OPERATION AND PERFORMANCE UPGRADE OF THE SOLEIL STORAGE RING

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Abstract

SOLEIL delivers photons to 25 Beamlines. Up to 24 very diverse Insertion Devices (ID) are now installed on the Storage Ring. The most recent one is a cryogenic in-vacuum undulator designed and built at SOLEIL. Work is continuing on beam dynamics and magnetic corrections to reduce the nonlinear effects of all these IDs. A new optics incorporating an additional quadrupole triplet in one long straight section has been successfully tested and will be put in operation by fall 2011. A new coupling correction will also be implemented in order to maintain the ratio between the vertical and the horizontal emittances at a fixed 1% for any IDs configuration. The electron beam orbit stability has been significantly improved reaching a residual noise of 200 nm RMS on all hard X-ray ID Beamlines. Photon LIBERA modules equip X-BPM located on the bending magnet Beamlines; they will be integrated soon in the orbit feedback loops. 4905 hours have been delivered in 2010 to the Beamlines with an availability of 96.3%. After seven months in 2011, the availability is of 98.3%.

OPERATIONAL PERFORMANCE

Several filling patterns are routinely used at SOLEIL during User operation, all of them in Top-Up mode. The most frequent one (82.5%) is the multibunch pattern where the Storage Ring is almost uniformly filled with 4 trains of 100 bunches (out of 416 buckets). A hybrid mode with a high charge single bunch in the middle of the unfilled quart, an 8-bunch and a single bunch mode are also used. Table 1 summarizes the current performances of these modes.

Table 1: The Different Filling Patterns at SOLEIL

Mode of operation	User Operation	Ultimate performance achieved
Multibunch	400 mA	500 mA
Hybrid	395 mA + 5 mA	390 mA + 10 mA
8 bunch	100 mA	100 mA
1 bunch	11 mA	20 mA

For all these modes of operation, the transverse chromaticities (+2 in horizontal and vertical planes) are kept constant. A Transverse FeedBack system successfully damps the transverse instabilities in all the operating modes; it maintains the vertical emittance around 40 pm.rad. As the users change freely field primary parameters of the IDs thanks to feedforward tables for maintaining the orbit, a software feedback, using two quadrupole families, keeps the tunes constant.

The availability of the photon beam during User operation in 2010 has reached 96.3% corresponding to a total of 4095 hours. This performance has been particularly affected by one single failure in the control part of the cryogenic plant of the RF system which caused a 58-hour beam interruption. It is interesting to mention that we hit the 100% availability twice during a complete week and that 99% availability has been reached for 14 weeks out of 34.

The Mean Time Between Failure (MTBF) is 41 hours which is almost 7 hours higher than in 2009. A record of 75 hours without beam loss has been reached during the last part of 2010. Over the period from January 2011 till end of July 2011, the availability figure reached 98.3% over 3059 hours of beam time. Over the same period, the MTBF has also been slightly improved and reached 44 hours. The operation group contributed to these improvements by implementing better diagnostics of the trips. They installed temperature and water leakage sensors and developed many high level applications programs for supervision and monitoring. Figure 1 summarizes the photon beam availability since 2007.

The Storage Ring is routinely operating at 500 mA in multibunch mode during Machine shifts and during radiation surveys of the Beamline hutches for qualifying them up to 500 mA operation. There are however vertical instabilities due presumably to ions that limit the feedback performance at 500 mA, which is currently under investigation. These instabilities are avoided by adopting the continuous multibunch filling and lowering the RF voltage [1]. The User operation at 500 mA design current is scheduled for the beginning of 2012, after the completion of the radiation safety tests of the Beamlines. The goal for 2012 is to deliver 5500 hours of user beam time.

