State of the SLS multi bunch feedbacks

M.Dehler, G. Marinkovic, R.Kramert, P.Pollet, T.Schilcher,
Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland
e-mail: Micha.Dehler@psi.ch

Abstract

In order to control coupled bunch oscillations in the SLS storage ring, feedback systems for all three planes were foreseen, which are realized as fully digital bunch by bunch systems. With the development of dedicated ADC and DAC boards, the feedbacks could be commissioned. Important parts of the computations for the transverse planes were implemented into the FPGA, making the DSPs originally planned to be used obsolete and allowing for an extremely low latency time of 300 ns. The systems give a larger freedom of choice for the beam optics and also lead to a better closure of the injection bump during top up mode. At present, systems for all planes have been commissioned and are in routine service.

INTRODUCTION

The Swiss Light Source (SLS) is a 2.4 GeV synchrotron light source at the Paul Scherrer Institut. As in other high current electron rings, coupled bunch instabilities can show up due to either resistive wakes and residual ions in the transverse case or due to higher order modes in the longitudinal plane.

Until now, transverse stability was obtained by a high chromaticity beam optics and by an inhomogeneous fill pattern in the ring. An additional contribution toward stable operation was obtained via Landau damping of a superconducting third harmonic cavity[1]. In order to have a higher flexibility in beam optics and a better performance in the longitudinal case, bunch by bunch feedback systems have been developed over the past years and commissioned in 2006. First, a technical overview of the systems is given, before preliminary results in operation are shown.

FEEDBACK SYSTEMS

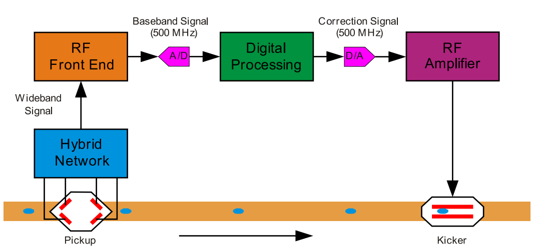

Figure 1: Functional blocks of a transverse bunch by bunch feedback system

The functional blocks of the system are shown in Figure 1. The feedback is a wide band system able to correct the positions of individual bunches, spaced 2 ns apart. Signals coming from button type pickups pass a passive hybrid network, where sum signals used for the longitudinal plane respectively difference signals for the transverse system are generated. The signals are fed into an RF front end [2] from Instrumentation Technologies mixing down the transverse signals and running a phase detection on the sum to obtain the longitudinal position. A digital system running at around 500 MS/s, consisting of an ADC, the digital filter and DAC creates the analog correction signal. Transversally, the signals are fed to the beam directly via broad band power amplifiers and strip line kickers. For the longitudinal plane, a single side band modulator mixes the signals up into the 1.25-1.5 GHz range, where they are amplified and fed to a longitudinal kicker. The analog parts have already been described in [3] and [4], hence we will concentrate on the description of the digital part.

Energy	2.4 GeV
RF frequency	499.65 MHz
Harmonic number	480
Transverse	
Tunes β_x, β_y	0.43/0.73
Damping time	9.0 msec
Kicker shunt impedance	14.5/20.0 kΩ
Installed amplifier power	500 W
Filter	IIR/8 tap FIR
Longitudinal	
Synchrotron tune ν_s	$1.9 \cdot 10^{-3} - 4.8 \cdot 10^{-3}$
Damping time	15.0 msec
Kicker shunt impedance	1.5 kΩ
Installed amplifier power	250 W
Filter	IIR/16 tap FIR

Table 1: System parameters

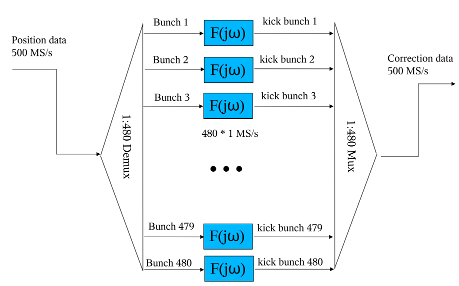

Figure 2: Data flux in the digital filter

Originally it was planned to do the calculation of the correction kicks with the help of digital signal processors [3].

But at the time of development of the new ADC and DAC firmware (basic description in [5]), it turned out, that the FPGA was able to manage the data flux with enough processing reserves to integrate the digital filter algorithm.

