CHARGE DISTRIBUTION MEASUREMENTS AT ALBA

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Abstract

Two different set-ups are used to perform quantitative measurements of the charge distribution at ALBA. The first consists in a real-time analysis of data coming from the Fast Current Transformer or from the buttons of a Beam Position Monitor installed in the Storage Ring. The second is performed at the diagnostic visible beamline Xanadu, using a Photomultiplier that measures the temporal distribution of synchrotron light. In both cases a quantitative estimation of the charge distribution is obtained after a dedicated data treatment and beam current measurements from the DC-Current Transformer. We compare results with both methods, and discuss differences and limitations with respect to the results from a preliminary Time Correlated Single Photon Counting set-up.

INTRODUCTION

ALBA [1] is a 3rd generation Synchrotron Radiation Source located in Cerdanyola del Vallés (Barcelona, Spain) operative since May 2012. The facility is composed by a full-energy injection system (Linac and Booster) and a Storage Ring, where a 3 GeV electron beam is used to produce light for 7 active beamlines. An 8th optical beamline, Xanadu, is used for electron beam diagnostic purposes.

We developed an on-line tool to monitor the longitudinal charge distribution, also called filling pattern. ALBA beam structure is composed by 448 buckets of 2 ns length ($\simeq$ 60 cm). The routinely used filling pattern consists on 10 trains of 32 consecutive bunches, the gap between two consecutive trains is composed by 12 empty buckets, and 8 more empty buckets follow the last gap (abort gap). This filling pattern allows the identification of the first train, as shown in Fig. 1.

Several tests were performed: we measured ALBA charge distribution using two analog devices (Fast Current Transformer and Beam Position Monitor) and an electro-optical device (a photomultiplier). This paper presents the experimental set-ups, measurements and results we achieved with each device and how we combined them to obtain the best response. Some applications of the filling pattern monitoring are also shown.

EXPERIMENTAL SET-UP

Analog devices detect the electro-magnetic field produced by the beam current, while electro-optical devices directly measure the intensity of the synchrotron radiation produced by the charge distribution. In both cases the direct quantitative information about the current per bunch is lost (unless previous calibration are done). We use these devices to measure the filling pattern and we integrate the information about the current reading the real-time value from the DC-Current Transformer (DCCT) located in the storage ring.

Analog Devices

The fast way to monitor the beam structure at ALBA consists in the observation of the signal of a Fast Current Transformer (FCT Bergoz 20:1 LD [2]) directly connected to an oscilloscope (Infiniium DSO80000B Series). The obtained signal is shown in Fig. 1 (yellow signal): trains and gaps are evident but the filling status of the different buckets is not clear. We also consider the sum of the four buttons of a Beam Position Monitor (BPM) and we observe the signal at the same oscilloscope (Fig. 1 in green).

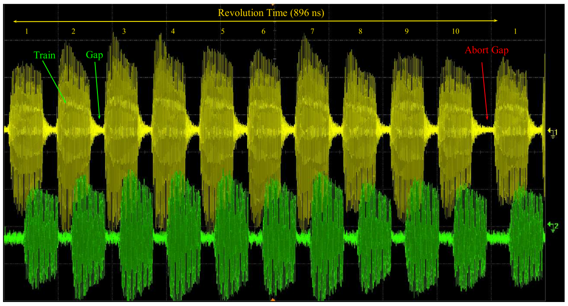

Figure 1: FCT and BPM signal, respectively in yellow and in green, used to monitor the filling pattern.

We use a Tango device server to interface the oscilloscope and the DCCT with the general ALBA control system. This allow to directly acquire signals from the devices and perform an on-line data treatment to obtain a better filling pattern result. The device server is also used to synchronize the oscilloscope trigger with the general timing system [3]. Figure 2 shows a sketch of the data acquisition for the FCT.

Electro-Optical Devices

The number of photons produced by the emission of synchrotron radiation is directly proportional to the number of electrons in the beam. To measure the charge distribution we detect synchrotron light using a fast photomultiplier (PMT Hamamatsu H10721-210 [4]). The intensity of the output signal of this device is proportional to the number of electrons in the bunch.

