FAST ORBIT CORRECTION FOR THE ESRF STORAGE RING

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Abstract

Today, at the ESRF, the correction of the orbit position is performed with two independent systems: one to deal with the slow movements and one to correct the motion in a range of up to 200Hz but with a limited number of fast BPMs and steerers [1]. The latter will be removed and one unique system will cover the frequency range from DC to 200Hz using all the 224 BPMs and the 96 steerers. Indeed, thanks to the procurement of the Liberas Brilliance and installation of new AC power supplies, it is now possible to access all the Beam positions at a frequency of 10 kHz and to drive a small current in the steerers in a 500Hz bandwidth. The first tests of the correction of the beam position have been performed. This new orbit correction system is also a powerful diagnostics system: the measurement and survey of the Ring's lattice parameters is possible thanks to the high measurement rate of very high resolution position data.

INTRODUCTION

The ESRF storage ring is a high brilliance source with low emittance values (ε_x =4.10^{-9} m.rad and ε_z=4.10^{-12} m.rad) generating 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. The layout of the correction scheme is shown in figure 1, all BPMs and steerers in place are used by the system.

System Layout

The design of our new system is based on the availability of the Libera Brilliance electronics and an associated "Communication Controller" developed at DLS [2] and using the Libera Rocket I/O ports. This allows the measurement and broadcast of the beam position at 224 locations with a very good resolution at a rate of 10 kHz. We are using the 96 corrector magnets embedded in the sextupole cores to steer the beam, and since the power supplies feeding these magnets are installed in four locations, this particular constraint sets the architecture and topology of our system. Therefore, the correction computation will be placed close to the power supplies and spread over 8 processors, 2 per location. For this processing, we selected a PMC module with fiber-optic transceivers and a Xilinx Virtex-5 FPGA. The code embedded in this FPGA has several functions:

1) Collect the data from the BPMs at 10 kHz
2) Obtain the parameters from the PCI
3) Process the corrections
4) Send the set-points to the power supplies.

The choice of performing the corrections inside the FPGA was driven by the fact that no real-time operating system was supported at the ESRF and also to take advantage of the efficiency of the FPGA. A first interesting feature is the capacity to do parallel computing and also the fact that the time lost transferring the data is very limited since all the functions are performed by the same device.

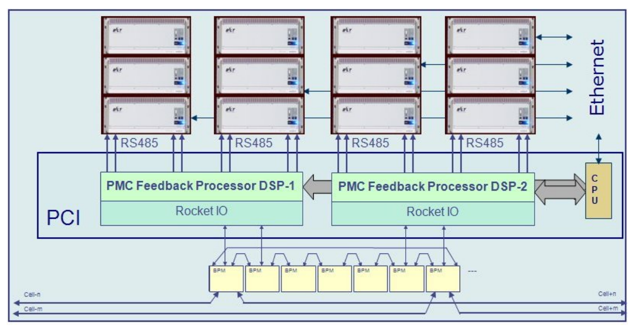

Figure 1: layout for 1/4th of the system connected to the Libera BPMs of one of the 32 cells.

Upgrade of the Corrector Power Supplies

The present slow correctors are implemented by 3 pairs of auxiliary coils placed on the yoke of the sextupoles. Using the proper combination of currents in these 3 coil pairs we can produce any combination of vertical and horizontal kicks. The bandwidth of these correctors is affected by the eddy currents in the sextupole core and at the surface of the vacuum chamber since the vacuum chamber all over the storage ring is made of 2mm stainless steel. The inductance of these correctors is also quite large: 0.6H, however, it is possible to achieve, given the small amplitude of the high frequency currents needed for the fast correction, a small signal bandwidth of 500Hz thanks to a proper design of the power supplies. These power supplies are controlled through the Ethernet network of our control system and an additional trim setting can be added at a rate of 10KHz on 10% of the full dynamic range. This is done through a RS485 port used to input the data in a deterministic way and with a delay limited to 20µs. Among the features of the power supplies, a diagnostic on each of the 288 channels is available to check the proper functioning of the serial links. One register per channel records the count of the possible errors in the data transmission.

