

SOLEIL BEAM STABILITY STATUS

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Abstract

This paper reports recent work for improving SOLEIL electron beam stability.

X-BPMs from four bending magnet beamline frontends have been inserted in the global orbit feedback loops during user operation. The corresponding source point stabilities have improved and results are reported.

Some of the new beamlines request more stringent stability than the existing ones. Their requirements are not only tighter for beam orbit but also for beam size and divergence stability. For these reasons, SOLEIL has decided to define beam quality criteria for each sensitive beamline. Then it can predict ahead of commissioning how well the beamline will likely perform.

A feedback on the vertical emittance, measured by a pinhole camera, has been introduced in order to reduce beam size and divergence variations due to magnetic configuration changes of a few insertion devices.

INTRODUCTION

Third generation light sources keep on improving their electron beam stability in order to provide a constant photon flux and brightness to their Beamlines (BLs). Synchrotron SOLEIL is now a mature facility providing photon beams to 26 BLs in Top-up injection mode [1]. However, there are new disturbances that will affect beam stability: i) the addition of Insertion Devices (IDs) for new BLs up to the 29 foreseen by 2015 ii) new operation in fast switching modes of a few helicoidal undulators in the VUV and soft X-ray part of the spectrum. The slow orbit feedback has been recently upgraded by including bending magnet photon Beam Position Monitors (x-BPMs) in the correction algorithm. Moreover a new feedback system acting on the vertical emittance is now routinely used during beam delivery. Finally, as BL requirements depend on the type and duration of experiments, dedicated stability criteria have been defined for estimating the photon beam quality the machine provides to each BL.

BENDING MAGNET XBPM IN GLOBAL ORBIT FEEDBACK SYSTEMS

At SOLEIL there are two global orbit feedback systems (interleaved slow and fast systems [2]), based on 122 electron Beam Position Monitor (e-BPM) readings but using two different sets of corrector coils. They have been in operation since 2008 and provide a very stable beam orbit to the ID users: 200 nm RMS vertical noise in the 0.01 Hz-1 kHz bandwidth and long term (8h) drifts below 1 μm RMS at the source points.

Whereas each straight section is equipped with an upstream and downstream e-BPM, there is no e-BPM

next to the dipole magnets. With x-BPMs on the dipole BL frontends one has additional information that can be used to better stabilize those source points in the vertical plane. In fact x-BPMs provide also a better position angular measurement resolution, since they are located at several meters from the source point: 4.7 and 7.73 meters for the two monitors that are installed in each of the four bending magnet BL frontends.

A beam shutter, controlled by the BL users, is located between the two x-BPMs. Therefore, the first monitor can be included in the feedback loops whereas the second one is used as an independent observable (Fig.1).

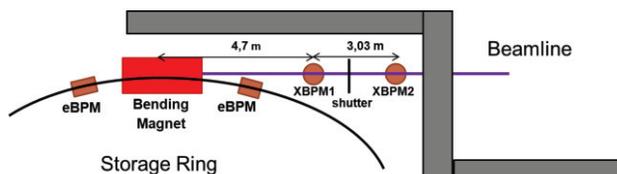


Figure 1: Schematics of a SOLEIL bending magnet beamline frontend (extraction angle at 1° from the entrance). There is a shutter between the two x-BPMs. Several magnets are between bending and e-BPMs.

In order to be integrated into feedback loops, x-BPMs are considered as additional BPMs in the response matrix with specific weighting factors. The correction algorithms are based on the SVD method [3].

After successful simulations and tests during machine physics studies, the four x-BPMs have been routinely included in the slow orbit feedback loop during user operation in March 2013. However, the fast orbit feedback loop running in parallel remains based on e-BPM readings only at the moment. For the four bending magnet BLs, the peak to peak photon beam position stability over one week measured on the second x-BPM has been improved by a factor of 1.3 to 3 (Table 1). Those preliminary results have been obtained with the same weight for e-BPMs and x-BPMs. Weight optimisation will be done during the coming weeks of user operation.

Table 1: Photon Beam Stability Improvement Measured at the Second XBPM of the Four Bending Magnet BLs

Beamline	ODE	METRO	SAMBA	DIFFABS
Stability improvement factor	1.7	1.3	3.2	2.1

Including the x-BPMs into the fast orbit feedback loop will also be studied. At the moment no further gain is expected in term of photon beam short-term stability.

BL STABILITY CRITERIA

All Insertion Devices (IDs) are freely controlled by the users and despite very high care in the ID construction, it remains challenging to completely avoid any detrimental effects on the orbit, size and divergence of the electron beam. Several points prompted us to define stability criteria for critical BLs: i) new BLs as well as a few existing ones claim higher sensitivities to electron beam property variations; ii) some existing BLs need to change their undulator configuration at higher speed; iii) the number of potentially perturbing IDs is going to increase until all beamlines are built. Table 2 shows the stability requirements expressed by the four most sensitive beamlines. Two crystallography BLs (PX1 and PX2) exploit photon beams produced by in-vacuum undulators in short straight sections. Anatomix and Nanoscopium are two long BLs (200 m and 155 m respectively) under construction for phase contrast imaging and coherent diffraction using radiation from two in-vacuum undulators canted by 6.5 mrad and installed on a long straight section.

