# COMMISSIONING OF SOLEIL FAST ORBIT FEEDBACK SYSTEM

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*Abstract*

The Fast Orbit Feedback system at SOLEIL is fully integrated into the BPM system equipped with Libera modules. Indeed, the correction algorithm has been embedded into the Libera FPGA which directly drives the power supplies of dedicated air coil correctors. The beam position measurements of the 120 BPMs are distributed around the storage ring by a dedicated network. Then, the correction is computed and applied at a rate of 10 kHz to 48 correctors installed over stainless-steel bellows, one on each side of every straight section. The BPM system has been operational for some time. The fast orbit feedback system is in its commissioning phase. The design and first results of the latter are reported.

## INTRODUCTION

The SOLEIL BPM system has been in operation from the start of the Storage Ring commissioning in May 2006 [1, 2]. The Storage Ring has 120 BPMs; 72 are located in the arcs and 48 at each end of the 24 straight sections. Instrumentation Technologies and SOLEIL developed a rack-mountable 1U BPM digital electronics called “LIBERA” [3]. It has been designed from the start for supporting a Fast Orbit Feedback embedded into the BPM FPGAs. The BPM digital electronics has subsequently equipped most of the new storage rings around the world.

The stability of the beamlines at the source points needs to be better than 1/10$^{th}$ the rms size and angular divergence of the photon beam, which depend on their location on the machine and on their maximum photon energy. They are shown in table 1.

Table 1: Beam stability requirements at source points with $\varepsilon_H$ = 3.75 nm.rad and $\kappa$ = 0.4% (convolution of the electron and photon beam sizes and angles)

| Photon Point Source | $\sigma_x$/10 µm | $\sigma'_x$/10 µrad | $\sigma_y$/10 µm | $\sigma'_y$/10 µrad |
|---|---|---|---|---|
| Bending magnets (≤ 35 keV) | N/A | N/A | 1.5 | 5.3 |
| Hard X-ray IDs (≤ 18 keV) | 39 | 1.5 | 0.55 | 0.51 |
| Soft X-ray IDs (≤ 1.6 keV) | 18.3 | 3.4 | 0.65 | 1.6 |
| HU 640 UV ID (≤ 0.04 keV) | 32 | 4.6 | 6 | 4.2 |

## SLOW AND FAST ORBIT FEEDBACK

Initially, the FOFB was mainly meant to suppress the residual vibrations at frequencies higher than 1 Hz; the slow drifts, below 0.01 Hz being corrected by the SOFB which is operational since May 2007 [2].

The SOFB, based on an SVD algorithm, acts on 56 correctors built in the sextupole magnets. One of the technological innovations at SOLEIL is the extensive use of NEG coated aluminium vacuum chambers in the arcs and straight sections. It improves the vacuum pressure and beam lifetime without increasing the broadband wall impedance. However, the eddy currents in aluminium suppress the magnetic field over few tens of Hz in the vacuum chamber, and prevent the use of the SOFB correctors for the FOFB.

In each plane the FOFB acts on 48 fast air correctors that are installed around stainless steel BPM bellows, at the ends of the 24 straight sections. The correctors can yield orbit kicks in the ±20 µrad range, with a 2.5 kHz cut-off frequency due to eddy currents.

## BEAM NOISE SPECTRUM

We identify three different ranges in the beam spectrum: i) the “high frequency” noise from 1 to 150 Hz, ii) the beam movements due to crane operation and undulator gap changes in the 0.01 to 1 Hz bandwidth, and iii) the slow drifts, mainly from thermal effects, from DC to 0.01 Hz.

The high frequency noise without orbit feedback is shown in figure 1. The integrated noise amounts to 3 µm in horizontal and 2 µm in vertical. The natural beam stability is within specifications (see table 1) in horizontal but needs to be improved by a factor of two in vertical. The main contribution to the vertical beam noise is at 50 Hz, the frequency of the mains. The lines at 46 Hz and 54 Hz correspond to the first eigen modes of the girders. The beam movements during crane operation or gap changes can reach up to 10 µm in vertical and need to be damped in both H and V planes. The slow drifts, after machine warm-up, are in the 50 µm range over an 8-hour shift without SOFB (5 µm and 2µrad are achieved in both plane during user operation with SOFB).

