ONLINE STUDIES OF THz-RADIATION IN THE BURSTING REGIME AT ANKA

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Abstract

The ANKA storage ring of the Karlsruhe Institute of Technology (KIT) operates in the energy range from 0.5 to 2.5 GeV and generates brilliant coherent synchrotron radiation in the THz range with a dedicated bunch length reducing optic. The producing of radiation in the so-called THz-gap is challenging, but this intense THz radiation is very attractive for certain user experiments. The high degree of compression in this so-called low-alpha optics leads to a complex longitudinal dynamics of the electron bunches. The resulting micro-bunching instability leads to time dependent fluctuations and strong bursts in the radiated THz power. The study of these fluctuations in the emitted THz radiation provides insight into the longitudinal beam dynamics. Fast THz detectors combined with KAPTURE, the dedicated KArlsruhe Pulse Taking and Ultrafast Readout Electronics system developed at KIT, allow the simultaneous measurement of the radiated THz intensity for each bunch individually in a multi-bunch environment. This contribution gives an overview of the first experience gained using this setup as an online diagnostics tool.

INTRODUCTION

ANKA is a synchrotron radiation source located in Karlsruhe, Germany, and is operated by the Karlsruhe Institute of Technology. It consists of a 110.4 m long electron storage ring, which can operate at energies ranging from 0.5 GeV up to 2.5 GeV. Beside the standard user operation a special operation mode is provided to the research community. This so called low-alpha mode allows the reduction of the bunch length down to a few picoseconds by making use of an adaptable magnet optics. Additionally, the pattern in which the RF-buckets are filled can be chosen ranging from a single electron bunch up to custom filing patterns provided by the Bunch-by-Bunch feedback system [1].

The short bunch length of a few picoseconds in the low-alpha operation mode leads to an increase in the emitted power in the lower THz band due to the coherent emission of synchrotron radiation for wavelengths in the order of or longer than the emitting structure. Partially, coherent synchrotron radiation (CSR) is also emitted for (slightly) shorter wavelength than expected by the bunch length. This happens above a certain bunch current when a modulation of the longitudinal phase space is induced by the CSR impedance. This effect in the longitudinal particle distribution is called micro-bunching instability [2]. Due to the temporally changing/evolving nature of these substructures the emitted power in the THz regime fluctuates strongly with characteristic frequencies. The frequency of the fluctuations depends on the bunch current as well as on the parameters of the longitudinal beam dynamics, such as the RF-voltage, the synchrotron frequency and the momentum compaction factor [3]. The fluctuations of the radiated power in the THz regime are often referred to as bursts, while the whole effect is called bursting. For user experiments relying on stable intensity, it is necessary to know for each machine setting above which bunch current the micro-bunching instability occurs and bursting starts.

To detect and monitor bursting, the peak-intensity of the emitted THz pulse of each bunch at each turn is recorded using a fast THz detector combined with a dedicated data acquisition system. The peak-intensity of each bunch, recorded in one measurement, for approximately 2.7 million consecutive turns, is called the bunch's THz signal in the following. For the measurements described below, a zero-biased quasi-optical broadband Schottky diode detector from ACST [4] was combined with the KArlsruhe Pulse Taking and Ultrafast Readout Electronics system (KAPTURE) [5], which was developed for this purpose. This combination opens up the possibility to simultaneously measure the THz signal of each individual bunch in a multi-bunch fill, over an almost unlimited number of turns (see Fig. 1).

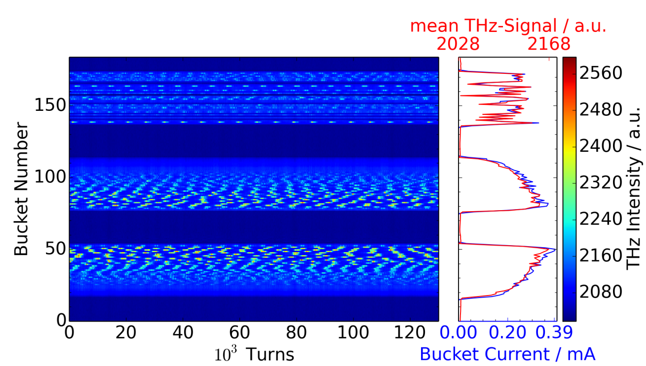

Figure 1: The peak-intensity of the THz pulses of all 184 RF-buckets is displayed over 130 thousand consecutive turns and shows strong fluctuations caused by bursting. A typical measurement takes one second and contains 2.7 million turns. The graph to the right shows the filling pattern.

