OPERATION AND PERFORMANCE UPGRADE OF THE SOLEIL STORAGE RING

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Abstract

After two years and a half of operation, the SOLEIL 3rd generation synchrotron light source is delivering photons to 20 beamlines with a current of 300 mA in top-up mode. The nominal current of 500 mA has been reached during machine tests. The new transverse feedback loop has enabled to improve the performance of the single bunch and multibunch beams. The long and short term vertical beam position stability is in the range of one micron thanks to the efficiency of the slow and fast orbit feedbacks which are now running in a complementary manner. Fifteen insertion devices are now installed in the storage ring, five are ready for installation, three are under construction, and a cryogenic undulator is under development. A big effort is being taken in order to compensate the effects of these insertion devices on the machine performances. The good operation performance achieved in 2007 (2 815 hours) has been improved in 2008 during which ~ 3 900 hours have been delivered to the users with a 95.7% availability and a 32 hours MTBF.

INTRODUCTION

As of May 2009 up to 20 beamlines have taken beam, 12 from Insertion Devices (IDs), 2 from IR ports, and 6 from dipole ports. In 2008, almost 1100 research scientists have performed experiments on the first set of 11 beamlines open to external users via peer review committees. Nevertheless, the main objective is to continue the optimisation of the accelerator system in order to reach the ultimate performances in brilliance, beam lifetime and beam stability. Further, the machine has been optimised to obtain shorter bunches in a special mode of operation using low intensity bunches and significantly reduced momentum compaction factor. In addition, new challenging beamlines are either under construction, using in-vacuum canted undulators or under design like a ~150 m long nano-probe beamline also using canted undulators and extra quadrupoles. The slicing project which aims at providing 100 fs long pulses to several beamlines (soft and hard X-rays) has been launched recently.

STORAGE RING PERFORMANCES

Beam Current

After the installation of the second cryomodule in May 2008, and the conditioning of its 2 RF cavities, it became possible to go beyond 300 mA. During the first trial in October 2008, and using only three RF cavities out of four, a current of 400 mA had been reached and maintained for more than one hour. The Transverse FeedBack (TFB) has shown its efficiency by maintaining the emittances coupling around 1% [1]. In the same day, the current was pushed easily to 450 mA until a sharp pressure rise in one flange (due to a geometrical defect) prevented us to go further. During the second trial in November 2008, a current of 455 mA has been reached by filling all 416 bunches in order to reduce the heating due to the current per bunch. This also increased the beam lifetime by 20%. During more than one hour, all the parameters of the vacuum system were at satisfactory values. Unfortunately, the tuner of one cavity got blocked stopping these tests prematurely. In January 2009, this problem was fixed and it was decided to lock the tuners of 2 cavities at positions optimized for 500 mA, and to ramp the voltage of these cavities during the beam current run up. We could then reach again 450 mA in March 2009. A new radiation control around the storage ring tunnel was performed at this current and found satisfactory. Finally, it was possible to reach 500 mA for a short while before a problem on one of the in-vacuum undulators tripped the beam. The 352 MHz solid state RF amplifiers delivered without any difficulty the required 125 kW RF power to each of the 4 RF cavities. The TFB efficiency needs to be improved in order to restore the beam vertical emittance which was increased from 30 pm.rad to 60 pm.rad at 500 mA in uniform filling [1].

Top-up

Since 2007, the machine was operated in “decay mode”, with the current varying from 250 mA down to 150 mA. Various activities have been done to prepare operation in top-up mode. Simulations of different possible failure cases demonstrated that in no circumstances the injected electrons can be transmitted to the beamlines front-end. Hardwired interlocks have been set-up: Top-up injection is possible only if the beam intensity stored in the storage ring is above 50 mA, and if the magnetic field of the transfer line dipoles guarantees that the energy of the incoming electrons is within a few percent of the ring energy.

After a careful and systematic radiation control of all beamlines optical hutches, the green light was given in March 2009 to operate the storage ring in top-up mode. Since that time, top-up has been operated routinely at 300 mA, in multibunch mode. The filling pattern is almost uniform, consisting of 4 batches of 100 bunches, which are topped up one at a time, thanks to the good flat shape of the 300 nsec Linac pulse.

Because the electron beam lifetime varies strongly according to the IDs configuration, it was not possible to opt for an injection cycle at fixed time intervals. An injection cycle starts every time the current goes below 300 mA, and perform one Linac pulse acceleration and injection. The statistics up to now showed that the complement current shots are between 1 to 1.5 mA which corresponds to a relative variation of the total beam current of 0.3 to 0.5%. The interval between two injections varies from 2 to 5 minutes. No constraint was set on the IDs which can be set at any gap (or any coil excitation) or any phase, and particularly the in-vacuum undulators, the magnetic gap of which can be set at their minimal value of 5.5 mm.