The synchrotron radiation is produced when the electron beam goes through a bending magnet. We only select the visible part choosing an appropriated position of the extraction mirror [5]. The light is guided at the ALBA optical

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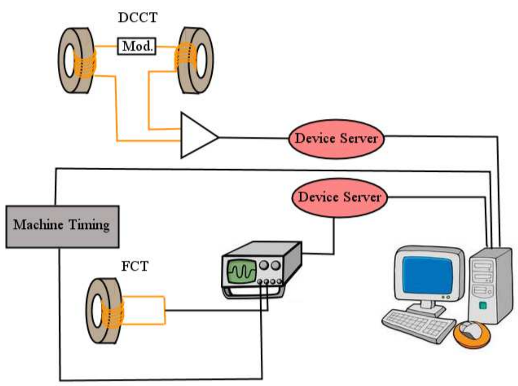

Figure 2: Sketch of the FCT experimental set-up for filling pattern measurements.

beamline Xanadu through a chicane of mirrors, filtered by a dichroic filter in order to select a narrow range of wavelength (400-500 nm), and finally detected by the PMT.

We directly connect the PMT to an oscilloscope (LeCroy Wavepro 7200), whose trigger is provided by the ALBA general timing system. The direct signal is shown in Fig. 3: trains and gaps are well defined and the oscillation on the top of the trains are consistent with the signals from the different bunches. In this case no device servers are (yet) developed and the data treatment is performed off-line.

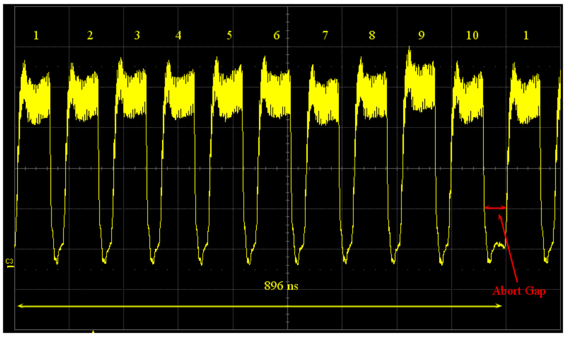

Figure 3: PMT signal observed at the oscilloscope.

Using the same PMT we prepared a preliminary Time Correlated Single Photon Counting (TCSPC) set-up [6], as presented in Fig. 4. Visible light reaching Xanadu is attenuated down to one photon per beam revolution, before reaching the PMT. The output signal is amplified and sent to a PicoHarp 300 module that acts as a Time to Digital Converter (TDC) [7]. The PicoHarp measures the time difference between the trigger signal synchronous with the head of the beam, and the signal detected by the PMT. The obtained temporal distribution corresponds to the charge distribution of electrons emitting the photons.

CHARGE DISTRIBUTION MEASUREMENTS

We tested the different experimental set-ups, implemented a data analysis to obtain a quantitative estimation of the current per bucket, and finally compared the results.

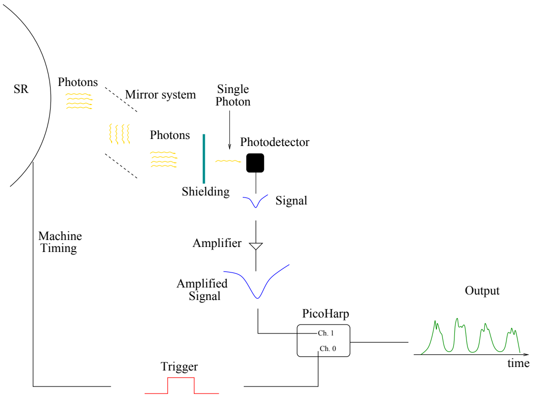

Figure 4: Sketch of the TCSPC experimental set-up.

Data Analysis

The data analysis is very similar for all the devices [8]. Data are acquired at a 3 Hz rate and averaged over 50 consecutive acquisitions to decrease the electronic background noise. We apply a 500 MHz low-pass filter to select the signal corresponding to the bunches repetition rate. The filtered signal is divided into time-windows of 2 ns, corresponding to the ALBA buckets length, and the estimation of the relative current intensity is given by the peak to peak amplitude (analogical devices) or the maximum amplitude (PMT) of the signal in the given time-window.

In the case of the TCSPC, no filter is applied and the filling pattern is obtained summing the number of photons counted in each time window.

After the relative estimation of the intensity of each bucket, the current read by the DCCT is distributed in the filling pattern, to provide the current per bunch.

Comparison Between Devices

Figure 5 shows the results of the data analysis for the FCT (blue), the BPM (green), and the PMT (red) for one train.

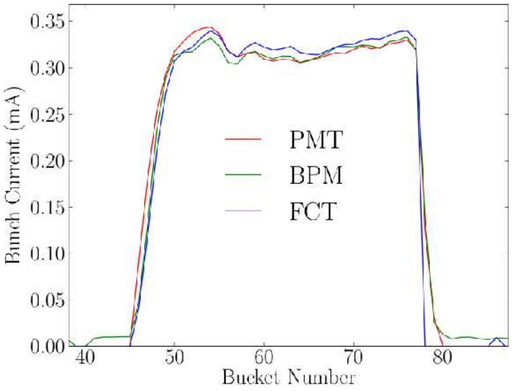

Figure 5: Results from the data analysis of a single train: note the long decay time of the PMT, and the small noise peak of the FCT at around 86 ns.

