IMPROVEMENT OF THE FAST ORBIT CORRECTION ON THE ESRF STORAGE RING

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Abstract

Until the end of 2008, the suppression of the closed orbit distortion on the storage ring of the ESRF was obtained using two separate systems: A slow system using 224 BPM and 96 correctors performing a correction every 30 seconds with a bandwidth of 1.5 10^{-2} Hz, and a fast system, using only 32 BPMs and 32 correctors but working at 4.4 KHz, damping the orbit distortion from 5 10^{-2} Hz up to 150 Hz; the 1.5 10^{-2} Hz to 5 10^{-2} Hz frequency span was left uncorrected [1].

This separation of the frequency range of the two systems by a dead frequency span avoided cross talks between them, but prevented the efficient cancellation of the very low frequency orbit distortions caused by the frequent modification of the insertion device (IDs) settings required by the beamlines operation. We found a way to coordinate the operation of the slow and fast systems in order to suppress this dead frequency span. This paper describes the principle and the beneficial effect of this new scheme, and its limitations. To overcome these limitations, we are now developing a single new orbit correction system that will damp the orbit distortion from DC to 150 Hz; this system will use the Libera Brillance BPM electronics recently implemented at ESRF, and new fast correctors. This new scheme is also briefly presented in this paper.

INITIAL SLOW AND FAST CORRECTION SCHEMES

Both slow and fast correction systems 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; for the slow correction 96 Eigen vectors are used; for the fast correction 16 vectors are used. As mentioned in the abstract, the slow and fast orbit correction systems used at ESRF were able to operate independently by leaving the 1.5 10^{-2} Hz to 5 10^{-2} Hz frequency span uncorrected; the cancellation of the DC response of the fast system was obtained by the following algorithm: the vector I_{av}, average value of the currents in the fast system correctors magnets is continuously computed; using the response matrix of the BPMs of the fast system to the fast correctors, it computes the position offset at the location of the fast BPMs produced by this currents set I_{av}. If we subtract this offset to the reading of the fast BPMs, it will result in the cancellation of the fast correctors currents at low frequency; the proper choice averaging time used for the calculation of I_{av} and for the frequency of the fast BPMs offset subtraction allows us to set the cut off frequency of the cancellation of the DC response of the fast system to 5 10^{-2} Hz. At the startup of the fast system, the initial offset of the BPMs is set at the values read before the loop closing, so the initial value of the currents set in the fast correctors magnets should be null. When the IDs settings are fixed, there are very few orbit perturbations in this 1.5 10^{-2} Hz to 5 10^{-2} Hz frequency span, so the choice of this dead span looked good. But over the last years of operation of the ESRF storage ring we found that the most detrimental cause of orbit distortion had become the frequent changes of the settings of the insertion devices (gap and phase) which perturb the orbit precisely in this 1.5 10^{-2} Hz to 5 10^{-2} Hz frequency span. Each of the most troublesome IDs have then been equipped with a feedforward correction system which sets the field of two dedicated correctors magnets located at both ends of the ID as a function of the insertion device settings, using a look up table; however the maintenance and periodic calibration of a large number of these feedforward systems is very inconvenient. To overcome this problem, we have implemented a control of the slow and fast orbit correction system allowing them to coordinate their correction over the DC to 5 10^{-2} Hz frequency span allowing the fast correction system to cancel without delay the orbit distortion caused during a change of the settings of an ID occurring during the 30 s time interval between two slow orbit corrections.

PRINCIPLE OF THE COUPLING METHOD

We are using the following scheme to operate both systems down to DC; the slow system computes and applies an orbit correction every T_s period of 30 s; it is able to offset the closed orbit over a range of several mm; in this new scheme, the fast system should also works from DC to 150 Hz between two slow corrections, without the scheme described above for the cancellation of I_{av}; the correctors of the fast system are only able to offset the closed orbit by a fraction of mm; so, before the computation of a slow correction, the slow system reads the vector I_{av}, average value of the currents in the fast system correctors ; using the response matrix of the BPMs of the slow system to the fast correctors, it computes the orbit offset at the location of the slow BPMs which was caused by the current set I_{av}; then by adding this offset to the real orbit read by the its BPMs, the slow system will compute a correction which will be the sum of the correction that he would apply plus the static correction already applied by the fast system; when the slow system applies this total correction, the fast system automatically removes from the fast correctors the set of currents I_{av}; in this way the slow system downloads the DC part of the correction from the fast system every 30 seconds avoiding the saturation of the power supplies of the fast correctors which have a much lower dynamic range than the slow correctors.

