

BEAM DIAGNOSTIC FEATURES OF THE ESRF MULTIBUNCH FEEDBACK

Jean Marc Koch, Graham Naylor, Eric Plouviez, Francis Epaud (ESRF, Grenoble)

Abstract

The ESRF storage ring is now equipped with a set of multibunch feedback systems. The main goal of the implementation of these systems is to prevent longitudinal and transverse instabilities. However, besides this main function, these systems provide a powerful diagnostic to study the longitudinal and transverse beam dynamics and document operation problems.

In this paper we give a short overview of these feedback systems and describe with more details their diagnostic function.

INTRODUCTION

The first motivation of this project was to allow the storage of 300mA with a uniform filling of the buckets of the ESRF ring, instead of the 200mA that we are presently able to store, with the help of a longitudinal feedback. The present limitation is due to the excitation of longitudinal coupled bunch instabilities by higher order modes (HOM) of our RF cavities. We also started in parallel the implementation of a transverse feedback; the additional work to design and implement transverse feedback was moderate; it would allow us to test new machine tunings while studying new modes of operation (16 bunch filling with topping up for instance) or to help stabilise the 300mA current, whose storage was made possible by the longitudinal feedback. It would also be a very powerful diagnostic for transverse studies. Both feedback systems are now meeting our expectation, and allowed us to store, with a uniform filling pattern, 300mA thanks to the longitudinal system and to reduce the horizontal and vertical chromaticity down to zero while storing 200mA thanks to the transverse systems.

LONGITUDINAL FEEDBACK DESIGN

We chose the now classical approach of detecting every turn the variation of the phase of each bunch with respect to its equilibrium phase, to derive from this phase deviation an energy correction to apply to the beam, and to produce this correction using a longitudinal kicker [1].

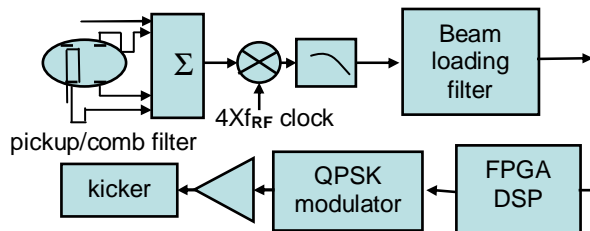


Figure 1: Layout of the ESRF longitudinal feedback .

We paid a lot of attention to achieve the best possible resolution in the phase measurement in order to reduce the maximum required kicker strength.

Kicker Design

Our kicker is a low Q pill box cavity following the design used at INFN Frascati[1]. With such a cavity we are able to produce a 600V kick using a 200W RF amplifier. To drive this cavity we are using the QPSK modulator scheme developed for the PEP longitudinal feedback [2]

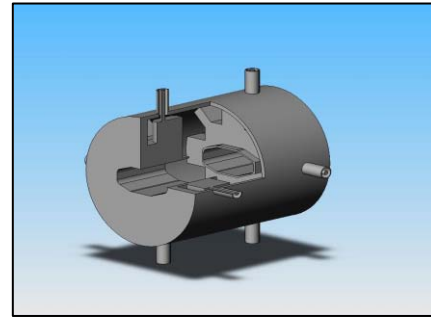


Figure 2: Longitudinal kicker shape.

Signal Processing Principle

We detect the beam signal using a set of 4 capacitive pickups. We combine the pickups signals with cables of different lengths to obtain a comb filter selecting a bandwidth of 352MHz around 1.4GHz (four time our RF frequency of 352.2MHz). We use a RF mixer as a phase detector (see figure 1); the output of the mixer is amplified to match the input range of the 14bit ADC of the FPGA DSP board resulting in the resolution detailed in the table 1.