Table 2: Electron beam stability tolerances required by the four most sensitive Beamlines for 1% coupling in horizontal (H) and vertical (V) planes.

Beamline	PX1	PX2	Anatomix	Nanoscopium
Duration	5 mn	30 mn	10 mn	8 hours
Position H	35 μm RMS	30 μm RMS	$\pm 12 \mu\text{m}$	$\pm 5 \mu\text{m}$
Angle H	3 μrad RMS	4 μrad RMS	$\pm 4 \mu\text{rad}$	$\pm 5 \mu\text{rad}$
Position V	1 μm RMS	1.3 μm RMS	$\pm 1 \mu\text{m}$	$\pm 1.5 \mu\text{m}$
Angle V	$\pm 1.5 \mu\text{rad}$	$\pm 1.5 \mu\text{rad}$	$\pm 1 \mu\text{rad}$	$\pm 1.5 \mu\text{rad}$
Size H & V	/	/	$\pm 5\%$ (6 h)	$\pm 2\%$
Div. H & V	/	$\pm 10\%$	$\pm 5\%$ (6 h)	$\pm 2\%$

The horizontal beam orbit stability requirements are not difficult to meet since the electron beam size and divergence in that plane are quite large ($\sigma_x \geq 215 \mu\text{m}$, $\sigma'_x \geq 17 \mu\text{rad}$). In the vertical plane, the tightest requirements correspond to 1/10 the beam size and 1/5 the divergence. Main issues are the tight beam size and divergence tolerances when they are needed for more than an hour. For the existing PX1 and PX2 beamlines, systematic measurements of the photon flux variations due to the most disturbing undulators have been performed and showed the flux variation to be less than 4%. This value needs to be reduced to 2%. Table 2 is a combination of both measured and estimated tolerances. For the two forthcoming BLs, only estimations based on numerical

simulations can give useful indications on how well the BL will perform with the present beam stability.

Once the tolerances defined, it is very instructive to simulate the percentage of useful beam time with respect to the total beam delivery for any given week of recorded data. The electron position and angle stability of all source points is computed, based on the two e-BPMs adjacent to each ID. The size and divergence evaluation at the source points are solely based on the beam size measured by the pinhole camera. In that simulation exercise, practically all the “would-be-lost” beam time is due to fast vertical emittance changes mostly driven by two helicoidal undulators (fig. 2).

The simulation is currently performed each week. Results during the first eight operating weeks of 2013 give an average of 100% for PX1, 83% for PX2; for Anatomix BL the stability ranges from 43% to 91% with an average of 70%; for Nanoscopium BL, the stability criteria are not reached yet. Further work and beam-based experiments are foreseen for refining the stability specifications. In any case, the vertical emittance stability is the major concern.

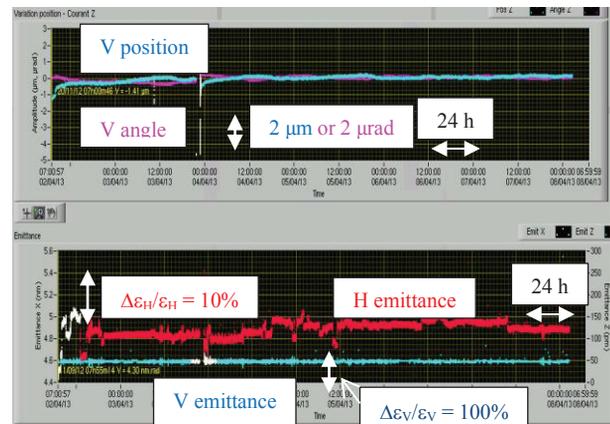


Figure 2: One week stability records of vertical position and angle as well as emittances for Anatomix BL. The white trace areas show beam times out of tolerance. The H emittance scale is much larger than the vertical one.

VERTICAL BEAMSIZE FEEDBACK

The so-called Anatomix-Nanoscopium optics creates a double minimum of the vertical beta-function in a long straight section by inserting an additional quadrupole triplet in its center and two canted in-vacuum undulators can be accommodated. This new nominal storage ring optics [4] has been put into operation for users at the beginning of 2012.

The systematic minimization of the betatron coupling is performed with all 32 skew quadrupole correctors (SQs) using the LOCO analysis of the measured response matrix [5]. The resulting coupling value (0.15%) is then increased to 1% by modulating the means of a dispersion wave generated by the same 32 SQs.

