THE SOLEIL BPM AND ORBIT FEEDBACK SYSTEMS

N. Hubert, L. Cassinari, J-C. Denard, N. Leclercq, A. Nadji, L. Nadolski, D. Pédeau;
Synchrotron SOLEIL, Gif-sur-Yvette, FRANCE

Abstract

SOLEIL is a third generation light source built in France, near Paris. Its BPM system is important for machine physics studies and for delivering stable beams to the users. A beam stable to 1/10th of the dimensions requires submicron stability in the vertical plane. The monitors anchored either to the girders or to the ground, are fixed points of the vacuum chamber. The electronics design was driven by combined efforts through active communication between accelerator laboratories (SOLEIL at first, later joined by DIAMOND) and Instrumentation Technologies. The result is the "Libera Electron" beam position processor. This paper reports on the performance of this new electronics installed on SOLEIL Storage Ring. It combines a 0.2µm rms resolution and micron level stability for beam delivery with accurate turn-by-turn measurements (3µm resolution at 0.8MHz) for machine commissioning and beam physics studies. It also features position interlock, tune measurement, and post-mortem capabilities. A Slow Orbit Feedback for correcting low frequency drifts (0 to 0.1Hz) is currently in operation. The Fast Orbit Feedback to be implemented soon will suppress higher frequency perturbations up to 100Hz.

INTRODUCTION

SOLEIL is a third generation light source built near Paris (France). It is designed for delivering to users very bright and stable photon beams. Its Beam Position Monitoring (BPM) system is based on a new digital electronics, the "Libera Electron", manufactured by Instrumentation Technologies. 146 BPMs equip the machine (first transfer line: 1, booster: 22, second transfer line: 3, storage ring: 120, tune monitors: 2). This paper reports on the SOLEIL BPM system, its commissioning and its use in the orbit feedback systems.

BPM BLOCKS AND CABLES

All 120 BPMs of the Storage Ring have the same vacuum chamber cross section (25x84mm). They include a bellow and a mechanical reference that is used for calibration, for survey, and for support. They have been manufactured at RIAL Vacuum (Italy), with electrodes and vacuum feedthroughs built by Saint Gobain (France). The horizontal separation of the button electrodes (Ø=10mm) is 16mm. It allows for a calibration factor of 11.2mm, identical in both planes. During the feedthrough design, a special attention was paid to their contribution to the vacuum chamber impedance, as well as to the heating power deposited by the beam on the button. The final design provides a good 50Ω matching up to 10GHz. A water cooling circuit stabilizes the BPM block temperature to 21±0.1°C.

The arc BPM fixtures are bolted to the magnet girders (Fig. 1). The straight sections BPM have a bellow on each side. They stand upon steel columns, directly anchored to the tunnel concrete slab.

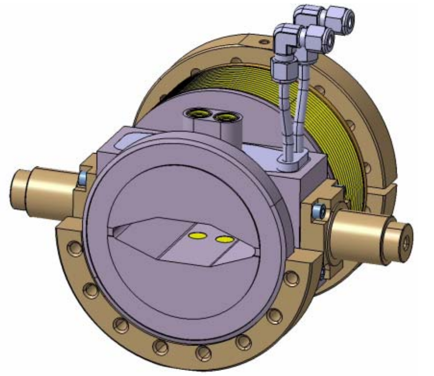

Figure 1: Arc BPM with bellow and cooling.

At several stages of the fabrication process, the proper insulation of the electrodes, and their capacitance matching, has been checked in order to minimize sensitivity differences between the four buttons of each BPM block.

The electrical offsets of the blocks have been measured with respect to their mechanical center and entered into a database for automatic correction (maximum electrical offset ≈ 600µm).

The blocks have been surveyed, and the survey offsets entered in the database for correcting the measured position (maximum survey offsets ≈ 500µm).

Because of their poor accessibility, we do not plan to disconnect the cables, even during vacuum chamber bake-outs. Therefore, 10cm long semi-rigid PEEK-insulated cables have been placed between the SMA feedthroughs and the long cables that take the signal to the processor. The four long cables of each BPM are enclosed in a shielded sheath and matched in length. Depending on the distance between the BPM block and its electronics, a different type of cable is used: either CNT195 22m long, or CNT240 33m long. The 352MHz signals get the same 5 dB attenuation in both cases.

BPM ELECTRONICS

Libera Modules

In 2002, SOLEIL initiated a new electronics concept of switched-electrode electronics with a small company. The result is the 'Libera Electron' digital electronics, manufactured by Instrumentation Technologies. It is composed of two main boards:

- An analog board with 4 multiplexed RF channels (automatic switching).

- A digital board with a powerful FPGA and fast inputs/outputs connections (Rocket I/O)

Libera Data Flow

Libera modules have five different kinds of data flows in order to meet several requirements.

