PARASITIC BUNCH MEASUREMENT IN e+/e– STORAGE RINGS

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ABSTRACT

The lepton storage rings DORIS and PETRA at DESY are used as sources for synchrotron radiation experiments. In normal operation the distance between bunches should be 96 ns in PETRA and in DORIS. The adjacent buckets must not have any stored particles or, in reality, as few as possible. This is particularly important for time-triggered photon measuring experiments. The principle of the 'parasitic bunch' measurement down to a fraction of 10^{-6} of the main bunch within 20 seconds is described. Additionally, the sources of the 'parasitic bunches' and the actions to minimize them are discussed.

INTRODUCTION

Fast time resolved X-ray measurements make use of the inherent time structure of a storage ring (SR). Depending on the size of the ring and the filling pattern (the distance between bunches) the active time window may be in the range of few ns to few µs. This allows studying kinetics in pump-probe experiments or dynamics using resonant scattering processes [1]. In particular the latter is very sensitive to spurious charge in the machine, which is usually accumulated in buckets adjacent to the intentionally filled bunch. For this reason most SRs used to produce synchrotron radiation have installed a system to detect the time structure of the machine with high sensitivity [2, 3]. In the following we describe a system, which has been installed at PETRA allowing us to detect spurious charge already during the injection process.

SOURCES OF PARASITIC BUNCHES - THE IDEAL MACHINE

All lepton SRs at DESY (DORIS, PETRA and HERA) have a 500 MHz RF-system, i.e. buckets are separated by 2 ns. All storage rings and the pre-accelerators are synchronized via a common bunch-marker system. However, not all buckets are filled with e^+/e^-. The normal bunch distance in PETRA is an integer multiple of 48 buckets (96ns). This means a maximum of 80 bunches may be injected. However, also other patters are possible. The situation at DORIS is similar. In an ideal storage-ring only the addressed buckets contain e^+/e^-. All other buckets must not have any stored particles. In any real machine some particles are stored in other buckets, in particular in the adjacent buckets, the so-called 'parasitic bunches'.

THE 'PARASITIC BUNCH' SITUATION

In principle any SR with non-uniform filling patterns should have parasitic bunches. This is due to the fact that in the initial stages of the pre-accelerator system bunches are rather elongated. In particular at DESY the situation is as follows [4, 5]:

Right after the electron gun and a focusing lens the ‚ante-linac-chopper' (a vertical electrostatic kicker combined with an upstream collimator) leads to a first bunching of the beam. This results in 10 to 60 ns long pulses at a repetition rate of 20 ms (50 Hz). In order to use the linac (running at 3 GHz) most efficiently those pulses are too long. Thus after further lenses and collimators the 3 GHz-prebuncher (a cavity with 20 kV gap-amplitude and a power of 1.5 kW) concentrates most particles in 50 ps long bunches. After being accelerated to 450 MeV in 12 linac modules particles are accumulated in PIA, a 28.9 m ring running at constant beam energy with a 10.4 MHz HF-system. In PIA several shots from the electron gun are accumulated in one bunch, which may then be several ns long. To reduce the bunch length further the accumulated beam is shortened in the last 40 ms before ejection to DESY-2 by a 125 MHz-system. This treatment reduces the bunch length to a rms value below 0.2 ns at a bunch distance of 8 ns. On the way to DESY-2 the beam extracted from PIA is again filtered by a 'post-linac-chopper' to suppress 8 ns-parasitic bunches. However, during the transfer from the 125 MHz-system at PIA to the 500 MHz-system DESY-2 2 ns parasitic bunches are created by any non-ideal behaviour in the transfer. This may be for example a deviation from the optimum setting of the DESY-2 injection energy due to jitter in the magnet currents or a wrong setting of the DESY-2 injection phase. The latter must be optimized for minimal longitudinal oscillations during injection. The same holds for the transfer from DESY-2 to PETRA and DORIS, respectively.

Further on we have learnt from first measurements that high PIA current causes post-bunches up to 6 ns. The reason for this behaviour is not clear yet, but it could be a longitudinal instability at high bunch charge.

THE PRINCIPLE OF THE 'PARASITIC BUNCH' MEASUREMENT

The parasitic bunch measurement is achieved by an avalanche-photo diode (APD) (EG&G, C30703F) [6] detecting scattered X-rays from a 1 mm thick graphite foil. It is located in the PETRA undulator beamline 31.3 m downstream of the dipole separating the lepton from the undulator beam. This dipole is used as source for the parasitic bunch measurements. The detector signals are amplified close to the diode by a fast three-stage amplifier. The overall time resolution is approximately 0.8 ns. The amplified signal is analyzed using a time-to-digital-converter (TDC) and a multi-channel-analyzer (MCA). To reduce the influence of the so-called "walk" and to reduce the background due to electronic noise the amplified detector signal is filtered by a constant-fraction-discriminator (CFD) (Fig. 1).

