DESIGN OF A FAST ORBIT FEEDBACK FOR SOLEIL

N. Hubert, L. Cassinari, J.C. Denard, A. Nadji, L. Nadolski, D. Pédeau
SOLEIL, Gif-sur-Yvette, France

Abstract

SOLEIL is a third generation light source under construction. Great care is taken at all levels of the machine design in order to reach beam stability at the micrometer level. In particular, a fast global closed-orbit feedback is foreseen for suppressing remaining beam vibrations up to 100 Hz.

The correction uses the computing resource of 120 BPM electronic modules, distributed around the storage ring. Each BPM module includes a powerful FPGA that in addition to its specific BPM task leaves enough room to embed a part of the fast feedback correction algorithm.

All the BPM data (including XBPMs in the future) have to be broadcasted to the 120 modules in order to compute the correction. Broadcasting the data is expected to be fast (around 20 us), thanks to eight multigigabit transceivers per module, and fast links between them. The architecture of the dedicated network is flexible enough to keep the feedback system functional even with a few disabled BPMs.

The correction is applied to 46 dedicated air-core correctors in each plane at a rate of 8 kHz. Simulations will be performed in order to optimize the system in the bandwidth of interest to the machine users.

INTRODUCTION

A third generation light source like SOLEIL has very tight orbit stability requirements. The level of the oscillations of the photon beam must not exceed one tenth of the beam size (see table 1) Great care is taken at all levels of the design to meet these requirements, from building foundations to girders design. The remaining beam motion will be suppressed by global orbit feedback. It is composed of a slow orbit feedback (SOFB) correcting slow beam position drifts and a fast orbit feedback (FOFB) for short term stability. This paper presents the present status of the FOFB system.

Requirements (um)	Long Section	Medium Section	Short Section	Dipole
H	28	18	39	6.2
V	1.7	0.8	0.8	2.5

Table 1: Photon beam stability requirements in each plane for each kind of sources.

SYSTEM COMPONENTS

Both feedback systems use the position measured by the same 120 BPMs in order to compute their correction with a Single Value Decomposition (SVD) algorithm. The SOFB applies its correction at a maximum rate of 10 Hz to 56 correctors in each plane (secondary coils in sextupoles). Those correctors are installed over aluminum vacuum chambers, which limit the correction frequency to ~30 Hz due to eddy currents. For the FOFB, dedicated air-core correctors are installed over the bellows next to the BPMs of the straight sections (fig. 1). Those bellows are in stainless steel and the frequency cut off is greater than 1 kHz.

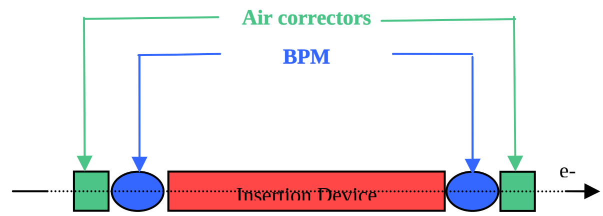

Figure 1: Location of the air correctors on the straight sections. Air correctors are effective in vertical and horizontal planes.

The system is composed of 120 BPMs modules, 46 air correctors in each plane with their power supplies.

Our BPMs are equipped with new electronics modules developed by Instrumentation Technologies [1], [2]. Those modules are based on FPGA technology with high speed communication ports. The large amount of resources of the FPGA allows us to embed the algorithm of correction in the module. In addition to calculating the beam position, the BPM modules perform all the processing of the FOFB. The algorithm computation is distributed on the modules around the storage ring, each one calculating the corrections for its dedicated corrector that is 1/46th of the algorithm.

Our power supplies are not yet ordered. They will house 16 bits DACs, power supplies and amplifiers. The command will come directly from a BPM module via its serial RS 485 link.

NETWORKING

Topology

A large amount of data has to be transmitted to all BPM modules as they all need the 120 positions to compute the correction. The high sampling rate of the correction, up to 8 kHz, requires a dedicated network.

The processing is distributed on the modules, and each module has eight multigigabit transceivers. A ring topology for this dedicated network is the most convenient.

This architecture is presented in figure 2. The BPMs are grouped in 16 cells (7 or 8 modules per cell). Two modules in each cell are carrying out the interface between their own cell and the others. In each cell, the 7 or 8 modules are linked together in a ring topology (fig 3).

