

## VISIBLE LIGHT DIAGNOSTICS AT THE ANKA STORAGE RING

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### Abstract

Synchrotron radiation in the visible light range is a versatile diagnostics tool for accelerator studies. At the ANKA storage ring of the Karlsruhe Institute of Technology (KIT), we have a dedicated visible light diagnostics beamline and two additional beam ports close to the radiation's source point. The visible light diagnostics beamline hosts a time-correlated single photon counting unit to measure the bunch filling pattern and a streak camera for longitudinal diagnostics. Recently, the beamline has been extended with a fast gated intensified camera to study transverse instabilities. The synchrotron light monitor ports were previously used for direct source imaging. Due to the diffraction limit the vertical beam size could not be resolved. One of the two ports has recently been equipped with a double-slit to allow for interferometric measurements of the vertical beam size.

In this paper we give an overview of the different setup modifications and present first results.

### MOTIVATION

ANKA, the synchrotron light source at KIT can be operated in two different modes. In the normal user operation mode the machine is operated with an energy of 2.5 GeV and a filling pattern consisting of a sequence of bunches ('train') followed by a gap. In the short bunch mode with an energy of 1.3 GeV the lattice is changed to lower the momentum compaction factor  $\alpha_c$ . By tuning the bunch length down (to the order of picoseconds), coherent synchrotron radiation (CSR) is emitted. Depending on the beam current, this radiation is either emitted constantly or in the so called bursts with a strong temporal fluctuation of the intensity. This latter mode requires a dedicated set of measurement tools for tracking the relevant parameters to gain further insight into accelerator physics. The charge distribution plays a vital role for these processes, either as the charge distributed over the bunches (filling pattern) or as the temporal and spatial profile of the different bunches. Incoherent synchrotron radiation can be used as diagnostics tool as its intensity is proportional to the bunch charge and thus the light pulse directly represents the charge distribution. Using the visible range simplifies the handling of the required components. At ANKA we have a dedicated visible light diagnostics beamline housing a set of experimental setups, additionally two dedicated beam ports for source point imaging are in use.

### VISIBLE LIGHT DIAGNOSTICS BEAMLINE

The beamline is located at a  $5^\circ$  port front end at a dipole magnet. Two off-axis paraboloid and two planar mirrors

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transport the light onto the optical table where they form an intermediate image that is rotated by 90 degrees relative to the beam. To allow parallel measurements for the different setups the light is split into spectral regions by using two consecutive short pass filters (see Fig. 1). Using those filters allows the realization of a dispersion-free beam path for the streak camera as this would deform the temporal shape of the light pulses otherwise.

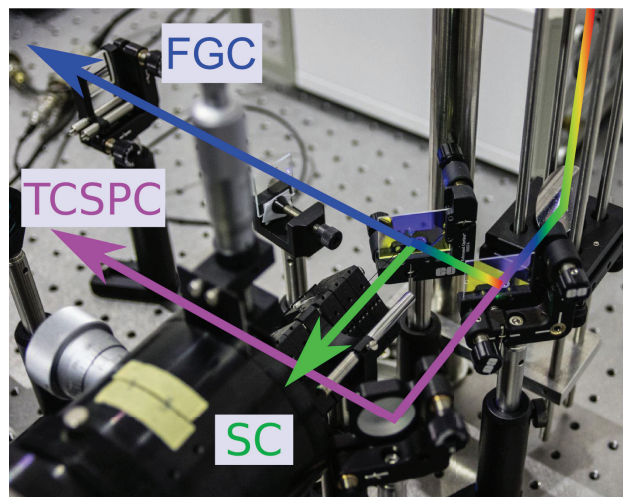


Figure 1: Picture of the of the setup for distributing the incoming light to the three different experiments (TCSPC: Time-correlated single photon counting, SC: Streak camera, FGC: Fast gated intensified camera) by using a sequence of two short pass filters ( $\lambda = 400$  nm and  $\lambda = 500$  nm).

