ORBIT STABILITY STATUS AND IMPROVEMENT AT SOLEIL

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Abstract

SOLEIL is a 2.75 GeV third generation synchrotron light source delivering photons to beam-lines since January 2007. Stability of the beam-line source points is crucial for the user experiments. Typically this stability has to be below one tenth of the transverse beam sizes. This is challenging especially in the vertical plane leading to submicrometer values. This paper will describe the position stability achieved today without and with the slow orbit feedback. Impact of different noise sources and present limitations will be described. To end an improvement strategy will be given for short and medium terms.

INTRODUCTION

Beam orbit stability is of paramount importance for maintaining performance of third generation synchrotron light sources. A total number of 14 beam-lines (BLs) already take the photon beams during daily operation in May 2008, namely exactly 2 years after the first beam was stored in the $3.73\,nm.rad$ emittance storage ring. The users are provided with a current of $250\,mA$, in 312 bunches out of 416 RF buckets, with a 15 to 20 hour beam-lifetime (depending on undulator configuration) and a 0.6 to 1.2% coupling value. The orbit stability has to satisfy a large community of users, extending from IR, VUV ($5\,eV$) to hard X-ray ($40\,keV$) photon energy. With a target stability of $1/10$ th of the beam sizes, the most stringent case is in the vertical plane with in-vacuum undulator based BLs ($0.5\,\mu m$ RMS stability). Table 1 summaries the present stability reached with the Slow Orbit Feedback (SOFB). The reached values are slightly increased when Users freely control their insertion devices (IDs) — see next sections.

Table 1: E-beam source point stability (RMS): Target and reached values with SOFB and for a 0.4 % coupling value.

Source points	**H-plane (μm)**		**V-plane (μm)**	
Straight section	Target	Reached	Target	Reached
Long SSs	32	4	**1.1**	1.6
Medium SSs	18	3	**0.5**	1.4
Short SSs	39	3	**0.5**	1.1
Dipoles	4	4	1.5	1.4

In the following sections, an overview of the orbit stability is given over long, medium, and short periods of time.

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LONG TERM STABILITY

The slabs for the storage ring (SR) tunnel and experimental hall were designed to provide a target vertical static deformation of less than $100\,\mu m/10\,m/year$. The $0.95\,m$ thick slab of the tunnel, supported by $140\;15\,m$ long piles, is monolithic and fully connected to the experimental slab. Thanks to a network of hydrostatic leveling system (HLS) [1], the tunnel slab settlement has been followed since August 2006. Figure 1 displays the vertical profile recorded every 2 months and shows an outstanding stability with a maximum peak-to-peak variation of 450 μm over a period of nearly 2 years (Electronics slow drifts: 7 μm RMS, HLS calibration: once a year). The mean drift velocity is measured to be $50\,\mu m/10\,m/year$ over the last year, except in a few location in 1/4 of the SR. As a consequence the natural closed orbit (without powering the steerer magnets) has almost not changed over the last 2 years.

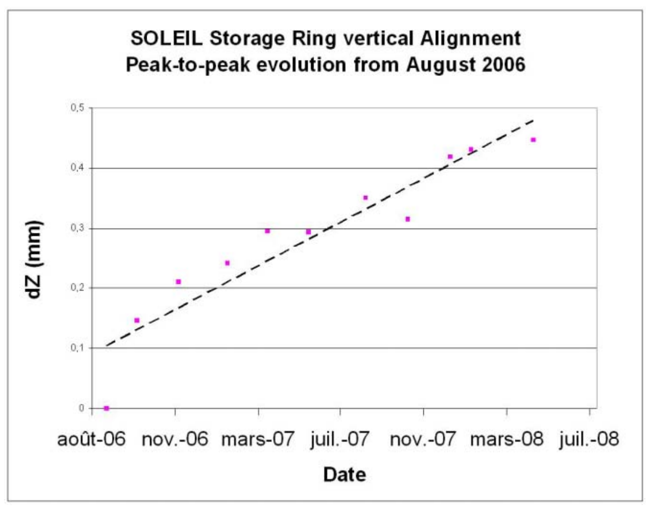

Figure 1: Stability profile of the vertical settlement of the tunnel slab based on measurements of the 56 girders, each equipped with 3 HLS.

The SR circumference variation is cyclic over 1 year with a $2.1\,mm$ amplitude and compensated by shifting the RF-frequency by $2.1\,kHz$. After each shutdown period the RF frequency has to be shifted typically by $+400$ to $+700\,Hz$, which could be explained by the switching off of the magnets and heavy tunnel activities during shutdown periods. Nevertheless recovering the frequency requires nearly a full week with stored beam.