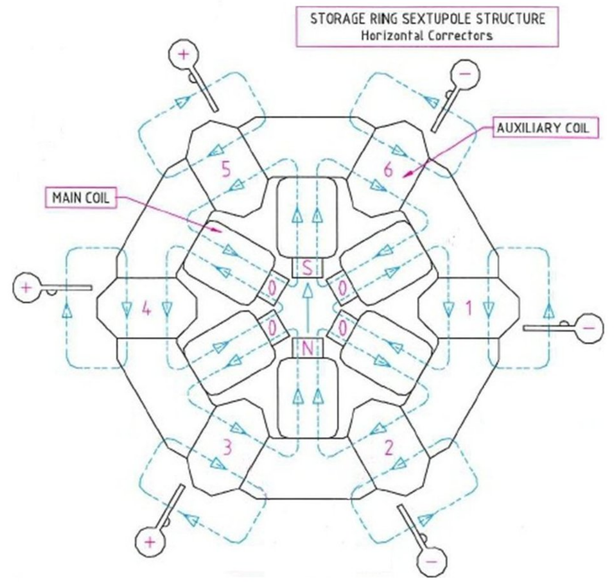

Figure 2: layout of the auxiliary correctors in a sextupole.

Orbit Correction Algorithm

We will derive the orbit correction from the BPM data using a correction matrix obtained from the inversion of the response matrix of the BPMs to each corrector. These response matrixes are inverted using the SVD method. We will use 96 eigen vectors for the inversion of the response matrix. Before starting the 10 KHz correction loop, we will measure the average orbit and set the corrector currents in order to suppress the error measured on this average orbit; these DC values will be applied using the Ethernet input of the power supplies. We will then start the fast correction loop which will add an additional trim current to the DC current set initially. During the first tests of this fast loop, we used a PI algorithm with an additional 50 Hz notch filter aimed to improve the damping of the perturbation at the AC main supply frequency for the 10 KHz iteration of the values of the trim correction currents. Over long periods of operation, the average value of the trim currents may eventually drift up to significant values. In this case, this average current will be added to the setting of the Ethernet input of the power supply, and the average value of the fast trim currents will drop to zero. In this way, if the fast loop is stopped, setting the values of the trim currents to zero will only result in a very small orbit jump and we keep the whole dynamic range for the fast correction.

Diagnostic

In addition to the 8 feedback processor/power supply controller modules, one FPGA PMC board has been added; this board is fully dedicated to diagnostics, and is able to log up to 10s of position and correction data; this board is a duplication of the so called "sniffer" developed for the SOLEIL and DLS orbit control systems[3]. It is also used to detect errors in the data collection by counting the "BPM data not received".

TESTS

Orbit Correction Test Setup

All the correctors are now equipped with their new power supplies and the BPM FA outputs are interconnected. At the beginning of 2011, we installed one power supply controller FPGA board based on Virtex-5 since the full batch was available mid year only. With this single board, we were able to receive the position from all 224 BPMs from the *Communication Controller* and to control the 6 correctors of 2 cells of the storage ring (Fig. 3).

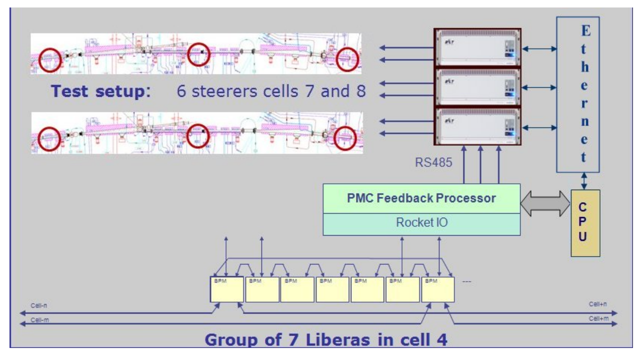

Figure 3: layout of the partial setup adopted for the tests.

Given the 16 fold symmetry of the storage ring, running a local correction over these two cells is enough to assess the potential performance of the full system. The correction bandwidth was set at 150Hz, and at this stage no weighting (Tikhonov regularization for instance [4]) was applied on the damping time of the upper order eigen vectors of the SVD decomposition. We recorded the position data with the sniffer module.

Tests Results

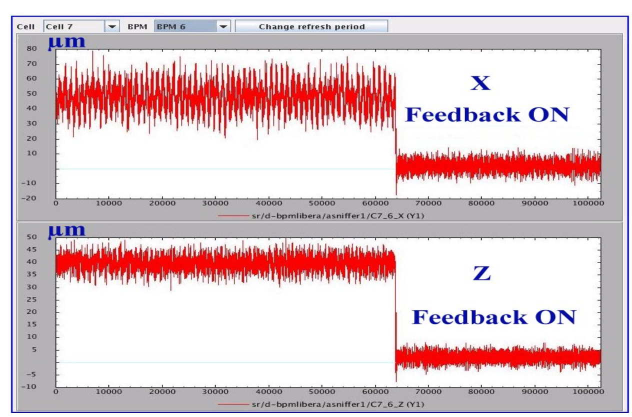

Figure 4: BPM signals with orbit correction OFF (left part) and ON (right). H scale = 10s of record, V scale = 10µm/div.

