NEW FAST ORBIT FEEDBACK ARCHITECTURE BASED ON LIBERA BRILLIANCE DEVICES FOR THE ESRF STORAGE RING

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Abstract

Within the framework of the upgrade of the ESRF, one important implementation regarding the source will be to improve the stability of the beam across the whole frequency range at which mechanical vibrations or electro-magnetic disturbances take place. The improvement of the existing orbit correction scheme based on separate slow and fast systems [1] will be achieved both by taking advantage of smart measurement thanks to the newly installed Libera Brilliance [3] and the use of more correctors than today. This new Fast Orbit Feedback will therefore rely on the 96 correctors integrated inside the sextupole magnets to cover the full frequency range all around the ring. Following the successful implementation of such a scheme at SLS (Swiss Light Source) and, more recently, at DLS (Diamond Light Source), re-using as much as possible pieces of software and ideas on hardware both from DLS and from Soleil, we have defined the architecture for the ESRF scheme which will be developed in this paper.

INTRODUCTION

The ESRF storage ring is a high brilliance source with low emittance values (ε_x =4.10^{-9} m.rad and ε_z=2.10^{-11} m.rad) and generates Xray from insertion devices installed on 5 m long straight sections. With β_x=36m and β_z=2.5m in the center of the high beta straight sections, the rms beam sizes at the BPMs located on both ends of the straight sections are σ_x= 380µm and σ_z= 14µm.

The parasitic motion of the beam due to slow drifts or high frequency vibrations of the quadrupole support girders must be kept at low enough values to avoid spoiling this emittance figure. Two kinds of motions can be observed: very slow drifts and vibrations at 7Hz, 30 Hz and 60 Hz. The amplitude of these vibrations at the ends of the straight sections is 10 µm rms horizontally and 3µm rms vertically.

224 BPMs and 96 steerers will be available to correct the orbit at a 10 KHz rate. The goal of this upgrade is to make an orbit correction in the main frequency range at which the beam motion occurs, from DC level to 200Hz. The layout of the system is shown in figure 1, all BPMs and steerers in place will be used for this correction.
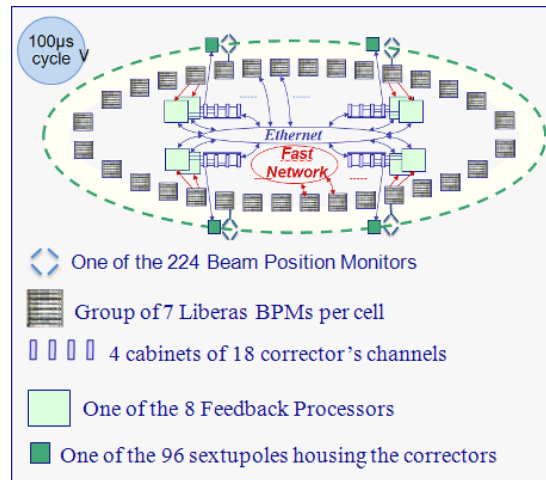

Figure 1: Layout of the orbit correction system.

ORBIT CONTROL

Principle

The distortion of the storage ring closed orbit in the vertical or horizontal plane is represented as a vector of 224 positions. Both closed orbits can be corrected by changing the correction vector, settings of the 96 corrector currents in each plane; we assume that the vertical and horizontal corrections are uncoupled. The response of the orbit to the correctors is linear and described by a response matrix which does not change with time. In the frequency domain, the bandwidth of the system is limited by the correctors, eddy currents in the vacuum chamber, inductance of the coils, and by the latency of the digital signal processing in the Libera processors. The frequency response of all the BPMs and all the correctors is the same.

A correction matrix is calculated by inverting the response matrix using the SVD method. Each result of the multiplication of the position vector by the correction matrix is used in an iterative algorithm in order to get a correction with a PID type response. In addition a narrow bandwidth correction using a dedicated notch filter in parallel with the PID reduces the level of the disturbance coming from the 50 Hz AC main frequency.

Beam Position Measurement

The beam positions are measured using capacitive electrodes. The 224 BPMs installed in the machine will be used as shown in figure 1. The Libera Brilliance will allow a resolution of 10nm/√Hz over the full operation intensity range from 5mA (in single bunch) to 200mA. They contribute for T_{BPM}= 200µs to the loop delay.

