

SPECTRAL AND TEMPORAL OBSERVATIONS OF CSR AT ANKA *

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Abstract

ANKA is a synchrotron light source situated at the Karlsruhe Institute of Technology (KIT). Using dedicated low- α_c -optics at ANKA we can reduce the bunch length and generate Coherent Synchrotron Radiation (CSR). Studies of the coherent emission in the time domain and spectral measurements in the THz range allow us to gain insight into the longitudinal bunch dynamics. To study interbunch effects we observed THz radiation generated by a single electron bunch either circulating alone in the ring or in a multibunch environment. In this paper we report recent progress in CSR observations using fast THz detectors and a Martin-Puplett spectrometer.

INTRODUCTION

The ANKA storage ring is a multipurpose facility for investigation of matter using synchrotron radiation. The electrons are accumulated at 500 MeV during the injection procedure. After that the beam energy can be ramped up to nominal 2.5 GeV. In recent years research activity on CSR at ANKA [1] has steadily increased. Since dedicated low- α_c regime [2] is regularly offered for accelerator physicists and users, systematical studies on beam dynamics using CSR are going on. ANKA is a storage ring, which offers especially good experimental opportunities to explore the dynamics of short bunches.

Since our last report on observation of bursting behavior using multiturn measurements [3] we improved and optimized this method to obtain a better frequency resolution. The new time-correlated single-photon counting diagnostics (TCSPC) [4] allows more accurate fill pattern determination. Furthermore, a new Martin-Puplett Interferometer (MPI) for CSR was built and successfully commissioned at the infrared beamline at ANKA. In addition, another short bunch diagnostics tool, a single shot electro-optical sampling setup [5] is currently under commissioning at ANKA, and will be available soon.

CSR AT ANKA

In regular user operation, the radiated power at long wavelengths (THz and microwave range) of the incoherent synchrotron radiation is very low and cannot be used for experiments. To overcome this limitation a dedicated low- α_c -

optics was developed for the ANKA storage ring [2]. In this mode the momentum compaction factor and thus the bunch length is significantly reduced. As the bunch length gets shorter the radiated power for wavelengths that are longer than the bunch length increases drastically (CSR). The advantage of coherent compared to incoherent emission is, that the radiation power scales with the square of the particle number contributing to the coherent effect. As a consequence, if the bunch length is sufficiently short almost all particles will contribute coherently, leading to an increase in radiation output by a factor of $10^7 - 10^9$ (corresponding to the amount of particles per bunch). Due to better longitudinal stability a beam energy of 1.3 GeV was chosen for the low- α_c mode at ANKA. The procedure of α_c -reduction can be described as follows: injection \rightarrow ramping to 1.3 GeV \rightarrow orbit correction \rightarrow change of optics in steps to target momentum compaction factor.

At nominal optics we observed the bunch length to be about 45 ps, and correspondingly the coherent radiation is theoretically expected at frequencies up to 22 GHz. However, frequencies below 60 GHz are suppressed at ANKA due to the metallic vacuum chamber [6] and cannot be observed in this regime. In low- α_c mode the bunch length can be decreased drastically. Hence the CSR can be observed above 60 GHz in the THz range.

OBSERVATION OF LONGITUDINAL DYNAMICS EFFECTS

The electrons in the front of a high density bunch can be influenced by a strong CSR self-field. This can initiate a process of microbunching. As CSR power depends strongly on the bunch length and shape, the observation of its temporal behavior is an important diagnostics method for longitudinal bunch dynamics.

For temporal observation of CSR in the THz range a ultra fast Hot Electron Bolometer (HEB) detector system [7] is used at ANKA. The detector is optimized for the CSR frequency range (0.2-1.5 THz) with a responsivity of 5 V/W and a noise equivalent power of $6 \cdot 10^{-9}$ W Hz^{1/2}. Its response time is below 165 ps, so that we are able to resolve consecutive bunches. The HEB detector system is read out with a 6 GHz LeCroy 7600A oscilloscope for real time mode and a 500 MHz LeCroy 64xi oscilloscope for external sampling mode. [3]

The current data acquisition routine delivers a signal corresponding to 10^5 sequential revolutions. This allows the application of a FFT with a resolution of about 40 Hz to

