THE ORBIT CORRECTION SCHEME OF THE NEW EBS OF THE ESRF

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Abstract

The ESRF storage ring is going to be upgraded into an Extremely Bright Source (EBS). The orbit correction system of the EBS ring will require 320 BPMs and 288 correctors instead of 224 BPMs and 96 correctors for the present ring. On the new ring, we are planning to reuse 192 *Libera Brilliance* [1] electronics and 96 fast corrector power supplies and the 8 FPGA controllers of the present system and to add 128 new BPMs electronics and 196 new corrector power supplies. These new BPM electronics and power supplies will not have the fast 10 KHz data broadcast capability of the components of the present system. So we plan to implement a hybrid slow/ fast correction scheme on the SR of the EBS in order to reuse the present fast orbit correction system on a reduced set of the BPMs and correctors and combine this fast orbit correction with an orbit correction performed at a slower rate using the full set of BPMs and correctors. We have made simulations to predict the efficiency of this scheme for the EBS and tested on the present ring a similar orbit correction scheme using only 160 BPMs and 64 correctors for the fast correction. We present the results of our simulations and experiments.

ISSUES

We aim at achieving a horizontal orbit stability consistent with the 100 pm horizontal emittance of the new ring (instead of 4 nm for the present storage ring). One cell of the new lattice including BPMs and correctors is shown on Figure 1.

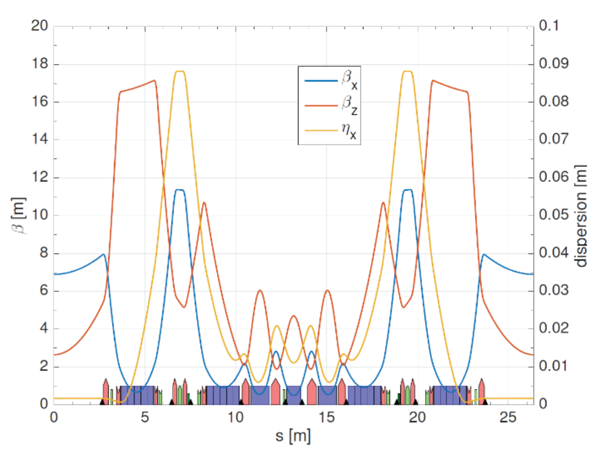

Figure 1: BPMs and correctors in the EBS lattice.
Black triangle: BPM
Small green rectangle: fast corrector
Large green rectangle: slow corrector (sextupole)

The orbit distortion in the frequency range going from .1Hz to 1Hz will come from changes of the parameters (gap and phase) of the ID insertion devices if they are not perfectly corrected against field integral defects. In the 1 Hz to 100Hz range the distortion will first come from the ground vibration filtered by the girder supporting the magnets. We expect that the frequency of the first resonance of the girder will be above 40Hz. The other source of orbit distortion are the spurious fields at the AC mains frequencies (50Hz and its harmonics) and the spurious fields coming from the booster operation (250ms ramp). The correction of these orbit distortions requires operating the orbit correction system in a wide bandwidth. The present fast orbit correction system cannot be easily upgraded to include the larger number of BPMs used on the new ring. Concerning the correctors, among the 288 correctors, 192 correctors will be embedded in the sextupoles; the core of the sextupoles will not be laminated; this will limit drastically the bandwidth of these correctors; the 96 others correctors will have laminated core and will be able to achieve a bandwidth of 500Hz and can reuse the power supplies of the present system. Given the tight time schedule of the project we wanted to avoid as much as possible any unnecessary risky development for the implementation of this fast orbit correction system. For this reason, we are testing an orbit correction scheme using the components of the fast orbit correction system working at 10 KHz of the present ring [1] combined with extra BPMs and correctors power supplies operated at a lower rate. The layout is shown on figure 2.

