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TURN-BY-TURN HORIZONTAL BUNCH SIZE AND ENERGY SPREAD STUDIES AT KARA

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Abstract

The energy spread is an important beam dynamics parameter. It can be derived from measurements of the horizontal bunch size. At the KIT storage ring KARA a fast-gated camera is routinely used for horizontal bunch size measurements with a single-turn resolution for a limited time span. To overcome the limits of the current camera setup in respect to resolution and time span, a high-speed line array with up to 10 Mfps, the KALYPSO system, is foreseen as a successor. The KALYPSO versions range from 256-pixel to 1024-pixel and allow unlimited turn-by-turn imaging of a single bunch at KARA. We successfully tested such a system at our visible light diagnostics port and present first results in this contribution.

INTRODUCTION

The KIT storage ring KARA (Karlsruhe Research Accelerator) can be operated in different modes including a short-bunch mode, where the dispersion is stretched in order to reduce the momentum compaction factor α_c. This *squeeze* shortens the electron bunches and they start to interact with their emitted coherent synchrotron radiation (CSR) in the bent sections of the storage ring. This self-interaction leads to the formation of substructures in the longitudinal phase space and to the occurence of the microbunching instability.

The knowledge of the energy spread, the longitudinal bunch profile as well as the CSR intensity are important for a possible reconstruction of the longitudinal phase space for a better understanding and a potential control of the microbunching instability. A first step towards this reconstruction is a simultaneous measurement of the energy spread and the CSR intensity. As the energy spread cannot be measured directly, indirect measurement methods have to be used. This can be achieved by measurements of the horizontal bunch size. From the horizontal bunch size σ_x the energy spread σ_δ can be accessed via

$$\sigma_\delta = \frac{1}{D}\sqrt{\sigma_x^2 - \beta_x \epsilon_x} \tag{1}$$

by taking the horizontal beta function β_x, the horizontal emittance ϵ_x and the dispersion D into account. For time-resolved horizontal bunch size measurement, a fast-gated camera (FGC) is regularly used at KARA. It allows to measure the horizontal bunch size with a single-turn resolution for at least every 6th turn [1]. This system is intrinsic limited by the number of data points per image. Thus one has to choose between a good temporal resolution and long time ranges. To overcome this limitation, a high-speed CCD line array can be used as it is the case here for the KALYPSO system.

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KALYPSO

The KALYPSO system is a high-speed line array DAQ system developed at KIT [2]. Due to its modular design, it can be equipped with different sensor materials with 256 up to 1024 pixels. With a frame rate of above 10 Mfps it allows turn-by-turn studies at KARA which has a revolution frequency of 2.7 MHz [3]. In addition, it allows to record long time ranges up to a continuous streaming of data. For the measurements discussed in the following, a silicon sensor with 256 pixels was used to sample the incoherent synchrotron radiation. Compared to the FGC setup with its mechanical and electrical delays (for details, see Ref. [4]), the KALYPSO system allows an instantaneous start of recording and therefore simplifies the synchronisation with other detector systems, e.g. for CSR measurements and electro-optical spectral decoding (EOSD) in the nearfield [5]. The latter uses the same KALYPSO DAQ architecture.

EXPERIMENTAL SETUP

For the energy spread studies we use the visible light diagnostics port with incoherent synchrotron radiation from the 5° port of a dipole magnet. The wavelength is in the range range (λ = 400 nm - 500 nm). A source point imaging is achieved by a set of two off-axis paraboloid mirrors (f = 1200 mm and f = 152.4 mm) and two cylindrical lenses for horizontal (f = 80 mm) and vertical focusing (f = 70 mm).

In order to determine the horizontal bunch size from the image, the filament beam spread function (FBSF) is required [6]. The FBSF is determined from optical simulations using the software OpTaliX and is plotted in Fig. 1. The final image on the sensor is the convolution of the horizontal bunch profile with the FBSF. In principle, a deconvolution can be applied to retrieve the horziontal bunch profile from the measurement data. To accelerate the data analysis and to overcome the numerical stability issues that occur for a deconvolution (noise amplification), we fit a convolution of a Gaussian curve with the FBSF to the data [4].