Orbit Corrections

The corrections will be induced by 96 steerers.
(Steerers: ~300µ-radian / Amp H or V)

These steerers are part of the sextupoles and are used in the present configuration to correct the orbit at a rate of one correction each 30 second. Tests have shown, both in lab and with beam, that we can make use of these steerers to induce deviations up to 60µ-radian to the beam at very low frequencies and 15µ-radian at a maximum rate of 200Hz. Eddy currents in these steerers and in the vacuum chambers contribute for Ts= 300us to the loop delay.

The digitally controlled power amplifiers will be used inside the closed loop in such a way that the whole system relies on the Beam Position Monitors. The beam stability, both long term and short term will therefore depend only on the stability of the BPMs.

In such a configuration, the stability of the current delivered by the power converters is not an issue when the loop is closed; nevertheless, the granularity is of concern since the system must be able to drive currents by steps of some 10uA in order not to induce digital noise in the loop.

This granularity will be obtained in 2 steps:

1) 16 bits DC from the Ethernet network will allow a rough adjustment to start injecting a current in the Storage Ring. This 16 bits DC will be scaled to currents of +/- 1.8A.

2) 16 bits from RS485 serial links accessible at 10 kHz will characterize the granularity for AC signals in a range of +/- 200mA. This input will be rate limited at 5mA/100µs by the internal firmware of the power converters in order for the output to never reach the maximum voltage.

SYSTEM LAYOUT

Overview

The 224 Liberas are connected together by means of RocketIOs with a serial data communication rate of 2.12Gbps either through copper links for the connections within the cells or optic fibers for the inter-cells connections. All the cells are connected towards a central patch panel. On this panel, we can implement the communication network according to the topology adopted. A 2D torus topology will be implemented in the same manner as the one adopted at Diamond Light Source [3]. The advantages of this topology are the redundancy in the data path and a shorter delay to get all the positions. Each Libera has four RocketIOs dedicated to the D.L.S. C.C. [3].

In the present configuration, the steerer DC power supplies are grouped in four locations around the storage ring. These DC power supplies will be replaced by new AC power supplies, and, as we have chosen not to modify the cabling to the steerers, we will keep this configuration with four stations where the corrections will be performed and the results transferred to the AC power supplies. In order to share the processing load, we will have two processing platforms per station.

Digital Signal Processing Hardware

The digital signal processing will be implemented on FPGAs. The corrections are computed at a rate of 10 KHz by 8 modules (Fig. 1) equipped with FPGAs Xilinx Virtex-II pro. The data transfer of the beam positions from Liberas to the Feedback Processors is made through optical links to two Rocket IOs of each FPGA (for redundancy purposes). The data transfer of the set points from each FPGA to the power converters is made through RS485 serial lines, one per channel. This is the way the set-points are sent in real time from the Liberas to the power supplies at Soleil [4].

SIGNAL PROCESSING

Simulations and Coding

The signal processing will be performed on the FPGA. Using Simulink and Xilinx System Generator (Fig. 2 & 3), we can complete all simulations and debugging inside the same environment in which we prepare the model for automatic code generation using Xilinx blocks.

We then launch Xilinx System Generator to automatically generate the VHDL code of the processing. The code is mixed with the handwritten code dedicated to the data transfer: Communication Controller, RS485 serial lines management and access to the PCI bus, the interface with the signal processing is done through shared memories.

The binary code for the FPGA is then produced with the Xilinx tools ISE.

Thanks to System Generator, an in depth knowledge of specialized programming language to code a function is not necessary. Furthermore, it is easy to share developments between people involved in the same project.

The beam motion is described in Simulink with noise and pass-band filters [fig.2] and introduced into the loop. The Libera is described by its delay and sampling function at 10 kHz and all the parameters such as the vectors from the inverse response matrix, the PID coefficients or notch gain are entered from Simulink to emulate the input of these coefficients from a remote server.