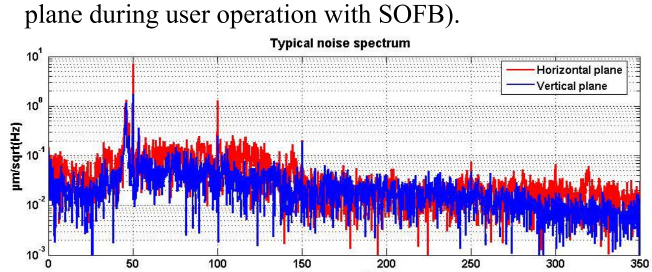


Figure 1: Natural beam spectrum without feedback. Most of the beam noise is below 150 Hz.

## FOFB ARCHITECTURE

### *Data Distribution*

In order to have a global system, the position data from each BPM module has to be distributed to all the points where the processing is done. This is done with a dedicated network, linking all BPM modules together. Two different kinds of link are used: copper cable links for the short connections within a cell, and 30-meter multimode optics fiber links between cells (Fig. 2).

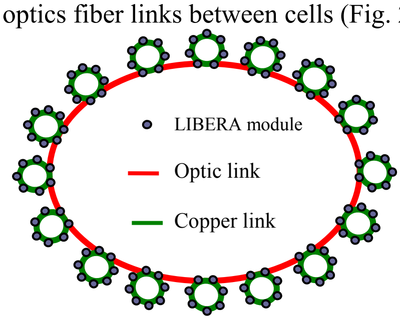


Figure 2: Topology of the dedicated network. In one cell, LIBERA modules are connected with a 'ring' topology with copper links. Two modules per cell are connected to the neighbouring cells with optics fibers.

### *FPGA Implementation*

The FOFB algorithm has been fully integrated in the BPM module FPGAs. On top of the processing for position measurement, we added our own Fast Feedback application. The application can be split into 5 main blocks (Fig. 3):

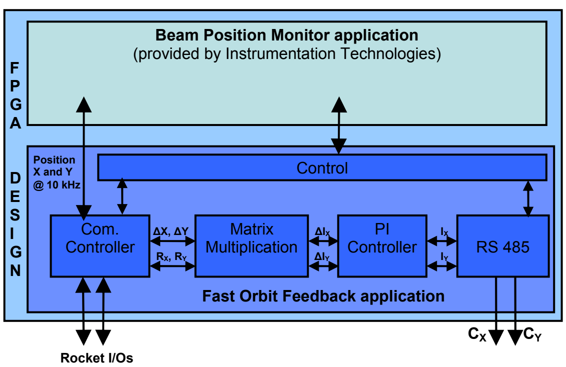


Figure 3: FPGA implementation.

- Communication Controller: for data distribution between BPM modules (see previous paragraph).
- Matrix Multiplication: To compute the correction, this block has to perform 120 multiplications and additions for each plane.
- PI Controller: To adjust the gain and suppress the uncorrected error of the loop.
- RS 485: This block shapes and serializes the correction set-points before sending them to the power-supplies on an RS 485 link.
- Control: This block allows the control and the monitoring of the Fast Feedback Application.

### *Latency*

The overall latency of the system is about 360 µs. The main part of this time is for processing the position data (BPM functionality) and takes around 190 µs.

## COMMISSIONING

The first tests of the SOLEIL Fast Orbit Feedback started in December 2007. The system modularity makes quite easy any configuration change. It allows quick changes in gain, PI Controller coefficients, as well as the number of correctors, of BPMs and of matrix eigen values involved in the feedback loop. Up to now, ten 8-hour machine shifts have been dedicated to these tests, allowing to solve a few bugs and address several issues. Only two configurations have been tested: 48 and 120 BPMs, with all 48 correctors.

