FILLING PATTERN MEASUREMENTS AT THE ANKA STORAGE RING

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Abstract

For many accelerator physics studies, e.g. the investigation of coherent synchrotron radiation (CSR), a precise knowledge of the quantitative filling pattern (i.e. the number of electrons per bunch) is essential. This can be achieved by either using a linear detector (analog recording) or by employing the method of time-correlated single photon counting (TCSPC). At the ANKA storage ring both methods are in use. The analog detection is based on the signal from a stripline or an annular electrode, the TCSPC uses a Single Photon Avalanche Diode (SPAD). In this paper we describe the experimental setups and present results of a comparison of the two techniques for single as well as for multi bunch filling patterns.

INTRODUCTION

With a circumference of 110.4 m and an RF-frequency of 499.69 MHz the ANKA storage ring has a harmonic number of 184. An electron gun with single and multi bunch capabilities allows the injection of user-defined filling patterns [4]. This includes also the possibility for single bunch operation with only one bucket filled, e.g. for investigations of coherent synchrotron radiation (CSR). As it is very important that the neighbouring buckets carry no charge at all, dedicated measurement techniques are necessary to determine the filling pattern. The most simple method is to use a fast and linear detector and sample its output with a high sampling rate. At ANKA we make use of the beam-induced electromagnetic fields by means of an annular electrode or a stripline. These analog measurements can suffer from a low signal-to-noise-ratio and other problems like signal reflections and ringing. A completely different way for detecting the filling pattern is the time-correlated single photon counting (TCSPC) [1]. It is based on the measurement of the time differences between single photon events and a revolution trigger. The distribution of these differences represents the filling pattern. This method has the potential for very precise measurements as it doesn't contain any analog signals that suffer from the problems mentioned above.

SETUP

For the filling pattern measurements three different devices are used. The analog recording is achieved by using an annular electrode or a stripline. They are part of the beam diagnostic system and are integrated in the beam pipe. The signals from these devices are read out by oscilloscopes. For the TCSPC we use the new visible light diagnostics beamline [2]. The attenuation of the light down to single photon level is achieved by using a silver-coated mirror sending almost all the light to the streak camera, but transmitting a small fraction (see Fig. 1).

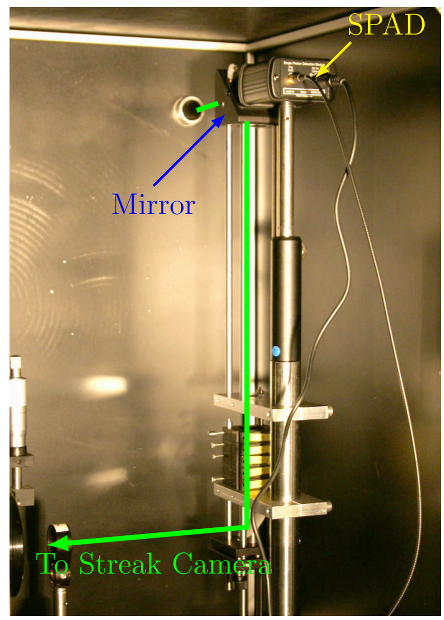

Figure 1: TCSPC-setup at the visible light diagnostics beamline, the setup is shielded by a metal box.

The detector is a single photon avalanche diode (SPAD) from idQuantique (id100-20) [3]. For each detected photon it delivers a 30 ns TTL-pulse that is sent to a histogramming device, in our case a LeCroy oscilloscope. This TCSPC-setup allows a maximum count rate of 300 s^{-1}. Due to a good background shielding the dark count rate is low and we have a dynamic range of 10^4. This is one order of magnitude above the values achievable with dedicated TCSPC-systems but in that way we can make use of this precise technique at a very low-efficient cost.

DATA ANALYSIS

The signals from the two methods are completely different and thus dedicated processing is required to compare them.

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Analog Recording

The stripline and the annular electrode are read out by a 600 MHz oscilloscope in the control room.

As first step the time axis is divided in intervals of 2 ns. The annular electrode delivers one pulse per bunch and thus the division is done in a way that the global maximum of the curve lays in the middle of the corresponding interval and for each interval the positive peak voltage is determined. Due to its principle the stripline delivers two pulses per bunch (a negative and a positive one), separated by roughly 1 ns. The interval division is now done that the global maximum is at 3/4 of the interval and the peak-to-peak voltage is taken as relevant value (see Fig. 2).

