MODIFIED DIGITAL FILTERING MAKES POSSIBLE "TRUE & PURE" TURN-BY-TURN MEASUREMENTS

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Abstract

Libera, the beam position processor, features the so-called TbT (Turn-by-Turn) data output, the data rate being exactly the revolution frequency of the accelerator. This data is essential for commissioning of the accelerator as well as for various machine physics studies. However, due to the "natural" properties of correctly structured filters (respecting the Nyquist theorem), the smearing between adjacent TbT samples is not negligible. The purpose of the modified filters in DDC (Digital Down Converter) block is to efficiently reduce smearing between adjacent TbT samples, especially with partial fill patterns. The usage of Modified DDC filters provides excellent results for the studies based on TbT measurements, with the benefit of "true & pure" TbT results (no smearing). The method, its implementation and first results are discussed in this paper.

INTRODUCTION

The smearing of TbT beam position data can be problematic for the precise measurements of certain accelerator characteristics (i.e. lattice parameters, such as the local Beta-function values and phase-advance). The basic principle of such measurements is to first apply a single-turn, flat & uniform kick to the whole beam, and then to measure, with all the TbT BPMs in the accelerator ring, the resulting Betatron oscillations of the beam for a large number of turns after the kick. At the ESRF Storage Ring such measurements are done on a beam that fills 33 % of the Ring. The advantages of such fill pattern are:

a) The individual turns are clearly separated from each other, and

b) the application of pure single turn flat kick is practically possible.

With regards to these kicker specifications, for the ESRF it means a flat field of 1 μs and rise- and fall- times (to less then a few % of the flat field strength) of less than 0.9 μs [1]. To maintain these advantages it was important that the smearing, introduced by the standard, relatively narrow DDC filters inside the Libera BPMs, was addressed. The elaboration and implementation of adapted DDC filters was done at Instrumentation Technologies. Tests on real beam were subsequently carried out at the ESRF on 8 individual Libera BPMs in the Ring [2].

SIGNAL PROCESSING

The signal processing chain on Libera Brilliance is composed of analog signal processing, digitalization on fast ADCs (Analog to Digital Converters) and the digital signal processing, see Figure 1. Within the digital part, digital bandpass filtering is first applied, the signal afterwards being brought to DC by mixing. Then, the TbT data bandwidth is obtained by means of lowpass moving average filters. Finally, the TbT data rate is obtained with proper decimation.

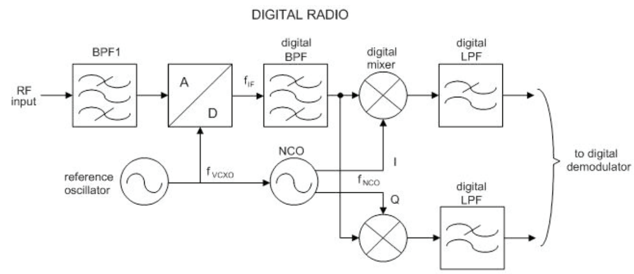

Figure 1: Signal Processing on Libera

Further signal processing to lower data rates for continuous data streams (serving fast feedback and monitoring) is not discussed in this article. Complete processing is implemented onboard a Virtex II Pro FPGA chip. Two main changes to the digital signal processing chain were introduced: wider bandpass digital filters and a narrower subsequent data acquisition window.

Digital Filters

The data coming into digital filtering has the bandwidth of approx 12 MHz, determined by bandpass SAW filters within the analog signal processing. The filters and procedures used for standard digital filtering are constructed by the book, as required by theory. To prevent unwanted aliasing, the 3dB bandwidth of the filters is always well below half of the output sampling rate. For the ESRF case, with TbT frequency of 355 kHz, the bandwidth of the TbT data reaches less than 150 kHz with standard filters. As it is known from the theory, the narrower the filters, the longer is the time response of the output data (i.e. 'ringing' of the filter response). It was therefore a logical choice to make the filters wider. The modified IIR bandpass filters (BPF1 on Figure 1) have been widened to approximately 3 times the TbT data rate.

Acquisition Window

The acquisition window of the standard moving average filters covers the whole TbT period, in the ESRF case this is 304 ADC samples or 2.81 μs. This is in principle correct since the useful signal is in principle distributed over the whole TbT period. But when the accelerator is filled with certain partial fills, the real signal will be distributed only on a certain sector of the TbT period, and the rest of the acquired data will consist mainly of noise. There is no sense to process the noise in the average moving filters and it can be discarded. To discard the part of the signal without meaningful information, the adjustable acquisition window for these filters was introduced. The delay and the length of the acquisition window can be parametrically chosen, the resolution of both parameters being in ADC samples (~9 ns).