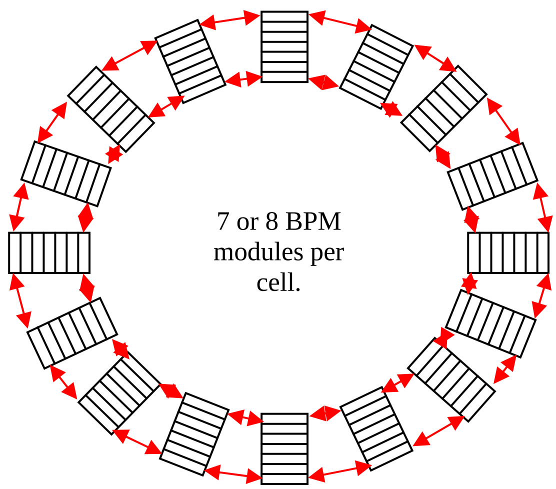

Figure 2: Topology of the dedicated network for the FOFB. Each cell has 7 or 8 BPM modules. The cells are connected with fibre-optic links.

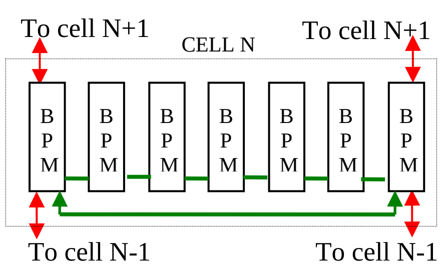

Figure 3: Topology of links in each cell. The BPM modules are connected with copper links.

Data transfer

The data transfer can be decomposed in three steps:

- Recovery of the data from each cell by the two modules carrying out the interface with the others cells. When all the BPM modules of a cell have their position data available, they send it to their two neighbors.
- Those 2 modules transfer data between cells.
- The same 2 modules deliver data coming from the other cells to the modules of their own cell.

Between cells data are transferred over fiber-optic links. Within a cell the data are transferred over copper links. The multigigabit transceivers of the modules allow data transfer up to 2 Gbits/s. That means that data transfer over the network should take around 10 us. This delay will be negligible with respect to the latency of the position processing (few 100 µs).

Modularity

The architecture gives the possibility to easily add or remove modules in a cell. For example, we can later include photon BPMs into the FOFB.

Reliability

The reliability of the system is improved by redundancy. Two modules are interfacing each cell with the others, so even with one failure per cell the system still works. The FOFB system will be down only after two modules of the same cell fail. The Mean Time Between Failure for the whole BPM system is 3 months. This probability is low enough to fulfill our requirements.

Moreover, the correction for each steerer is computed by two different BPM modules. One is chosen to actually apply the correction. A switch will allow to select the other module in case the first one fails.

SIMULATIONS

Two types of simulation can be performed to design and optimize the system: The first one gives us the efficiency of the correction algorithm depending on the number of parameters of the response matrix (number of BPMs and correctors). The number of correctors is fixed by the number of straight sections, but the number of BPMs has to be optimized. In the second one, the behavior of the system loop has to be modeled. Each step or element taking part in the system influences the response because of their delay or bandwidth.

Correction algorithm

The purpose is to determine how many BPMs to include in the FOFB in order to meet stability requirements. The correction algorithm is based on an SVD method. We apply a perturbation on the beam of 10 µm rms, assuming that the value of ground vibration is 1 µm rms and the girder amplification factor is 10. The correction efficiency is compared in two different configurations: 48 and 120 BPMs. For this simulation, we consider that the response of the loop is perfect. The beam displacement is calculated by averaging the result of 100 different machines.

- The first configuration is 48 correctors (2 per straight section) and 48 BPMs (each one is placed just next to a corrector). In this case the system is linear, and the correction for the steerer is calculated with only the position given by its associated BPM. In this case, the beam is perfectly stabilized in straight sections where the requirements are the tightest. This system fits the requirement for the straight sections but not those of the dipoles, where no correction is applied (fig 4).
- In the second configuration, 120 BPMs are used in the algorithm. By including more than 48 BPMs in the FOFB system we will increase the perturbation in the straight sections but gain in efficiency in the dipoles. That's what is shown in fig 5. This configuration suits the beam stability requirements in the dipoles but not anymore for some straight sections (short ones).

The first implementation will be done with 46 correctors (no correctors on the injection section). The number of BPMs and the weight they have in the algorithm will be optimized experimentally in cooperation with the insertion devices users and the dipoles users.

