

# OBSERVATION OF BURSTING BEHAVIOR USING MULTITURN MEASUREMENTS AT ANKA\*

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## Abstract

Since a few years coherent synchrotron radiation (CSR) created from short electron bunches is provided by the ANKA light source of the Karlsruhe Institute of Technology. Depending on the bunch current, the radiation is emitted in bursts of high intensity. These bursts of high intensity THz radiation display a time evolution which can be observed only on long time scales with respect to the revolution period. We have studied the emission characteristics of THz CSR over multiple revolutions using a detector system based on a hot electron bolometer (HEB). Its time response of 165 ps allowed to resolve the signals of individual bunches within a multi-bunch environment. This paper presents results of the experimental longterm tracking of the emitted THz signal from bunches for different bunch currents.

## INTRODUCTION

The ANKA synchrotron radiation source located at the Karlsruhe Institut of Technology in Germany can be operated in the range between 0.5 and 2.5 GeV. A dedicated beam optics with reduced momentum compaction factor is regularly used to provide the users with THz CSR from short bunches [1]. Coherent synchrotron radiation is emitted for wavelength equal to or longer than the bunch length. The total synchrotron radiation power of a bunch consisting of  $N_e$  electrons is given by [1]

$$P_{\text{total}} = N_e P_{\text{incoherent}} (1 + N_e f_\lambda). \quad (1)$$

The form factor  $f_\lambda$  describes the longitudinal charge distribution of the bunch. For a Gaussian shape bunch with RMS bunch length  $\sigma_s$  the form factor can be expressed as

$$f_\lambda = e^{-\frac{2\pi\sigma_s}{\lambda}}. \quad (2)$$

For short bunches, the coherent emission dominates and causes a quadratic dependence of radiated power on bunch current. Even a small deformation or change of bunch length, e.g. due to a change in RF voltage or potential well effects, will therefore cause a visible change in emitted radiation power. The strong self fields can act back on the bunch and cause a microbunching instability. Above a certain threshold current the CSR emission therefore occurs in bursts of intense radiation [2]. Figure 1 shows the THz

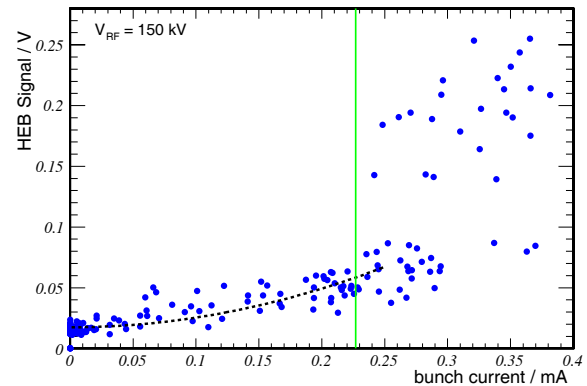


Figure 1: Using inhomogeneous filling pattern and fast THz detector it is possible to determine a bursting threshold using a one shot measurement.

power measured with a HEB based detector system as a function of bunch current. Due to the short response time of the detector, signals of individual bunches within a multi-bunch environment can be distinguished and an instantaneous measurement of the threshold current becomes possible. The current for which the quadratic increase of signal with current changes into a much stronger dependence on current is easily visible in Fig. 1.

## Bursting Emission of CSR

The intensity of the emitted radiation during a burst is significantly increased w.r.t. steady state emission. Some users of the THz radiation don't require particularly constant emission characteristics and could profit from the higher intensity. A better understanding of the long term behavior of those bursts could help to improve the conditions for those users.

The frequency of occurrence as well as the amplitude of the radiation bursts depends on the bunch current. However, in a user run, the buckets adjacent to the emitting bunch are also filled. This implies that wake fields generated by those bunches can also influence the emission of CSR via a deformation of the line density of the bunch in question. Indeed this has been observed at ANKA. Measurements and simulations of bunch deformation due to various sources in the ANKA storage ring are reported in [3] and [4].

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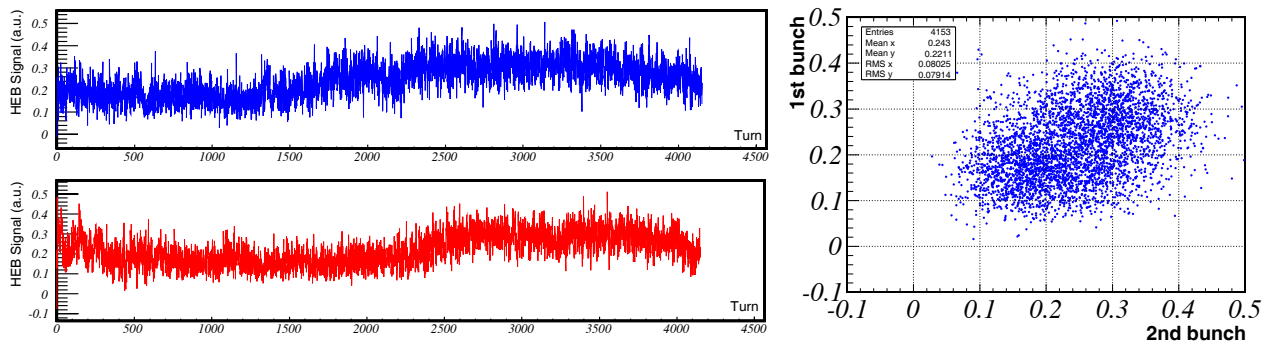


