A FAST GLOBAL FEEDBACK SYSTEM TO CORRECT THE BEAM POSITION DEVIATION IN THE ESRF STORAGE RING

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Abstract

ESRF is a 3rd generation synchrotron radiation source based on a 6 GeV storage ring. It is optimised to produce radiation in the X ray range using insertion devices. X-ray beam size and divergence at the source points are in the micrometer and micro radian range. A fast global feedback system has been implemented on the ESRF storage ring in order to correct the vertical closed orbit distortion caused by fast perturbations like mechanical vibration of the magnets. This feedback uses 16 BPMs (beam position monitors) and 16 dipoles correctors magnets and apply corrections at a 4.4 KHz rate. It achieves a damping of 6dB of an initial orbit distortion of 2 micrometer rms, in the .1 to 200Hz frequency range. We will present the main guidelines followed for the design of the feedback system and the technical choices made. We will discuss the optimization of the control of such a system and compare its specific requirements to the requirements of others beam orbit diagnostics and orbit control systems also implemented at ESRF.

1 INTRODUCTION

The ESRF storage ring is a high brilliance source with low emittance values ($\varepsilon_X = 4.10^{-9}$ m.rad and $\varepsilon_Z = 4.10^{-11}$ 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 BPM locations 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 quadrupoles support girders must be kept at low enough values to avoid spoiling this emittance figure. We observe two kinds of motions: 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 slow drifts are corrected every 30 seconds by a global correction method using the measurements made over the whole machine by the 224 BPMs of the closed orbit measurement system [1]. We are adding another correction system to damp these vibrations in the vertical plane. These vertical vibrations are smaller compared to the horizontal vibrations, but not negligible compared to the incoherent motion due to the vertical emittance.

2 SYSTEM CONFIGURATION

This system uses 16 BPMs and 16 correctors to correct the orbit at a 4.4 KHz rate in order to provide an extra damping in the 10^{-2} to 200 Hz frequency range. The layout of the system is shown on figure 1. The number of BPMs and correctors, the BPM resolution and the orbit correction rate have been optimised according to criterions developed in section3.

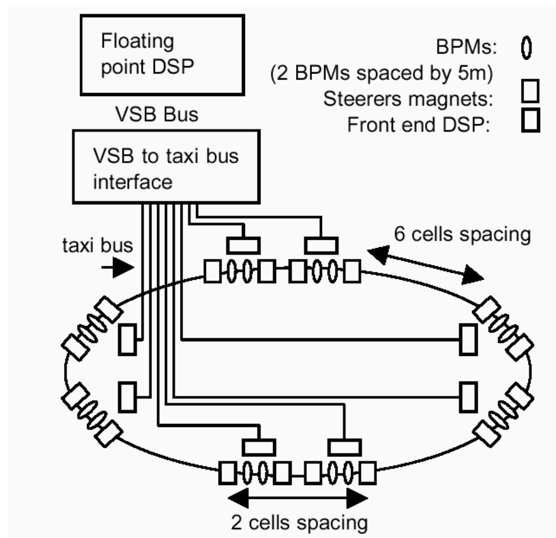

Figure 1: Layout of the global feedback system.

2-1 Beam position measurement

The beam positions are measured using capacitive electrodes installed at both ends of the straight section. The BPMs of eight straight sections are used as shown in figure 1. Special attention has been paid to the noise of the electronics in order to achieve a resolution of 20nm/√Hz over the full operation intensity range from 5mA (in single bunch) to 200 mA [2]. They contribute for Tbpm=17ms to the loop delay.

2-2 Orbit corrections

The correction kicks are produced by sixteen air coil steerer dipoles. These steerers are located near the ends of the eight straight sections equipped with BPMs, between the adjacent quadrupole triplets and the dipoles. The steerers are powered by wide band power amplifiers and are able to produce up to 40 µ-radian kicks in a 1 KHz bandwidth. They contribute for Ts=0.3ms to the loop delay.