The charge distribution is very similar for the three devices. Nevertheless the PMT always presents a peak at the

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beginning of the train, due to the internal gain modulation which is also notable in Fig. 3. Lowering the gain or the photon flux does not change the result. Moreover both the PMT and the BPM present a long decay time (around 4 ns [8]) and the current data analysis is not able to distinguish this type of noise from a real bunch. Finally results from the FCT always presents a good time resolution but are affected by a strong electronic noise in the gaps. The same happens to BPM results, while the one from the PMT are not affected by this problem.

Time Correlated Single Photon Counting

The performance of the TCSPC strongly depends on the characteristics of the PMT. With the current set-up we are able to distinguish between empty and filled buckets with a dynamic range of $\simeq 10^3$, but any relative or quantitative estimation of the charge per bunch is not precisely determined. Raw results from the TCSPC are depicted in Fig. 6 showing the clean signal in the gaps.

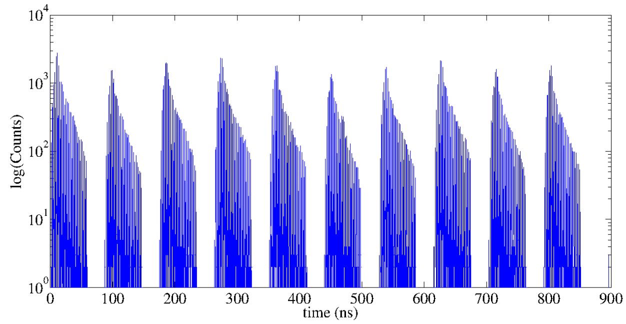

Figure 6: TCSPC raw data in logarithmic scale.

The problems with the charge distribution are due to the time response of the PMT. Figure 7 shows the response of the device to a single photon. We calculate the standard deviation of the output signal to be approximatively 0.9 ns, while conventional TCSPC detectors has usually an instrument response time around 0.05 ns [6].

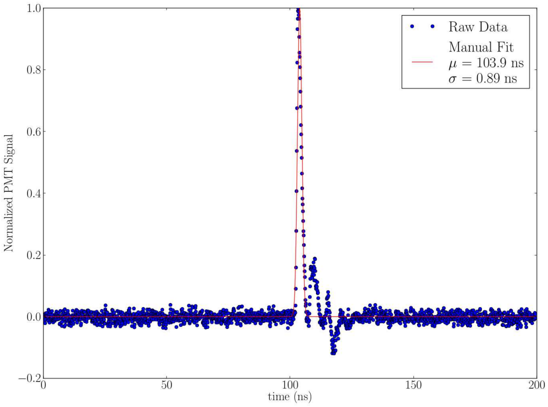

Figure 7: Response of the PMT to a single photon.

Results

Combining the optimal temporal resolution obtained with the FCT and the absence of noise in the gaps of the PMT, we obtain a good definition of the beam longitudinal structure. An example is shown in Fig. 8 where TCSPC data are used as mask to improve the results of analog devices: the final result is compared with the result obtained using only data from the FCT: the time response is good and no noise is present in the gaps.

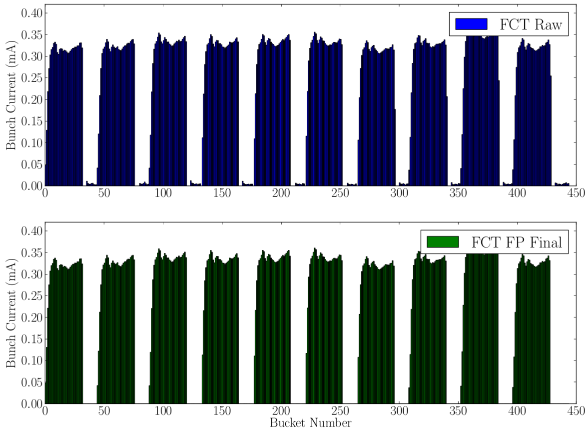

Figure 8: Results from the FCT (top) and from the merge between FCT and TCSPC (bottom).

Obtained results provide an optimal filling pattern measurement but in this way it is not possible to obtain an on-line monitoring. For the time being we use the FCT to perform real-time measurements but an upgrade of the TCSPC is foreseen.

APPLICATIONS

The development of different techniques and of the data analysis allow to achieve a reliable filling pattern measurements using the FCT. Results are stored in the general archive and a complete history of the machine filling pattern is available. Next, we present some practical applications.

