BUNCH BY BUNCH TRANSVERSE FEEDBACK DEVELOPMENT AT ESRF

Eric Plouviez , Philippe Arnoux, Francis Epaud, Jean Marc Koch, Graham Naylor, Franck Uberto
(ESRF, Grenoble)

Abstract

This paper describes the bunch by bunch transverse feedback implemented at ESRF. The first motivation of this project was to be able to cope with the constraint of the future operation of the ESRF with a stored current increased from 200mA to 300mA with a uniform or quasi uniform filling, but we were also interested in possible improvement of the operation with others filling patterns (16 and 4 bunches filling for instance). Our system uses a classical scheme: The signal coming from a set of button type electrodes is demodulated in a homodyne RF front end and processed in a FPGA DSP to derive a correction signal which is applied to the beam with a wide band stripline kicker. Depending on the filling pattern of the storage ring (uniform filling or filling with a small number of high charge bunches), different kind of transverse instabilities have been observed in the past, due to the resistive wall impedance, ion trapping or mode coupling. We have tested the effect of our system in these different situation and report also the results of these tests. These tests showed that our feedback system was efficient against all these instabilities by greatly increasing the current threshold for their occurrence both with null and positive values of the chromaticity.

INTRODUCTION

The first motivation of this project was to allow the storage of 300 mA with a uniform filling of the buckets of the ESRF ring, instead of the 200 mA that we are presently able to store. This increase required first the implementation of a longitudinal feedback [1] since the present limitation is due to the excitation of longitudinal coupled bunch instabilities by higher order modes (HOM) of our RF cavities). We then also started in parallel the implementation of a transverse feedback; the additional work to design and implement transverse feedback was moderate and we could need it to cope with extra transverse problems due to the 300 mA current stored with the help of the longitudinal feedback; it also allowed us to test new machine tunings while studying new modes of operation (16 bunch filling with topping up for instance) It is also be a very powerful diagnostic for transverse studies.

TRANSVERSE FEEDBACK DESIGN.

Feedback Layout

There are 2 separate systems for the vertical and horizontal plane. The layout of a feedback system is shown on figure 1. The main storage ring parameters important for our transverse feedback design are summed up in the table 1:

Table 1: Main storage ring parameters.

Beam Energy and ΔE/E	6 GeV and 10^{-3}
RF / revolution frequency	352.2MHz / 355KHz
Transverse damping time	7 ms
Tune (H/V)	13.39 / 36.44
Synchrotron frequency	1.6 to 2 KHz

The beam signal pickups are capacitive electrodes of 10 mm diameter (H) and 12 mm diameter (V) located in high beta H and V locations (36m for both plane). To get the vertical beam position signal we combine the signals of 2 electrodes located on the center of the upper and lower side of the vacuum chamber with a gap of 36mm. For the horizontal signal we combine the signals of the four electrodes of a regular BPM pick up block mounted in a 20mm gap vacuum chamber. A RF mixer is used to detect the position time current signal by a synchronous detection of the difference signal of the BPM pick up signals. We perform the detection on the 4th harmonic of the RF frequency in order to increase the sensitivity and to ease the filtering of the 0 to 176 MHz base band signal from the RF clock spurious signal. Between the □ RF combiner and the RF mixer, the pick ups signal go through a comb line filters which turns the single pulse induced by each bunch in a train of 4 pulses evenly spread inside an RF period, in order to better condition the beam signal for the detection at the 4th harmonic of the RF frequency. The amplitude of the $4Xf_{RF}$ beam signal generated by a 1nC bunch at the output of the comb filter is 15mV/mm both for the vertical signal and for the horizontal signal, including a loss of -3dB in the cables.

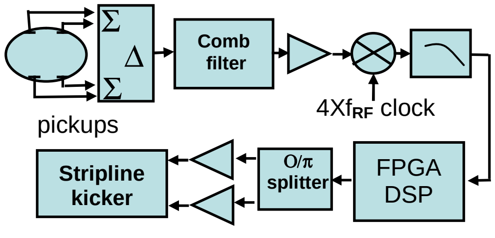

Figure 1: Layout of a transverse feedback system

We are using separate vertical and horizontal stripline kickers to apply the correction kicks. The βvalue at the location of each kicker is 36m for both kickers. The horizontal stripline design is similar to the high shunt impedance design used at SLS [2]. Each blade of a stripline is fed by a solid state power amplifier. The stripline length and amplifier power are:

- 35 cm and 100W/200MHz BW for the horizontal kicker
- 23 cm and 50W/200MHz BW for the vertical kicker .