ORBIT CORRECTION LAYOUT

The orbit control of the new EBS ring will use 10 BPMs and 9 correctors per cell in order to get a closed orbit, averaged in a bandwidth of a fraction of Hertz, close enough to the ideal orbit to allow the required lifetime and coupling control (this orbit correction is not perfect but only optimal since the number of correctors is less than the number of BPMs); the corrector settings for this optimal correction are obtained by multiplying the orbit distortion vector by a correction matrix M_{cors} obtained by inverting the M_{res} response matrix of the system using the SVD method. The 320 BPM pickups will be connected to two types of electronics: 192 *Libera Brillance* electronics of the type used on our present orbit correction system which will used be both for the slow and fast orbit correction; the others 108 BPMs will be connected to new and simpler electronics. The design of these new BPM electronics will most likely be an evolution of the simple *Spark* electronics [2] already used on the BPMs of our booster. Two types of magnets will be used for the orbit correction: 96 dedicated corrector magnets which will be driven by the power supplies used on the present system with a bandwidth of about 500Hz for

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small signals and 192 correctors which will be embedded in the sextupoles and driven by new power supplies. So among these BPMs and correctors, a subset of 192 fast BPMs and 96 fast correctors which are already used for the slow correction can also get position data and produce corrections at a rate of 10 KHz. The position data from these electronics are broadcast at a slow rate on the Ethernet network, to be used by the slow orbit correction and on a dedicated fast network using the *Communication Controller* protocol [3] at a rate of 10 KHz. A set of 8 FPGA power supply controller boards are also connected to this network; these FPGAs compute the $CorX_f$ and $CorZ_f$ fast correctors setting vectors and apply these settings to the fast correctors input using serial lines. The fast correctors setting are obtained using a reduced correction matrix M_{corf} obtained using the same SVD method to invert the response matrix of the reduced set of BPMs to the reduced set of correctors. The multiplication of the correction matrix M_{corf} by the error position vector is done at the rate of 10 KHz. The results of these multiplications are then iterated in order obtain the combination of a PID corrector with a bandwidth of 120Hz and a narrow bandwidth damping around 50Hz of the AC mains related position oscillation. The fast correctors have a dual control: the full range of the power supply can be controlled with Ethernet at a slow rate; a fast trim current can be added at 10 KHz over a dynamic range of 10% of the full range to provide the fast orbit correction. So the current delivered by the fast correctors is the sum of a slow setting $CorX_s$ and $CorZ_s$ applied by the slow orbit correction and a fast setting $CorX_f$ and $CorZ_f$ applied at 10 KHz by the fast orbit correction.

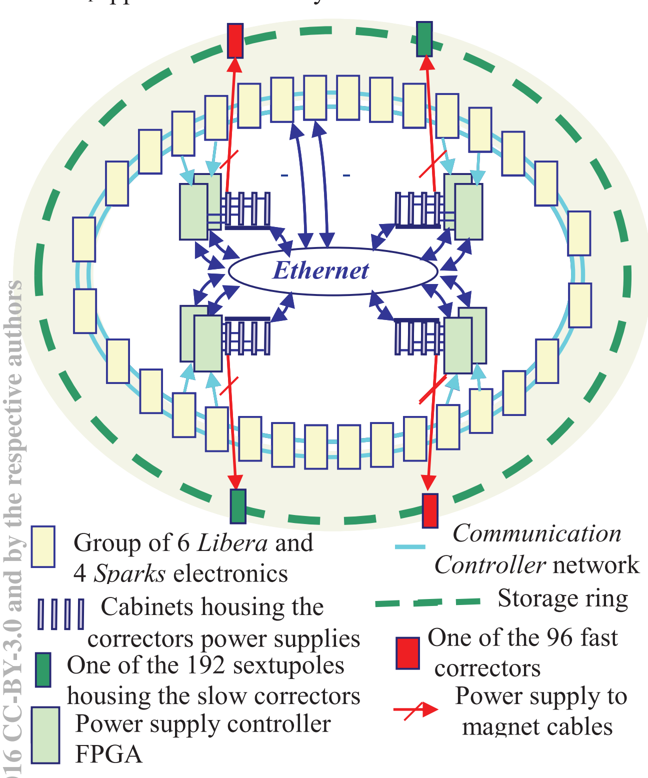

Figure 2: Layout of the EBS orbit correction system.