Figure 2: Turn by turn CSR signal evolution of neighbor bunches in multibunch environment. The emitted radiation of leading bunch (upper graph) as well as following bunch (lower graph) shows bursting behavior on the long time scale. This dataset was taken at the synchrotron tune  $f_s = 12.1$  kHz with corresponding period of  $83 \mu\text{s}$ . The longitudinal damping time in low- $\alpha$ -optics is about 10 ms. The total time of this data set is about 1.5 ms with approximately 4150 consecutive turns. The correlation ellipse (right graph) shows clearly that the signals of the neighbor bunches are not fully independent.

## EXPERIMENTAL SETUP

### Detector System and Radiation Generation

To detect the THz signal of individual bunches a detector system based on a superconducting NbN ultra-fast bolometer was used [5]. The detector covers the spectral range from about 0.15 to 3.0 THz. The coherent radiation itself is generated as coherent edge radiation in the fringe field of a dipole magnet. The ANKA-IR1 beamline where the measurements presented in this paper were performed, offers an angular aperture of  $45 \times 15 \text{ mrad}^2$ . The time structure of the CSR signal is obviously determined by the RF system and the filling pattern. Due to an upgrade of the e-gun and timing system [6], both single as well as multi-bunch mode are now available at ANKA. Arbitrary filling patterns can be used to study the influence of the interaction of adjacent bunches on the CSR. Variations of the bunch current, the momentum compaction factor and therewith the bunch length, the RF voltage and frequency were used to scan the parameter space for CSR generation.

### Data acquisition

The detector signal was recorded with a LECROY digital oscilloscope (WR64Xi, WP7300 and WM8600A) with high sampling rates of 10-20 GS/s and a bandwidth of 0.6, 3 or 6 GHz. The high bandwidths are needed to resolve the rise time of the short THz pulses. The signal can either be recorded with maximum sampling rate for an excellent mapping of the filling pattern over a limited number of revolutions (typically about 4150) or with specifically reduced sampling for very long observation times (about  $10^6$  turns) but only for one bunch within the fill.

For the latter case, the external sampling mode of the oscilloscope was used. In this mode the revolution frequency is used as external clock. Here one sample is taken per revolution on the maximum of bunch's peak. The new timing system at ANKA offers to delay the revolution frequency in

10 ps steps, up to 368 ns, thus the position of the trigger can be set manually to sample the THz-signal of the bunch under observation. An FFT of a thus acquired data set yields a frequency resolution of about 5 Hz. The advantage in comparison to standard spectrum analyzer measurements is the possibility to investigate the bursting in the time domain as well as in the frequency domain.

## RESULTS

Measurements of the longterm evolution of the THz emission have been performed for many different parameters of the accelerator. For example, the bunch length has been varied changing the momentum compaction factor and total accelerating voltage. A wide bunch current range was covered and many different fill pattern configurations were used.

### Multi-Bunch Filling

The bursting behavior within a multi-bunch filling was studied for deliberately inhomogeneous fills where adjacent bunches show different single bunch currents. Figure 2 shows the measured THz signals of two adjacent bunches within a multi-bunch fill (upper plot shows the leading, lower plot the following bunch) for about 4150 revolutions corresponding to about 1.5 ms. It is clearly visible that the two bunches show an almost simultaneous increase of the signal intensity. Figure 2 (right graph) shows the correlation of the two CSR signals. Whether this is due to an external excitation or to a coupling between adjacent bunches still needs to be investigated.

### Single Bunch Studies

To study the evolution of bursts over longer timescales the external sampling method was used. However, in this case only the signal of a single bunch can be recorded at a time.