Table 2 shows the main parameters of the feeback.

Table 2: Main feedback parameters.

Feedback parameters	*vertical*	*horizontal*
Measurement range	+/-.15mm	+/-1.5mm
Resolution at 200mA	3µm	3µm
Max. kick strength /turn	.2 10^{-6} rd	.4 10^{-6} rd
Min. damping time	60µs=$20T_{rev}$	300µs
Added noise	.7µm	.1µm

The vertical resolution is set by the thermal noise of the input amplifier of the RF front end; the horizontal resolution is set by the resolution of 14 bits ADCs at the input of the FPGA DSP (13 effective bits). The minimum achievable damping time is imposed by the kicker stength and the position measurement range; the measurement range chosen for each feedback is set by the amplitude of the position oscillation caused by the injection kicker of the storage ring that we need also to control. The added noise is derived of the position resolution and of the feedback damping time ([1] and [2]). The damping time is given for ζ=0; if it not the case, the figure is not so straightforward to derive…

DIGITAL SIGNAL PROCESSING

DSP Platform

Due to the high resolution requested for the error signal measurement, we decided to perform this data acquisition without any under sampling ie with a 352.2 MHz sampling and processing rate. Such a processing rate is only achievable if we use a FPGA processor. After considering the different platforms and programming environment potentially adequate for our project, we went for the following solution: we use a special development of the *Libera* bunch signal processor developed by *I-Ttech* for the error signal acquisition, signal processing and correction signal generation. The main feature of this product are: up to 500 Msps ADC and DAC sampling rate with 14 bits resolution, *Virtex II pro* FPGA with 64 Mbits of DDRAM for data logging.

Programming Environment

We wanted to be able to reprogram flexibly by our self the details of the feedback algorithm and we could not rely on a dedicated expert in FPGA programming for this project, therefore we specified that the *System Generator* programming environment should be available for the *Libera* platform. *System Generator* is a graphical programming environment developed by *Xilinx* and the *MathWorks* which allows defining and validating a processing algorithm at the bit and sample level using a library of *Matlab/Simulink* models provided by *Xilinx*., The availability of this kind of programming environment is one of the reasons to the relatively short time that was needed for the coding and testing of the feedback algorithms on the FPGA during this project.

Control

A *Tango* device server takes care of the loading of the configuration parameters of the feedback and of the downloading of the buffer and DDRAM data

Signal Processing Principle

Since the error signal is a position signal and the correction signal is applied as an angle kick, the error signal should be the derivative of the error signal. Actually we approximate this derivation by a $\pi/4$ phase shift which is easier to implement in the DSP; an extra phase shift is added since the phase shift between the error and correction signals will also be function of the betatron phase shift between the BPM and the transverse kicker; we use an 8 taps FIR in the vertical plane and a 7 taps FIR in the horizontal plane, without decimation.

BEAM TESTS

Between the end of 2006 and spring 2008 we have tested the effect of the transverse feedback on various transverse instabilities observed on our storage ring.

Instabilities Due to Ion Trapping

Some ESRF users require a uniform filling of the storage ring instead of the partial filling that is usually used in order to get rid of ion accumulation close to the bunches path; with a uniform filling pattern, even after weeks of vacuum conditioning, the vertical emitance is increased from the usual operation value of 20pm.rd up to 35 pm.rd by instabilities induced by ion trapping; the vertical feedback reduces this beam blow up and brings back the emitance to its initial value. The spectrum of the vertical beam position, with and without feedback is shown on figure 2 showing the larger amplitude of the lines at the betatron $N.f_{rev}\text{-}f_{\beta v}$ satellites between 2 and 10 MHz which are the usual signatures of ion trapping instabilities and their reducion by the feedback.

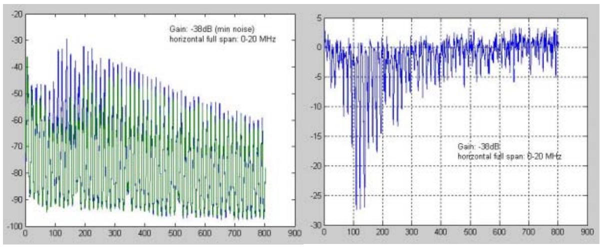

Figure 2: Left: spectrum of the vertical position of the beam blown up by ion trapping instability (blue), and stabilized by the feedback (green); full span 0-20MHz; Right: relative amplitude of the betatron lines without and with vertical feedback (5dB/div)

During the tests of the longitudinal feedback at 300mA, this ion trapping problem was particularly severe; we could only achieve 300mA storing during the few hours required by our tests by using also the vertical feedback to control these vertical instabilities.