This setup allows us to study the potential influence of a multi-bunch environment on the bursting behavior of each bunch. Furthermore, if these multi-bunch influences are known, then the information from all bunches with different currents in a multi-bunch fill can be used to speed up measurements like a characterization of different machine set-

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tings. Measurements which normally required a full current decay over several hours can now be done within seconds.

MULTI-BUNCH EFFECTS

With the combination of an ultra-fast THz detector and KAPTURE it is now possible to study potential influences of a multi-bunch environment on the bursting behavior of a bunch. In first measurements the bursting threshold of each bunch in a multi-bunch fill was determined by measuring the THz signal of all bunch individually during a full current decay. The results showed a small but significant spread between the bursting thresholds of the different bunches.

As the spread of the bursting threshold for all bunches in a multi-bunch environment is small, it will be neglected for the following measurements and only considered as an error on the overall detected bursting threshold.

BURSTING THRESHOLD

The threshold current, below which the micro-bunching instability does not occur, is specific to the machine parameters. In the following paragraph, a fast measurement principle using a multi-bunch measurement is demonstrated and used in a parameter sweep over the RF-voltage and magnet optic.

Measurement Principle

The general principle to determine the bursting threshold employs the dependency of the standard deviation of the THz signal on the bunch current. Previously the mean of the signal has been used for this kind of measurements [6]. Here we instead propose to use the standard deviation, which has proven to be more accurate. The bursting threshold is then visible as a kink in the standard deviation. The THz signal is constant below the threshold and with the bursting it starts to fluctuate over the turns, which naturally increases the standard deviation.

The measurement time is shortened drastically by using the information from all bunches, instead of following the decrease in current for one bunch over time. Consequently, to get useful information over the whole interesting current range a tailored filling pattern has to be used. In these measurements, the first two trains showed a linear increase / decrease in the bunch current over the bunches (first rising, second falling) and the third train had random current values. The minimal and maximal current were chosen in such a way that they included all expected thresholds for the different settings in the scan. For such a measurement the standard deviation of the THz signal of each bunch over the corresponding bunch current is shown in Fig. 2. The color of the points corresponds to the position of the bunch in the train. Figure 2 shows that bunches below the threshold at 0.2 mA show hardly any fluctuations compared to bunches with higher current.

This method was used to quickly map the threshold for different settings of the RF-voltage and the magnet optics. The latter was varied stepwise by changing the current in

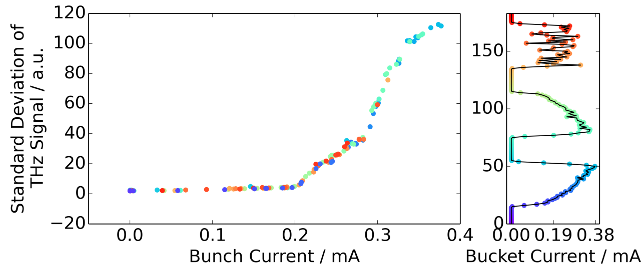

Figure 2: The calculated standard deviation of the THz signal of each bunch is plotted over the corresponding bunch current. The current profile was patterned to resample the whole current range.

the quadrupole and sextupole magnets after a predefined recipe. For each optics step, the RF-Voltage was then ramped stepwise through all desired values.

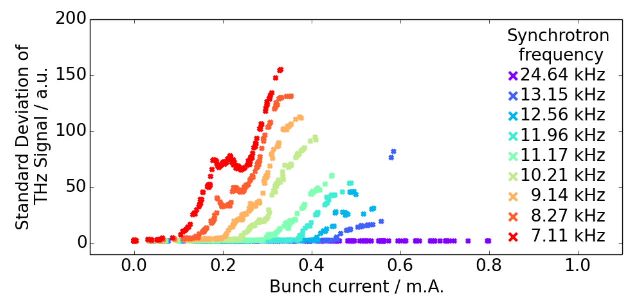

Figure 3: The standard deviation of the THz signal displayed over bunch current is shown for different settings of the magnet optics (with constant RF-voltage), which result in different synchrotron frequencies indicated by color [7].