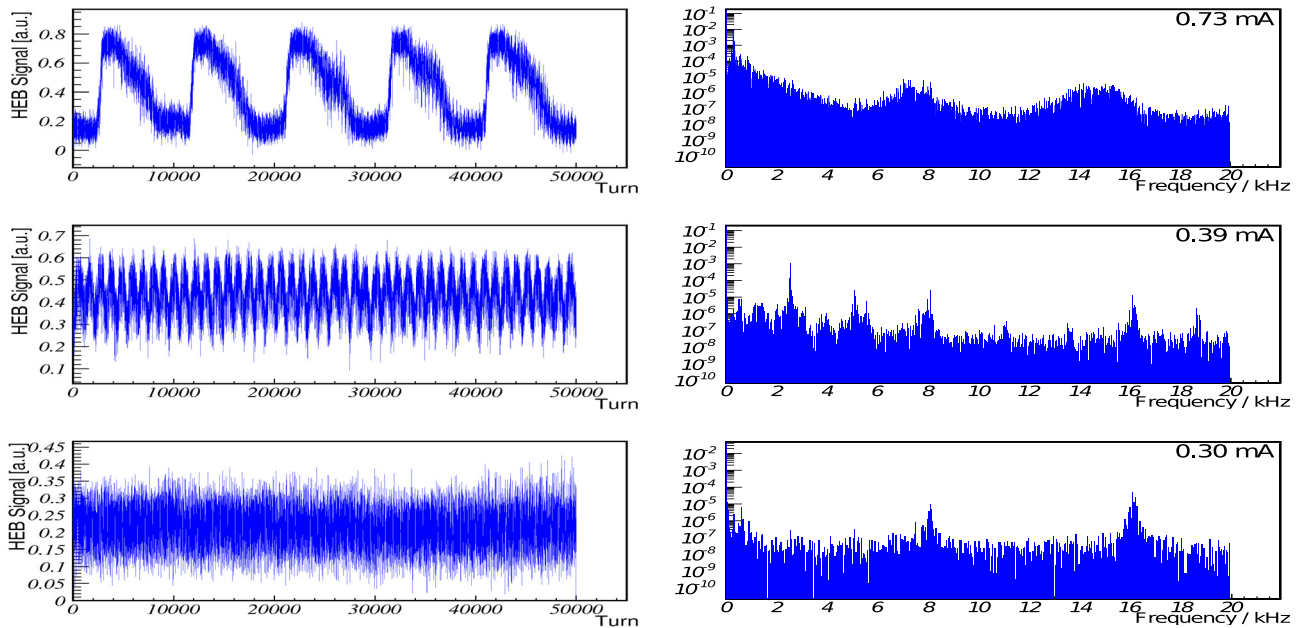


Figure 3: Observation of bursting at ANKA in single bunch mode using external sampling setup at different currents. The upper row left shows a sawtooth-type pattern of bursting far above of the bursting threshold. In the frequency domain (upper row right) a lot of excitations around of synchrotron harmonics ( $f_s = 8.1$  kHz) can be observed. The middle row left shows evolution of THz signal of this single bunch at lower current. Its frequency distribution is dominated by different peaks at and in between of synchrotron harmonics. Close to the bursting threshold (expected value around 0.22 mA) the oscillation modes decrease (lower row right). In frequency domain there is still some activity above DC and at the synchrotron harmonics.

Figure 3 shows bursting radiation at different currents above the threshold current. For the given machine parameters ( $f_s = 8.1$  kHz), the threshold is expected at a single bunch current of 0.22 mA [2]. A sawtooth-type bursting was observed at a single bunch current of 0.73 mA. A FFT of the time series shows the synchrotron frequency at about 8 kHz, slightly below the frequency determined from a button monitor signal. The  $2f_s$  harmonics is clearly visible as well. At low frequencies the data set shows a classical noise spectrum at this current. Together with the extremely broad synchrotron harmonics this is the expected behavior for a bunch deep in the bursting regime. At the lower current of 0.39 mA an oscillation with lower amplitude was observed, but the frequency of the burst seems to be higher. The longitudinal spectrum shows a lot of peaks in between  $f_s$  harmonics. The synchrotron frequency has moved closer to the button monitor value. Further decrease of the bunch current to 0.3 mA changes again the emission behavior and the bursting is only observable at  $f_s$  harmonics. The second  $f_s$  harmonic indicating a bunch shape oscillation becomes dominant which is in agreement with ongoing simulation studies [7].

## SUMMARY

Multiturn measurements of CSR have turned out to be an important diagnostics tool for storage rings with short bunch operation. Together with fast detectors the bunch

behavior can be studied over long time periods and even within a multi-bunch environment.

## ACKNOWLEDGMENTS

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## REFERENCES

- [1] A.-S. Müller at al., Far Infrared Coherent Synchrotron Edge Radiation at ANKA, PAC 2005
- [2] M. Klein at al., Studies of Bunch Distortion and Bursting Threshold in the Generation of Coherent THz-Radiation at the ANKA Storage Ring, PAC 2009
- [3] N. Hiller at al., Observation of Bunch Deformation at the ANKA-Storage Ring, IPAC 2010
- [4] M. Klein at al., Analysis of THz Spectra and Bunch Deformation Caused by CSR at ANKA, IPAC 2010
- [5] A. Semenov at al., Monitoring Coherent THz-Synchrotron Radiation with Superconducting NbN Hot-Electron Detector, IRMMW-THz 2009
- [6] A. Hofmann at al., Single Bunch Operation at ANKA: Gun Performance, Timing and First Results, IPAC 2010
- [7] priv. comm. Y. Cai