FRONTEND MEASUREMENTS AND OPTIMIZATIONS AT LIBERA BRILLIANCE BPM ELECTRONICS DURING COMMISSIONING OF THE PETRA III SYNCHROTRON LIGHT-SOURCE

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Abstract

New 3rd generation synchrotron light sources like Petra III utilize high-accuracy beam position measurement (BPM) systems to achieve the desired precision for beam position measurement and control, as needed for electron/positron beam stability and brilliance of the delivered photon beam. To reach the design goals, specifically adapted and parameterized commercial-of-the-shelf (COTS) Libera Brilliance BPM processor electronics are used within the Petra III BPM system. Quality of the acquired position measurement and orbit control data is highly dependent on the properties and setup of the analog and digital frontend of such BPM electronics. This paper shows influences and optimizations at the BPM system frontend of the Petra III light-source in reference to corresponding measurements done during the accelerator commissioning phase.

INTRODUCTION

The commercial Libera Brilliance BPM electronics (firmware V1.87) used at Petra III offers simultaneously usable data paths both for narrow-band high precision so-called slow-acquisition (SA) and for fast wideband First-Turn-, Turn-by-Turn- (TbT), decimated Turn-by-Turn- and Post-Mortem (PM) data. A special Desy-type low-latency Turn-by-Turn data path delivers raw I/Q-data via a special hardware interface (MOLEX) towards the Petra III Fast-Orbit-Feedback (FOFB) system[1][2]. An additional internal so-called fast-acquisition (FA) data path is used in the Libera for fast orbit interlock control.

In the Petra III environment, all of these data paths must be accessible simultaneously, e. g. delivering SA data for orbit measurements and corrections during user-runs, while simultaneously measuring dynamical beam parameters like frequency maps via TbT measurements. The performance and quality of the mentioned data paths are affected in different ways by the built-in frontend optimization methods.

The analog and digital frontend of the Libera Brilliance BPM electronics is built-up of 4 identical RF input paths, which are interchangeable by means of an analog and a corresponding digital crossbar-switch matrix (see principle block diagram at Fig. 1 [2]).

Using a compensation method patented by the manufacturer company Instrumentation Technologies, the 4 RF input signals can be continuously switched in a cyclic manner, while the corresponding measurement data are simultaneously corrected and the beam position is evaluated from the corrected values. This technique serves for improvement of the analog input properties of the frontend electronics (improved noise level and drifts of acquired phase- and amplitude values, see Fig. 2).

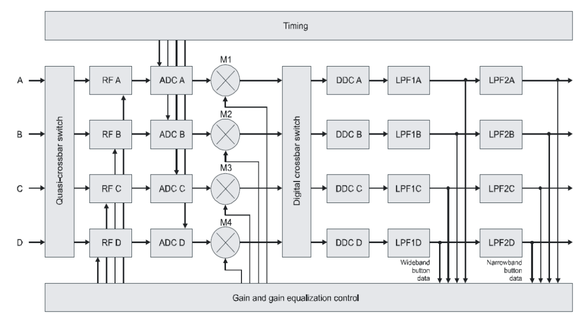

Figure 1: Libera frontend DSC switching architecture based on Instrumentation Technologies patented method and device [3] (courtesy Instrumentation Technologies).

The synchronous correction of the data measured in each switch-state of the crossbar-switches is calculated individually for each RF path by using a corresponding pair of coefficients for amplitude and phase correction, measured during a preceding calibration phase (learning). Through this electronics concept, even amplitude and phase differences of the signal-path segments located between BPM button electrode and electronic input can be acquired and corrected. This correction method also incorporates limitations that are shown later on in this paper.

Libera Brilliance BPM electronics provide a so-called Digital Signal Conditioning- (DSC-) mechanism which works in a two-stage scheme, first learning optimized correction parameters (so-called DSC coefficients) and then applying corresponding correction parameters to each of the 4 RF-input-paths on-the-fly during normal operation. The DSC scheme offers amplitude and phase correction of the data subsequently acquired for each of the RF-input paths in use. An automatic-gain-control (AGC) mechanism is also implemented under embedded Libera software control, which optimizes the mapping between each pre-conditioned RF-input-signal and the input signal range of the ADC-channels. It also delivers a measure for the current input power which is used as an index for access to the DSC coefficient lookup-table described in the next paragraph.

The amplitude and phase differences, measured during DSC learning are valid only for the currently configured input attenuation (dependent on the current input power) and the corresponding RF-switch-matrix settings. This is why the resulting correction coefficients are stored inside a huge matrix-like lookup-table within the Libera unit. For each theoretically selectable input-level (-100dBm up to +10dBm) and all possible switch-matrix positions (16 possible settings, but only 4 are used in Libera Brilliance), this lookup-table holds the corresponding amplitude and phase coefficients in a list of sub-matrices.