Results

Figure 3 shows the resulting curves for a sweep over different magnet optics for constant RF-voltage. The synchrotron frequency for each optic is indicated by the color of the curve. A clear decrease of the threshold for a decreasing synchrotron frequency is visible. This corresponds nicely to the expected behavior, as a lower synchrotron frequency indicates a lower momentum compaction factor and, therefore, a shorter bunch length. For a shorter bunch length the critical charge density above which the micro-bunching instability still occurs is reached at a lower current.

In Fig. 4 the different bursting thresholds of a combined scan of the RF-voltage and magnet optic are plotted as a function of the measured synchrotron frequency. The black points corresponds to the measurement shown in Fig. 3 where the RF-voltage was kept constant at 4×300 kV. For the other points, the color indicates the RF-voltage and the dashed lines connect measurements taken at the same magnet optics. Again, the data follows the expected behavior: The threshold decreases for a reduction of the bunch length, which occurs due to a magnet optic with a lower momentum

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compaction factor (indicated by the lower synchrotron frequency). The threshold also decreases for an increase of the RF-voltage leading to a shortening of RF-bucket (resulting in a higher synchrotron frequency).

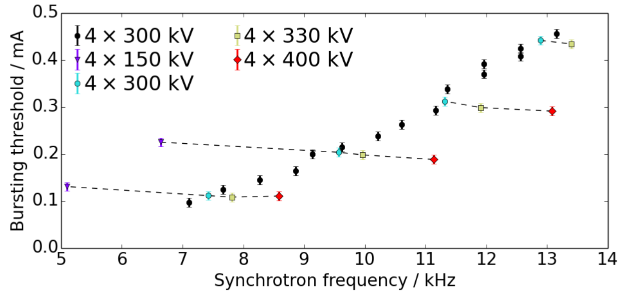

Figure 4: The bursting threshold for a combined scan is shown over the synchrotron frequency. The error bars include the error of the algorithm for the automated threshold detection, the bunch current measurement as well as the expected spread of the threshold due to multi-bunch effects.

BURSTING BEHAVIOR

Not only can the bursting threshold be determined from a short multi-bunch measurement with a tailored filling pattern, it can also give hints about what bursting behavior is to be expected. Usually, a spectrogram is used to display the changes in the bursting occurring during the decay of the bunch current. Such a spectrogram shows the Fourier transform of the THz signal over the bunch current, revealing current ranges which show different bursting behaviors [3].

In a short multi-bunch measurement with a tailored filling pattern, the bunches show all the different bursting behavior corresponding to the different current ranges at the same time. The resulting spectrogram has a limited resolution on the current axis, due to the limited number of bunches and hence current points, as shown in Fig. 5. So the current resolution is traded for the short measurement time of one second.

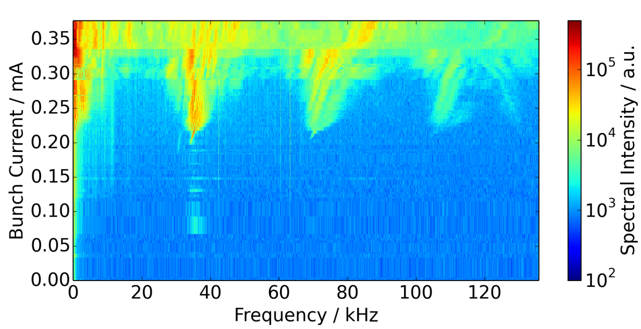

Figure 5: The fast Fourier transform of the THz signal of each bunch is plotted in rows sorted by the bunch current, resulting in a spectrogram showing the development of the bursting frequencies over the current normally obtained by a time consuming decay of one single bunch.

However, the different dominant bursting frequencies and the bursting regions are still visible and give a good impression on the bursting behavior to be expected at these accelerator settings.

CONCLUSION

Using the combination of a fast THz detector, like the zero biased quasi-optical broadband Schottky diode, and KAPTURE allows us to monitor all bunches in a multi-bunch fill simultaneously on a turn by turn basis.

Multi-bunch fills were used to speed up time consuming measurements, such as the characterization of the bursting behavior for different accelerator settings. It was shown that it is possible to measure the bursting threshold as well as a rough spectrogram of the bursting frequencies for one setting of the RF-voltage and magnet optic within seconds. With this method it is possible to provide a map of the bursting threshold and of the behavior for different accelerator settings using only a single fill.

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