The following data flows are available to the control system:

- ADC data is a 16ksample buffer at the sampling rate of the converters: around 109MHz.
- Turn-by-turn data at revolution frequency: 846kHz for the storage ring; 1.9MHz for the booster. This kind of data (buffer up to 100ksamples) was extensively used during the commissioning and now allows monitoring of the booster and its transfer lines, machine physics studies (the resolution is 3µm on the storage ring) and tune measurements.
- Turn-by-turn data decimated by 64. The decimation factor has been chosen in order to visualize a complete booster ramp in one 16ksample buffer.
- Slow Acquisition Data is a continuous flow of data at 10Hz that gives the mean position of the stored beam. The system accommodates large current variations and different bunch patterns; it provides a good accuracy and a very good resolution (0.2µm rms) for the slow orbit feedback.
- Fast Acquisition Data is a 10kHz continuous data flow available inside the FPGA for fast orbit feedback processing.

RF Channel Crosstalk

The accurate measurement and correction of the machine coupling relies on the BPM readings. A crosstalk measurement campaign has been carried out. It has been done with a generator, a horizontal beam displacement was simulated with an attenuator and its effect measured in the vertical plane. The average crosstalk value is -1.77% with a standard deviation of 2.5% (Fig. 2). Our first approach will be to apply a correction factor on each Libera. Another option would be to replace the Libera RF board.

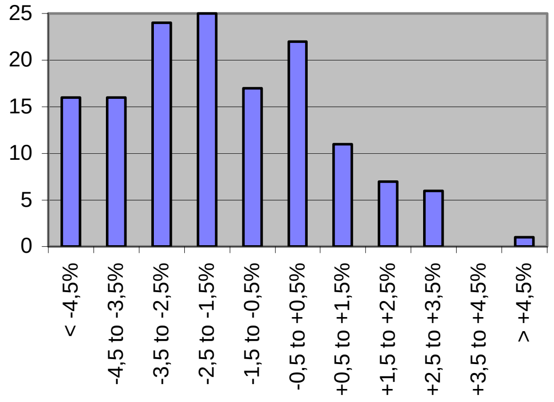

Figure 2: Crosstalk measurement (.Z/.X in %).

Other Functionalities

On top of the position measurement, the Libera modules have the following functionalities:

- Position Interlock: When the beam goes outside a predefined position range, the BPM electronics provides a low latency interlock signal used for killing the beam and prevent any damage to the machine [1].
- Post-Mortem: After a trigger is applied to a dedicated input, the Libera stores in a 16 ksample buffer the turn-by-turn measurements preceding the trigger.

CONTROL COMMAND

As the very first Libera user, SOLEIL has been deeply involved in the early stages of its Control System Programming Interface (CSPI) design. While the SOLEIL control system is based on TANGO [2], it has been decided to provide a generic and flexible interface in order to ease the integration of the Libera into any control system. This generic approach provides a way to factorize the common software components and allows any Libera user to benefit from features additions and bug fixes. We also suggested designing the CSPI so that one can choose between embedded or external runtime strategies. The CSPI abstracts the communication link and a simple recompilation is now enough to switch to "Libera embedded" or "external host" running of control system agent representing the Libera module.

The SOLEIL software architecture maps the physical deployment of the BPMs on the facility. Thanks to the object oriented nature of TANGO, each BPM module is exposed as an instance of the dedicated device-server. Through its attributes and commands, the latter provides the user with an exhaustive access to the Libera configuration parameters and data sources.

For both the booster and the storage ring, a so called "logical" TANGO device collects the beam position on each Libera device and makes the beam orbit available to the control system clients.

COMMISSIONING PROCESS

The BPM electronics was still under development when the machine commissioning started. Libera functionalities and data flows became available step by step. The first one was the turn-by-turn data. It facilitated the beam injection and the correction of the first turns and allowed online tune measurement. After the beam was stored, we received and commissioned the Slow Acquisition data flow. The position interlock functionality has been used later, in order to protect the machine for stored currents exceeding 20mA. The Automatic Gain Control automatically adjusts the attenuation at the input of the Libera to accommodate the whole current range from 0 to 500mA: it works up to 1Hz injection rate.

The system resulting from a new design, we encountered many inherent remaining bugs. All new functionalities were tested in the lab previously to being deployed on the machine. But the main difficulty was to detect and reproduce on a few modules in the lab sporadic events that could occur on one of the 120 BPMs on the machine. Nevertheless, we could always trust Instrumentation Technologies to quickly find solutions to the problems.

ORBIT FEEDBACKS

Slow Orbit Feedback

The slow orbit feedback (SOFB) has been put into operation since January 2007. The correction scheme relies on 120 BPMs and 56 corrector magnets in both planes. Theses correctors are secondary coils located in the sextupole magnets. Corrector power supplies use 20 bit DACs both for readback and setpoint values. Maximum corrector strengths are 0.9 and 0.7mrad.