The loop gain was optimized experimentally, and the actual behaviour compared with the expected performance deduced from the open loop measurements.

Up to now, tests were performed without the SOFB running, assuming that the Fast Orbit Feedback should be able to correct even DC components (drifts due to crane displacements or insertion gap changes). In order to measure these effects, several tests have been performed: i) comparing long time (several hours) orbit record with and without feedback, while changing insertion gaps and moving the cranes ii) frequency spectrum analysis on BPMs, and on the few X-BPMs currently available on the dipole beamlines.

## EXPERIMENTAL RESULTS

The FOFB reduces the high frequency noise (1 to 100 Hz) within the σ/10 goal for all source points, especially in the case of the hard X-ray beamlines in the vertical plane (Fig. 4). The improvement is significant up to 50 Hz, but there is a noise addition above 100 Hz. The integrated noise is suppressed by nearly a factor of two in the 1-350 Hz bandwidth. A further optimization of the eigen value number should lead to even better results.

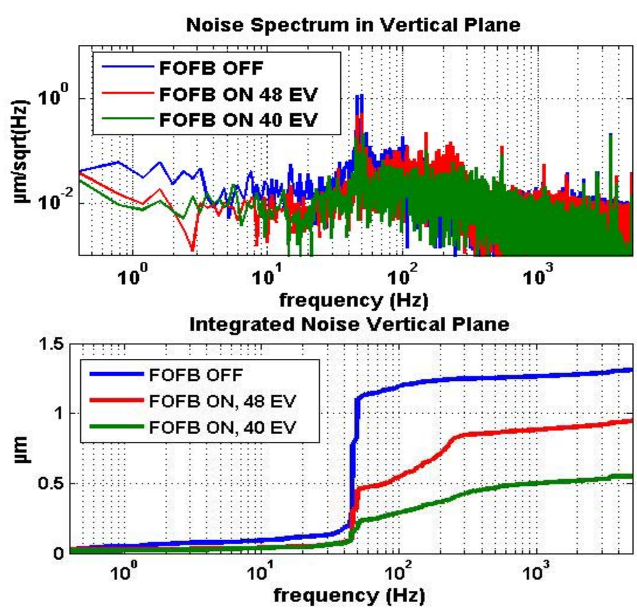


Figure 4: Vertical beam noise with and without feedback (measurement done on a BPM outside the feedback loop).

In order to measure the FOFB effect in the 0.01-1Hz BW we repeated 4 times the same transitions in gap and phase of some insertion devices with 4 configurations: no Orbit Feedback, SOFB ON, FOFB ON with 48 BPMs and FOFB ON with 120 BPMs. The FOFB strongly suppresses all beam movements in this frequency range (Fig. 5).

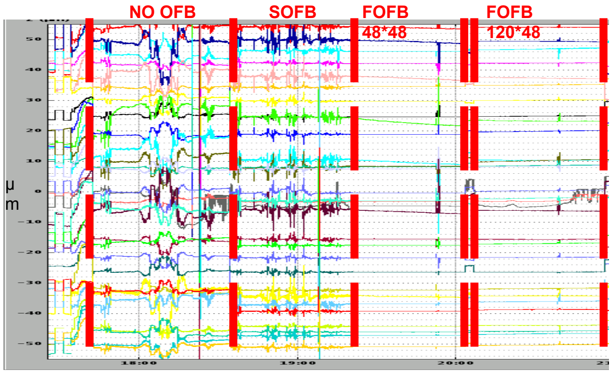


Figure 5: Vertical position at source points: good suppression of beam position perturbations during gap changes(0.01 Hz-1 Hz BW). In this case, perturbation are intentionally larger than during standart user operation.

From table 2, showing peak to peak drifts of the position at source points after few hours, we found that the optimum configuration is 120 BPM x 48 correctors in the vertical plane. It leads to a better stabilization at the bending magnet source points. Since it is not an issue in the horizontal plane, the configuration 48 BPMs x 48 correctors is better in this case. The air-corrector strength after a few hours of operation remains relatively small which gives confidence for operation up to an 8-hour shift, between two beam injections.

