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STUDIES OF BURSTING CSR IN MULTI-BUNCH OPERATION AT THE ANKA STORAGE RING

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Abstract

The ANKA storage ring can generate brilliant coherent synchrotron radiation (CSR) in the THz range due to a dedicated low-α_c-optics with reduced bunch lengths. At higher electron currents the radiation is not stable, but occurs in powerful bursts caused by micro-bunching instabilities. This intense THz radiation is very attractive for users. However, the reproducibility of the experimental conditions is very low due to those power fluctuations. Systematic studies of bursting CSR in multi-bunch operation were performed with fast THz detectors at ANKA using a dedicated, ultra-fast DAQ-FPGA board. The technique and preliminary results of these studies are presented in this paper.

INTRODUCTION

The synchrotron radiation source ANKA is located in Karlsruhe, Germany. The user facility is based on an electron storage ring with a circumference of 110.4 meters and is being operated by the Karlsruhe Institute of Technology. Main points of research are experiments with x-rays and infrared radiation. For user operation the ring is filled twice per day with up to 220 mA at a beam energy of 0.5 GeV. Then the beam is ramped to a nominal energy of 2.5 GeV. In standard user operation usually 3 - 4 trains consisting of around 35 electron bunches are filled, the so called multi-bunch mode. For a few years special user operation with reduced bunch length in the order of few picoseconds is realised and offered to the research community. In this mode, coherent synchrotron radiation is generated for electro-magnetic waves with a wavelength in the order of or longer than the electron bunch length. Due to this, one usually observes a strong amplification of the radiation spectrum in the THz band. Moreover, above a certain current threshold, a coherent modulation of the longitudinal particle distribution (microbunching) occurs due to CSR impedance [1]. This particle dynamics effect changes the characteristics of the CSR tremendously. The microbunching structures fulfill a coherence condition for shorter wavelengths. This leads to an instantaneous increase of the radiated THz power. Observation in the time domain shows bursts of radiation which occur with different periodicities in dependence of the bunch current. The characteristics of the bursting patterns are unique for different sets of accelerator parameters [2]. At the ANKA storage ring a lot of effort was put in characterising the bursting effects in special user operation while only a single bunch was filled. The single bunch operation mode was used due to the limitations of the read out methods, but allowed using dedicated diagnostics tools to monitor the bunch length in parallel. Due to progress in the multi-bunch readout electronics development a completely new type of measurement was realised at ANKA. The KAPTURE (KArlsruhe Pulse Taking and Ultrafast Readout Electronics) [3] system opens up a possibility to monitor the THz radiation of all bunches in the ring over a principally unlimited number of turns.

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MULTI-BUNCH EFFECTS AT ANKA

An indication of bunch-bunch interactions at ANKA was previously presented in [4]. A new diagnostic method for bunch length and shape measurements based on electro-optical (EO) spectral decoding was successfully commissioned at ANKA [5]. Beyond the primary goal of this diagnostics, wake fields, caused by passing of the bunches through the EO setup, were also measured. The shape of the measured wake field is in good agreement with the simulation [6]. The result shows, that electric fields caused by a primary electron bunch does not decay to zero at the position of the following bunch. This fact could explain an interaction mechanism between neighbouring bunches. Another study at ANKA using sensitive detectors in the microwave range of the synchrotron spectrum shows, that the signal corresponding to a single bunch inside the ring has ringing for a length of several hundred nanoseconds (bunch distance at ANKA: 2 ns). The nature of this long signal tail is hypothetically connected to wake fields. The result of this study is presented on this conference in [7]. In order to investigate multi-bunch effects a dedicated diagnostics for bunch-by-bunch monitoring of THz signal for single bunches in multi-bunch environment is needed.