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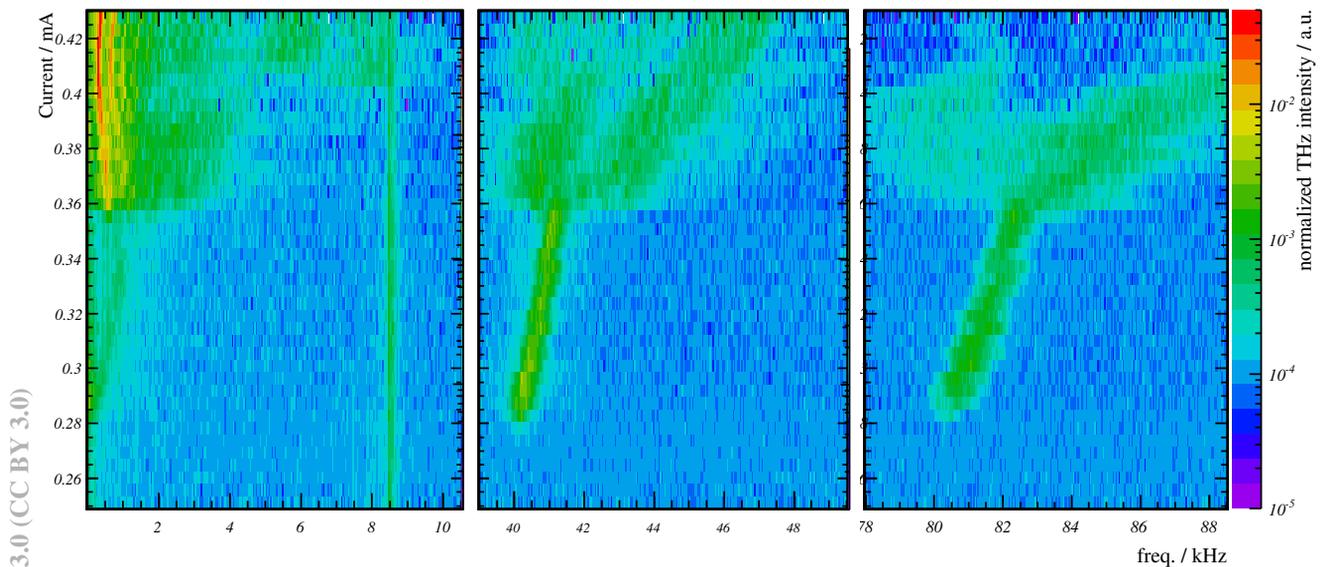


Figure 1: Instability spectrum of low frequency bursting is shown on the left diagram. Bursting occurs at currents > 0.28 mA and changes mode at 0.36 mA. The main instability can be found at about $400\text{--}600$ Hz and drifts with the current. Its harmonics are also clearly observable. The $1f_s$ frequency line can be seen at 8.5 kHz. The middle and left figure show typical bursting patterns with onset at the same thresholds.

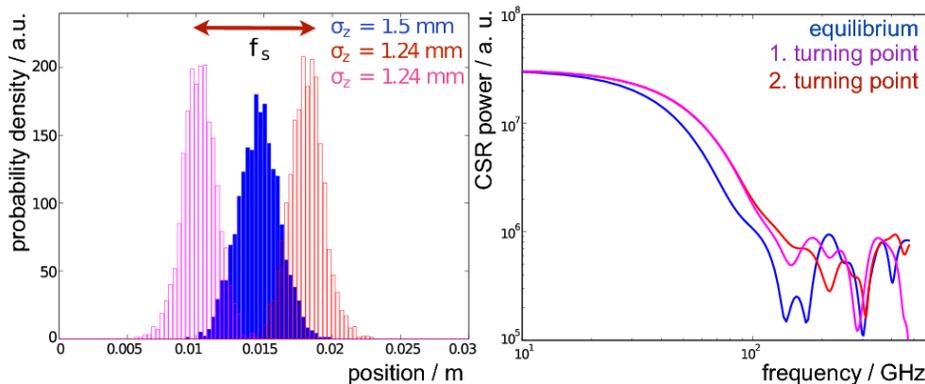


Figure 2: Synchrotron oscillations of the bunch cause fluctuations of the CSR power with $2f_s$ and higher harmonics.