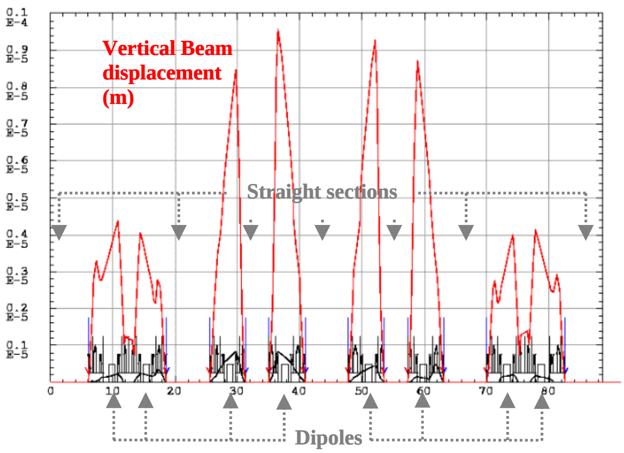

Figure 4: Static simulation of FOFB algorithm with 48 air correctors and 48 BPMs in vertical plane over. 10 µm rms displacement of girders is assumed. Perturbations are perfectly suppressed in straight sections, but the remaining noise in the dipoles does not fit our requirements.

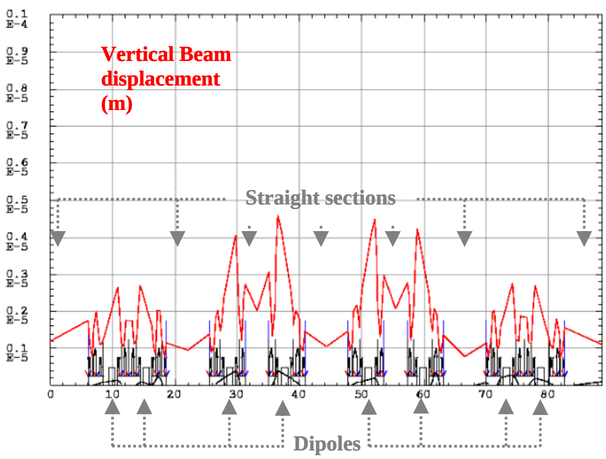

Figure 5: Static simulation of FOFB algorithm with 48 air-correctors and 120 BPMs in vertical plane. 10 µm rms displacement of girders is assumed. Requirements in dipoles are met but not for all straight sections.

Correction loop

The correction loop contains several elements that influence system response. Frequency response of power supplies, vacuum chamber and coils present high enough cut off frequencies to allow corrections to 100 Hz or higher. The correction is computed by a Proportional Integral Derivative (PID) controller. The design of this controller is important in optimizing the efficiency of the loop. The system has been modeled: power-supplies, vacuum chambers and coils are assimilated to low-pass filters (with fc > 1 kHz), and BPMs are assimilated to delays.

The closed loop response shows a damping of the perturbation between 0 and ~100 Hz. But the system also introduces a small amplification of the noise just after this bandwidth. Most of users are very sensitive to beam perturbations at low frequency (<100 Hz). Nevertheless perturbation above 100 Hz can also be harmful for few experiments. The purpose is to find the best compromise between noise suppression at low frequency and noise amplification at higher frequencies.

The design of the BPM modules and of the dedicated network topology is aimed at minimizing the processing delay. For this simulation, we consider that the efficiency of the algorithm is 100 %.

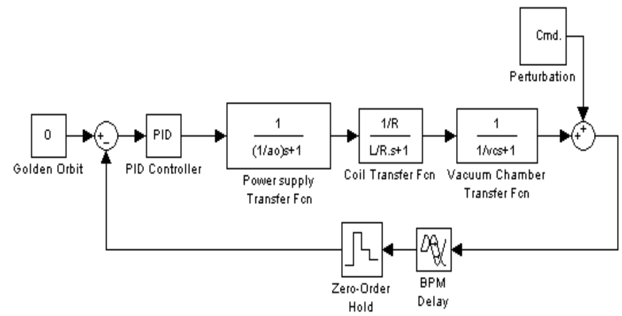

Figure 6: Model of the correction loop.

INTERACTION WITH SOFB

Each feedback system has its own frequency range. In order to avoid any crosstalk between the two systems, one fighting the other [3], and in order to avoid any frequency dead band where none of the systems is efficient, we make them communicate. Based on the ALS system [4], SOFB will update the setpoints of the FOFB system, and will take in charge its DC component.

STATUS

BPMs modules and air correctors are currently under production. Power supplies for the correctors will be ordered soon. The correction loop is under optimization.

ACKNOWLEDGMENTS

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REFERENCES

[1] A. Kosicek, "Libera Electron Beam Position Processor", PAC'05, Knoxville, May 2005, to be published.

[2] J.C. Denard, "Preliminary tests of a new kind of BPM system for SOLEIL", this conference.

[3] C. Schwartz and L. Emery, "Compensating the frequency deadband of the APS real-time and DC transverse orbit correction systems", Proceedings of PAC 2001, Chicago, p. 1234.

[4] C. Steier et al, "Operational experience integrating slow and fast orbit feedbacks at the ALS", Proceedings of EPAC 2004, Lucerne, p. 2783.