2.3 Digital signal processing hardware

The digital signal processing is implemented as shown on Figure 1. The corrections are computed at a 4.4 KHz rate by a VME board equipped with a TI C40 floating point DSP and an extra VSB bus [3]. The data transfer (beam positions and correctors settings) is made through this VSB bus. The data transferred through the VSB bus are transmitted on eight optical data links to eight front-end VME crates close to the location of the eight groups of BPMs and steerer magnets through two interface boards. The data transfer at both ends of the optical fibres is done with "taxi bus" drivers implemented on IP modules developed at ESRF [3]. These "taxi bus" IP modules are implemented on VME boards developed at ESRF, equipped with a AD2171 fixed point DSPs; two DSP boards, each equipped with four taxi bus drivers and a VSB bus interface, manages the data transfer between the eight optical fibres and the main DSP board. At the other ends of the fibres, eight of these fixed point DSP boards, also equipped with ADC and DAC IP modules, manage, in addition to the data transfer on the taxi bus, the data acquisition from the BPMs and the programming of the steerers current. A clock signal at 4.4 KHz , a subharmonic of the 355 KHz revolution frequency, is distributed all around the machine and synchronises these processes as well as the multiplexing/demultiplexing of the BPM signals. The time allocation for the data management is distributed in the following way:

- Analogue to digital conversion & reading 12µs
- Computing and writing to IP-taxi of data 18µs
- Transfer of the data through optic fiber 6µs
- Reading by the concentrator of 16 data 10µs
- Transfer on VSB to Dbv44 22µs
- *"Main signal processing" 111 µs*
- Transfer on VSB from Dbv44 22µs
- Writing to the IP-taxi 8µs
- Transfer of the data through optic fiber 6µs
- Reading by the front-end and steerers setting 10µs

Almost half the time of the loop is available for the main algorithm execution.

2.4 Digital signal processing software

For the programming language, priority is of course given to high level code ("C") but the fixed-point processor (ADSP2171) for given functions, requests that coding is made at assembler level to respect the timing.
The floating point TMS320C40 is exclusively programmed in "C" language. Thanks to the compiler efficiency, there is almost no gain at using assembler.

3 SIGNAL PROCESSING

3.1 Correction algorithm

From the 16 positions, we calculate a correction vector using the matrix of the response of the feedback BPMs to each steerer. This matrix is inverted using the SVD method. In the vertical plane, due to the lower value of the vertical tune (14.39), 16 position measurements are sufficient to calculate a correction reducing usually the rms orbit static distortion by a factor Ds=3 (fig.2). The best efficiency is achieved with 8 eigen vectors for the correction calculation. The final distortion damping D will result from the combination of Ds and Dd, the dynamic damping provided by the feedback loop, with :

$$D=1/(1/Ds+1/Dd)$$

Achieving a much larger value of Ds, using a larger number of BPM and correctors, would be useless due to the limited value of the dynamic damping Dd achievable. This limitation is due to:

- The resolution of the BPMs.
- The delay between the position measurements and the correction as explained below.

3.2 Dynamic correction parameters

The static correction vector is used to compute the actual correction applied to the beam using the previous correction values and a proportional integral iterative algorithm (PID type). In addition, the correction is cancelled at very low frequency (10^{-2}Hz) to decouple the fast orbit correction from the slow orbit correction..
The PID dynamic parameters have been chosen in order to meet the following requirements:
- We want a significant damping from 7Hz to 60Hz, the lowest and highest frequency in the spectrum of the orbit distortion observed at ESRF.
- We want to achieve a dynamic damping Dd, integrated over the full spectrum, consistent with the static damping Ds of 3 given in 3-1.
Simulations have shown us that a PID with a cut-off frequency fc of 200Hz would achieve a dynamic damping Dd of 3 providing the delay Td between the distortion measurement and the correction is less than .5ms (or 1/10.fc) and the BPM resolution better than 20 nm/√H..
The need to use high resolution BPMs goes without saying: one could try to make up for an insufficient BPM resolution by increasing the BPM number but it is not a good tactic since the resolution improvement is only proportional to √N, when the delay due to the computation time is proportional to N^2. This delay increase will eventually reduce the loop bandwidth and the dynamic damping achievable.
The importance of the delay is often neglected: the total loop delay must be less than 1/(10 fc) in order to have a stable loop and if we do not want to amplify too much the input signals above the cut-off frequency.
The delay is given by the addition of Tbpm, the correction computation and data transfer time Tc, and the correction fields rise time Ts.
We have achieved a Tc of about 0.2ms as explained in 2.3, which allows a sampling rate of 4.4KHz. The total loop delay is 0.67ms, a slightly excessive figure.