The plots of figure 4 show the reduction of the horizontal BPM signals observed at the beginning of a straight section (β_H=36m, upper plot) and the reduction of the vertical BPM signals observed in the achromat (β_V=36m, lower plot).

The feedback performs as expected in term of bandwidth and damping of the 50 Hz. We have also tested that starting from an orbit already set by a slow orbit correction, turning on or stopping the fast loop was not causing any significant orbit jump. The plots of figure 5 also show that the noise created by the loop overshoot in the vicinity of the cut-off frequency is negligible thanks to the very low noise of the *Libera Brilliance* electronics.

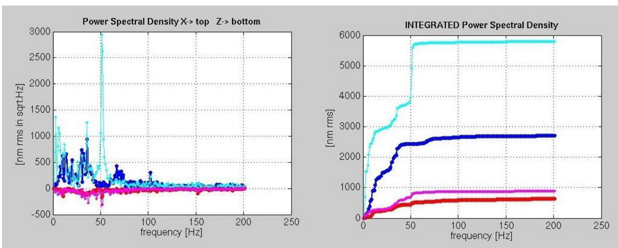

Figure 5: Power spectral density (left) and integrated power spectral density (right) averaged over the BPMs of the 2 corrected cells with and without orbit correction. Light blue, dark blue: H signals, purple, red: V signals.

Another test has been performed to assess the capability of the correction to drastically reduce the effect of the gap motion on the beam position. In fig. 6 we can see at first a record with no correction, the second part shows the result with a feed-forward control the efficiency of which depends on the beam parameters, and lastly with the Fast Orbit Feedback "ON", the beam stays at its position within 1µm during the phase changes.

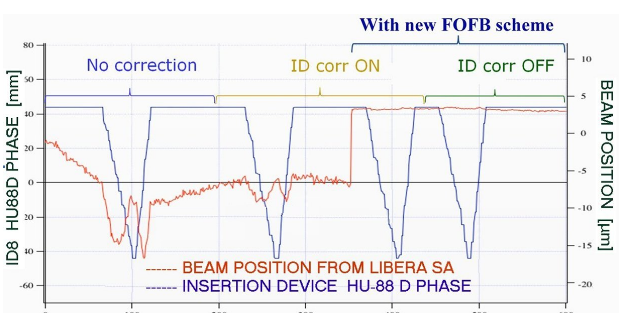

Figure 6: Correction of a beam displacement induced by an insertion device motion (Courtesy of J.Chavanne).

Other Measurements

The resolution of the 10 KHz FA data is 600nm in the range of currents that we store in operation. Such a resolution allows the measurement of SR parameters such as the measurement of the matrix of the response of the BPMs to the corrector current, or the analysis of the SR optics coupling with a very low excitation of the beam and a short acquisition time; applying excitation signals modulated by a sine signal at a well chosen frequency and a narrow bandwidth analysis of the beam response at this frequency, using the method tested at DLS [5], we checked that with a measurement time of 1s, a resolution of 6nm was achieved. We have used the sniffer to record the response of the BPMs to a 40 Hz modulated kick from a horizontal corrector over 1 second. The horizontal response amplitude is 5µm (left plot of figure 7); the vertical response (right plot) which is due to the coupling of the horizontal and vertical optics is very clean, though its amplitude is only 150nm.

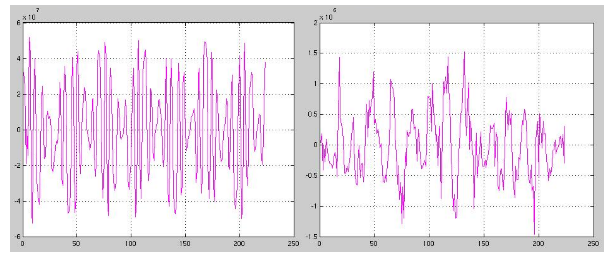

Figure 7: Horizontal (left plot) and vertical (right plot) response of the beam to a horizontal kick of 150nrad.

CONCLUSION

We have tested the performance of this system on a part of our storage ring covering 2 of the 32 cells and the damping of the orbit distortion that we achieved on this part of the ring fulfil our expectation. We recently have installed and carefully tested all the components of our new orbit correction system, the next step will be to put this system in operation with a high level of reliability, this part requires a special attention for the sequencing and the diagnostic of the system.

ACKNOWLEDGEMENT

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