Combined Effect

The combination of these changes on filters and the acquisition window significantly reduces the amount of smearing. On one hand, wider filters reduce the tail of the single pulse signal, while on the other hand the gap between consecutive acquisition windows allows the tail to be flattened to an almost negligible amount: samples with low amplitudes are excluded from processing in moving average filters. Figures 2 and 3 show a schematic presentation of the amplitudes of consecutive TBT output samples. The beam is injected and damped after the first turn, after the standard (Fig. 2) and the modified (Fig. 3) digital processing. The resulting TbT samples are graphically presented as blue dots.

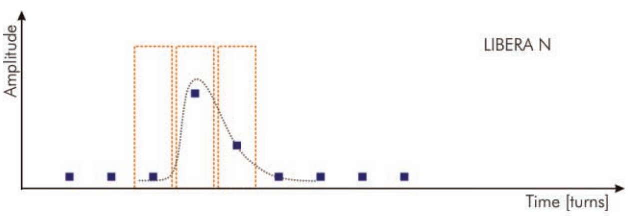

Figure 2: Standard filtering and acquisition window

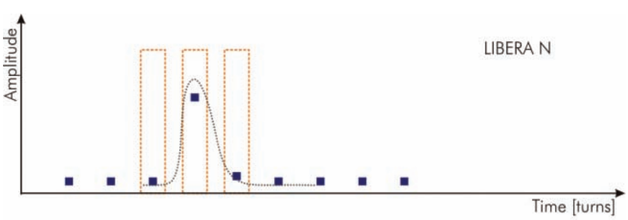

Figure 3: Wider filtering (reduced tail) and selectable acquisition window (in orange)

TESTS ON REAL BEAM

After initial laboratory tests of the modified signal processing, first beam tests were performed at the ESRF in Nov. 2007 on 8 independent Libera BPMs distributed around the Storage Ring. With the Ring in 33 % filling mode, the length of the acquisition window was set to a fixed value of 100 units (out of full width of 304 units per TBT period, i.e. corresponding to 33%). The correct delay (or phase) value for each BPM has been determined first, in order to precisely synchronize this window with the beam fill. This has been done by a simple routine that scans this window in the range of one TBT period and records the so-called Sum signals at each delay setting. The optimum delay value (at max Sum signal) was obtained and then programmed into each Libera. This optimum delay value needs to be determined only once after the installation of the Liberas and their cabling.

Pure Single Turn Measurement

The ideal way of checking whether each Libera unit around the Ring sees indeed only one single turn (i.e. no smearing) and also whether they all see that turn at the same turn-number, is to inject the 1us electron beam into the Ring and to totally suppress it after 1 single turn. This is easily obtained by setting a strong current in one of the last (vertical) orbit steerers before the injection zone: The beam makes 1 full turn and is then 100 % dumped in the vacuum chamber roof. Each Libera thus saw 1 μs of RF signal only. The injected current (at injector) was 2mA. This signal, as seen on Libera at ADC rate (107.9MHz), is plotted on Figure 4.

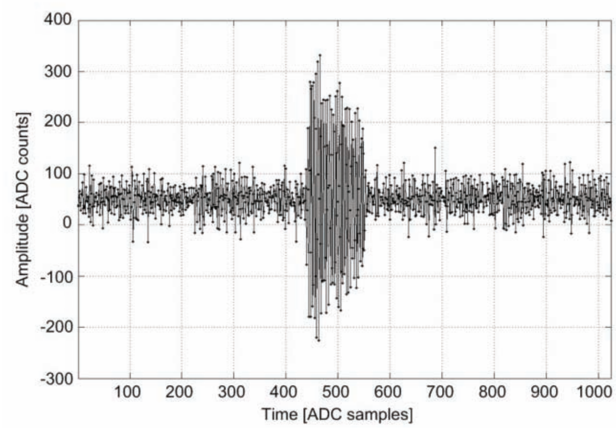

Figure 4: Single Turn, ~1μs long signal, in ADC samples on Libera

The effect of the modifications was expected to be seen on the TbT rate data (355 kSps): to remove smearing between adjacent TbT samples, especially with such, partial filling pattern. The Figure 5 shows exactly this in practice; the SUM output of the unit. Here the effect of the modified filters is evident: one single spike and no noticeable smearing. This result should be compared with the illustration on Figure 3.