Sources of Coupling Variations

Most of the 25 IDs [7] presently installed in the SOLEIL storage ring display an integrated skew gradient less than a few tens of Gauss when operated at their maximum magnetic field. Considering the $\sqrt{\beta_x\beta_z}$ product along the ring, a given skew gradient default effect will be significantly enhanced when located in a long straight section. It is the case for the 10 m long HU640 electromagnetic undulator. It changes the coupling from 0.8% to 1.4% when switching its horizontal B-field component from 0.1 to - 0.1 T. Moreover, coupling variations are amplified when several other ID fields are close to their maximum values. The interplay of the various ID skew gradient defaults, the bare machine coupling sources and the SQ fields may lead to a 0.4% to 1.8% maximum peak coupling variation.

Vertical Beam Size Control

As aforementioned, stabilizing the vertical beam size and divergence become essential for at least four high-energy beamlines. Then, a feedback system that stabilizes the transverse vertical emittance has been implemented in September 2012. Based on the vertical beam size measured with an X-ray pinhole camera [8], new values for the 32 SQs are computed in order to keep the vertical electron beam emittance constant. It consists in modifying the pure vertical dispersion amplitude by steps, without acting on the betatron coupling.

The present system makes a new correction every 3 seconds. It aims at maintaining the vertical beam emittance to 50 ± 2.5 pm.rad. The coupling variations have been significantly reduced in this way (Fig. 3); this feedback system is mandatory during user beam delivery. However, transient vertical emittance spikes due to the electromagnetic HU640 remain; they are too fast for the present correction speed.

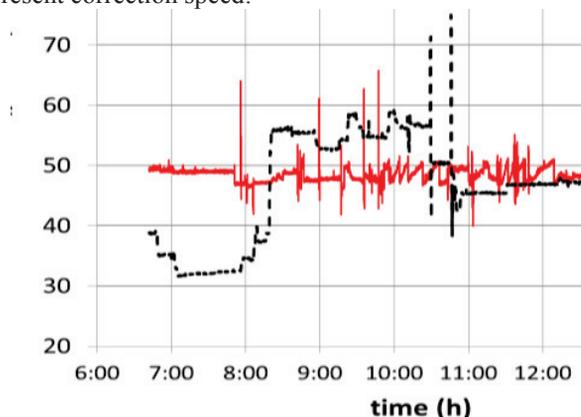


Figure 3: Evolution of the coupling versus time w/ (red) and w/o (black dotted) global feedback correction on the coupling value, observed during the typical restart of the user session on Tuesdays.

Better stabilization of the vertical emittance to 50 ± 1 pm.rad and increase of the correction rate up to 2 Hz are under development. The present speed limitation is

mainly due to the pinhole camera software acquisition scheme. As a consequence, the present feedback system will not be able to correct the coupling variation occurring during the foreseen 200 ms fast switching of the HU640 horizontal B-field, and the 8 mm/s high speed gap variation of an APPLE II undulator. The new operating modes for these two undulators are planned for the end of 2013. For that reason, coupling look-up tables using local correctors are also under investigation in order to cancel out the ID skew gradient errors at their sources.

CONCLUSION

Electron beam position and angle of the SOLEIL source points are reasonably stable at the sub-micrometer and sub-microradian level, and fit well the BL requirements. Vertical position stability has been improved for bending magnet source points by the insertion of x-BPMs in the slow feedback loop. However, a few BLs in construction claim a vertical emittance stability that cannot presently be achieved. A better evaluation of the actual needs is currently under investigation; machine improvements are planned with a better and faster feedback system and with correction tables that should compensate the emittance coupling variations induced by a few undulators. Possible solutions on the BLs themselves are also going to be investigated, especially appropriate photon flux data that could be used in the experiment acquisition post-processing.

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REFERENCES

- [1] A. Nadji et al., "Operation and Performance Upgrade of the SOLEIL Storage Ring", these proceedings.
- [2] N. Hubert et al., "Global Fast Orbit Feedback System Down to DC Using Fast and Slow Correctors", DIPAC'09, Basel, May 2009, MOOC01, <http://www.JACoW.org>
- [3] N. Hubert et al., "Introduction of Photon BPMs in SOLEIL Global Orbit Feedback Systems", IBIC'12, Tsukuba, October 2012, MOPA39, <http://www.JACoW.org>
- [4] P. Brunelle and al., "New Optics for the SOLEIL Storage Ring", IPAC'11, p. 2124-2126.
- [5] LOCO, Beam Dynamics Newsletter 44, ICFA, Dec. 2007
- [6] Computation using the TRACY III tracking code.
- [7] M.-E. Couprie et al. "A panoply of insertion devices at SOLEIL for a wide spectral range and flexible polarisation", Synchrotron Radiation Instrumentation Melbourne, Australia, 27 September - 2 October 2009, AIP Conference Proceedings 2010, 1234, p. 519-522.
- [8] M.-A. Tordeux and al., "Ultimate resolution of SOLEIL X-Ray Pinhole Camera", DIPAC'07, p. 180-182.