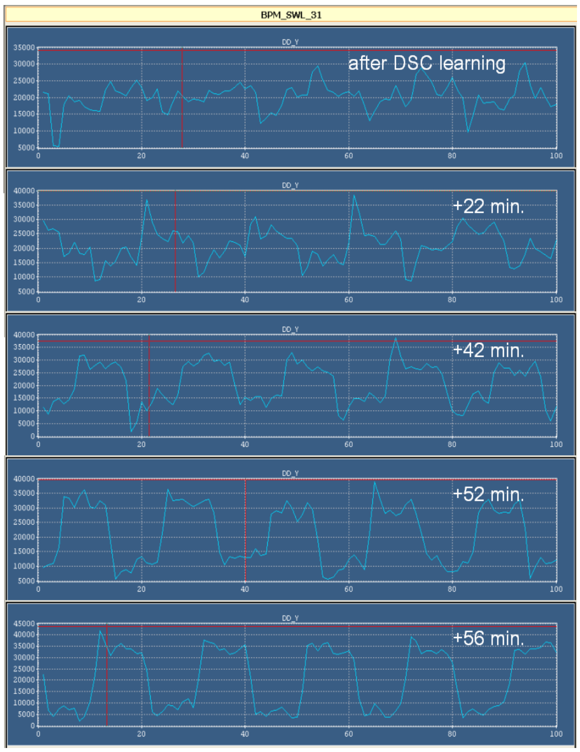

Figure 2: Drift of DSC switching amplitude vs. time (zero beam offset, vertical TbT, 40-bunch time-resolved mode, 80mA (const.), FOFB on, TopUp mode, const. ambient temperature +/- 1° at the electronics).

Optimized DSC correction coefficients can be calculated on demand by a self-calibrating DSC learning algorithm on the basis of the input signals measured at each of the 4 RF input channels. After calculation these coefficients are stored in the presently used lookup-table (RAM). This self-calibration mechanism may be switched on and off in the Libera configuration. In addition, the calculated coefficients can be reset for a restart of the self-calibration mechanism, and they can also permanently be stored on-demand in a non-volatile memory (FLASH) for later reuse after a Libera reboot.

In theory, the DSC learning of all Liberas should always be switched on, for permanent optimization of the correction coefficients, yielding minimum drifts of SA data during user-runs. Unfortunately, activation of DSC switching also results in a performance degradation of all data streams which are using data delivered directly by the TbT-data source. Even internal FA data (orbit interlock) are degraded by switching due to relatively wide bandwidth of approx. 2 kHz.

Libera-internal mechanisms (filtering, acquisition window timing etc.) were implemented to overcome these limitations (see Libera documentation for detailed descriptions). Unfortunately even beyond, permanent DSC learning is not suitable due to some limitations of the implemented DSC learning method which can result in degraded data integrity. An adapted method for compensation of these drawbacks will be described later which utilizes the advantages of the implemented DSC learning algorithm, widely discarding its disadvantages.

Machine studies at Petra III indicated that the generation of switching artefacts is independent of the present Libera fan speed, and mainly correlated to the Libera ambient temperature.

LIMITATIONS OF DSC

Early machine studies at Petra III showed significant impacts of beam losses on the quality of simultaneously calculated DSC correction coefficients. As the Libera-internal switching frequency (13kHz singe-switching-step frequency => 3.3kHz round-robin switching frequency for all 4 switching steps) is subdivided from the machine revolution frequency (approx.. 130.1kHz at Petra III), at maximum one single switch-path can be set during one revolution period (turn). A complete DSC learning cycle needs 4 consecutive turns (4 different switch-positions) as a calculation base for all amplitude- and phase coefficients corresponding to the present input level. The quality of calibration is highly dependent on constant input signal properties during the calibration cycle. A reasonable limit for a button signal level gradient suitable for DSC learning is given by an input signal voltage change of the resolution specified for the auto-calibration, occurring faster than the calibration data acquisition period, i. e. $< 4 * 7.68\mu s$. A procedure for detection of such gradients is proposed at the end of this paper.

Large input signal gradients during the DSC acquisition interval, related to changes in beam position, beam current, bunch current or bunch pattern may result in a degradation of the DSC correction coefficients, evaluated from these measurements. Such strong gradients are mostly related to deviations of beam properties in general or nearby the BPM position as well as on perturbed or corrupted input signals of the electronics (e. g. EMC).