Adjustment of the Fast System Goal Orbit

The ideal orbit that the fast system working down to DC will try to reach is the orbit that was measured at its start up and which was set previously by the slow system; the ideal beam position set as a goal for both the slow and fast system at the location of the fast system BPMs is the same at the system start; however this is usually no longer true after, for instance, one hour of beam decay and ID setting changes, because the orbit distortion to cancel may have significantly changed, and due to the difference in the basis and number of the Eigen vectors used by both systems for the orbit correction computation.

The solution would be to continuously adjust the goal orbit of the fast system to follow the change of the optimum orbit set by the slow system; the solution that we found to achieve that was to eventually reintroduce a cancellation of the DC response of the fast system through a change of the fast BPM offset, as in the initial operating mode without coupling to the slow system, but this time with a cut-off frequency much lower than the 1.5 10^{-2} Hz cut-off frequency of the slow correction, and not higher as previously; now the bandwidths of the slow and fast system are not separated by a dead frequency span but overlap; in this way, the average value of the correction applied by the fast system between two slow corrections is almost unchanged compared to a fast correction down to DC and the I_{av} vector read by the slow system to cancel the DC current in the fast system magnets is also nearly unchanged; then the only effect of the suppression of the DC response of the goal orbit of the fast system is the automatic adjustment of the fast system to the slow drifts of the goal orbit of the slow system. The evolution of the currents of the fast magnets after storage ring refill, with this algorithm, is shown in Fig. 1, no divergence is visible.

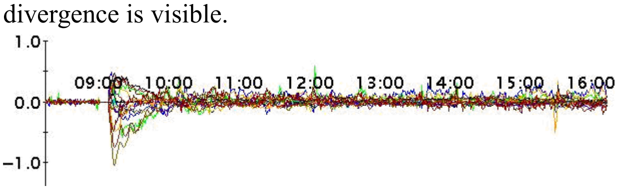

Figure 1: evolution of the horizontal fast correctors currents over a 7 hours beam decay.

EFFECT ON THE BEAM STABILITY

Effect on the Beam Stability

The plot of Fig. 2 shows a typical record of the position read by a horizontal fast BPMs, with a bandwidth of 0.1 Hz, without and with slow and fast correction coupling; after coupling, the low frequency orbit distortion occurring between two slow correction are very well damped by the fast system.

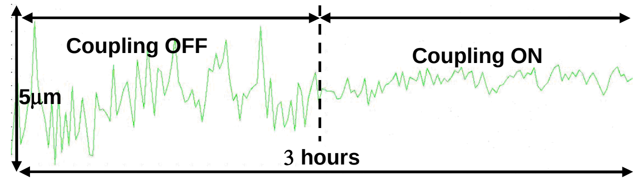

Figure 2: Effect of the operation of the fast orbit correction down to ultra low frequency.

Case of Local Orbit Perturbation

In the case of a single local perturbation, the correction produced by the fast system will not be very effective in the interval between the two correctors surrounding the perturbation; this interval will extend over at least one cell but can be as large a three or four cells, due to the low number of fast correctors (32 horizontal and 16 vertical correctors). Unfortunately we are faced with this type of single local perturbation in the case of the change of an ID setting. It is a major limitation of our present orbit correction scheme.

UPGRADE PROJECT

If we want to avoid having locally large local orbit distortion when the cause of the distortion is localized, we must drastically increase the number of fast BPMs and fast correctors. Since the former slow BPMs of our storage ring are now equipped with *Libera Brillance* electronics [2], we now already have a set of 224 very high resolution BPMs with an orbit measurement rate of 10 KHz. Concerning the correctors, we considered two options: to use the present set of 96 slow correctors with low bandwidth power supply, and increase the number of fast correctors, or to increase drastically the bandwidth of the slow correctors power supply, and use only one type of fast correctors.

Correctors Magnets

The present slow correctors are implemented by adding 3 pairs of auxiliary coils on the yoke of the sextupoles; using the proper combination of currents in these 3 coil pairs as shown in Fig. 3, we can produce any combination of vertical and horizontal kicks. The bandwidth of these correctors will be affected by the eddy currents in the sextupole core and at the surface of the vacuum chamber (the vacuum chamber all over our storage ring is made of 2mm stainless steel). Measurements showed that the vacuum chamber is the main cause of the magnet field attenuation due to eddy currents, compared to the eddy currents in the sextupole core; but the inductance of these correctors is also quite large: 0.6 H. However, it is possible to achieve, for the small currents amplitude needed for the fast correction, a bandwidth of 150 Hz for these correctors with a proper design of the power supply. This bandwidth is lower than the bandwidth of the present air cored fast correctors, but it should be possible to make up for it by a proper design of the controller of the orbit control loop, so the implementation of dedicated fast correctors is not an absolute requirement as it would be on ring built mostly with Aluminium vacuum vessels.

Simulations showed that using a PID type controller instead of the PI controller that we are using now is a solution; more sophisticated controllers like the IMC controller can also be used [3]. So for the future we will go for an upgrade of our orbit correction system using a single type of correctors, instead of mixing fast and slow correctors as in our present system.