Finally the acquired 184 voltage values are normalized to one. This allows the comparison of the different measurement techniques and by multiplying with the measured integral beam current we get the quantitative filling pattern.

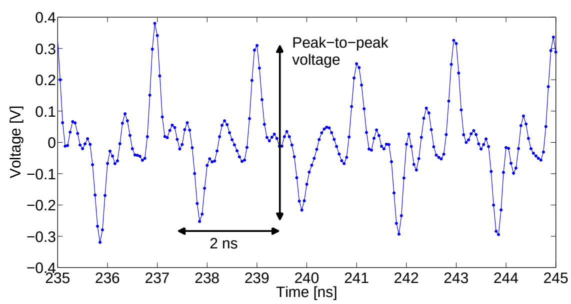

Figure 2: Detailed view of the stripline signal for a multi bunch filling-pattern. The signal consists of two pulses per bunch and the peak-to-peak voltage is taken as relevant value.

TCSPC

The TTL-pulses from the SPAD are sent to an oscilloscope with an integrated histogram function. The division in 2 ns intervals is done in a way that the maximum is in the middle of the corresponding interval. As the events stemming from an individual bunch normally are spread over 3 channels, the events from these channels are summed up and the 184 values are normalized to 1.

RESULTS

In normal user operation the filling pattern of the ANKA storage ring consists of three trains with roughly 33 equally filled bunches per train. A modified three-train-pattern can be seen in Fig. 3.

The three trains and their substructure are resolved by both methods. A very important point is the signal level for the empty buckets (e.g. between 0 ns and 50 ns). For these buckets the TCSPC signal level is one order of magnitude lower than that of the stripline. This shows the higher dynamic range of TCSPC compared to analog recording and allows a more precise determination of buckets really

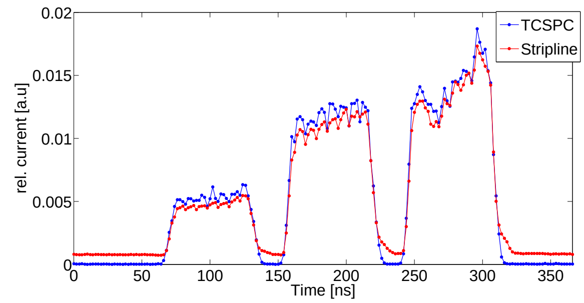

Figure 3: Multi bunch filling pattern recorded by TCSPC (blue curve) and a stripline (red curve).

filled with electrons. Also important is the comparison of the standard deviations of the two methods (see fig. 4). Due to its operation principle the stripline is sensitive to transverse oscillations of the bunches. These oscillations increase over the three trains and can also differ from fill to fill. In contrast the standard deviation of the TCSPC is only determined by poisson statistics i.e. it can be improved by using a faster electronics that allows higher count rates.

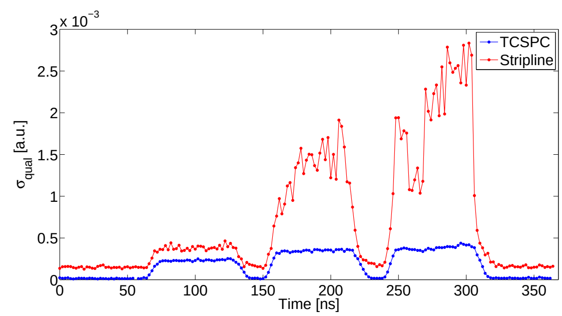

Figure 4: Standard deviation of a multi bunch filling pattern measured by TCSPC (blue curve) and a stripline (red curve).

The advantages of a higher dynamic range can also be exploited in single bunch mode as can be seen by comparing the raw data of the stripline and the TCSPC (See Fig. 5). The stripline signal shows only one bucket filled with electrons and there are no hints for a second one. The corresponding TCSPC data shows that there was more than one bucket filled, a second peak can be seen 2 ns after the main peak. For that situation the bunch purity i.e. the ratio of the main bunch and the ”unwanted” spurious bunch can be determined and one gets $1.7 \cdot 10^2$ [5].

We also investigated the influence of a decaying bunch length on the signals of the analog recording. In the so called ”Low-alpha mode” (used for investigations of CSR) the bunch length strongly depends on the bunch current [2].

For excluding bandwidth dependent effects we measured the signal amplitude over the bunch current (and thus of the bunch length). The signal amplitude decays linearly with the current (see Fig. 6) and thus bandwidth effects can be neglected .