Residual Orbit Distortion

The rms amplitude of the residual orbit distortion is determined by the number of BPMs and correctors and by the frequency of the distortion that we want to damp. As mentioned above we are using the combination of PID corrector with a band width of 120Hz and a narrow bandwidth damping of the 50 Hz position oscillation. The left plot of Fig.3 shows the damping of the orbit distortion achieved by our present system as function of the frequency (PID only, 50 Hz notch inactive). The right plot shows the overall effect of the correction on our present ring, which is a reduction by roughly a factor of 2 of the fast orbit distortion from 1 Hz to 1 KHz; it is obvious that the residual orbit distortion above a few Hz is mostly due to the limited bandwidth of the PID corrector; so it does not make any significant difference if the full set or a reduced set of BPMs or correctors are used.

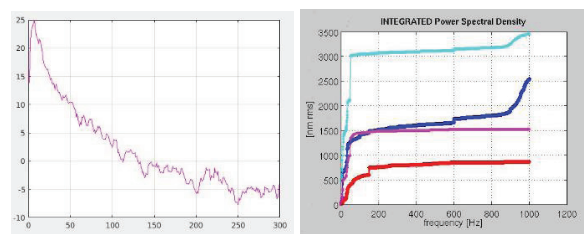

Figure 3: Left plot: fast PID correction effect versus frequency in dB Right plot: integrated spectrum of the orbit distortion; Light blue/horizontal without feedback, dark blue/horizontal with feedback, purple/vertical without feedback, red vertical with feedback.

To illustrate this point, we have simulated for the EBS the orbit correction efficiency seen by the 320 BPMs when using only 192 fast BPMs and 96 fast correctors for the correction, for different patterns of orbit distortion (random quadrupole motion and ID defects). The damping efficiency is still very good as shown on Fig. 4, 5 and 6, so the effect of using a reduced set of BPMs and correctors for the fast orbit correction is negligible compared to the effect of the limited bandwidth of the fast orbit correction.

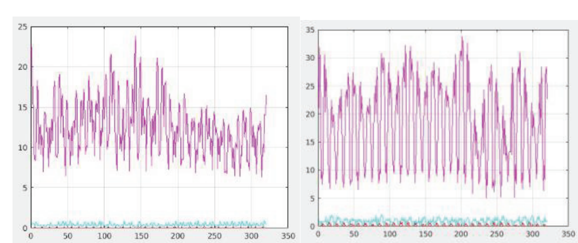

Figure 4: Orbit distortion rms due to random quadrupole displacements (purple) and rms of orbits corrected using the full (red) or reduced set (blue) of BPMs and correctors

Left: vertical, right: horizontal

H scale: BPM number, V scale: µm

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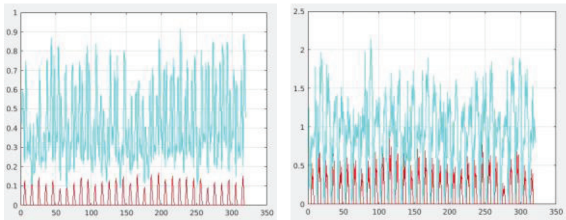

Figure 5: Detail of the corrected orbits rms of Figure 4.

The quality of the correction in the case of a distortion caused by kicks located inside the straight section (caused by badly corrected IDs) shown on Figure 5 is even better due to the availability of two fast correctors immediately upstream and downstream of the orbit perturbation

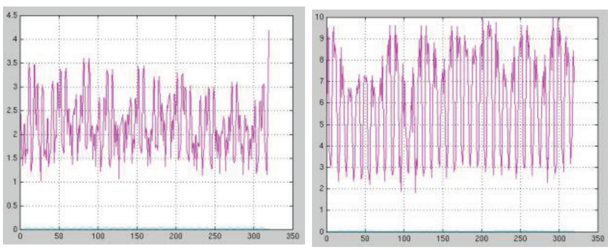

Figure 6: rms effect of kicks in the straight sections.

Left: vertical, right: horizontal

Purple: distorted orbit, blue: corrected orbit

H scale: BPM number, V scale: mm

COMBINATION OF THE SLOW AND FAST CORRECTION

The fast and slow correction orbit control when operating in parallel must exchange data in order to converge toward the same closed orbit and avoid generating corrections aiming at opposite orbit changes [4].