Uniform Filling and Zero Chromaticity

In order to test the potential of the transverse feedback to allow the operation at 300mA without increasing the vertical and horizontal chromaticity and spoiling the lifetime, we tested our feedback system at 200 mA with a uniform filling pattern and zero chromaticity in both planes. The beam could be stored without problem with a feedback damping time of about 50 x T_{rev}.

Single Bunch Filling at Zero Chromaticity

At zero chromaticity, the threshold of the TCMI instability is about .5mA; using the vertical feedback, it was possible to store up to 2.5 mA; this is a significant effect but of no real practical use for the operation of our storage ring since the nominal current per bunch is at least 6mA for our time structured mode of operation (16 bunches filling pattern) .

Single Bunch Filling at Reduced Chromaticity

Actually, it seems that the best compromise in term of chromaticity choice for our storage ring is operating it with a relative vertical chromaticity value (dQ/Q)/(dP/P) of about .2; with this value, the effect of the amplitude dependency of the tune starts to hide the beneficial effect of the chromaticity reduction, so it is useless trying to further reduce it. For this reason we also tested if the feedback could increase the threshold of the head tail instability current limitation at this optimal chromaticity value. With a reduced chromaticity of .2 this threshold is 2.7 mA without feedback. Using the vertical feedback the threshold increases up to 5mA routinely and occasionally up to 7.5mA, using a high feedback gain corresponding to a damping time of about 6 x T_{rev}. We attribute the erratic value of the maximum storable current to the fact that the gain required to stabilize the instability in single bunch is much higher than the maximum gain value avoiding the saturation of the feedback kicker during the injection oscillations; we are now planning the implementation of a more powerful kicker set up. This unexpected efficiency against head tail modes of oscillation seems to be due to the fact that the damping time with feedback was much shorter than the synchrotron period (150 x T_{rev}).

DIAGNOSTICS FUNCTIONS

Data Storage

In addition to the DAC output, the ADC signal can be used to load a set of 4K buffers or a 64MB DDRAM. The DDRAM allows storing a large amount of data without particular preprocessing (raw ADC data of FIR output data), to be studied in case of post mortem analysis. The downloading of the SDRAM through the network can be rather long (several seconds for a 2048 X 992 data file), so it is usually more convenient to download the 8K data buffer. These buffers are used to store decimated data; the decimation can be done bunch by bunch or mode by mode; the mode by mode decimation is done by the FPGA with a digital down converter using a numerically controlled oscillator (NCO) with I and Q outputs. The data storing can be triggered by an external signal, by a software trigger, or if a signal level inside the signal processing flow exceeds some preset threshold.

Test Signals Generation

In order to calibrate the feedback and make tune measurements, a signal generator is implemented in the FPGA; the data coming from the NCO can be sent to the DAC input to produce sine signals at any Nf_{rev} +/- $f_{\beta v}$ frequency; this NCO signal can also be modulated by a 40 kHz bandwidth noise to measure the tune; An external single turn kicker is also available for both planes.

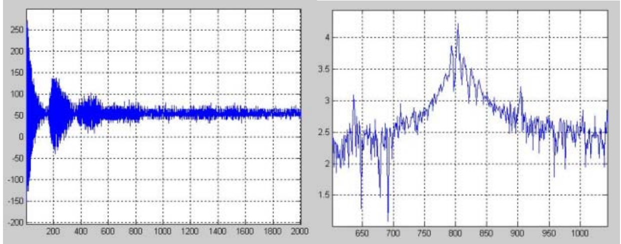

Figure 3: Left: turn by turn signal of a single .2mA bunch among 992 after a single turn kick of 1.5µrad (horizontal scale: turn number) Right: tune measured with the same signal .

CONCLUSION

The implementation of a transverse bunch by bunch feedback is now a well proven technique thanks to the experience gained on feedback systems implemented on many machines during the last 10 years. The processing power available on recent FPGA allows in addition to the feedback function, the implementation of very powerful diagnostics functions.

REFERENCES

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