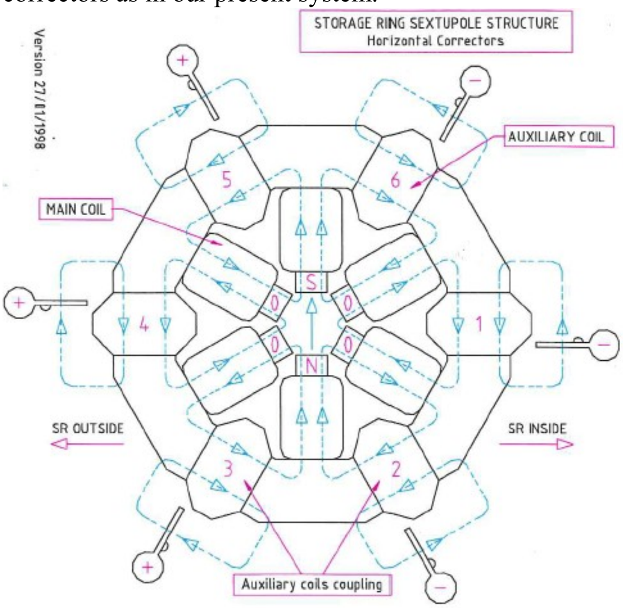

Figure 3: Layout of the auxiliary correctors in a sextupole.

New System Layout

The design of our new system will be based on the availability of the *Libera Brillance* electronics and an associated "Communication Controller" developed at DIAMOND [3] using the *Libera Rocket I/O* ports, which allows the measurement and broadcast of the beam position with a very good resolution at a rate of 10 KHz. As indicated above we want to use the corrector magnets embedded in the sextupole cores; we also want to use the existing cables connecting the magnets to the existing power supplies, so the new fast power supplies of the corrector will be located in the same cabinets as the old one, in 4 different technical galleries; this constraint sets the architecture and topology of our system;

Since the power supplies will be spread in 4 locations, we will also distribute the correction computation in the same locations, over 8 processors; For the choice of the processor, we noticed that SOLEIL and DIAMOND were using a PMC board embedding a *Xilinx Virtex 2 pro* FPGA to concentrate the 10 KHz BPM data for diagnostics purpose using the Communication Controller, and that a FPGA model and a Tango device server were already available for this application; the RS485 digital outputs for the digital control of the power supply are also available for this type of board; with a ready-to-use communication interface with the BPMs and the correctors, this board appears as an almost natural choice as a platform for the orbit correction calculation, after addition of the feedback algorithm in the FPGA model.

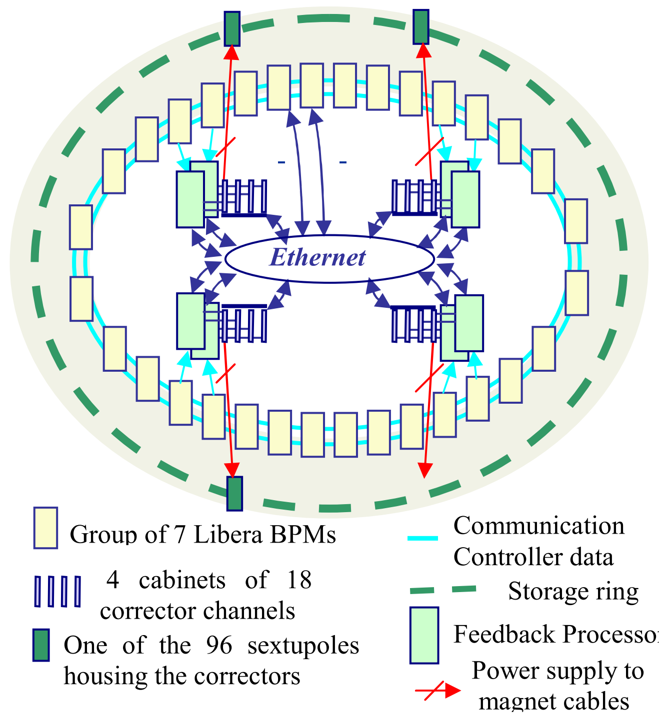

Figure 4: Layout of the future orbit correction system.

CONCLUSION

We have managed to combine the operation of two very heterogeneous orbit control systems using different BPMs, different correctors, with very different dynamic characteristics, to obtain a stable orbit correction on their combined frequency range of operation, without uncorrected frequency span. However, for the future upgrade of our orbit control system, we have decided, in order to end up with a simpler layout, to use only one type of BPMs and correctors; this choice is possible since the vacuum vessels of our storage ring are made of stainless steel instead of aluminium, which is a big advantage, at least in this respect.

REFERENCES

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