FIRST-TURN AND STORED BEAM MEASUREMENTS WITH SINGLE BUNCH FILLING PATTERN USING TIME-DOMAIN PROCESSING AT KEK-PF

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Abstract

High sensitivity and precision are two of the most important properties of the electron beam position processors. They are crucial when measuring the orbit of the first turn, of the first few turns and of a stored beam with a partial or a single bunch filling pattern. So far, the orbit of the first turn has been measured on the base of a raw ADC data processing. In parallel to the processing path that uses digital down conversion for calculating the turn-by-turn data, the new Libera Brilliance+ instrument comprises also an advanced solution. A large ADC buffer for raw data analysis (~8 ms) is combined with the new time-domain processing that returns precise turn-by-turn data. The article presents this new functionality of the instrument and illustrates it with measurement results from the KEK Photon Factory storage ring.

TEST SETUP

The extraction of the bunch was done by septum magnet only. The bunch charge was around 0.1 nC with corresponding beam current around 0.16 mA. The bunch was not stored. The purpose of the test was to detect the bunch and measure its position with turn-by-turn data buffer, as the final goal. The Libera Brilliance+ was used as the electron beam position processing electronics.

The Libera Brilliance+ was connected to the pick-up location close to the extraction point with ~100 m long RF cables. The instrument contains a programmable attenuator with 31 dB range only, without any amplifiers. Therefore, the measurement conditions may be considered challenging.

In addition, all compensation mechanisms were disabled in the Libera Brilliance+ for all measurements presented in this paper. The input signal level detected by the signal processing chain was around -65 dBm and the programmable attenuator was set to 0 dB attenuation. Automatic control of the attenuators (AGC) was disabled.

The sensitivity parameters of the buttons for the Libera Brilliance+ were:

k_x = 17.41 mm
k_y = 16.67 mm

The second part of the tests was done with stored single-bunch beam. The interest was a comparison between the two turn-by-turn processing chains, one working in time domain processing (TDP) and the other working with digital down conversion (DDC).

MEASUREMENTS

Kicker and Pulsed Sextupole Magnet Injection

Traditional beam injection for storage ring is done by pulsed local bump produced by several kicker magnets. It is, however, difficult to provide the complete closed bump because of the magnetic field errors, timing jitters and nonlinear effects, such as from sextupole magnets inside the bump. To solve this problem, a new beam injection method has been developed at KEK Photon Factory and uses a pulsed sextupole magnet (PSM). The injected beam is captured into the ring acceptance by a kick of the PSM while the stored mean passes through the center of the PSM where the magnetic field is almost zero. Using this method, the photon beam for SR users remains of high quality even during the top-up injection [1].

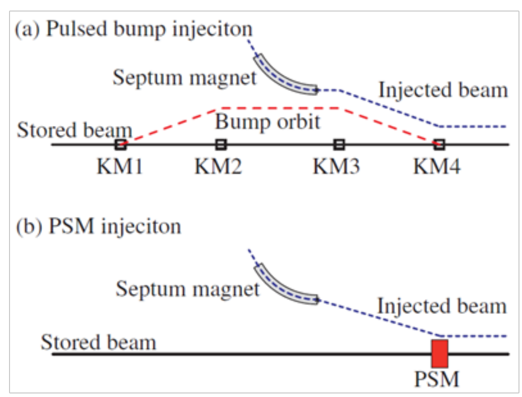

Figure 1: Conventional vs PSM injection [1].

See Figure 1 for schematic overview of both injection schemes. First set of measurements were done with injecting a single bunch into an empty storage ring using both injection schemes.

The bunch was injected into the storage ring 96 µs after the injection trigger at 1 Hz repetition rate. It was kicked out about 100 ms after the injection.

As a reference for measurements with Libera Brilliance+, the oscilloscope readout showed the beam just before and immediately after the injection trigger. It is presented in Figure 2. The oscilloscope read-out was compared with raw ADC data from Libera Brilliance+.

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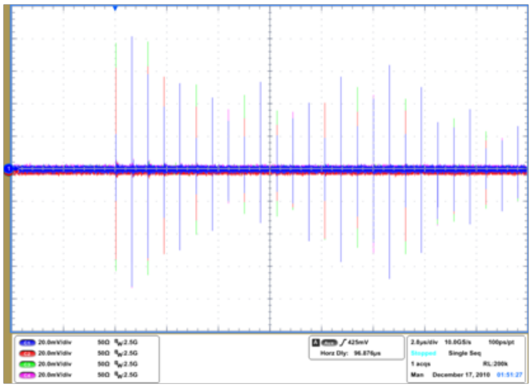

Figure 2: Oscilloscope read-out during kicker injection.

Plots in Figure 3 show the raw ADC data from the Libera Brilliance+. For nicer presentation, the absolute SUM value is plotted with the same time scale as in Figure 2. The injection occurs approximately 97.6 ms after the injection trigger was received by the Libera Brilliance+. The expected timing was ~96 ms. Difference may be due to trigger cable length. The upper plot is a result of the kicker injection. The bunch was stored until kicked out.

