron radiation measured by KALYPSO.

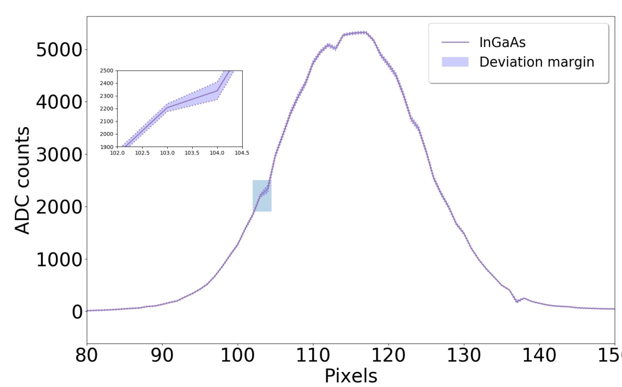

Figure 6: Single-shot laser beam profile of 1560 nm laser.

OUTLOOK AND FUTURE WORK

We have developed KALYPSO, an ultra-fast line array camera, for wide spectral range applications currently operating with frame rates up to 2.7 MHz. The detector has been installed in several experiments in KARA and other accelerator facilities as well. The detector presented in this paper is the latest version and shows promising improvements compared to its predecessor. The next version of this detector, capable of working up to 12 MHz, is in its final stages and will soon be available for measurements.

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