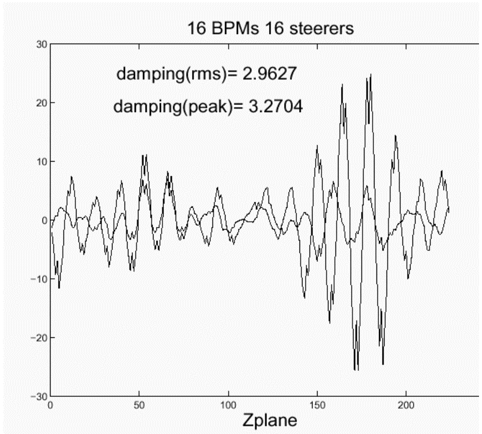

Figure 2: Example of static orbit correction obtained with our 16 BPMs/16 steerers system

4 TESTS OF THE SYSTEM

The measured damping efficiency obtained is shown on the transfer function in figure3. The signals delay induces some unwanted signal amplification above the loop cut off frequency for the larger values of the feedback bandwidth as shown in figure 3. Eventually, the optimum value of the bandwidth of our feedback, giving a good damping of 7 Hz to 60 Hz lines and a moderate amplification of high frequency signals is 150 Hz.

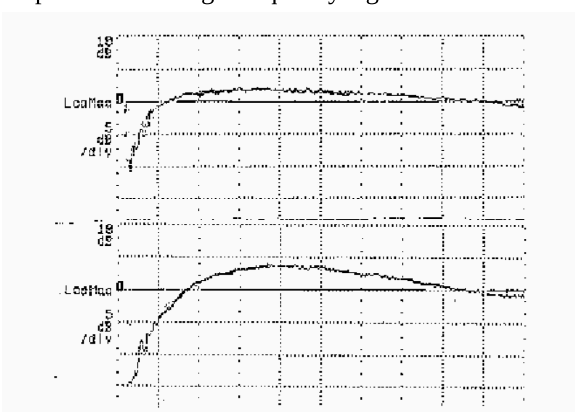

Figure 3: recording of the transfer function of the loop (BW= 100 Hz and 200Hz, 10 dB/div, span 0 to 1KHz)

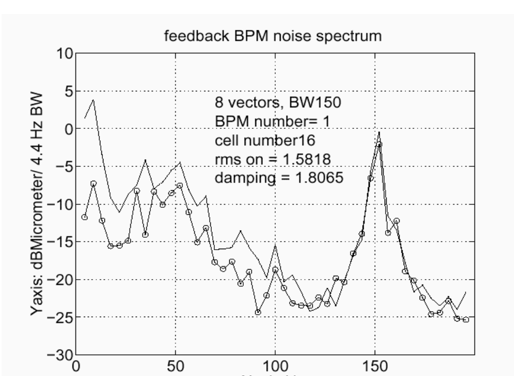

Figure 4: Spectrum of the beam position motion signal of a feedback BPM with feedback off and on

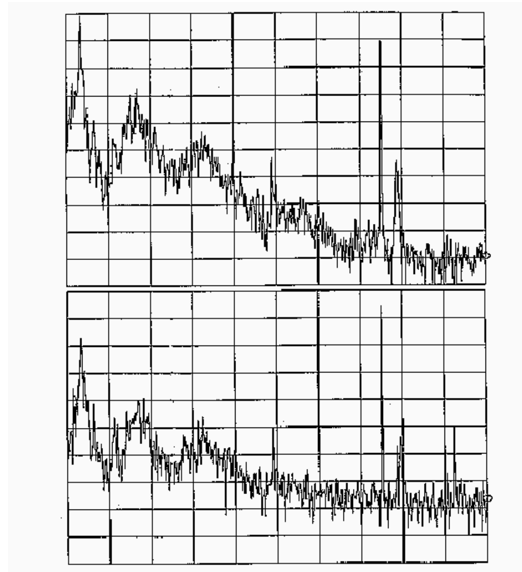

Figure 5: Spectrum of a dipole X ray beam position 25 m away from the source with feedback off and on (5dB/div, 200 Hz span).

5 CONCLUSION

The system works. It is mostly efficient on the lowest frequency orbit distortions, which are the most harmful for the users. The principle of the correction is not original but the efficiency of this scheme at high frequency and on very small orbit distortion required a careful optimisation of the performances of its different component performances. The key parameters in such a system according to our experience are the noise of the BPMs, the risetime of the correctors, the number and location of the BPMs and steerers which will allow to make an efficient use of the processing speed.

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