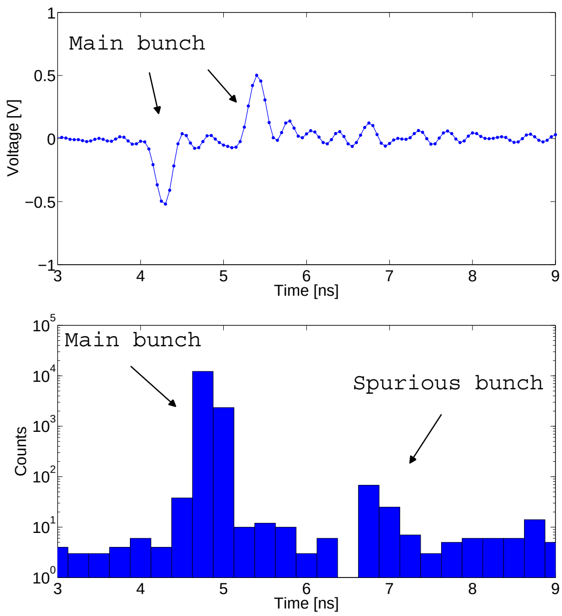

Figure 5: Stripline (above) and TCSPC (below) raw data for a single bunch fill.

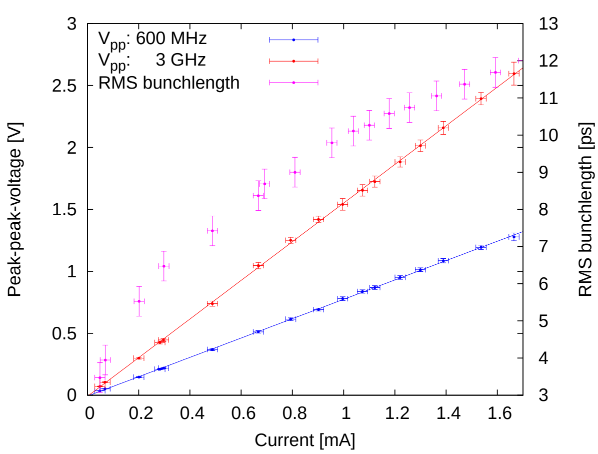

Figure 6: Decay of the stripline peak-to-peak voltage over bunch current, detected with oscilloscopes with different bandwidths (red and blue curve). The pink curve shows the bunch length decay over the current.

Quantitative Filling Pattern

To get a quantitative filling pattern is it not only necessary to measure the electron distribution (normalized to one) but also the total beam current. At ANKA we use a DC Current Transformer (DCCT). As this device is based on the shift of a hysteresis curve by the beam-induced magnetic field it is sensitive to external magnetic fields like those caused by magnets close to the DCCT. In our case the most critical magnet is a horizontal corrector magnet as its current can change during operation for orbit correction reasons and because measurements showed that it induces the largest current offset in the DCCT.

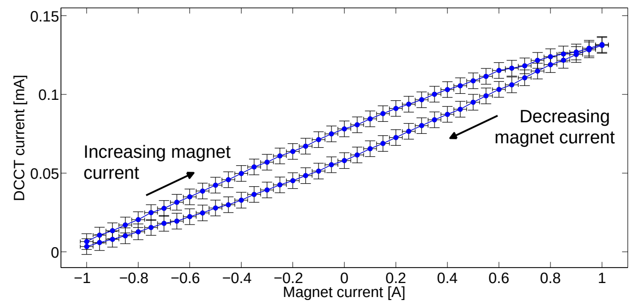

Figure 7: Current offset induced in the DCCT by the horizontal corrector magnet 3.1 installed close to the DCCT.

This offset can be measured by stepwise cycling of the magnet, see Fig. 7. This offset has to be taken into acount especially for single bunch operation and the measured beam current has to be corrected by the offset measured after dumping the beam.

Another point is the acquisition time of the different methods regarding the fact that ANKA has no top-up mode and thus the current decays continuously. For the analog recording this is no problem as the acquisition times are in the range of some seconds. For the TCSPC they are in the range of minutes and depending on the beam lifetime the current decay has to be taken in to account and leads to a higher uncertainty for the measured beam current. This leads to a trade-off for quantitative measurements at ANKA: For short beam lifetimes the analog measurements deliver better results, for a long lifetime the TCSPC is the better choice.

CONCLUSION

The setup presented here allows to exploit the technique of time-correlated single photon counting in a very cost-efficient way. This does not enable the precision achievable with commercially available system but we could show that TCSPC delivers more precise results compared to analog measurements.

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