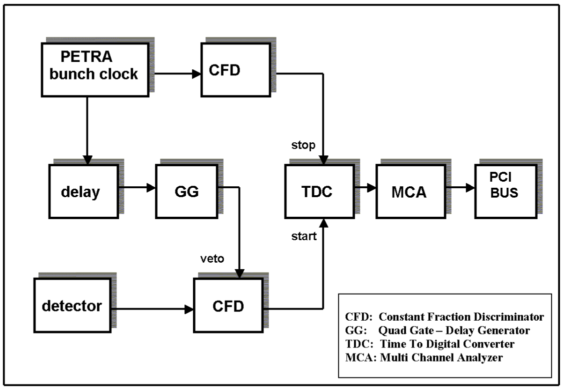

Fig. 1: Standard signal processing of the 'parasitic bunch' measurement (schematically).

The CFDs, used also in the synchronizing bunch-clock branch, are fast NIM-modules. Thus the start- and stop-signals are short 5 ns pulses triggering the TDC. The TDC digitizes the time lag between start (detector) and stop (bunch-clock) pulse and stores the event in the MCA.

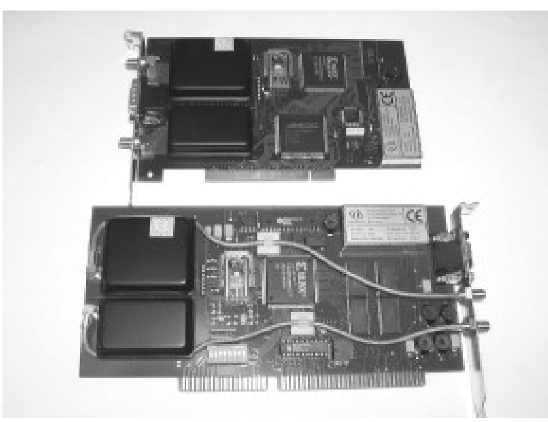

Fig. 2: Pictures of the TDC-boards ‚TimeHarp' (PicoQuant) for PCI- and ISA-bus. CFDs and MCAs are included.

The TDC-board [7] (Fig. 2) offers 4096 channels with minimum width below 40 ps and can work at count rates up to 3 MHz (300 ns recovery time).

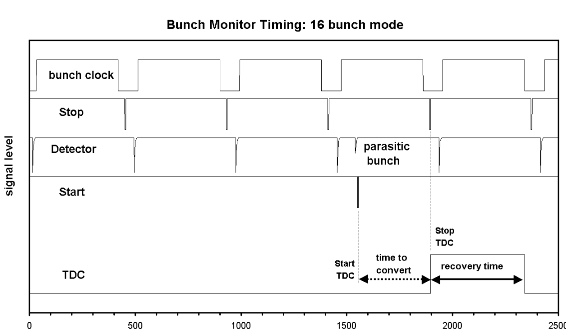

Fig. 3: Schematic pulse sequence for PETRA 16 bunch mode. Near 1500 ns an event due to a parasitic bunch is plotted.

A second mode uses a TAC (time-to-amplitude-converter) converting the time delay to uni-polar pulses digitized in turn by an ADC in 'peak height analysis mode'. The timing-diagram in Fig. 3 shows schematically the pulse sequence. A gate blocks start events generated by main bunch signals. To measure a histogram not affected by recovery-time and pile-up effects, the detector count rate should be limited to below 1.5% of the sync rate. In addition the detector must be carefully shielded (see Fig. 4) against stray light, which similar to light from parasitic bunches, reaches the detector with a time delay.

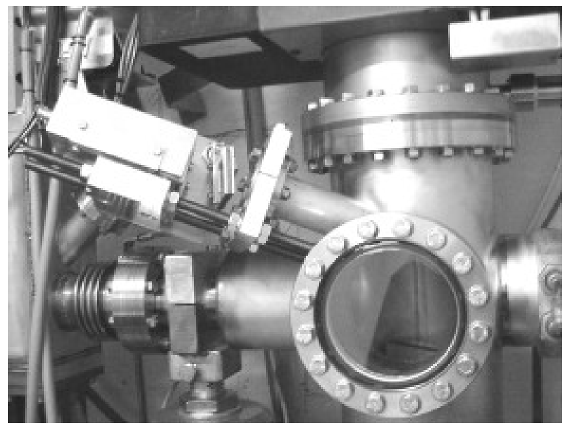

Fig. 4: Parasitic bunch monitor in PETRA. Left: APD-detector, with lead shielding, electric connections and slit. On the right edge of the picture the holder for the graphite foil is seen.

For the machine operation a Server and Client was developed in VisualBasic-6 under Windows NT4. LabVIEW, C++, Delphi and Visual Basic are supported as well. Driver Libraries for Linux are available.

EXAMPLES OF MEASUREMENTS, IMPROVEMENT OF THE SITUATION

To test the performance of the timing system an ex-situ histogram was taken with signals 2 ns apart supplied by a waveform generator (Fig. 5, note that all measurements are displayed on logarithmic scale).