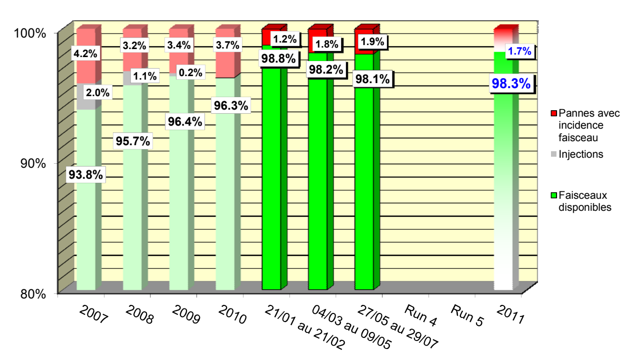

Figure 1: Beam availability since year 2007.

Reducing Insertion Device Effects

We have already reported that a significant reduction of injection efficiency and beam lifetime are observed when using specific ID configurations in daily operation [2]. This is essentially the case when the five U20 in-vacuum undulators all located in short straight sections at a rather high horizontal beta function (18 m) are closed at their minimum magnetic gap of 5.5 mm together with the 10 m long HU640 undulator, in its linear vertical polarization mode. There is an on-going effort for suppressing these non-linear effects [3]. Since November 2010, a new optics, with a smaller horizontal beta function (5 m instead of 11 m) at the HU640 location and a different sextupoles setting improved the beam lifetime and the injection efficiency. In the multibunch mode at 400 mA, the beam lifetime is now always greater than 10 hours and the injection efficiency larger than 60% whatever the users IDs configuration. Also, minimising the betatron coupling down to 0.1% and restoring the 1% emittance coupling via the vertical dispersion should lead to additional improvements as compared to the operation with 1% natural coupling [3]. Several Machine tests, with the horizontal beta function further reduced in the short straight sections (14 m instead of 18 m) are also promising. In parallel to these improvements, beam-based measurements using closed orbit bumps inside the IDs listed above are being used to measure transverse field integral variation in order to anticipate some passive magnetic corrections [3].

Beam Position Stability

At SOLEIL, the Slow Orbit Feedback (SOFB) and the Fast Orbit FeedBack (FOFB) operate together thanks to a sophisticated communication protocol. The short and long term stabilities at all the source points are within 1 µm in both planes which is satisfying for the users. Nevertheless, the efforts for improving further the orbit stability are still going on. During Top-up injection, DC and AC perturbations have been observed on the Storage Ring horizontal closed orbit. Typically, the Beamline source points can be shifted by up to 10-20 µm and the amplitude of the 3 Hz frequency noise seen on the beam is amplified by a factor 9. These perturbations originate from the imperfect compensation of the magnet Booster power supplies currents. These disturbances have been compensated at the source using a wire loop in the Booster cable tray, fed by an in-house developed power supply [4]. Other types of low frequency noise sources have been identified and localized which allowed reducing the 0.01 Hz-to-500 Hz noise from 600 nm to 200 nm RMS at the in-vacuum ID locations [5]. A special care has been given to the new 160 m long beamline ("Nanoscopium") where very strong constraints are imposed in terms of mechanical and thermal stability. New stands made of Invar have been designed and installed for four electron BPMs of the machine and the photon BPM in the Frontend is also made of Invar. Moreover, a dedicated Hydrostatic Level System will monitor movements of the most critical elements of the Beamline. On the other hand, bending magnet photon BPMs data will be included in the orbit feedback loops in order to improve further more the beam stability at the bending magnet hard X-ray beamlines [5].

INSERTION DEVICES

The installation of IDs is steadily going on with very diverse types. There are now 24 IDs installed on the Storage Ring: 4 electromagnetic helical including, the 10 m long HU640, 12 APPLE II type undulators with periods ranging from 80 to 36 mm, 6 in-vacuum undulators (5xU20+1xU24) and one high magnetic field in-vacuum wiggler to cover the 20-50 keV photon energy range [6]. This summer, a R&D cryogenic in-vacuum undulator (U18) made of Pr2Fe14B and vanadium permendur has also been installed [7]. Its magnetic measurements and their corrections have been first performed at room temperature, and then the undulator has been mounted inside the vacuum chamber where a dedicated Hall probe bench has been used in order to perform on-axis measurements (spectrum optimization) at low temperature. The commissioning of this first prototype and especially the heat budget with beam in different filling patterns will start soon. Two other undulators, the EMPHU and another conventional in-vacuum undulator (U20) are being measured and planned to be installed in a few months. Besides, a pulsed wire bench has been developed at SOLEIL for reducing the measurement time of an undulator and for providing a measurement method without lateral access [8].