As the name bunch by bunch feedback implies, the incoming position data is demultiplexed into 480 (the number of bunches in the SLS storage ring) data streams,each at approximately 1 MS/s and each containing the positions of one individual bunch. These get processed by dedicated filters and all streams multiplexed into a 500 MS/s signal suitable for reconversion into the analog domain by the DAC.

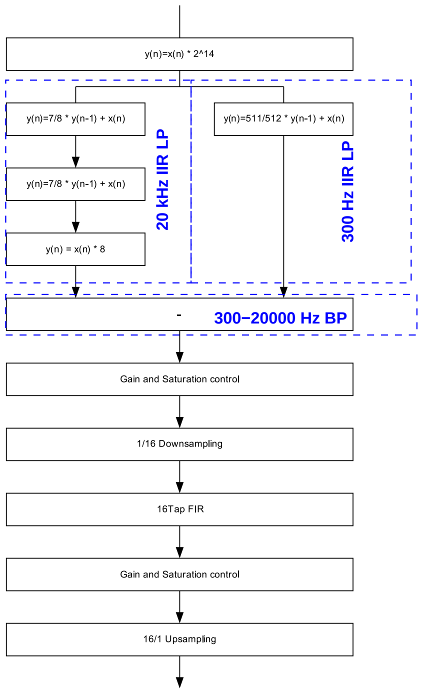

Figure 3: Longitudinal feedback filter setup for individual bunches

Figure 3 shows the processing of the individual bunch data in the longitudinal plane. After normalizing the data, the stream is split and sent into two IIR low pass filters. Subtracting both gives a band pass limited signal from 300-20000 Hz (Fig. 4), where the common mode as well as high frequency perturbations coming from the betatron tunes have been suppressed. Only the synchronous frequencies between 2 and 5 kHz will pass with negligible amplitude and phase variations. Apart from suppressing unwanted signal components, the big advantage of this approach is the additional averaging due to the reduced bandwidth. With a nominal data width of 8 bits coming from the ADC, we observed an effective resolution of 13 bits in laboratory measurements.

After a gain adjustment to minimize rounding errors in the following stages, the data stream is down-sampled by a factor 16 and then sent through a configurable FIR filter with 16 taps. A second gain adjustment and a 16:1 up-sampling stage complete the data processing.

For the transverse signals the processing is similar with

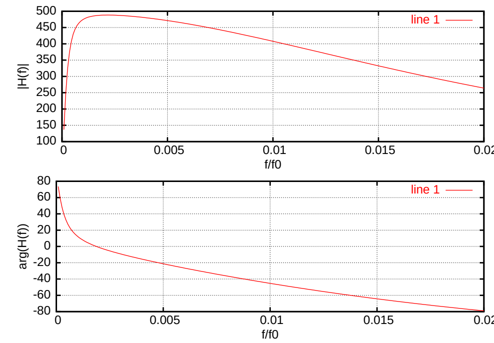

Figure 4: Characteristics of introductory IIR filter used in the longitudinal feedback

the following differences. The preprocessing consists of a IIR high pass cutting the common mode as well as low frequency signals up to 20 kHz. Down- and up-sampling stages have been eliminated and the user defined FIR filter has eight taps.

COMMISSIONING RESULTS

Longitudinal

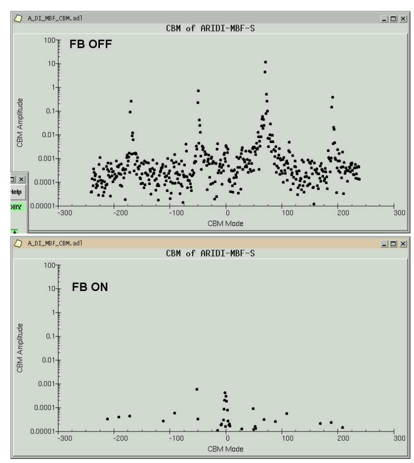

Figure 5: Screen shots of longitudinal CBM spectra without (upper) and with feedback (lower)

The presence of the third harmonic cavity (3HC) in the SLS storage ring [1] poses a special challenge in setting up a bunch by bunch feedback. As the ring is filled, more voltage gets induced in the 3HC with increasing beam current and the synchrotron tune goes from 4.5 kHz down to approximately 2 kHz. Whereas this could be compensated for by simultaneously adjusting the filter coefficients of the feedback, there is also a second effect. As we get to the onset of an instability, the longitudinal oscillation changes the beam spectrum so, that less voltage gets induced into the 3HC. The stabilization effect by the cavity goes down, the instability gets stronger, we get even less voltage etc. until we end up with a wildly oscillating beam and a strongly increased synchrotron tune.