Table 1: Phase Detection Resolution

Phase detector sensitivity (RF mixer)	$\approx 6\text{mV}/^\circ$
Noise ($Z_0 = 50\Omega$, BW = 176 MHz, N=6dB)	12 μV rms
Phase detector turn by turn resolution $\delta\phi$	$2 \cdot 10^{-3}^\circ = 4\text{fs}$
usable range (14 bit ADC, LSB = $\delta\phi$)	$\pm 32\text{ps}$

In our storage ring, the ratio between the energy and time amplitude of a longitudinal oscillation is 0.4KeV/fs; so our time resolution of 4fs is equivalent to an energy resolution of 1.6KeV. For each bunch, we derive the correction signal from the error signal by averaging over 9 to 11 turns, followed by a 16 tap FIR; the result is a 2 KHz bandwidth bandpass filtering around the synchrotron sideband frequency plus a $\pi/4$ phase shift. This phase shift

is equivalent to the derivative needed to turn a phase error signal into an energy kick correction signal [3].

TRANSVERSE FEEDBACK DESIGN

Feedback Layout

There are 2 separate systems for the vertical and horizontal plane. The layout of the transverse feedback is shown in figure 2.

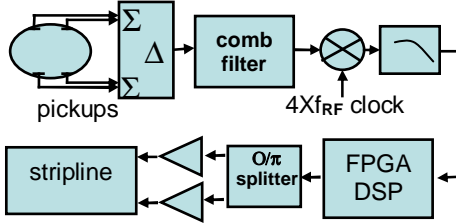


Figure 3: Layout of a transverse feedback system.

The beam signal pickups are 11 mm diameter capacitive electrodes located in high beta H and V locations (36m for both plane). The RF front end detects the position using 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. We use strip line kickers to apply the correction kicks. Each blade of the strip line is fed with a 100W/200MHz BW solid state power amplifier.

Signal Processing Principle

For the transverse feedback we make the same derivative/phase shift approximation as for the longitudinal feedback, but 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.

Table 1: Transverse Detection Resolution

Feedback parameters	vertical	horizontal
Measurement range	+/- .4mm	+/- 1.5mm
Resolution at 200mA	0.7μm	0.7μm
Kick strength per turn	$0.3 \cdot 10^{-6}$ rd	$0.6 \cdot 10^{-6}$ rd
Min. damping time τ_{\min}	75μs	300μs
Added noise for $\tau = \tau_{\min}$	0.15μm	0.07μm

DIGITAL SIGNAL PROCESSING

DSP Platform

Due to the high resolution requested for the error signal measurement of both longitudinal and transverse systems,

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-Tech* 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 14bits 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 allow 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 for the relatively short time that was needed for the coding and testing of the feedback algorithms on the FPGA during this project.

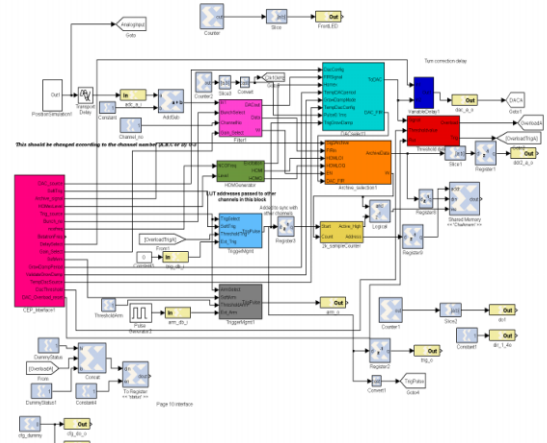


Figure 4: Development of diagnostic facilities on the FPGA using Simulink.

Bunch by bunch feedback algorithms are now relatively standards so it would have been possible to get a totally turn key feedback system without the *System generator* environment. However, it is very convenient to have, in addition to the feedback loop, several diagnostics function which are less standard, such as the open loop analysis tools, grow damp measurement, mode by mode or bunch by bunch tune measurement ... These functionalities are more difficult to specify in advance to a subcontractor; downloading and processing the bunch by bunch /turn by turn DDRAM data is also very inefficient except for the purpose of post mortem analysis of unexpected events.

Performing pre processing in the FPGA to reduce the data rate is a good solution, using a DDC algorithm for instance. The availability of the *Simulink/System Generator* environment proved especially powerful in this respect.