MEDIUM TERM STABILITY

Temperature Stability

To ensure orbit stability over minutes to hours, both the tunnel and experimental halls are thermally regulated around $21°C$ within $\pm 0.1°C$ and $\pm 1°C$ respectively. For the storage ring, the $21°C$ water cooling circuit runs all over the year, including during the shutdown periods. In practice the radial flow of the air conditioning units (ACU) inside the SR tunnel is within specification. Nevertheless in one quarter of the SR, variations of up to $0.5\,°C$ of the air temperature are observed. Special tuning of the regulation loops is foreseen this year, and some ACUs may be added in some SSs. For instance the $10\,m$ long HU640 electromagnetic ID increases locally the temperature by $2.5°C$ inducing a $10\,\mu m$ residual orbit drift in both planes, not compensable by the SOFB.

Experimental Hall Activities

During Users operation, carefully construction of new beam-lines is allowed since induced orbit perturbations (high frequency, but below $5\,\mu m$ amplitude) not disturbing too much BL data acquisitions.

Dedicated measurements of the effects of the two 7 T moving cranes have revealed orbit distortions up to $15\,\mu m$ peak-to-peak in both planes (Fig. 2). This effect is mainly static and related to the position of each crane along the ring circumference. Being out of tolerance in H-plane was not expected. It turned out that the crane supports are not perfectly disconnected from the tunnel slab. Oscillation amplitudes are still difficult to understand. Measurements using 3D-geophones, before SR commissioning, showed that dynamic peak amplitude could be as large as $1.3\,\mu m$ in the vertical plane for a specification of $1\,\mu m$ but only if the crane was moving at high speed. Lattice amplification factors are 16 and 3 in horizontal (H) and vertical (V) planes. Since then it has been decided to allow only low speed crane motion and to fully disconnect the crane supports form the experimental slab.

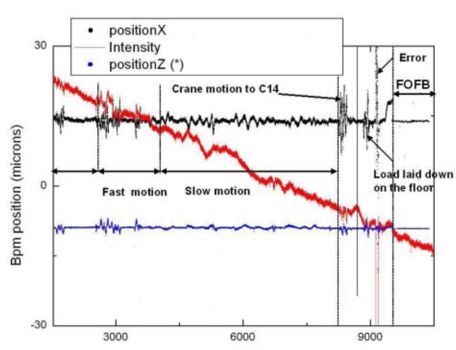

Figure 2: H & V distortions of the photon beam due to the moving crane positions monitored on a BL.

Another source of perturbation was found with a 2 T fast switching magnet used for dichroism experiments on a the BL. This magnet is located in the experimental hutch close to the external SR shieding wall. The orbit perturbation was $\pm 8\,\mu m$ and $\pm 3\,\mu m$ in respectively H- and V-planes with a switching frequency of $0.2\,Hz$. In order to minimize the $10\,\mu T.m$ fringe fields, a new magnetic shielding has been installed around the magnet and tested successfully.

Injection Perturbations

In order to prepare top-up operation, a few studies have been done to identify noise sources during injection process. When the $3\,Hz$ booster power supplies are running at full field, the beam noise level increases significantly: on all Beam Position Monitors (BPMs) the noise level rises from 0.220 up to $0.600\,\mu m$ RMS in H- and from 0.060 to $0.200\,\mu m$ in V-plane. The situation is even worse in the cells 14 and 15 close to the booster ring with BPM RMS values up to $1.6\,\mu m$ in H-plane. The perturbation contribution is twofold: not equal currents in the 2 families of quadrupole magnets, and not exactly identical currents in the 2 power supplies (PSs) of the dipoles (sextupole interferences are weaker). Both the e-beam and the BPM readings see a 3 Hz perturbation. A dedicated power supply powering a compensating current loop is being built ($60\,A$ peak current). Moreover the orbit perturbation is roughly a factor 3 larger when ramping up from 0 A to nominal values just before starting injection (transitory state).

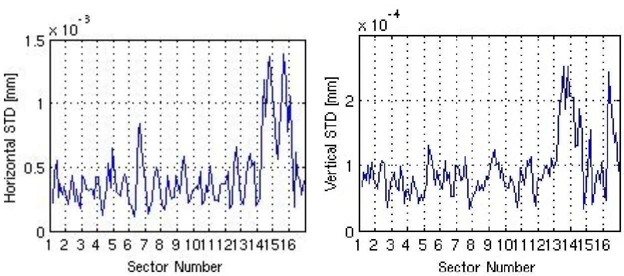

Figure 3: Noise induced by booster operation measured on the BPMs of the 16 SR cells (left: H-plane, right: V-plane).

Other perturbations are introduced by the stray field of the thick septa and by the not perfect matching of the 4 injection kicker magnets. This results in a $3\,ms$ long H-beam disturbance of $\pm 150\,\mu m$ peak for the thick septa; A $100\,\mu m$ RMS betatron oscillation in H-plane and $60\,\mu m$ RMS in V-plane is introduced by the kickers. Fine tuning, tilt compensation of the kickers, and new shielding of the septa are underway [2].