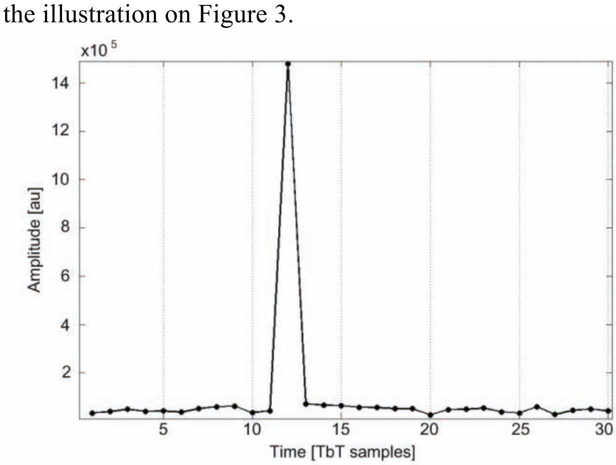

Figure 5: SUM signal at TBT data rate

Beam Arrival

The second experiment was performed by injecting the beam into the ring and allowing it to circulate (i.e., the beam was not dumped after the first turn). There was no RF power to the cavities and the beam survived for 60 to 70 turns. The arrival of the beam (similar current as for first measurement) on six Libera units around the ring is shown in Figures 6 (zoomed) and 7, the SUM signal being displayed. Again, one can observe independent measurement of each TbT sample.

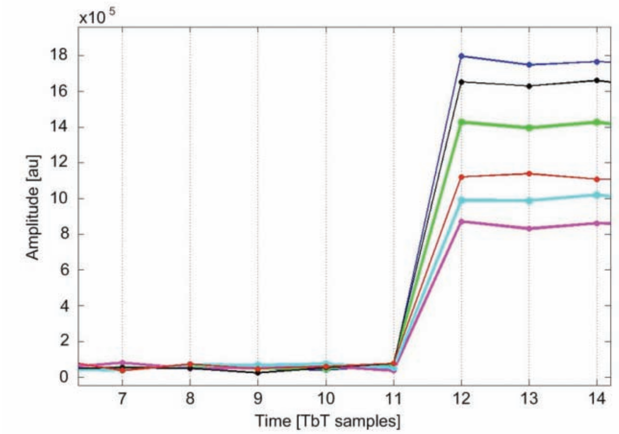

Figure 6: Arrival of the beam, sum signal

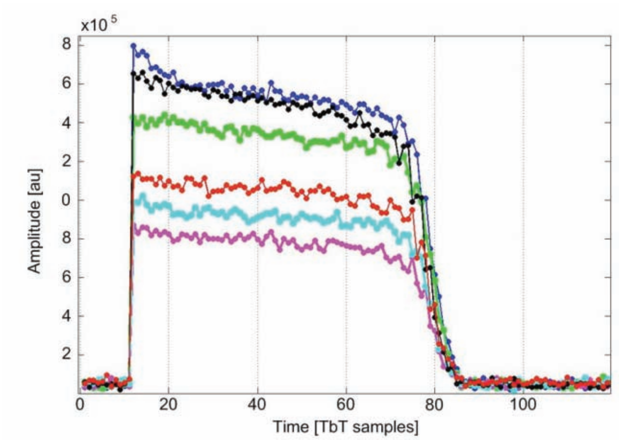

Figure 7: Arrival of the beam, surviving few cycles without RF power, sum signal displayed

Kicked Beam

Figures 8, 9 and 10 show the horizontal position after a kick with a 1µs flat kicker during a single passage of the beam (black line). In the ring, there was a current of approximately 38mA in 33% fill. For comparison, the position of the same beam without a kick was also measured (red).