Optimizing the digital filter settings just for the synchrotron tune of the stable beam becomes counterproductive. As the instability shows up, the tune moves off the optimized value. Capturing an instable beam may be impossible, since the synchrotron tune is far off and the feedback rather inefficient. At present, we are working with rather wide band filters to cope with these effects, but development work is still going on.

Screen shots of the longitudinal coupled bunch mode spectra are shown in Figure 5. In the spectrum without feedback one sees clearly the big modes induced by higher order modes in the main RF cavities. With running feedback, these are reduced by several orders of magnitude and no more visible to the beam line users.

Transverse

Depending on the actual pressure profile in the vacuum system, which can change due to new vacuum chambers being built into the storage ring, we may see coupled bunch modes in both planes due to ion instabilities. Resistive wall instabilities are presently suppressed by employing an increased chromaticity.

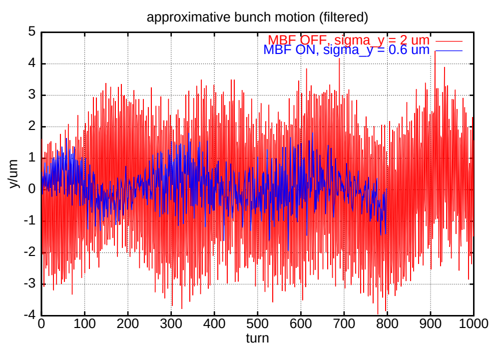

Figure 6: Vertical bunch motion at nominal chromaticity with and without feedback

Having the chromaticity reduced to the nominal value, the beam starts to oscillate as shown in Figure 6. The rms amplitude of 2 μm is to be compared with the vertical beam size of 10 μm and is already visible for the beam lines. Switching on the feedback reduces this to a value of 0.6 μm, which is already at the resolution limit of the system.

The feedbacks actually act on all beam jitters and reduce the damping time needed until the beam reaches its equilibrium. An important source is jitter introduced by the injection kickers. Whereas the horizontal jitter has been mostly eliminated by careful tuning of the kicker strength, one still sees a vertical kick. The vertical kick and subsequent oscillation is seen by the beam lines as an enlarged beam with a corresponding reduced photon flux density. Figure 7 shows the vertical beam size as measured via a synchrotron radiation monitor versus the time after injection. Without feedback the beam increases from an equilibrium size of 14 μm to a value of 35 μm. 15 milliseconds are required for the beam size to come back. With running feedback, the beam

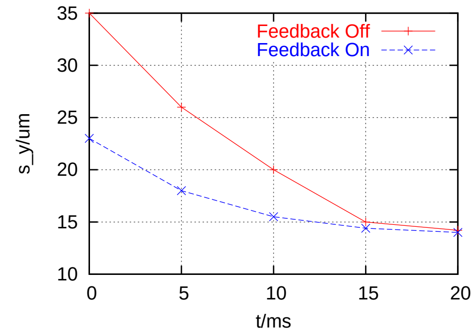

Figure 7: Vertical beam size as seen by synchrotron radiation monitor versus time after injection (Camera shutter time 250 μs/turns, beam current 190 mA

size only increases to 23 μm and needs only 10 milliseconds to damp down. Since the beam lines are working with longer shutter times, the drop in photon flux is no more visible. Gating the experimental data acquisition during injection is no more necessary.

As mentioned, the effects are much less pronounced horizontally. At injection, we see beam sizes of 58.5 μm (feedback off) versus 58.1 μm (feedback on) compared to an equilibrium value of 57.5 μm.

SUMMARY

For the control of coupled bunch instabilities at the SLS storage ring, feedback systems for all three planes have been commissioned and put into operation. These are bunch by bunch systems running digital filters on all individual bunches. The real time data processing using high performance FPGAs has a low latency of the whole system of 300 ns and allows for more sophisticated filter algorithms increasing the resolution of the systems. Apart from the stabilization purposes, they give full diagnostics of individual bunches and help to eliminate transient beam jitters occurring at injection.

REFERENCES

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