A frequent reason for strong input signal changes are beam losses, which can corrupt correction coefficients based on DSC learning input signals, that were acquired in the period of beam loss. Figures 3 and 4 below show the impact of beam loss induced input signal gradients on the Liberas for the 227 BPMs at Petra III in such a situation. Figure 3 represents the steady state condition after DSC learning at stable beam (40 bunches, 55mA, FOFB on, no Top Up) with fixed BPM input levels (AGC off) immediately before an artificial beam dump lasting approx. 9 turns (80% → 20% intensity loss) was triggered. During the beam dump, the DSC minimum turn-by-turn learn limit (see Libera documentation for details) was deceeded, so the formerly running DSC learning process was automatically stopped and set manually to the 'no DSC learning' state on purpose afterwards. After the beam had been recovered again to the same conditions as before the dump, the picture at Fig. 4 was taken, showing significantly more BPMs with larger deviations in the TbT-sigma as before the dump. Here the TbT-sigma serves as a measure for the magnitude of the switching artefacts, which in turn is a measure for the DSC correction coefficient quality. Investigations at different beam currents (25/35/45/55mA) showed an increase of this dump-induced switching effect at beam currents above 45mA.

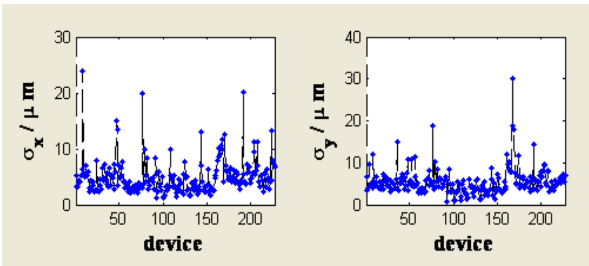

Figure 3: Standard deviation of DSC-optimized TbT readings before beam dump (40 bunches, 55mA, FOFB on, no Top Up).

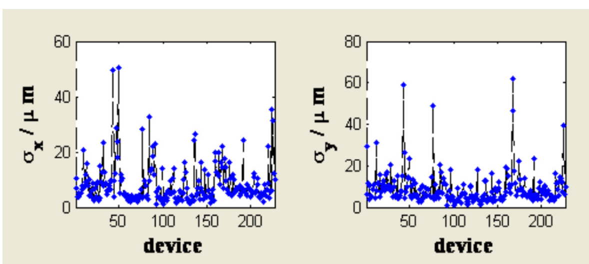

Figure 4: Standard deviation of TbT readings after beam dump during DSC learn phase (same beam properties; note the different scales for both figures).

Incorrectly calculated DSC correction coefficients not only result in increased switching amplitudes, but also increase the effect of a switching drift. The switching effect itself describes invalid big differences (i. e. exceeding the required resolution) of amplitudes and/or phases between measurement data of two or more of the simultaneously acquired 4 ADC channels. The biggest impact of switching can be observed in all wideband data streams, directly incorporating TbT data (i. e. 1st-turn/TbT, decimated TbT, Fast Orbit Feedback TbT, Post Mortem) and also in the fast acquisition data responsible for orbit interlock generation (BW = 2kHz).

In slow acquisition (SA) data, the effect of switching is nearly suppressed by the strong averaging over 100ms (approx. 13021 Petra III turns). TbT switching amplitudes up to 1mm have been observed because of badly balanced DSC coefficients. The Petra III Fast-Orbit-Feedback system is able to suppress switching artefacts of up to 200µm peak-peak.

IMPROVEMENTS AND OUTLOOK

To overcome the negative effects of switching and DSC, we suggest two steps of improvement embedded inside the Libera module:

- For suppression of coefficient corruption, DSC correction coefficients acquired during a period with a Post-Mortem trigger (usually correlated with a beam loss or beam dump) should be discarded, if this feature is enabled at the user configuration
- Present AGC input level shall be acquired and compared before and after acquisitions for calculation of new DSC coefficients. These coefficients should be discarded, if the acquired input levels are different.

For efficient filling of new or cleared DSC correction sub-matrix ranges, a fast and optimized DSC learning scheme has been implemented at Petra III. This so-called powerlearning scheme loops DSC learning cycles for a whole range of forced input level settings at a certain input signal level +/- 5dB, as ADC input signal properties are usually very similar in such a range. Another new automatic parameterized, scalable DSC learning scheme was invented and integrated into the so-called TopUp-engine of Petra III, that launches DSC learning cycles on a regular basis only in periods without TopUp charge injections and constant input power level. This scheme is optimized in a way that minimizes the periods of active DSC learning (also minimizing the danger of DSC learning during beam losses), while maximizing the frequency of DSC learning to keep the DSC correction coefficients at an optimized level. To overcome the danger of long phases without DSC learning due to bad beam lifetime, watchdog-timeout-counter-driven DSC learning cycles may even override TopUp injection periods (DSC coefficients acquired during TopUp injections are even better than freely drifting TbT switching artefacts over a long period of time).

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