### Time-Correlated Single Photon Counting

For precise measurements of the filling pattern we use the time-correlated counting of single photons. The setup consists of a single photon avalanche diode (id100-20 from IDquantique [1]) and a histogramming device (PicoHarp 300 from PicoQuant [2]). The timing resolution of the setup is defined by the detector with a typical resolution of 40 ps, whilst the PicoHarp300 is operated with a channel width of 8 ps. To avoid deformations of the histogram due to too much events falling into the dead time we operate with count rates below  $5 \cdot 10^5$  1/s. The combination of the small sensitive area of the detector ( $20 \mu\text{m}$  diameter) and an iris lens mounted on the detector's C-mount leads to a good suppression of background light and thus we can operate the setup without any additional background light shielding. As the absorption depth of the photons in the solid state detector becomes smaller with decreasing wavelengths [3] we use a narrow bandpass filter (center wavelength 400 nm) to suppress the resulting diffusion tail in the histogram (see Fig. 2). This

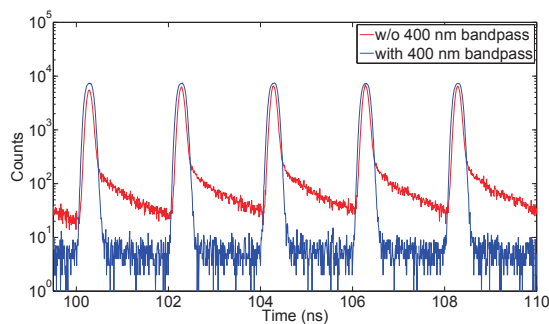


Figure 2: Time-correlated single photon counting histograms for a single bunch fill at ANKA. The red curve has been taken without a bandpass as for the blue curve it was introduced into the optical beam path. This leads to a suppression of the diffusion tail and increases the dynamic range for bunch purity measurements up to  $1 \cdot 10^4$ .

leads to a dynamic range for bunch purity measurements of  $1 \cdot 10^4$ .

These precise measurements of the filling pattern can be used for impedance studies using custom made filling patterns [4].

### Streak Camera

A streak camera (Hamamatsu C5680 [5]) is used for measuring the longitudinal bunch profile and its fluctuation. Further analysis of the measurement data is done by using an in-house developed processing and analysis software. This software automatically determines the noise level and the synchrotron oscillation for the camera images and corrects for them. Based on the corrected data it calculates the RMS bunch length (see Fig. 3) and allows a comparison with the values calculated based on simulations.

As this technique is not single-turn we have to average over many turns. Even though, it is an excellent instrument for

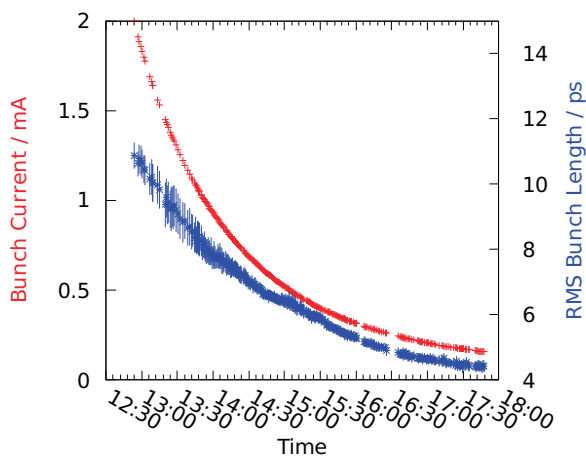


Figure 3: Bunch current (red) and corresponding RMS bunch length (blue) for a beam current decay in the short bunch mode.

tracking the bunch length and its shape for different accelerator parameters. With its resolution of 4 ps it gave evidence to bunch profile deformations [6] and length fluctuations in the short bunch mode [7].

### Fast Gated Intensified Camera

To study transversal effects onto the beam recently a new setup for measuring the horizontal beam shape and position was commissioned. This setup is based on a fast gated intensified camera (Andor iStar 340T [8]) and a galvanometric mirror [9] that allows to pick a dedicated bunch and track it over many turns [10]. The intermediate image of the source point is vertically stretched and horizontally squeezed by a set of cylindrical lenses. The galvanometric mirror is used to place these images across the camera sensor before it is finally read out with a comparatively low rate. Thus we can track the horizontal shape and position of one dedicated bunch over many turns. The maximum repetition rate of the gate limits us to every 6th turn. The camera and the optical system (except for the galvanometric mirror) were installed in spring 2015.

## SYNCHROTRON LIGHT IMAGING & INTERFEROMETRY

For transversal beam size measurements we use two different techniques.

- Synchrotron Light Monitors (SLM): Source point imaging systems at two different ports using a camera. The vertical resolution is limited due to diffraction to a value of  $\sigma_y = 174 \mu\text{m}$  caused by a crotch absorber in the vacuum chamber. Thus it is not possible to resolve the vertical beam size that is expected from simulations to be around  $60 \mu\text{m}$  but it can be used for measuring the horizontal beam size nevertheless.
- In-air X-ray detectors (DIAX): This system allows the determination of the vertical beam size but can only be used at energies above 2.2 GeV and thus it is not suitable for injection or short bunch mode operations with energies of 1.3 or 1.6 GeV [11].