NEW DEVELOPMENTS

Double Mini Vertical Beta Function Section

Two independent beamlines for imaging and coherence are planned in one of the long (12 m) straight sections (SDL13) by adding a quadrupole triplet in its centre providing two sections with low vertical beta function. The two sections will accommodate two canted 5.5 mm gap in-vacuum undulators. In addition to the quadrupole triplet, two sextupoles, two BPMs, two combined H/V air correctors, a 4 magnet chicane and the upstream in-vacuum cryogenic undulator are already installed as well as the common FrontEnd. A part of the equipment is shown in Fig. 2. Extensive simulations and experimental optimizations have been performed to prepare the operation of the Storage Ring with this additional quadrupole triplet that reduces the machine symmetry from four to one [3].

Figure 2: A part of the SDL13 straight section. That shows one magnet of the chicane (in red), one of the two additional BPMs on its Invar support, three quadrupoles (in blue), two sextupoles (in yellow) and the U18 cryogenic in-vacuum undulator.

Low α mode and Coherent Synchrotron Radiation (CSR) Emission

A low momentum compaction factor (α) optics is now available at SOLEIL. It has the advantage to keep small the horizontal emittance and also to control the second order term of the momentum compaction factor [3]. Using this optics with α= 4.4 x 10-5, one tenth of the nominal value, a bunch length of 4 ps RMS for 70 μA bunch current, without collective effect has been reached, CSR in the THz frequency range has been produced and recorded on the IR Beamline AILES [9]. This radiation is an attractive source for spectroscopy. Time resolved experiments are also interested in operating the Storage Ring with low α mode. Two full days are planned in December 2011 with a hybrid filling pattern (20 mA in 312 bunches and one 70 μA isolated bunch).

Femto-Slicing Project

While the final version of the Femto-Slicing project [10] is now postponed for lack of funding, a cheaper version is under study. It is less ambitious in terms of laser performance and number of beamlines that will benefit from the femtosecond pulses. The new plan is to share a laser used by one of the SOLEIL beamlines (CRISTAL [11]) which characteristics (2.5 kHz, 3 mJ) still allow a good separation between the core and the slice beams as shown in [12].

High RF Power Solid State Amplifiers

After nearly 6 years of operation and 30 000 running hours, the SOLEIL solid state amplifier technology has largely proved its value with near 100% operational availability, a MTBF greater than 5 000 hours for the four amplifiers of the Storage Ring and greater than 15 000 hours for the Booster amplifier [13]. In the meantime, thanks to the acquired expertise and the arrival of a new generation of transistors, we have carried out developments which led to twice the output power for the elementary modules (700 W at 352 MHz and 500 MHz), while improving the performance in terms of gain, efficiency, linearity and thermal stress. The increasing interest for this technology has led SOLEIL to collaborate with several other laboratories and conclude a transfer of know-how with the French company ELTA-AREVA.

New Design of a Fast Switching Power Supply

A power supply able to switch between +/- 350 A within 50 ms, without any current overshoot and with a very good current resolution over the full scale (50 ppm) has been designed and constructed in-house at SOLEIL [14]. This power supply is to be used for the electromagnetic/permanent magnet helical undulator (EMPHU) [15] and allow for fast switching of the photon polarization.

Improvements of the Injection Pulsed Magnets

For suppressing the vertical residual orbit bump, an active corrector is under development and a modification of the thin-wall metallic chamber of the thick septum is in preparation. The cooling of the thin eddy current septum has been improved in order to keep it to an acceptable temperature up to 500mA stored beam [16].

Beam Based Measurements

Among on-going developments at SOLEIL, bunch length measurements using incoherent synchrotron radiation fluctuation has been developed [17], the electron beam energy has been measured using spin depolarization method [18] and the first measurements with a kicked off axis bunch for pseudo single bunch operation mode have been performed [19].

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