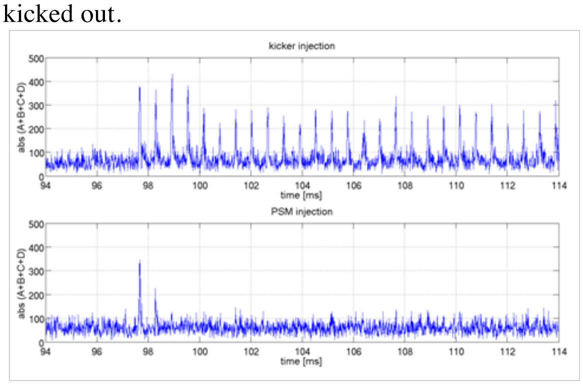

Figure 3: Kicker injection vs PSM injection.

The lower plot in Figure 3 shows the result of the PSM injection. During this measurement, the injection efficiency was low. The total charge decreased rapidly in only two turns after the injection. The main reason was that the injection angle was not adjusted precisely.

The difference in oscillations during injection is significantly lower with PSM injection. The vast improvement is seen in the horizontal position, see Figure 4.

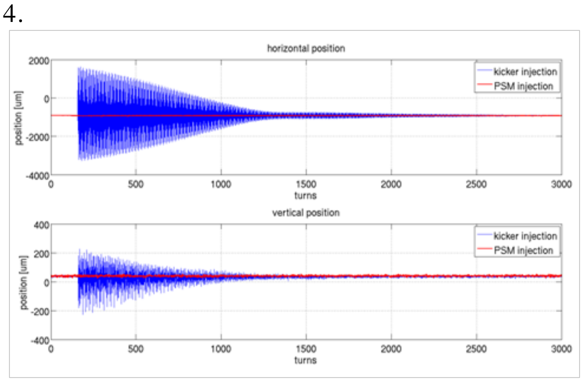

Figure 4: Injection oscillations in the turn-by-turn data.

Single Bunch, First Turn

It was questionable whether the Libera Brilliance+ will be able to detect the first turn of a single bunch. The bunch charge was 0.1 nC. The AGC detected the input signal level at -65 dBm. There was no immediate indicator that the bunch was detected at all. After increasing the length of the buffer for the raw ADC data to 20,000 samples, there was a small spike seen in the second half of the buffer in the A and D electrodes (Figure 5). After zooming in, the ADC data showed some distractions at around 11,500th ADC sample, which is around 98 us after the trigger arrival. At KEK-PF storage ring, this time corresponds to ~157 turns.

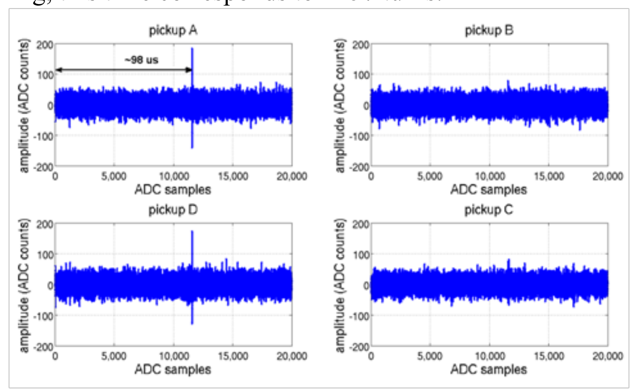

Figure 5: Single bunch as seen in the ADC buffer.

The injection is mostly seen in the horizontal and very little in the vertical direction. This confirms the correctness of the ADC data, which showed the excitation in electrodes A and D. The Libera Brilliance+ offers two parallel turn-by-turn processing chains: digital down conversion (DDC) and time domain processing (TDP). The DDC offers precise and robust processing for the turn-by-turn positions but it is limited when measuring fast transient phenomenon, such as first-turn of a single bunch. For these special measurements, the TDP is more powerful and convenient. The data rate is exactly the same as the DDC data rate that is revolution frequency rate. The position calculation formula remains the same, but the amplitudes are calculated from the ADC data directly.

$V_a = \sqrt{\sum_{i=1}^{D} x_i^2}$, where

Va … amplitude of channel A

D … decimation from ADC to turn-by-turn data

x … raw ADC sample (counts from 1 to D)

As the RF cables and/or trigger cables may introduce certain delay, the actual positioning of the raw data may be adjusted precisely with 1 ADC sample precision with reference to the desired start of the turn. In our case, this was not done.

The TDP buffer is presented in Figure 6. The response is seen in the A and D amplitudes and consequently in the horizontal position (rounded with black dashed circle). The bunch was seen in turn no.159, which was expected.