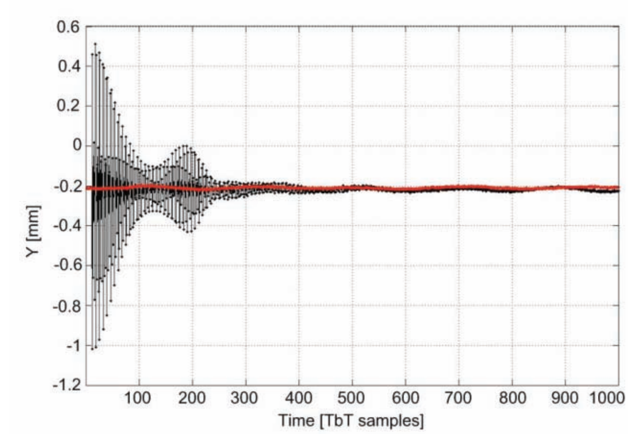

Figure 8: Kick of the flat 1us kicker to the beam, big picture

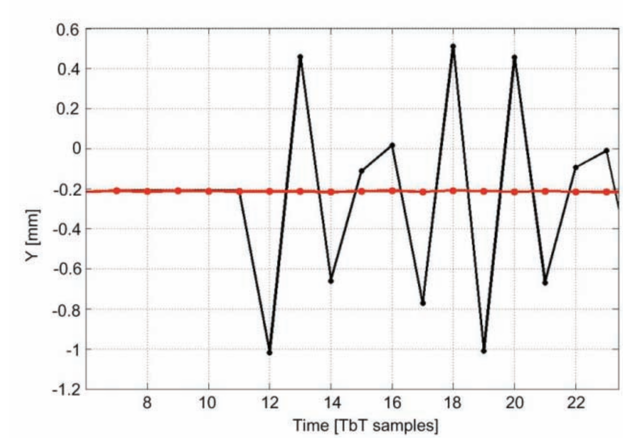

Figure 9: Kick of the flat 1us kicker, first samples

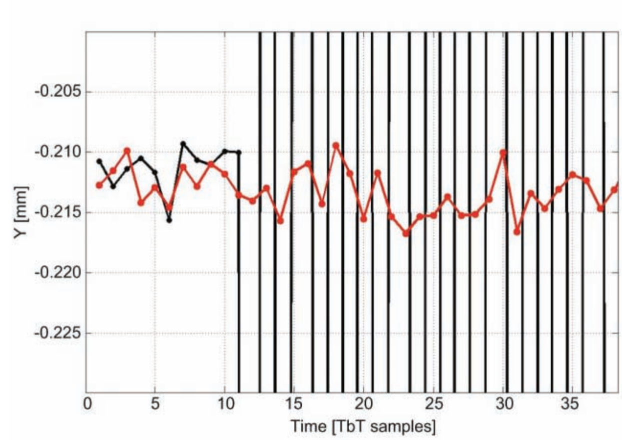

Figure 10: Kick of the flat 1us kicker, position zoom

From the Figures above it can be seen that the measured oscillation resulting from the kick was fast and flat. From the Figure 10 one can also estimate the RMS of the non-disturbed data (red), under such conditions (38 mA at 33 % fill), it is approximately 2um RMS.

SUMMARY AFTER THE MEASUREMENTS

The idea of using modified digital filtering has been confirmed in practice as a very efficient way to obtain true and pure TbT measurements without smearing of the adjacent TbT samples. This is an example of how the digital system can be successfully tailored to a special task just by a change in software. The test results gave very clean and expected results. The initial phase and synchronization adjustment of these filters with respect to the exact RF pulse arriving at each individual Libera BPMs from its BPM buttons is also very easy to perform thanks to programmable delays inside the Libera itself. We would like to emphasize successful collaboration between users (ESRF) and manufacturers of the instrument (Instrumentation Technologies).

Modified vs. Standard Filtering

The use of the modified filters is, as was expected, advantageous for a detailed study of machine parameters. For normal operation, the use of standard filters is still recommended, the main reasons being:

- Ease of use. The setting of delay and width parameters of the acquisition window is not straightforward and requires good understanding of synchronization issues.
- For the normal operation (beam monitoring, fast global orbit feedback …), the difference in performance seems to be negligible.
- The synchronization of the acquisition with the RF frequency must be perfect to keep the acquisition window synchronous with the signal. During normal operation, however, it is recommended to perform slightly asynchronous acquisition (controlled offset-tune) to enhance performance of Libera.

Possible Further Developments

To cover even more complex modes of operation, one improvement has been discussed already. Currently, the modified filters can deal with only one acquisition window within the TbT period. The use of a matrix structure may be considered to cover any possible combination. For example, the ESRF TbT period is composed of 304 ADC samples. There would be an option to choose which ADC samples are taken into consideration and which not. This would enable users to use modified filters, for example, in the four bunch mode, as is illustrated in Figure 11. All kinds of different hybrid modes could be covered. The benefit to users of such improvement is to be investigated.

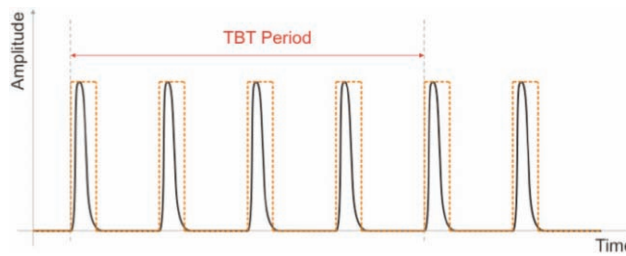

Figure 11: Modified filters and four bunch mode, acquisition windows in orange

REFERENCES

[1] B.K.Scheidt, “Breaking New Ground with High Resolution Turn-by-Turn BPMs at the ESRF”, DIPAC’01, Grenoble, 13-15 May 2001

[2] B.K. Scheidt, “ESRF-Liberas-Nov-2007-A.doc & ESRF-Liberas-Nov-2007-A.ppt”, test report