In Fig. 2 one single-turn horizontal profile is plotted together with the corresponding fit.

This allows to determine the horizontal bunch size with single-turn precision. To benchmark the data analysis, we

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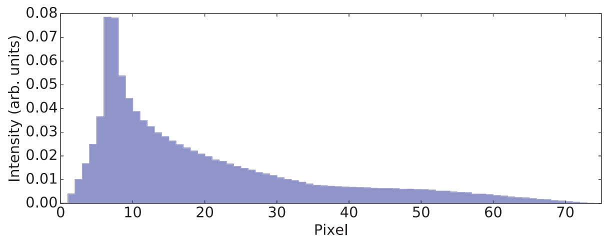

Figure 1: FBSF for the KALYPSO setup determined by optical simulations. Due to the particularities of the setup and as the bunch is moving during the acquisition process, the FBSF consists of a peak followed by a long tail.

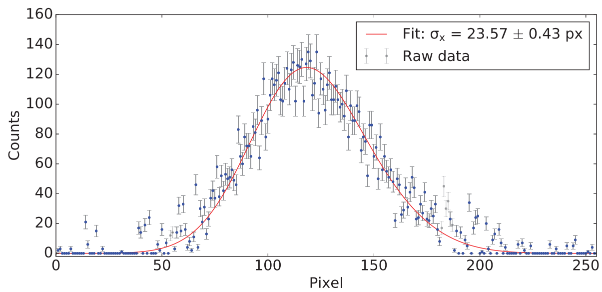

Figure 2: Single-turn profile recorded using the KALYPSO system and the corresponding fit to the data. The shape of the data is taken into account by the fitting function as this functions contains the FBSF.

compared KALYPSO and FGC measurements for identical machine settings and bunch currents. Such a benchmarking data set is plotted in Fig. 3. It can be seen that the horizontal bunch size measured with KALYPSO and the one measured with the FGC agree quite well. The sawtooth like behaviour is due to the bursting of the bunch, which is induced by the micro-bunching instability.

For time-resolved studies of the CSR, fast Schottky diodes with a sensitivity in the THz range are used. For the measurements discussed in the following, an oscilloscope in the segmented mode was used to sample the Schottky diode signal. In addition, an avalanche photo diode (APD) sensitive in the visible wavelength range is used to sample the

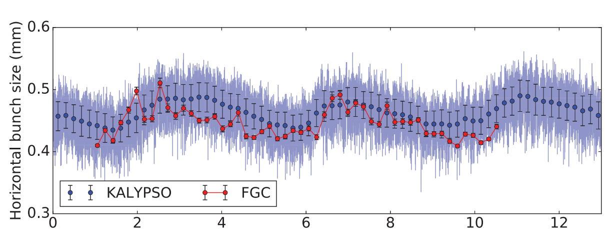

Figure 3: Horizontal bunch size measured using KALYPSO (blue, the dots corresponds to a profile histogram) and the FGC (red) for identical machine settings and bunch currents. For better visibility, the two curves were aligned horizontally.

incoherent synchrotron radiation. It acts as a timing reference to check the synchronisation of the various detector systems [4].

MEASUREMENTS

A proper synchronization of the various detector systems is crucial. To check and calibrate this synchronisation, RF phase steps can be used which lead to a strong synchrotron oscillation visible to all detector systems. If the recorded time ranges are sufficiently long, also spontaneous onsets of the synchrotron oscillation can be used. Such an onset is plotted in Fig. 4, which shows the horizontal bunch position and the intensity of the incoherent synchrotron radiation recorded by an avalanche photo diode (APD).

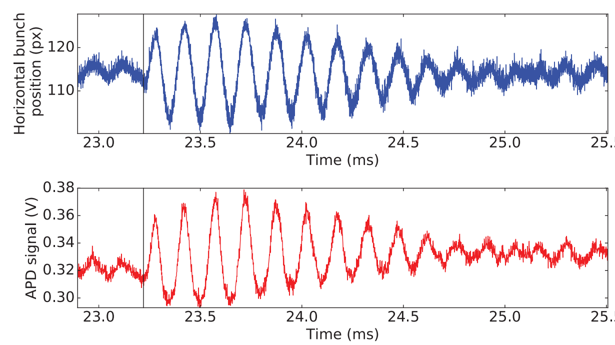

Figure 4: Top: Horizontal bunch position recorded with KALYPSO, Bottom: Incoherent synchrotron radiation sampled by an APD in the visible range. The vertical black line depicts the onset of a synchrotron oscillation.