To overcome the diffraction limit and to be able to measure the vertical beam size even at injection energies one of the two SLM recently was equipped with a double slit to allow interferometric measurements. The vertical beam size  $\sigma_y$  can be calculated according to Equation 1 by determination of the visibility  $V$  of an interference pattern (see Fig. 4) [12]. The visibility is the normalized intensity difference between maximum and minimum values of the corresponding interferogram. The calculation is further based on the wavelength  $\lambda$ , the slit separation  $D$  and the distance between source point and slit  $r$ .

$$\sigma_y = \frac{\lambda r}{\pi D} \cdot \sqrt{0.5 \cdot \ln\left(\frac{1}{V}\right)} \quad (1)$$

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As a trade-off between robustness, resolution and a uniform illumination a slit separation  $D$  of 3 mm is used. The optical setup also contains a bandpass filter ( $\lambda_{\text{center}} = 550 \text{ nm}$ ) for the highest camera sensitivity and a polarizer to prevent negative interference between different polarization components. With this setup we achieve a resolution of  $60 \mu\text{m}$ .

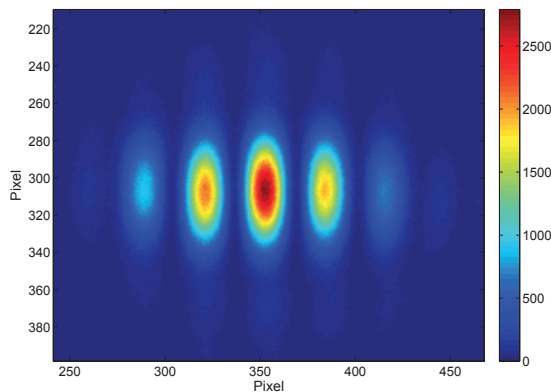


Figure 4: Interference pattern acquired with the upgraded Synchrotron Light Monitor (SLM). The beam size is calculated using the visibility (parameter for the contrast between maximum and minimum intensity), for the interferogram shown here it is around  $61 \mu\text{m}$ .

A set of different neutral density filters that can be exchanged by remote leads to a high dynamic range and thus we are able to cover the whole beam current range at ANKA (0.1 mA - 240 mA). With this setup we can now track the vertical beam size at different machine states, e.g. in the short bunch mode when we tune the bunch length down by changing the lattice (see Fig. 5) to achieve a lower momentum-compaction factor  $\alpha_c$ .

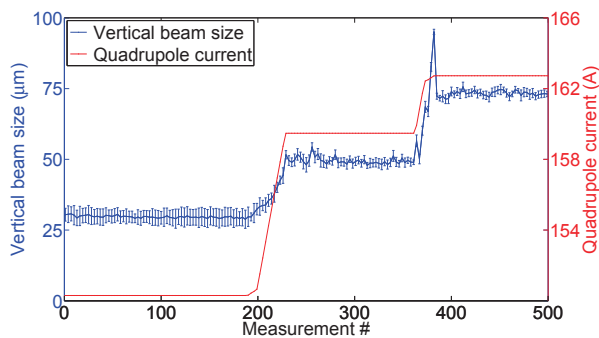


Figure 5: Vertical beam size (blue) and excitation current of one of the quadrupoles families (red). By changing the quadrupole current the momentum compaction factor  $\alpha_c$  is decreased. While the vertical beam size is increased the bunches are squeezed longitudinally.

## CONCLUSION & OUTLOOK

Due to its constant emission (no bursts) and the linear dependency of the bunch charge incoherent synchrotron radiation is a useful tool for accelerator diagnostics. It can be used for measuring the temporal and spatial charge distribution. At ANKA we make use of different beam ports and techniques for those measurements, see Table 1. After the installation of the galvanometric mirror the setup based on the fast gated intensified camera will be fully operational in summer 2015.

Table 1: Summary of the Different Measurement Techniques used for Visible Light Diagnostics at ANKA

	$\sigma_x$	$\sigma_y$	$\sigma_s$	Filling pattern	Turn-by-turn ?
Time-correlated single photon counting				✓	
Streak camera			✓		
Fast gated intensified camera	✓			(✓)	✓
Interferometry		✓			

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