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A FAST GATED INTENSIFIED CAMERA SETUP FOR TRANSVERSAL BEAM DIAGNOSTICS AT THE ANKA STORAGE RING

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Abstract

ANKA, the synchrotron light source at Karlsruhe Institute of Technology (KIT), can be operated in different modes including the short bunch operation with bunch lengths compressed to a few picoseconds. In this mode, coherent synchrotron radiation (CSR) is emitted leading to beam instabilities. For gaining further insight into those processes, a setup based on a fast gated intensified camera was installed recently at the visible light diagnostics beamline of the ANKA storage ring. The experimental layout consists of an optical setup, which magnifies the image of the beam in the horizontal and demagnifies it in the vertical plane to obtain a projection of the horizontal beam shape, the camera itself and a fast scanning galvanometric mirror that sweeps this image across the sensor. This allows the tracking of the horizontal bunch size and position over many turns.

In this paper we present the setup and show first measurement results.

INTRODUCTION

The synchrotron light source ANKA, located at the Karlsruhe Institute of Technology (KIT), can be operated at energies from 0.5 GeV up to 2.5 GeV. In addition to normal operation at 2.5 GeV, a short bunch operation at 1.3 GeV is regularly offered [1]. By lowering the momentum compaction factor α_c, bunch lengths of a few picoseconds are reached, leading to the emission of coherent synchrotron radiation (CSR) in the high GHz and THz range. Furthermore in short bunch operation micro-bunching instabilities and thus strong bursts of THz radiation occur. Their periodicity and power strongly depend on the bunch current. Various investigations of micro-bunching instabilities were performed at the ANKA storage ring, characterizing the coherent radiation bursts [2] and the corresponding longitudinal bunch profile [3].

The measurement setup presented in this paper, based on an idea of J. Corbett [4], will allow the observation of the horizontal bunch profile on a single turn base. It can be used for the observation of transverse bunch profile fluctuations, e.g. during micro-bunching instabilities.

EXPERIMENTAL SETUP

Optical Setup

The experiment is under commissioning at ANKA's visible light diagnostics beamline, which is located at a 5° port front end at a dipole magnet. There are various experiments located at the beamline, such as Time-Correlated Single Photon Counting (TCSPC) and a streak camera. The optical beam path from the source point to the fast gated intensified camera is shown in Fig. 1. A cooled planar mirror is used to filter the visible range from the synchrotron radiation spectrum. After passing through an optical chicane, the visible spectrum is split into three wavelength regions for the different experiments by using dichroic mirrors. This separation is performed directly after the second off-axis paraboloid mirror and is not shown in the drawing. For the fast gated intensified camera blue light in the range from 400 nm to 500 nm is used. More information on the other experiments carried out at this beamline can be found in [5].

The optical chicane contains two off-axis paraboloid mirrors of different focal lengths, creating a real image of the incoherent synchrotron radiation, directly representing the bunch's transverse charge distribution. It is shown in the upper part of Fig. 2.

Being the smallest aperture in this setup, the diaphragm leads to a diffraction limit of about 150 μm in the vertical plane, compared to a vertical beam size of less than 100 μm [6]. Thus, this experiment is exclusively designed for monitoring the horizontal bunch profile. To gain sensitivity in the horizontal plane, the image is stretched by two cylindrical lenses of different focal lengths. The resulting image can be seen in Fig. 2.

The last planar mirror in front of the camera will be a fast rotating, galvanometric mirror. To track the horizontal bunch profiles over many turns, this mirror sweeps the stretched images over the camera sensor, fast enough (> 500 deg/s) to place the images of consecutive turns clearly separate next to each other. A schematic scheme is shown in Fig. 3.

Fast Gated Intensified Camera

The existing transverse beam profile monitors at ANKA have a slow acquisition rate (> 50 Hz) and a relatively long exposure time (typically hundreds of μs to 1 s). Thus they are integrating over many bunches and bunch revolutions due to the minimum bunch spacing of 2 ns and a bunch revolution frequency of 2.7 MHz.

In order to observe the horizontal beam profile of a single bunch for a single turn, a fast gated intensified camera (Andor iStar 340T [7]) was installed. The optical gate with a width of less than 2 ns allows the imaging of single synchrotron radiation pulses even in a multibunch environment, since the bunch spacing at ANKA is 2 ns. A maximum gate repetition rate of 500 kHz enables the imaging of the synchrotron radiation pulse of a certain bunch at every 6th turn for the tracking of the bunch profile on fast timescales.