EXPERIMENTAL APPROACH

The solution for the study of multi-bunch effects at ANKA is the newly developed KAPTURE system in combination with fast THz detectors [8]. The last point is crucial for the independent observation of adjacent electron bunches separated by 2 ns. The signal from the detector is fed into a preamplifier and then into a 4-channel power splitter using a high bandwidth coaxial connection. Afterwards all signals are connected to a 4-channel sampling board. By using a 12-bit ADC, a track-and-hold circuit and a delay unit per channel an intelligent sampling of the signal is possible. At ANKA the bunch-by-bunch acquisition is performed with the sampling frequency synchronous to the THz pulse repetition rate of 500 MHz. The digitised values are transferred

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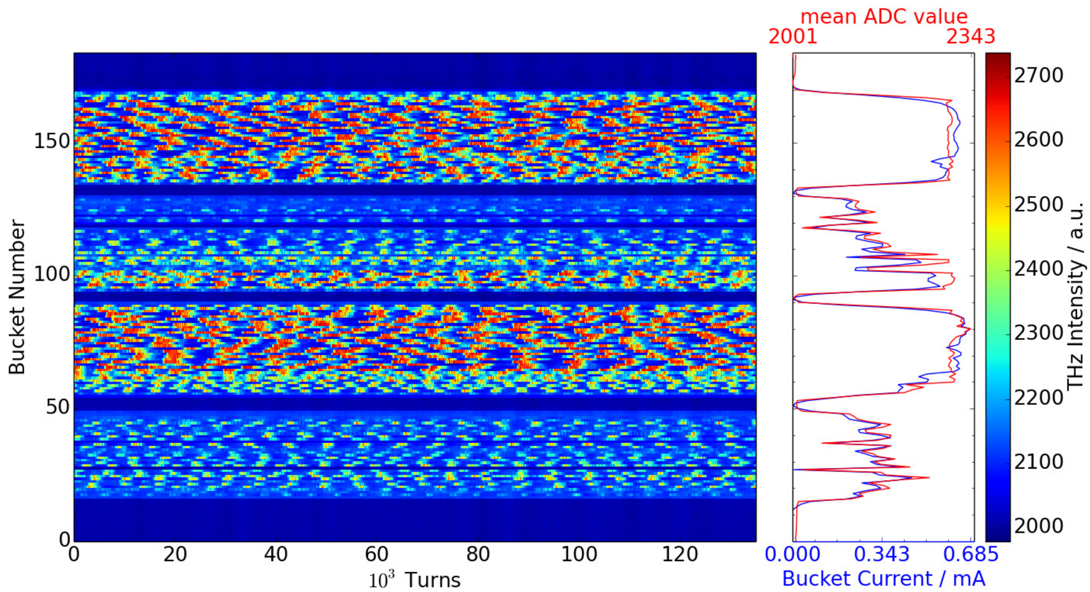

Figure 1: The THz signal measured using fast ACST Schottky Diode detector by the KAPTURE system with four trains consisting of approx. 33 bunches is shown on the left side for around 140 thousands consecutive turns. The intensity is color coded. On the right side the corresponding bucket current is shown in blue and the mean THz signal in red.

via DMA (direct memory access) to the RAM of the control PC. The data acquisition procedure and transfer is real time controlled by a FPGA. Using four ADCs with variable sampling points (3 - 100 ps) relative to the 500 MHz sampling clock, an effective local sampling rate with up to 300 GS/s is easily achievable. Furthermore, this allows the reconstruction of the peak value and the temporal position of the detector pulse. Using 4×12-bit resolution the resulting data rate reaches 32Gbit/s, which can easily exploit the performance and capacity of modern data storage systems. On the one hand, a certain amount of bunches or even turns can be skipped to reduce the data rate. On the other hand, a dedicated real time FPGA-based pre-processing and a GPU-based post-processing is being developed as more a elegant solution.

RESULTS AND DISCUSSION

All measurements were taken at the infrared beamlines (IR1, IR2) at ANKA, which have an acceptable transmission grade for THz radiation. Figure 1 shows a typical data set taken using the KAPTURE system in the bursting regime in multi-bunch mode. In this example four trains consisting of 33-35 bunches can be recognised. The color density plot shows the evolution of the intensity of all 184 buckets in the time domain. Only around 120 thousands turns are displayed here for the better visualisation of bursting. The whole data set contains about 1 second of data, that corresponds to 2.7 millions turns. On the left side the calculated mean of the THz intensity and the measured bunch currents are shown. For the determination of bunch current the single photon counting method is implemented at ANKA [9]. The filling pattern was specifically tailored using the recently installed Bunch-by-Bunch Feedback system [10]. Accordingly, different bursting behaviours for different bunch currents can be observed in the left side. For the investigation of bursting effects a frequency analysis e.g. FFT of the time domain data can be performed. These frequency domain data displayed for a given bunch current in 2D gives spectrogram. In Fig. 2, spectrograms of three arbitrarily chosen bunches within the same fill and for the same time range are shown with the dashed line marking the same bunch current in every picture. Only marginal differences can be observed at the first look. It seems that the bunches show similar bursting behaviour for similar bunch currents. The investigation of similarities and differences of bursting spectrograms will provide a useful tool for the study of bunch-bunch interactions.