A top-up control program is continually monitoring the parameters of the injection chain, i.e., the Linac, TL1, Booster and TL2 equipment, the storage ring injection pulsed magnets, PSS and interlocks. The top-up is inhibited if the values are out of range, or if the injection efficiency is below a pre-determined value. The Booster power supplies are synchronised and can be switched ON and OFF within 10 seconds.

Many efforts were made to minimize the perturbations induced on the stored beam: extra magnetic shielding added around the active septum magnet and neighbouring vacuum vessels, improvement on kicker pulses identity, compensation loop in the Booster to minimize the 3 Hz perturbation. Presently the residual oscillation of the beam in the horizontal plane reaches 100 to 150 µm. Further improvements are expected, though harder to achieve.

The first feedback from the beamlines is very encouraging, even from the infra-red beamlines! The signal/noise ratio read on the detectors is significantly improved and the stability of the optical elements and of the photon beams is highly appreciated. Up to now, no beam trips have occurred due specifically to top-up. Top-up in hybrid and 8 bunch modes will be tested soon.

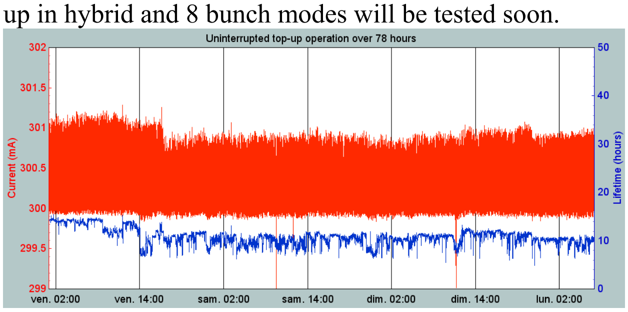

Figure 1: Beam delivery in top-up mode. The beam current is in red, and the beam lifetime in blue.

Beam Lifetime

The average pressure at 300 mA is now around 8 10^{-10} mbar, the RF voltage optimised for the best use of the cavities when the tuners are locked is about 3.7 MV and the coupling is close to 0.7%. Without IDs, in the multibunch mode where all the 416 buckets are filled, the measured beam lifetime at 300 mA is almost 17 hours. It can reach 21 hours if we run with lower RF voltage. This value can be significantly reduced (down to few hours) when the 10 m long HU640 undulator is in the LH mode at maximum field, and/or when the 3 in-vacuum undulators are at 5.5 mm gap and with some configurations of the 7 APPLEII undulators. Experimental investigations are being performed, using Frequency Map Analysis, tune scans, or more recently, resonance driving term measurements [2], and together with the preparation of a robust linear and nonlinear model [3] they should enable to better understand the mechanisms and to cure or reduce these effects. It was observed that the beam lifetime is very sensitive to the betatron tunes values for some IDs configurations. In some situations, a variation of the tunes by 10^{-3} can result in a 50% lifetime reduction. A software feedback which, using two quadrupole families, keeps constant the tunes, was recently implemented and significantly minimizes the amplitudes and number of drops in the beam lifetime.

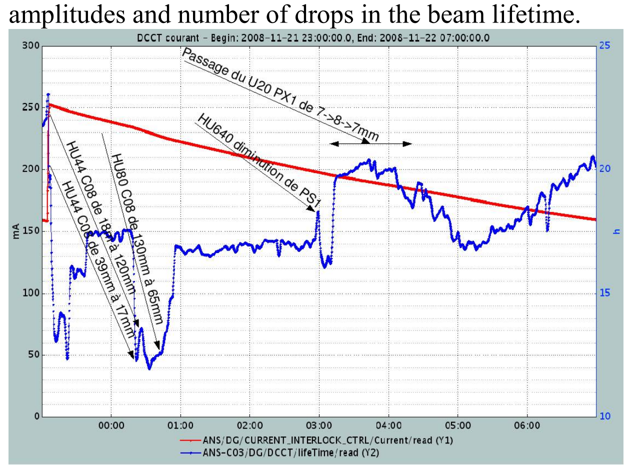

Figure 2: Beam lifetime fluctuations due to ID gap changes.

In December 2008, a full week was dedicated to a hybrid mode, where ¾ of the machine was filled with a total current of 240 mA (in 312 bunches) and a single bunch of 8 mA was stored in the middle of the empty quart. The beam lifetime of the multibunch beam was about 17 h while it was about 8 hours for the single bunch.