Data Recording

Thanks to the Communication Controller,[3] all the 224 X and Y positions are available on any of the Libera BPMs on unused SFP (Small Form-factor Pluggable) connected to Rocket-IOs. An additional station identical to the 8 dedicated to the correction has been installed to record the positions at 10 kHz in a buffer of a maximum length of 15s. The material and software are almost identical to the ones used at Soleil for this function

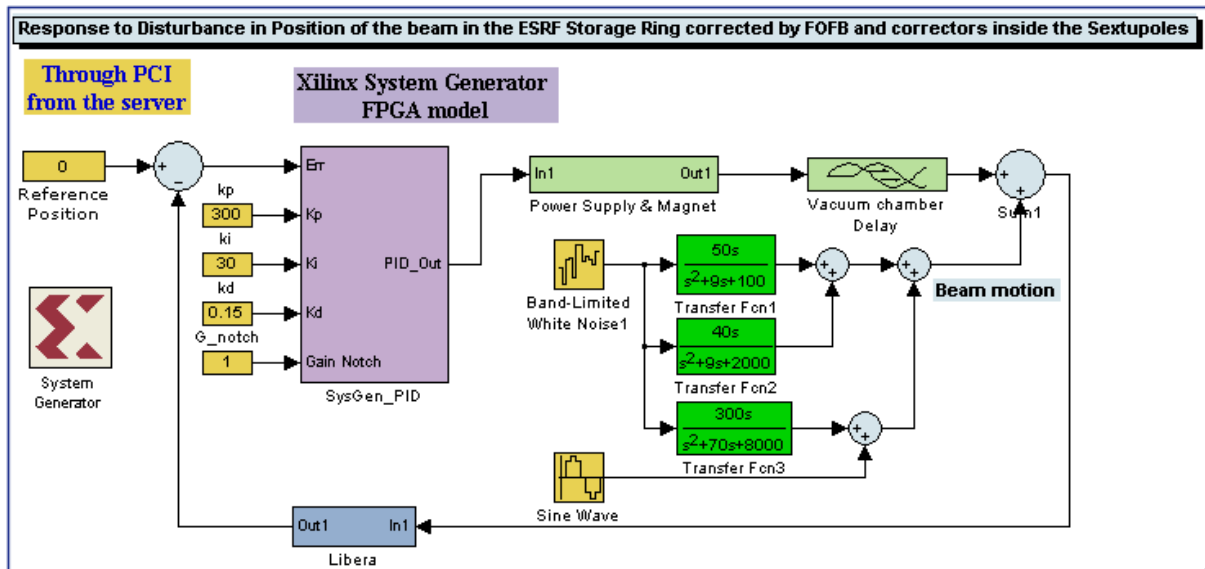Process Tuning and Feedback Systems

Figure 2: Simulink and Xilinx System Generator give access to both simulation and coding in the same environment.
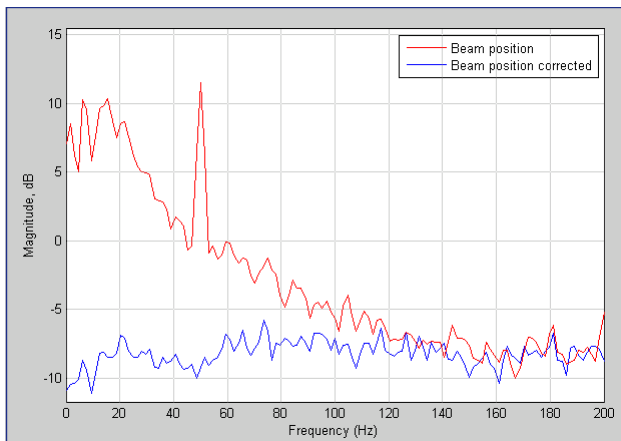

Figure 3: Spectrum of the simulated beam motion before and after correction by the FOFB.

CONCLUSION

The first step of the implementation of this new version of the Fast Orbit Feedback is, after the successful installation and commissioning of the digital BPMs electronics [2], the set-up of the communication controller [3] which will be completed before the end of this year. The procurement of the new power supplies for the steerers has been launched, and all channels will be received before mid 2010. At first, these power supplies will only replace the DC function and be driven by the slow orbit correction through the Ethernet network. When the processing devices are ready, the power supplies will be connected to them to accept set-points at full rate, i.e. 10 kHz.

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