Both detector systems recorded the onset of the synchrotron oscillation at the same point in time which is therefore a cross-check for the synchronization between them.

In the following, we focus on the studies of the horizontal bunch size as a measure for the energy spread and the CSR intensity recorded by a broadband Schottky diode. Such a measurement is plotted in Fig. 5. There, both curves have the

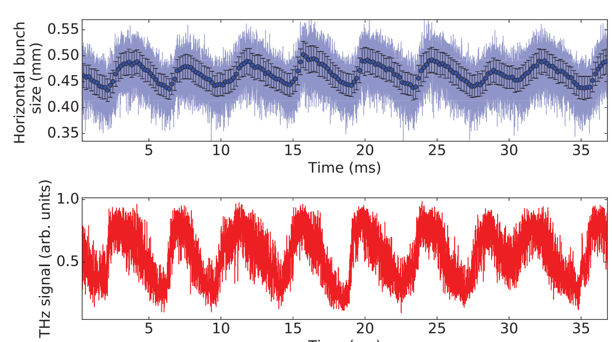

Figure 5: Top: Horizontal bunch size recorded with KALYPSO, to overcome the noisy structure a profile histogram is applied to the data. Bottom: Corresponding CSR signal recorded by a broadband Schottky diode.

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same modulation period length with the minimum horizontal bunch size close to the onset of the CSR burst. Due to the ability for turn-by-turn studies, these onsets can be studied in more detail to investigate potential phase difference between the minimum horizontal bunch size and the onset of a burst. Such a zoom-in is illustrated in Fig. 6.

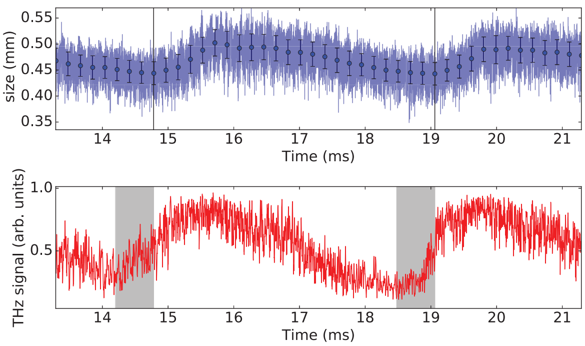

Figure 6: Detailed zoom-in into the data from Fig. 5. Top: Horizontal bunch size recorded with KALYPSO, to overcome the noisy structure a profile histogram is applied to the data. Bottom: Corresponding CSR signal recorded by a broadband Schottky diode. The grey bar depicts the time range, where the horizontal bunch size is stil decreasing, while the CSR intensity already starts to increase.

There, the grey bar indicate the phase offset between the rise of the energy spread - given by the horizontal bunch size - and the onset of the CSR burst. The emission of CSR is coupled to the occurence of substructures in the longitudinal phase space. At the beginning of a burst, these substructures do not lead to an overall increase of the energy spread, which is still shrinking due to radiation damping. After 0.5 ms - which corresponds to approx. 4 synchrotron periods - the instability driven blow-up of the energy spread starts to dominate and the bunch size rises.

This example clearly demonstrates the potential of KALYPSO for time-resolved energy spread studies. It is possible to study both the time-structure of the CSR bursts in the range of milliseconds and the phase offsets between the different parameters derived from the longitudinal phase space in parallel.

SUMMARY

Using a KALYPSO system for horizontal bunch size measurements allows studies of the energy spread with a single-turn resolution. At KARA, we use a silicon sensor and bending radiation from a dipole magnet and take the FBSF into account to determine the horizontal bunch size from the KALYPSO data. As KALYPSO allows an instantaneous start of the recording, an intrinsic synchronisation to other detector systems is possible, which allows simultaneous studies of the energy spread and the CSR intensity.

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