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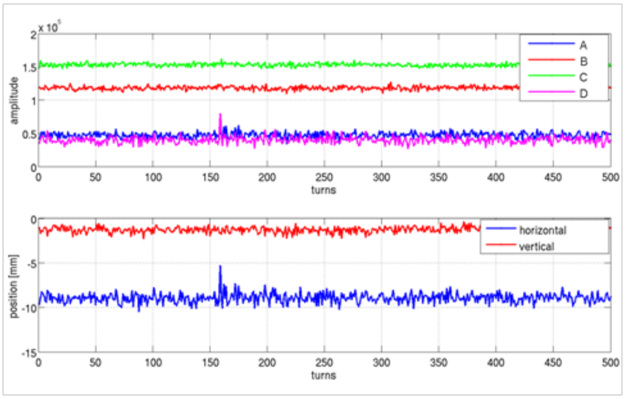

Figure 6: First turn seen in the TDP buffer.

Despite demanding measurement conditions (cable length, very low bunch charge), the measurement result was reproducible and the bunch position was easily extracted from the noise.

Single Bunch, Stored Beam

After the single bunch was stored, the input signal level increased to -59 dBm still at 0 dB attenuation setting. Peak ADC counts reached around 400, which is less than 1.5% of the full ADC scale. Such signal conditions are extremely challenging for the DDC algorithm as consequent turns overlap and final result does not show true position per turn. In addition, the RMS is relatively high.

We were comparing the performance of the DDC and TDP processing chains. The criterion was the RMS noise. Better results were expected from the TDP since the position calculation is taking only the ADC samples that are relevant for one turn. Positioning of the bunch in the turn relative to Libera's understanding of the point zero in the turn can be seen in the "TBT window" and adjusted with the parameter ("Phase offset"). Having access to this buffer and parameter becomes very useful when having installation of multiple Libera Brilliance+ units and wanting to follow the bunch's journey around the whole ring. The data in the TBT buffer is raw ADC data, but presented as it enters the turn-by-turn processing chains. An example for our case is in Figure 7. The upper plot is the data as in buffer while the lower plot is a SUM of all channels (for nicer view especially with low signal level).

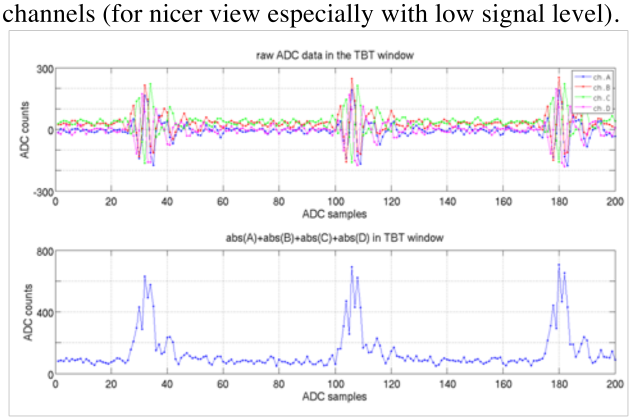

Figure 7: TBT window content.

4096 samples (turns) were recorded from each of the turn-by-turn processing chains. The mean values for both positions differ quite a lot but the trust goes to the TDP. As seen from Figure 8, the RMS of position in the TDP buffer is significantly lower (lower plot) thus scaling the SNR also.

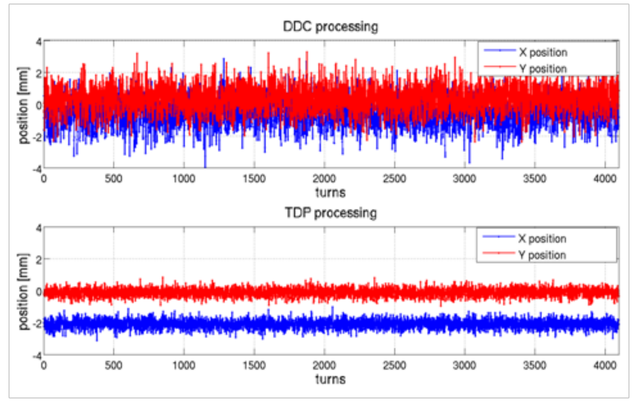

Figure 8: Turn-by-turn data comparison.

In numbers, the improvement factor of the TDP against the DDC chain is around 3, see also Table 1.

Table 1: DDC and TDP Processing RMS Comparison

Position	DDC processing	TDP processing
Horizontal (X)	868 µm	271 µm
Vertical (Y)	826 µm	253 µm

Similar results (the improvement factor between 2-3) were seen also in Doris storage ring at DESY but with much higher signal level.

CONCLUSION

Despite challenging measurement conditions, the Libera Brilliance+ proved to be the beam position processor of highest performance. The raw ADC data matched perfectly with oscilloscope read-out, furthermore, we were able to continuously monitor the injection from the scratch with the turn-by-turn data. The new Time Doman Processing chain provided precise data (position, SUM) from the first and later few turns. Combined with the TBT window and the ADC mask functionality, the TDP offers new possibilities to precisely explore the behaviour of the orbit during the first few turns of a single bunch or hybrid mode.

REFERENCES

[1] Hiroyuki Takaki et al.: "Beam injection with a pulsed sextupole magnet in an electron storage ring", Phys. Rev. ST Accel. Beams 13, 020705 (2010).

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