Another study based on the KAPTURE system, for the determination of the bursting threshold at different momentum compaction factor (α_c) settings and at constant rf-settings was performed at ANKA. The bursting threshold is the current above which the emitted CSR intensity fluctuates. If a single bunch mode is used, a complete bunch current range needs to be observed. Instead of waiting for a single bunch to pass through the whole current range, it is also possible to use multiple bunches with different bunch currents to save time. This kind of instant bursting threshold measurement method using the mean of the THz signal for all 184 buckets and corresponding single bunch currents has been used in the past [11]. However another method using the standard deviation of the THz signal has shown higher reliability. Above the threshold the standard deviation is increasing significantly, due to the starting fluctuations. The standard

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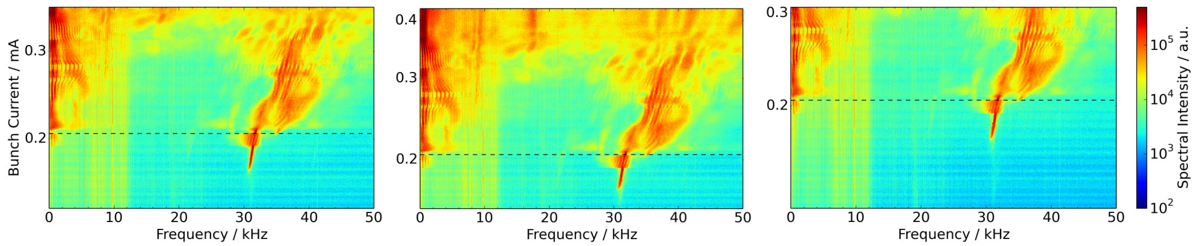

Figure 2: A frequency analysis of the time domain signal taken simultaneously for different bunches in the same fill gives insight into the bursting behaviour of each bunch in a multi-bunch environment. Here three bunches with different initial currents were taken. The horizontal lines mark the different points in time where the bunches have the same current. The differences in the spectrograms are not obvious and have to be investigated properly. The studies of bunch-bunch interactions are in progress.

deviation of the signal in dependence on the single bunch current is displayed in Fig. 3 during a reduction procedure of α_c at ANKA, where the strengths of focussing magnets are changed in steps. Every color indicates a data set, which corresponds to certain beam optics with the shown synchrotron frequency f_s. For beam optics with lower α_c (corresponds to the lower f_s) the instability threshold is significantly reduced. Due to the existence of different bursting regimes the standard deviation does not increase constantly. Especially for f_s = 7.11 kHz a change of bursting regime is visible at 0.2 mA.

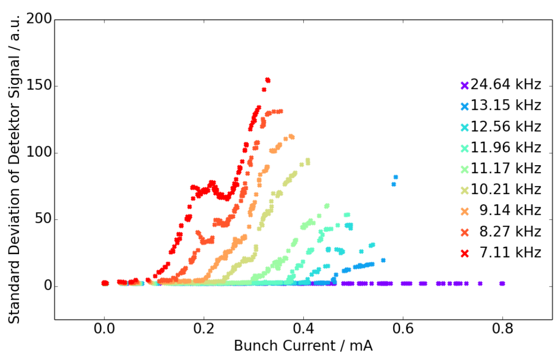

Figure 3: The bursting threshold study for different momentum compaction factors at constant rf-conditions is shown. The usage of the KAPTURE system based methods allows the monitoring of the bursting threshold during changes of the beam optics.

SUMMARY AND OUTLOOK

The fast THz detector system in connection with the KAPTURE acquisition system in multi-bunch mode with tailored filling pattern was successfully commissioned. This method with a very high potential opens up new diagnostics possibilities such as the instantaneous measurement of the bursting threshold and chromaticity effects on longitudinal particle dynamics. Studies on bunch-bunch interaction using pattern recognition for the comparison of spectrograms and statistical approaches are in progress.

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