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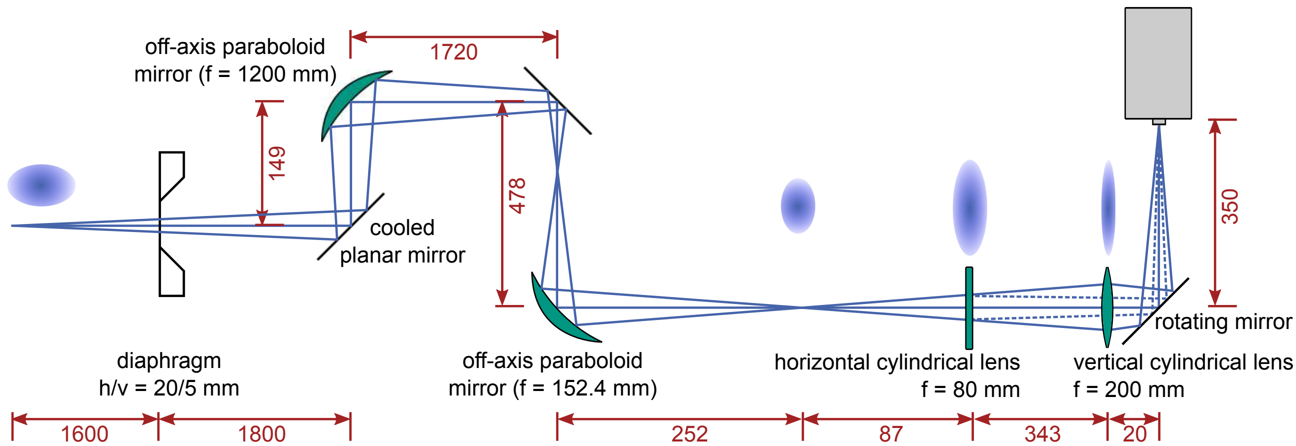

Figure 1: Optical setup for the fast horizontal beam profile measurements. The source point is imaged twice using off-axis paraboloid mirrors of different focal lengths. After the second image the beam ellipse is stretched by cylindrical lenses in order to yield a better resolution on the horizontal plane. For reasons of clarity the dichroic mirrors, used for splitting the light for different experiments, are not included.

Experiment Control and Synchronization

For the experiment control a software was developed in-house. Based on the Andor Software Development Kit, it is used for programming the camera as well as starting measurements and the image readout. The same software is capable of programming an arbitrary waveform generator, which is then used for steering the galvanometric mirror.

When an acquisition is started via the software, the arbitrary waveform generator is activated to wait for a trigger signal. This signal is sent by the camera at the start of an exposure.

Since the galvanometric mirror does not perform a full rotation but has to be driven forward and backward, the light pulses are swept over the sensor twice. To avoid an overlay of the two sweeps, the arbitrary waveform generator gives a logic "high" on it's second output channel while the mirror is moving forward. This logic signal is combined with a beam synchronous signal, generated by the ANKA timing system [8], to trigger optical gates of the camera.

The camera's internal Digital Delay Generator (DDG) is used to shift the optical gate in relation to the trigger signal. By adjusting the internal delay, one individual bunch can be selected for measurements.

For one acquisition 60 to 80 bunch profiles will be placed on the camera sensor with a temporal separation of 6 or more turns. The temporal separation can be freely adjusted corresponding to the timescale of the effect to be investigated, enabling the observation of frequencies from 225 kHz down

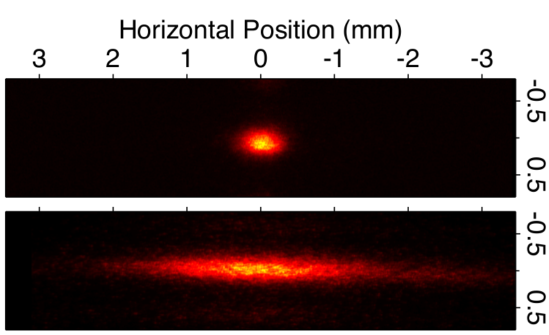

Figure 2: The top figure shows the real image after the second off-axis paraboloid mirror. The beam ellipse is stretched using two cylindrical lenses of different focal lengths, yielding a magnification of 2.6 in the horizontal plane. The stretched image is shown in the lower figure. The images were taken by the fast gated intensified camera and are rotated by 90°.