resolve also the very slow bursting modes. Lower frequencies can be measured by recording more revolutions, which of course come at the expense of longer acquisition times. Fig. 1 shows the resulting longitudinal instability spectra in single bunch mode as a function of current, where color-code corresponds to the frequency amplitude. We observe three significant frequency ranges. In the low frequency range ($0\text{--}10$ kHz) the $f_s = 8.5$ kHz line can be clearly seen at all currents. This artifact line has nothing to do with CSR: It comes from intensity oscillations caused by the fact that we sampled the THz signal with the fixed revolution clock, which is not synchronized to the actual bunch position due to longitudinal synchrotron oscillations (external sampling). Around the DC bin we observe bursting radiation above the threshold of ~ 0.28 mA; the mode changes again at ~ 0.36 mA. Above this value the main low frequency instability seems to be at $\sim 400\text{--}600$ Hz and its harmonics. It drifts and gets more intensive at higher currents. Looking at the next significant pattern between 39

and 49 kHz shown in Fig. 1 (middle), the onset of bursting is again observable at 0.28 mA and around 40 kHz. For higher currents this line drifts up to 41 kHz and spreads at 0.36 mA. Similar behavior occurs at 80 kHz, probably the 2nd harmonic. As expected the bursting intensity decreases at higher harmonics. The last (hardly observable) harmonic at 120 kHz is not shown here.

In the future the data acquisition process will be further optimized. In collaboration with the Institute for Data Processing and Electronics (IPE) at KIT, a special ultra fast acquisition board based on a field programmable gate array (FPGA) is in development. Using this system it will be possible to take a THz signal simultaneously for all buckets for an unlimited amount of turns. The concept is based on multi channel acquisition to compensate the f_s line. Furthermore, the implementation of the system will include real-time analysis and limit the data stream tremendously [8].

Tracking Studies

To investigate effects of beam optics on CSR radiation, simulations using the Accelerator Toolbox (AT) particle tracking code were performed. We used a transversally well matched particle distribution with a slight energy mismatch. As a consequence an oscillation with the synchrotron frequency f_s was initiated. As shown in Fig. 2 (left) the bunch shape oscillates twice per synchrotron period. This changes the spectral emission of the CSR accordingly (Fig. 2, right). Thus the integrated power oscillates with $2f_s$. Fig. 3 shows the described behavior at ANKA at $2f_s = 17$ kHz. This effect occurs around the bursting threshold and could be explained by change of the bunch shape.

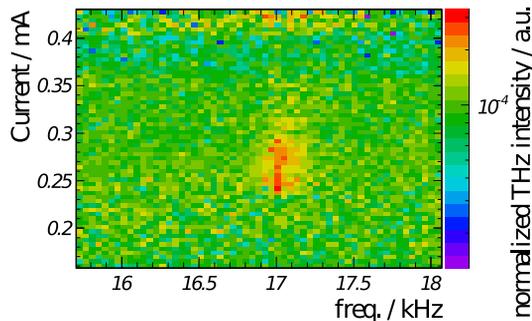


Figure 3: Expected longitudinal oscillations with f_s cause $2f_s$ fluctuations of CSR. It is remarkable that this line appears only around the onset of bursting at 0.24 - 0.30 mA

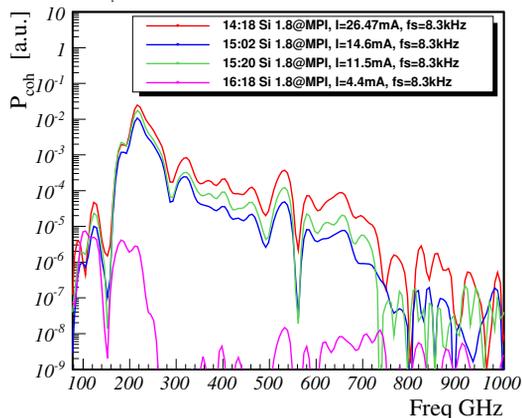


Figure 4: Spectra of CSR for different currents at the synchrotron frequency of 8.3 kHz. As expected there are additional high frequency components above the bursting threshold that disappear for low currents.

MARTIN-PUPLETT INTERFEROMETER

In 2011 a Martin-Puplett Interferometer (MPI) setup was assembled at ANKA for high resolution spectral measurements in the THz range. The optics aperture size was chosen to be above 100 mm to avoid transmission losses. After a short commissioning phase the device was used for accelerator physics studies. For comparison we took CSR

spectra at the ANKA IR1 port using a silicon-based bolometric detector, which were found to be in good agreement with the Michelson spectrometer. Fig. 4 shows exemplarily several multi bunch measurements at $f_s = 8.3$ kHz for different currents. We observed a very broad spectra above the bursting threshold. Below this threshold the spectrum changes significantly and contains, as expected, only low frequency components. As next upgrade a nitrogen purge and a dedicated THz chopping system is planned.

SUMMARY

A Martin-Puplett Interferometer was commissioned for the frequency domain diagnostics of CSR at the ANKA storage ring. For time domain studies of bursting CSR, an external sampling method was employed that allows detailed systematic studies of longitudinal instability spectra. With the achieved high resolution over a wide frequency range, intriguing structures at very low bursting frequencies could be revealed.

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