Data Handling

A Tango device server has been written to load the main parameters of the data processing such as mode number, tune frequency offset, gain etc., and to download the data buffer generated by the FPGA processing;

Graphical Control Application

A graphical user interface has been developed using *Matlab* in order to test the operation of the feedback and to launch the various diagnostic routines implemented on the FPGA, as well as to perform further post processing. The *Matlab* scripts control the FPGA using the device server commands.

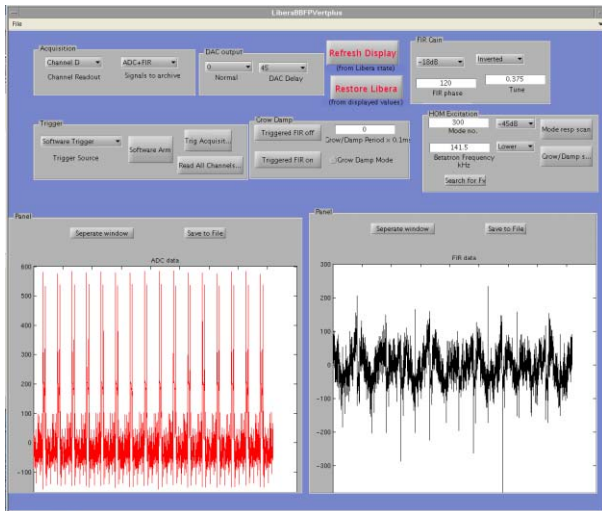


Figure 5: Test Graphical user interface to launch utilities.

Measurement of Open Loop Characteristics

The stability of the feedback loop for all modes is verified by exciting the beam at each mode frequency and measuring the amplitude and phase response of the open loop:

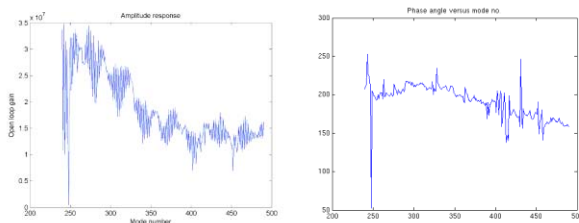


Figure 6: Variation in loop gain (left) and open loop phase response (right) as a function of mode no. (Longitudinal feedback).

Grow Damp Measurements

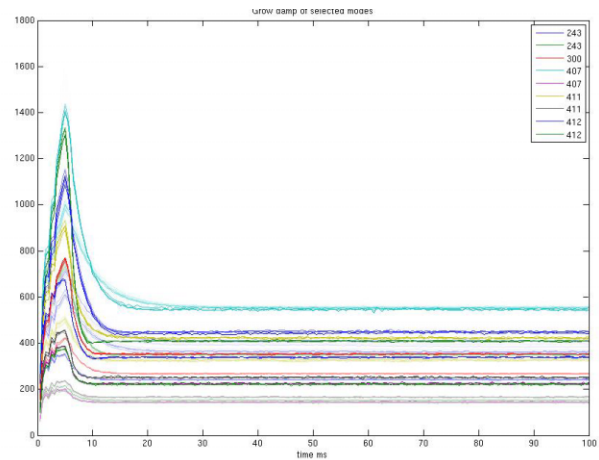


Figure 7: Layout of a transverse feedback system.

The control application is able to configure the feedback operation to couple artificial HOM excitations in the case of longitudinal feedback loop and momentarily open the loop so as to measure the growth rate and damping rate of individual modes.

Future Developments

We are now planning to implement on the transverse system a tune monitor, and some instability interlock functions.

CONCLUSION

The implementation of a bunch by bunch feedback used to be a very challenging task. It is now a well proven technique thanks to the experience gained on feedback systems implemented on many machines during the last 10 years. In addition, thanks to the availability of fast and accurate ADC and DAC, powerful DSP using an FPGA, and a user friendly programming environment, it proved to be a relatively straightforward piece of equipment to design and implement. The diagnostics functions that can be implemented -thanks to the processing power of the FPGA and the ease of programming offered by modern development tools, are also a big asset of our system.

REFERENCES

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