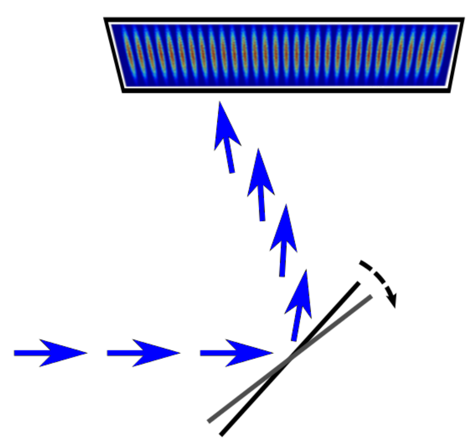

Figure 3: A galvanometric mirror sweeps the transversally stretched synchrotron light pulses over the camera sensor, allowing the observation of horizontal bunch profile fluctuations on short timescales. The camera's fast optical gating ensures the monitoring of a selected bunch, while all other bunches are blanked out.

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to 1 Hz, limited by the camera's gate revolution and exposure time. This includes the typical frequencies of microbunching instabilities at the ANKA storage ring [9].

TEST EXPERIMENTS

For test measurements before the installation of the rotating mirror, a beam synchronous trigger signal was directly applied to the DDG. In two different acquisition modes either one (single gate) or about 100 gate openings (multi gate) have been triggered per exposure, i.e. either a single synchrotron radiation pulse or an overlay of 100 pulses of the same bunch has been captured and read out. An image of a single gate measurement can be seen in the lower image of Fig. 2. In order to evaluate the horizontal spot size and position, each image has been projected on the horizontal axis and a Gaussian distribution was fitted to it.

The two acquisition modes have been used alternately in order to investigate fluctuations of the spot profile. Fig. 4 shows the evolution of the horizontal spot size and position during different machine settings. The middle graph shows the increase of the quadrupole currents, resulting in a reduction of the momentum compaction factor α_c and hence a decrease of the bunch length [3]. For the first change in quadrupole current one sees a clear increase in the horizontal beam size, which is expected due to the increase of the beta function. For the second, much smaller increase of quadrupole current, the changes are barely visible. The overall spread of the beam size seems to increase for both, single and multi gate mode. For the horizontal position, one sees not only a step for the first quadrupole change, but also a clear increase in the fluctuations of the single gate measurements, hinting a transversely instable beam. A possible reason for growing fluctuations is the appearance of micro-bunching instabilities for this machine settings. This hints at the potential of this method to study the transverse dynamics of bunches in the micro-bunching regime.

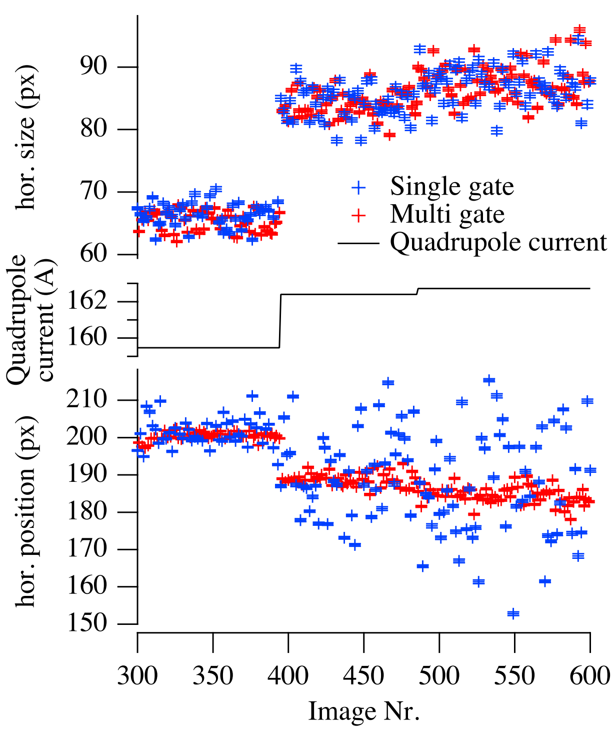

Figure 4: Horizontal spot size and position for single synchrotron radiation pulses (blue) and overlays of about 100 pulses (red) for changing machine parameters. The increase of quadrupole currents causes a reduction of α_c and hence a decrease of the bunch length. Both the spot size and the position fluctuations of single synchrotron radiation pulses increase for lower values of α_c.

CONCLUSION AND OUTLOOK

The fast horizontal beam profile monitor at ANKA will be capable of acquiring 60 to 80 profiles with a separation of at least 2 µs, leading to a resolvable frequency range from 225 kHz up to 1 Hz, including the typical frequencies of micro-bunching instabilites at the ANKA storage ring.

First measurements without a rotating mirror have confirmed strong dependencies of the horizontal beam profile and it's fluctuations on the machine settings. With the full setup a time-resolved observation will be possible for relating these effects to their specific timescales. This will give us further insight into the effects of transverse beam dynamics occurring due to beam instabilities.

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