Other sources of orbit perturbations are the residual orbit from the imperfect orbit feedforward correction for each ID. Even if these systems work well, residual orbit is in the order of 2 to $5\,\mu m$ RMS in both transverse planes. For electromagnetic undulators, the situation can be worse with spikes resulting of non perfectly synchronized power supplies (different internal time responses, no dynamic control for reaching the setpoint values): up to 19 power supplies for main and correction coils equipped for instance the HU256 IDs. For feedforwards of motorized IDs, the synchronization of the motors together with the corrector magnets is penalized by the slow response of the PSs. Several tasks are engaged to improve the situation: new firmware of the power supplies will lead to a $30\,Hz$ communication. A so called on-the-fly feedforward is under commissioning for increasing correction rate. For fast electromagnetic IDs, tests are performed in order to use waveforms and analogical feedforwards. It is critical for this type of IDs to allow further than $10\,Hz$ correction rate since faster control is needed in order to diminish hysteresis related cycling times and to be able to switch field polarity at a few hertz rate [3].

Orbit Drifts with Current

With the SOFB running, source point drifts due to current beam decay from 250 down to $160\,mA$ reach $5\,\mu m$ position and $2\,\mu rad$ angle peak-to-peak values in both planes.

Moreover above some current thresholds a few BPM readings give fast or slow drift offsets up to $10\,\mu m$ peak to peak starting above a $150\,mA$ stored beam 4. Investigations have shown the BPM electronics is not responsible for these offsets. The issue comes from the BPM blocks themselves : some electrodes have at given current sudden offsets. Precise diagnosis require to break out the vacuum; BPM blocks may be replaced in the future.

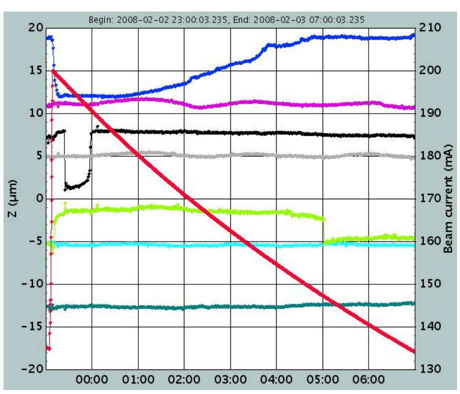

Figure 4: V-orbit drifts from 200 to 130 mA for a few BPMs during e-beam current decay.

SHORT TERM STABILITY

A Slow Orbit FeedBack (SOFB) has been running since January 2007. It consists of 56 steerers in both planes and 120 BPMs. The correction rate is $0.1\,Hz$. Plans are foreseen to increase this rate once the steerer power supplies will be upgraded to allow faster than $10\,Hz$ communication rate. The RF frequency is used as an additional horizontal corrector in the orbit response matrix to compensate for circumference variations. The algorithm is based on SVD method where all singular values are used.

The closed orbit is stabilized below $5\,\mu m$ peak in both planes for fixed ID parameters. Slow thermal drifts are correlated with out of specification tunnel air temperature regulation and with beam current dependance.

Thanks to the free HOM $352.2\,MHz$ super-conducting cavities, with a $0.1°$ phase stability, no longitudinal noise is injected in the horizontal plane (via H-dispersion function).

Figure 5 displays the typical e-beam noise monitored on a BPM (no feedbacks). The main spectrum lines are $46\,Hz$ (first girder eigen mode), $50\,Hz$ mains and its harmonics (Booster is turned off during the measurements). Integrated noise reaches $2\,\mu m$ RMS in V-plane. A Fast Orbit FeedBack (FOFB) [4] has been under commissioning for a few months and should be put into operation during next fall. Using fast air coil correctors upstream and downstream of all straight sections, it should especially help damping residual orbit and transient effects from ID feedforwards. To increase dipole source point stability, XBPMs may be incorporated in the feedbacks in the future.

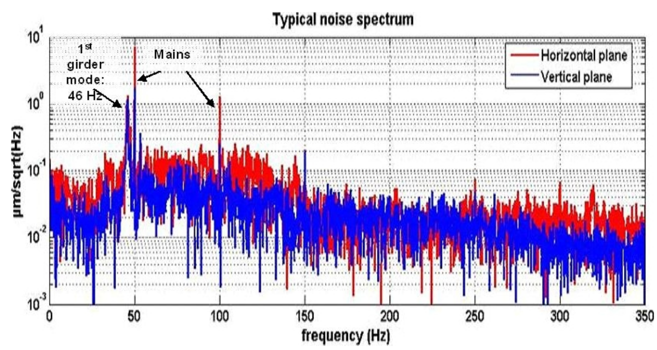

Figure 5: Typical horizontal (red) and vertical (blue) power spectrum density of the beam noise recorded on one BPM.

CONCLUSIONS AND PERSPECTIVES

A few micrometer stability is reached for daily operation using the SOFB. Efforts are put on reduction of the distortions coming from non perfect feedforward systems, cultural noise, moving crane, booster operation, ... The forthcoming FOFB should allow to correct orbit distortions up to $150\,Hz$ to a micrometer level. For reaching sub micro stability, top-up operation (2009) is required, but major work has still to be done in order to allow transparent injection without gating signal the data acquisition on the BLs.

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