The SOFB is implemented as a global feedback using the SVD algorithm: currently 56 and 32 singular values are used respectively in the horizontal and vertical planes. The RF frequency is an extra horizontal corrector coping with global circumference variation.

The system is implemented in the control-room as a Matlab programme. It runs at a 0.2Hz rate with 80% single step gains.

First results are very encouraging. Without SOFB, the orbit shift is a few tens of µm after several hours. Turning it on, orbit excursions reduce down to a few µm. Figure 3 is an example of position/angle stability during a 15 hour shift for a given beamline.

To get this performance for all beamlines and in a steady way some fine tuning of our system is still needed.

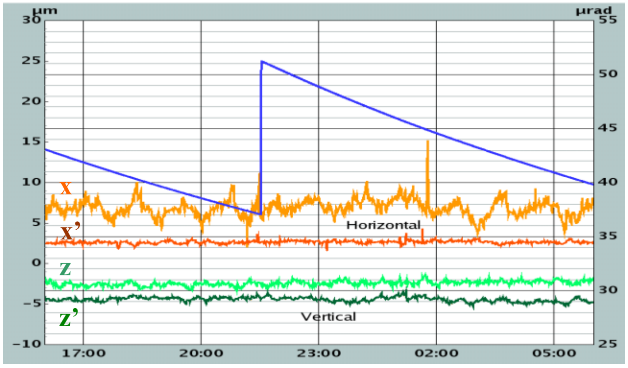

Figure 3: Angle (µrad) and position (µm) stability in both planes for a medium straight section. The blue curve exhibits the beam current for a 15 hour shift.

Fast Orbit Feedback

The fast orbit feedback (FOFB) is a global feedback under development. Its purpose is to correct orbit distortions up to 100Hz. The use of a frequency deadband between SOFB and FOFB will be implemented as a first step. The final aim is to be able to have a FOFB bandwidth starting from DC following a philosophy close to the ALS's one [3].

The FOFB uses up to 120 BPMs and 48 dedicated air coil correctors providing 20µrad maximum strength in both planes. These latter are installed around the upstream and downstream bellows of each of the 24 straight sections.

The SVD correction processing is distributed all around the storage ring, as embedded in the Libera FPGA. The Liberas of the 48 BPMs adjacent to the straight sections calculate the correction for their nearby correctors using the position data of the 120 BPMs. Then the Libera directly drives the magnet power-supply using a dedicated 10kHz serial RS485 link.

The bandwidth of the subsystem, (power supply + corrector + chamber), has been recently measured on the beam. The cut-off frequency at -3dB level is 2.4kHz in vertical and 3kHz in the horizontal plane (Fig. 4).

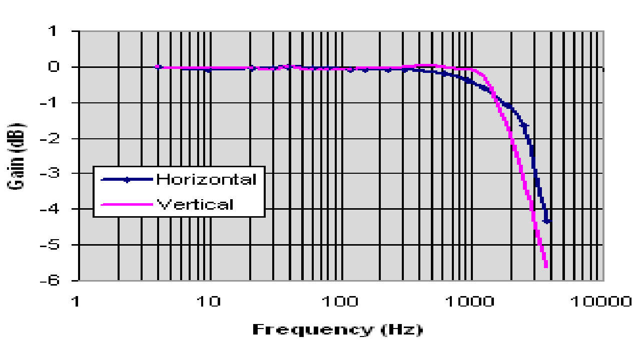

Figure 4: Bandwidth of the power supply + corrector + vacuum chamber + beam, measured on a BPM.

All BPM data are transmitted to each Libera used in the FOFB thanks to Diamond 'Communication Controller' [4] through a 2.12Gbits/s private network. The overall system latency (from position processing to power supply) is expected to be about 300µs.

CONCLUSION

A lot of effort as been put into the design of the Libera by Soleil and Instrumentation Technologies teams. It resulted in a BPM system quickly put in operation on the first days of commissioning. Even after several months of increased functionality, there are still a few improvements to bring. The SOFB is in commissioning phase and gives already promising results. The FOFB is under development, and we expect to close the loop this year.

ACKNOWLEDGEMENTS

We would like to thank all the Instrumentation Technology staff involved in the Libera project. We are also grateful to I. Uzun from Diamond Light source for his collaboration in the fast feedback project. We also thank J-M. Filhol that believed from the start that this ambitious BPM system would end up satisfying Soleil needs.

REFERENCES

[1] Y-M. Abiven, "Machine Protection System for Soleil Storage Ring", DIPAC'07, Trieste, May 2007.

[2] TANGO collaboration web site: http://www.tango-controls.org

[3] C. Steier et al. "Operational Experience Integrated slow and fast Orbit Feedbacks ath the ALS", EPAC'04, Lucerne, July 2004.

[4] G. Rehm, "Digital EBPMs at Diamond: Operational Experience and Integration into a fast Orbit Feedback", DIPAC'07, Trieste, May 2007.