Principle of the Data Transfer Between the Slow and Fast System

We are using the scheme implemented first at the ALS [5]. The position data vectors X_s and Z_s used by the slow system are the position obtained from the 320 BPMs without any trim; the position data vectors X_f and Z_f used by the fast system are the sum of the direct position reading from the 192 fast BPMs plus the offset vectors X_{off} and Z_{off}. The system starts with orbit set using the slow correction system only; When the fast system starts operating, the offsets are set in order to start the fast correction with X_f=0 and Z_f=0; in this way the fast correction will not modify the average closed orbit set by the slow correction and will only damp the fast variation of the orbit with respect with this average orbit. Since the optimal average corrected orbit set by the slow system will slightly change depending on the evolution of the sources of the orbit distortion, the offset vectors X_{off} and Z_{off} must also be slightly modified accordingly. The sequence to update the slow correctors and fast BPMs offsets settings is the following:

- Add the average over 1 s of $CorX_f$ and $CorZ_f$ to the settings $CorX_s$ and $CorZ_s$ in order to suppress the contribution of the fast correction to the DC correction.
- Measure the orbit X_s and Z_s using the 320 BPMs.
- Get the optimal settings $CorX_s$ and $CorZ_s$ of the slow correctors using the full matrix M_{cors}
- Get the orbit change ΔX_s and ΔZ_s that would result from the application of the new corrector settings, if the fast orbit correction was not active.
- Add ΔX_s and ΔZ_s to the offsets X_{off} and Z_{off} in order to get X_f=0 and Z_f=0 with the new X_s and Z_s orbit which will prevent the fast correction from interfering with the slow correction.
- Apply the new settings $CorX_s$ and $CorZ_s$

TEST OF THE COMBINED SLOW AND FAST ORBIT CORRECTION ON THE PRESENT ESRF STORAGE RING

We have tested the orbit correction scheme described above on our present ring; the orbit correction system of this ring can use 224 BPMs and 96 correctors which can be used in a slow or fast correction scheme as shown on Figure 5. For our test we have set up our system to provide a fast orbit correction at a rate of 10 KHz using 160 fast BPMs and 64 fast correctors in parallel with a slow orbit correction using 224 BPMs and 96 correctors at a rate of .1Hz.

The resolution of the BPMs and correctors data are detailed below:

- Slow position data: 1nm/32bits
- Fast position data: 256nm/16bits
- Orbit offset data: 16nm/16bits
- Fast correction: 3nrad /16bits
- Slow corrections: 30nrad/16bits

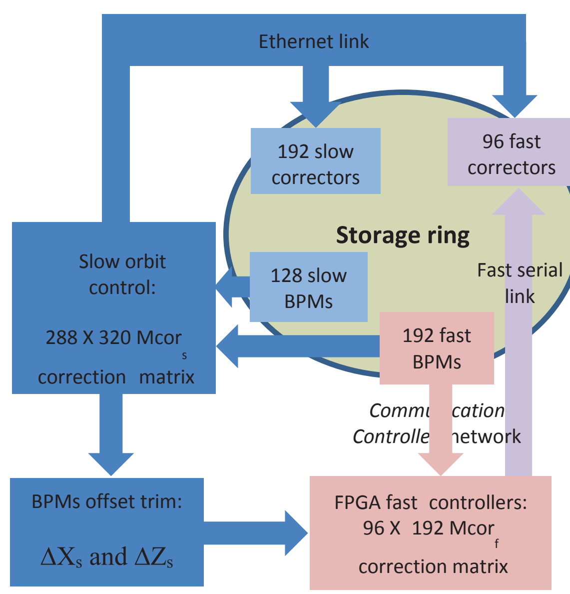

Figure 5: Layout of the control of the orbit correction system used for the test.

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Test Result

We wanted to check the following points:

1. Long term stability of the loop
2. Quality of the correction at high frequency (above 1Hz)
3. Quality of the correction at low frequency

Concerning the points 1 and 2 there is no difference between the effect of the fast correction using the 224 BPMs and 96 correctors and the effect of the hybrid fast/slow system. The figure 6 shows the spectrum of the orbit distortion observed on our ring without fast orbit correction and with the hybrid correction scheme that we were testing. There is no observable difference compared to the damping obtained using the full set of BPMs and correctors.