Beam Position Stability

A Slow Orbit FeedBack (SOFB) running at 0.1 Hz and using the closed orbit correction scheme (120 BPMs and 56 dipolar correctors in each plane, located in the sextupoles) was operated since January 2007. It was maintaining the orbit excursions within few microns at all the source points of the machine, IDs and dipoles.

A Fast Orbit FeedBack (FOFB) running at 10 kHz and using 48 dedicated air coil correctors installed around the upstream and downstream bellows of each of the 24 straight sections was then set up in operation in September 2008, hence replacing the SOFB during the users shifts. It was providing a very efficient correction of the fast beam motions up to 150 Hz, such as the ones corresponding to the 47 Hz, first eigen mode of the girders, or induced by the 3 Hz Booster power supplies or by the overhead cranes, and a better suppression of the imperfect compensation of the transitory effects observed during the changes of the IDs magnetic field values.

Nevertheless, and as expected, the FOFB could not correct the long term drifts of the dipole source points.

Efforts have been then put in order to run both feedbacks together at the same time. Recently, the two feedbacks have been operated together during a user run of six weeks and the results are very satisfactory [4]. The short and long term stability at all the source points is around 1 micron in the vertical plane and 2 microns in the horizontal plane.

The front-ends of eleven beamlines are now equipped with X-BPMs: 5 dipole beamlines with 2 vertical X-BPMs each, 2 in-vacuum undulator type beamlines with 2 H and V X-BPMs each and 4 APPLEII undulator type beamlines with 1 H and V X-BPM each.

OPERATION

During 2007, first year of user operation, the availability of the beam was already good and reached 93.8%. In 2008, the total operation time was 5 568 hours spread over 7 runs. The beam time for machine studies was reduced to 26%. Up to 3 882 beam hours were effectively delivered to the beamlines and associated radiation controls, resulting in an availability of 95.7% of the scheduled beam time. The MTBF reached 32 hours over the year whereas the average failure duration including the refill is 30 minutes. The availability over the 2 first run of 2009 reaches 96.2%. With the top-up operation, the longest uninterrupted beam delivery period was 78 hours.

NEW DEVELOPMENTS

New Insertion Devices

There are now 15 IDs installed on the ring: 4 electromagnetic helical undulators, 7 APPLEII undulators with period ranging from 80 to 44 mm, and 4 in-vacuum undulators U20. Recently, the fourth in-vacuum undulator had to be taken out of the ring because of a default in the liner on top of the magnets which got loose and was reducing the physical aperture. Five IDs, are ready to be installed, two are under construction (an in-vacuum wiggler to cover the 20 keV-50 keV photon energy range) and an electromagnetic/permanent magnet helical undulator for fast polarization switching. R&D on cryogenic in-vacuum undulator has also been launched [5].

Towards Operation with a Low Momentum Compaction Factor

An optics featuring low momentum compaction factor (α) together with a rather low emittance optics (8.5 nm.rad) has been achieved. Thanks to recent improvements brought to the storage ring model [3], the machine tuning to these optics have been successfully done either on live with beam by moving from one optics to another by tuning the quadrupoles, or by injecting directly to the required optics with rather good efficiency of 30%.

The low α optics are characterised by measuring the corresponding synchrotron frequencies and bunch lengths. For example, a 440 Hz measured synchrotron frequency was the signature of α /100 optics (4.45 10^{-6}). On the other hand, it was not possible to measure a bunch length shorter than ~2 ps due to the limited resolution of our current streak camera. Starting from α/60 optics and down, the Coherent Synchrotron Radiation (CSR) could be observed on the Infrared beam line AILES in the Tera Hertz region. Nevertheless, some noise induced by a significant horizontal beam position fluctuation was spoiling the experimental conditions at the beam line. This work is still in progress.

Other developments

Double "mini-β_z" optics in a long straight section: In order to accommodate on a 12 m long straight section two new ID beamlines, with canted undulators, an additional quadrupole triplet will be installed in the centre of the straight section to create vertical focusing in both sides. First tests will be performed in fall 2009 to optimize the optics with the new tunes

Femto-Second Electron Beam Slicing: The possibility of producing 100 fs photon pulses was recently decided at SOLEIL [6]. Different studies are underway such as the investigation for the best laser possible, calculation to determine the best choice for the modulator, optimisation of the electron energy modulation, ratio between the laser beam waist and the electron beam sizes and the optical path of the laser beam up to the modulator. At least, two beamlines will benefit at the same time from the slicing process, one VUV for time resolved electron spectroscopy and one for hard X-Ray diffraction in the sub-ps time scale.

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