Top-Up Input

Top-up operations are foreseen at ALBA to start in 2014. The on-line data analysis allows to calculate the charge to re-inject in each bucket to obtain a uniform and constant filling pattern. Moreover the synchronization with the general machine timing guarantees a correct identification of the buckets.

The procedure for the filling pattern calculations is shown in Fig. 9: the current to be re-injected in each bucket is obtained by subtracting the measured filling pattern from the ideal one.

Bunch by Bunch Lifetime

Knowing the filling level of each single bunch, we measured the bunch by bunch decay time. We observe that emptiest bunches have a longer lifetime with respect to the others, as shown in Fig. 10.

We also prove the relation between single bunch intensity (I_B) and lifetime (τ_B) and the total beam intensity (I) and lifetime (τ), given by:

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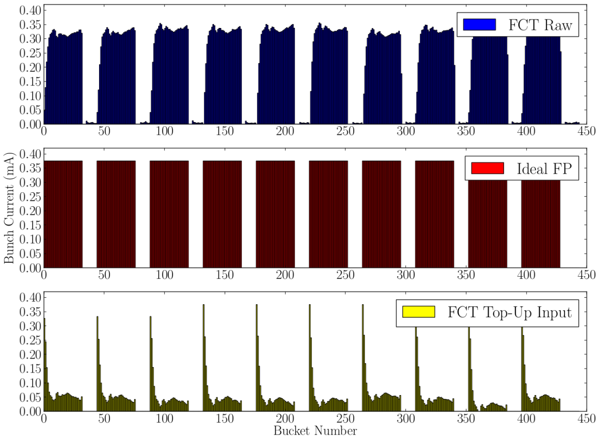

Figure 9: Top-up procedure: the measured filling pattern (top), the ideal filling pattern (middle), the current to be re-injected in each bucket during top-up (bottom).

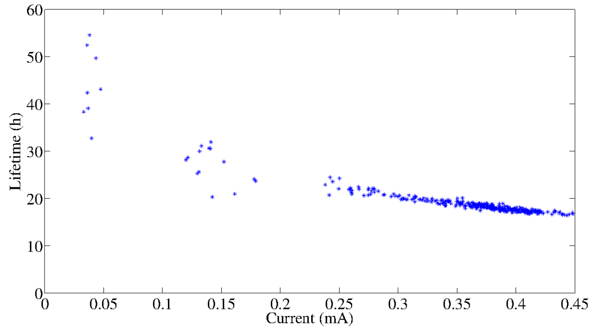

Figure 10: The lifetime of each bunch as function of the current.

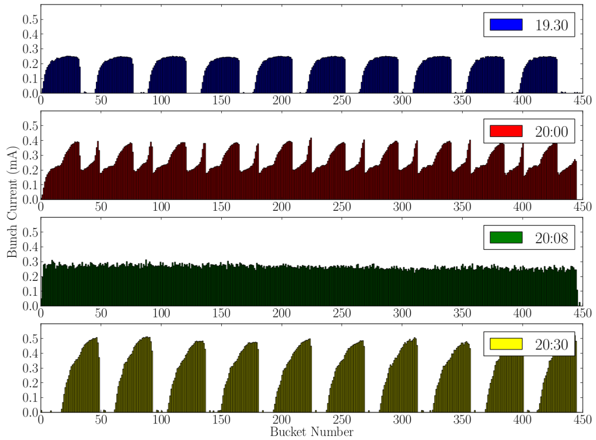

Figure 11: Sequence of the filling pattern before (in blue) and after (in red) the re-injection and during (in green) and after (in yellow) the beam killing.

$$\tau = \frac{I}{\sum_{B=1}^{448} \frac{I_B}{\tau_B}}$$

where 448 is the machine harmonic number. Results were in agreement with the standard lifetime measurements routinely performed at ALBA.

Correlation with Transverse Instability

During ALBA second users run, after the routine evening re-injection, we observed a sudden increase of the transverse beam size. The beam had to be killed and re-injected. Checking the archived data we found out that the increase of the transverse size was due to the anomalous filling pattern generated by a shift of the linac timing in the re-injection. This caused the generation of a continuous filling pattern that increases the probability of ion trapping and affects the beam stability. The shift of the linac timing is evident in Fig. 11 comparing the first and last plots.

SUMMARY AND OUTLOOK

We performed measurements of the ALBA charge distribution using different devices and techniques. Combining the different result we were able to identify the buckets, obtain a reliable representation of the filling pattern status and a good temporal resolution. We also proved that the TCSPC results were strongly affected by the characteristic of the PMT used. Further tests with a new faster devices are foreseen in the next future.

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