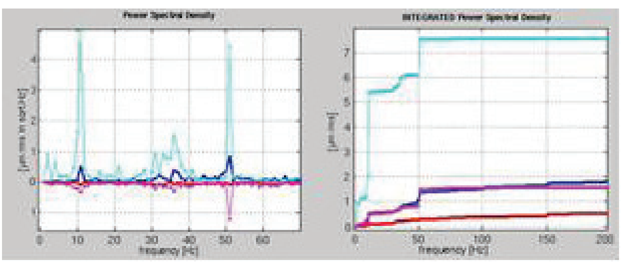

Figure 6: Spectrum of the orbit distortion (left plot). Integrated spectrum of the orbit distortion (right plot). Light blue/horizontal without feedback, dark blue/horizontal with feedback, purple/vertical without feedback, red vertical with feedback

Concerning the point 3, a slight degradation of the stability can still be observed as shown on figure 7. Figure 7 shows the difference between the position measured at 2 Hz by the *Liberas* "slow acquisition" outputs and the rolling average over 60s of the same positions. The right part of the plots shows the stability observed when the full set of BPMs and correctors is used for the fast and slow correction; the left part of the plots shows the stability observed when the full set of 224 BPMs and 96 correctors is used for the fast correction. The central red part of the display corresponds to the switching time between the two orbit correction modes, when the orbit correction is inactive. The slow correction and the corresponding trim of the offset vectors of the fast correction position data was done every 45 seconds. We have not yet found the reason of the slight horizontal orbit drifts observable with a periodicity of 16 around the ring circumference (16 being the number of super periods of our lattice). However, the amplitude of these drifts is only a fraction of micron.

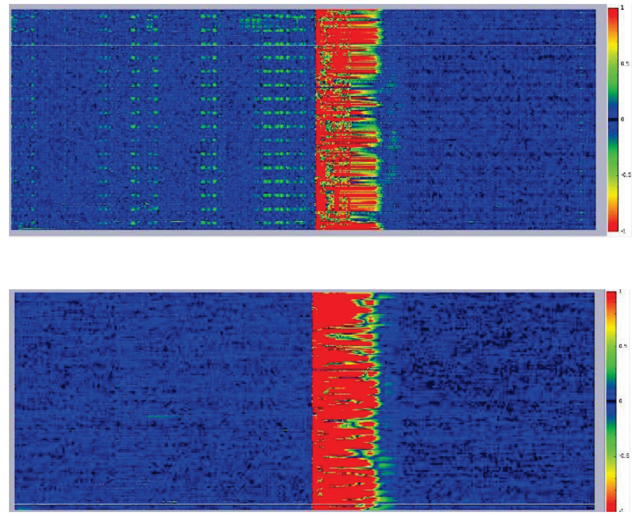

Figure 7: Display of the stability of the orbit stability with the hybrid slow/fast correction scheme (left part) and the normal correction scheme (right part).

Horizontal full scale: 500 s.

Upper/lower plot: horizontal/vertical stability display.

Vertical full scale: +/- 1 µm (red on the colour scale)

CONCLUSION

We have tested that we will be able to implement an orbit correction system on the storage ring of the EBS using the components of the system working on our present ring. The extra components required for the orbit control of the new ring which will use 320 BPMs instead of 224 BPMs and 288 correctors instead of 96 correctors will be controlled at a slow rate so their integration in the control of the orbit correction will be straightforward. The orbit stability achieved during our tests meets the stability requirement of the new EBS ring.

REFERENCES

[1] E. Plouviez *et al.*, 'The New Fast Orbit Correction System of the ESRF Storage Ring", *Proceeding of DIPAC 2011*, Hamburg, Germany, paper MOPD74.

[2] G. Jug *et al.*, "Development of Compact Electronics Dedicated to Beam Position Monitors in Injectors and Boosters", *Proceeding of IBIC 2013*, Oxford, UK, paper WEPC18.

[3] S. Uzun *et al.*, "Initial Design of the Fast Orbit Feedback System for Diamond Light Source", *Proceedings of ICALEPCS 2005*, Geneva, paper PO2.030-2 (2005).

[4] N. Hubert *et al.*, "Global Fast Orbit Feedback System Down To DC using Fast and Slow Correctors", *DIPAC 2009*, Basel, Switzerland, paper MOOC01.

[5] C. Steier *et al.*, "Operational Experience Integrating the Slow and Fast Feedbacks at the ALS", *Proceedings of EPAC 2004*, Lucerne, Switzerland, paper THPLT141.

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