Table 2: Few-hour stability with FOFB,from DC to 0.01 Hz (slow drifts). Peak to peak measurements at 200 mA with SOFB switched OFF (machine shift).

| Photon Source | | ΔX µm | ΔX' µrad | ΔY µm | ΔY' µrad |
|---|---|---|---|---|---|
| Bending Magnet ≤ 35 keV | σ/10 | N/A | N/A | 1.5 | 5.3 |
| | no FOFB 3 h | 39 | 9 | 15 | 1.4 |
| | 48x48 for 3 h | 2.3 | 1.4 | 6.2 | 0.9 |
| | 120x48 for 3 h | 0.2 | 0 | 0.3 | 0.1 |
| Hard X-ray IDs | σ/10 | 39 | 1.5 | 0.55 | 0.52 |
| | no FOFB 3 h | 13 | 1.3 | 2.7 | 1.4 |
| | 48x48 for 3 h | 0 | 0 | 0 | 0 |
| | 120x48 for 3 h | 0.3 | 0 | 0.3 | 0.1 |
| Soft X-ray IDs | σ/10 | 18 | 3.4 | 0.65 | 1.6 |
| | no FOFB 3 h | 9 | 2.1 | 5 | 1.4 |
| | 48x48 for 3 h | 0 | 0 | 0 | 0 |
| | 120x48 for 3 h | 0.5 | 0.1 | 0.5 | 0.1 |
| HU 640 (UV) ID | σ/10 | 32 | 4.6 | 6 | 4.2 |
| | no FOFB 3 h | 10 | 0.4 | 3.4 | 0.3 |
| | 48x48 for 3 h | 0 | 0 | 0 | 0 |
| | 120x48 for 3 h | 0 | 0.1 | 0.6 | 0 |

## COMPATIBILITY WITH SOFB

As previously mentioned, the Slow and the Fast Orbit Feedback systems have different sets of correctors. The Slow Orbit Feedback operates from DC to 0.05 Hz. At the moment, the FOFB is operating from DC to 100 Hz. With different correctors and a common operating frequency band, the two systems are not compatible.

Two options are considered:

- The first one is to separate the two systems by their operating frequency range. It would keep the two systems completely independent. But it will also create a frequency dead-band (from 0.05 Hz to 0.1 Hz) where beam movement will not be corrected (Fig. 6 a).
- The second option is to keep the FOFB system working down to DC. In this case, a slow system will have to read the DC part of the current in the fast corrector and transfer it on the slow correctors. The two systems would not be independent and a reliable communication needs to be implemented between them. The main advantage of this solution is to reduce beam movements in the whole frequency range (Fig. 6 b).

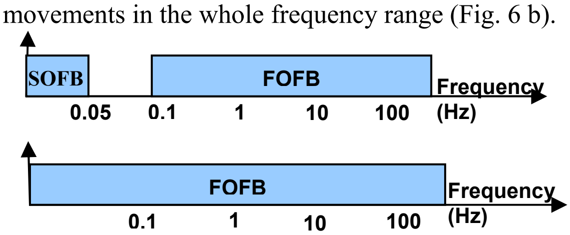


Figure 6: Two options: a) 2 independent systems with a dead-band, b) FOFB correcting from DC.

## CONCLUSION

The Slow Orbit Feedback suppresses efficiently the slow drifts due to thermal effects, but has no significant effect on beam movements and vibrations faster than 0.05 Hz. The Fast Orbit Feedback corrects efficiently the latter and seems to be able to correct well enough the slow drifts. The initial idea that consisted in having the two feedback systems working simultaneously but separated in the frequency domain by a dead band may not work properly for suppressing the perturbations caused by the cranes and by the undulator gap changes. We are investigating a communication process between the two feedback systems in order to use the FOFB down to DC with occasional relief of its DC correction by the SOFB.

The Fast Orbit Feedback system gives very promising results and is expected to be available for user operation in the coming months.

## ACKNOWLEDGEMENTS

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