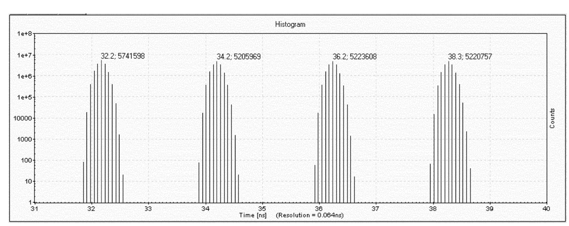

Fig. 5: Histogram of pulses from a STANFORD wave generator with roughly 2 ns distance (FWHM = 160ps).

Figures 6 and 7 show examples of a decent and a bad filling in PETRA. The situation for optimum settings of the pre-accelerators is depicted in Fig. 6. Besides the main bunch at 525.5 ns two pre-bunches with 10^{-3} at 2 ns and 10^{-5} at 4 ns normalized to the main bunch are visible.

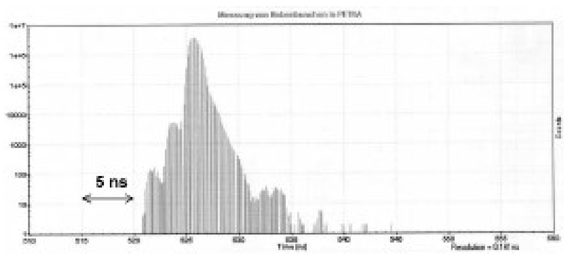

Fig. 6: Main bunch and parasitic bunches from 4 ns 'before' to some 10 ns 'after' the main bunch. This plot represents a reasonably clean pattern.

"Behind" the main bunch the measured intensity decays to a level of 10^{-6} within 8 ns. The parasitic post bunches are not resolved as clearly as the pre-bunches as the detector response is asymmetric with a broader tail on the falling edge [6] and stray light may contribute to the detected signal. Even after 8 ns some intensity is visible detecting few 100 spurious positrons circulating several meters behind the main bunch.

Fig. 7 shows a measurement during an injection with wrong setting of the DESY-2 injection energy. Strong pre and after bunches are visible in a range of 30 ns.

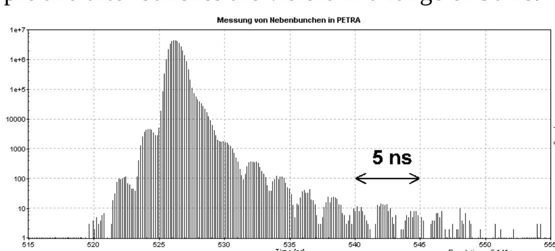

Fig. 7: Main bunch and parasitic bunches from 6 ns 'before' to some 20 ns 'after' the main bunch. These data were taken at reduced DESY-2 injection energy (450 MeV).

A systematic study of the influence of several machine parameters in the pre-accelerator chain has resulted in the following conclusions:

The most sensitive parameter is the DESY-2 injection energy; if this value is too low parasitic bunches up to 20 ns are injected into PETRA. Parasitic bunches in the region up to 6 ns are created if the current in PIA exceeds 40 mA. Further on the 500MHz-DESY-2-RF-phase must be adjusted properly otherwise 2 ns parasitic bunches are injected to DORIS or PETRA. The same holds for the timing (time zero of the deflection electric field) and collimator position of the 'post linac chopper'.

As a tool to avoid parasitic bunches the control software of DESY-2 knows the so-called 'ejection-veto'. When enabled, the software checks the setting of the injection energy and blocks ejection if the difference is outside the defined tolerance.

POSSIBLE IMPROVEMENTS OF THE ‚PARASITIC BUNCH' MEASUREMENT

The main point for improvements concerns the comfort of using the control software i.e.:

- automatic detection of the position of the main bunch relative to the bunch marker
- evaluating the intensity in all buckets and reporting the relative population of parasitic bunches for operators
- 'Fit to PETRA buckets', i.e. display the histogram in a 2 ns pattern
- display several histograms simultaneously to detect changes quantitatively
- creating a file-system for histograms
- using the veto in the detector branch to gate out the main bunch. This reduces the counting time as higher flux may be used without running into recovery time problems.

Concerning the hardware the HV setting should be remote controlled. To increase the resolution a smaller and faster APD now available commercially could be installed. In addition a remote controlled filter will increase the flexibility concerning counting time and injected current.

CONCLUSION

We have reported a system to detect parasitic bunches in the e+/e– machine PETRA at DESY. The monitor detects X-rays scattered by a graphite foil 1 mm thick with an APD detector and fast electronics. The control software allows to routinely detect the filling pattern during the injection process. In case of unacceptably high parasitic bunch intensity the injection may be interrupted and continued with optimized pre-accelerator parameters.

For the upgraded machine PETRA-III, a third generation X-ray source at extremely low emittance (1 nmrad), we plan to install a similar system. This will allow optimizing the injection process in particular in top-up mode operation. One can think of either running in a 'single trigger mode' evaluating the filling of every bunch in the machine on a level of nA between two injections (roughly one minute apart). On the other hand by triggering the system after every bunch the purity of the bunch filling may be checked and optimized.

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