OPERATION AND PERFORMANCE UPGRADE OF THE SOLEIL STORAGE RING

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Abstract

SOLEIL delivers photons to 26 beamlines and 3 new ones are under construction together with the femto-slicing project. Up to 5 filling patterns are available for the users including a low-alpha mode; all of them are in Top-Up injection. The beam current for the users has been increased to 430 mA in the multibunch hybrid mode. The Storage Ring (SR) is running with a new optics incorporating an additional quadrupole triplet in one long straight section. The beam position stability remains excellent. Vertical positions from the dipole X-BPMs have been included in the orbit feedbacks loop with very encouraging results. A feedback loop maintaining the emittance coupling value close to 1 % for any Insertion Device (ID) configuration has been implemented. Up to 25 very diverse IDs are now installed on the SR, and several others are under design or construction. In-house developments are being carried out in several domains such as construction of a spare SR dipole power supply and of 50 and 80 kW-500 MHz solid-state amplifiers.

OPERATIONAL PERFORMANCE

Up to five filling patterns are routinely used at SOLEIL during user operation, all of them with Top-Up injection. Table 1 sums up these patterns and their characteristics and Figure 1 shows their distribution during 2012.

Table 1: Five Different Filling Patterns for SOLEIL Users

Filling pattern	User operation	Achieved ultimate performance
Uniform	430 mA	500 mA
Hybrid	425 + 5 mA	420 + 10 mA
8 bunches	88 mA	110 mA
1 bunch	11 mA	20 mA
Low-Alpha	4.7 ps RMS 65 μA/ bunch	2.5 ps RMS 10 μA/bunch

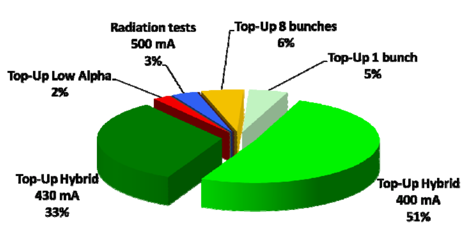

Figure 1: Distribution of the five filling patterns delivered to the beamlines in 2012.

The multibunch hybrid filling pattern (train of 312 bunches + 1 high current 5 mA single bunch) is overwhelmingly requested: 83.8 % of the total number of shifts. The number of hours dedicated to Low-Alpha operation was more than doubled with respect to 2011.

In 2012, 5133 out of the 5341 beam time scheduled hours were delivered to the beamlines. The beam availability dropped by 2.3 % with respect to previous year to reach 96.1 %. The main reasons of this important increase of the downtime (3.9 %) are related, on one side, to the utilities: important failures were reported on the compressed air and two water cooling systems (2 %). On the other side, the SOLEIL facility suffered from a significant increase of the power outages (0.8 %): 14 beam trips were due to drops shorter than 1 second of the electric power resulting in 14 hours of beam interruption and 4 total main power outages occurred (the longest one lasted more than 8 min and affected all the SOLEIL facility) with a cumulative downtime of 30 h. Several actions have been decided to improve the long-term maintenance of the utility services. Proposals and complex backup solutions are under study to enhance the quality of power delivered by the electric company. The Mean Time Between Failures (MTBF) has slightly increased from 47 h to 49 h as compared to 2011; nevertheless the Mean Time To Recover (MTTR) was longer in 2012. It is worth noting that despite this very difficult context, the beam was provided to up to 25 beamlines with an availability of 100 %, more than 99 % and 98 % during respectively 5, 15, and 22 weeks over the 37 scheduled weeks. The sustained efforts on the reliability and robustness of the control system and all the equipment have enabled us to automate and easy up the operation.

Since January 2012, the SR is operating with a new optical setting incorporating an additional quadrupole triplet in the middle of one of the long straight sections in order to host two canted in-vacuum undulators for the forthcoming ~180 m long Nanoscopium and ANATOMIX beamlines [1]. This modification has totally broken the existing four-fold symmetry of the ring; a large number of machine shifts were dedicated to assure no degradation of the machine performance in different beam filling modes, particularly the beam emittance, injection efficiency and beam lifetime, against various ID configurations. Since September 2012, the beam current for the users has been increased from 400 mA to 430 mA in the hybrid multibunch filling pattern. The quality of the photon beams delivered to the beamlines has been

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ceaselessly improved: removing the current dependency at high current per bunch of the Beam Position Monitor (BPM) readouts enables to deliver the same electron beam positions irrespectively of the operation modes or ID configurations. Five feedback loops are currently used altogether during user beam operation to assure the highest stability in term of positions, divergences and beam sizes of the electron beam. Thanks to two active orbit feedback systems (slow and fast systems) the short and long term (8 h) position stabilities at all the source points are constrained within 1 µm RMS in both planes. The low frequency noise sources have been identified and minimized, which allowed reducing the integrated noise below 200 nm RMS at the ID locations for the frequency range 0.01-1000 Hz. More recently, X-BPMs from four bending magnet beamline frontends have been inserted in the global slow orbit feedback loop during user operation [2]. Tune feedback has been made fully transparent to all beamlines in 1 and 8 bunch filling patterns by adding an ultra-low current bunch in between two high current bunches, for tune measurement. Since September 2012, the ratio between the vertical and horizontal beam emittances is maintained close to 1 % for any ID configurations [2].

Low-Alpha Mode

A number of noteworthy improvements was made during the past one year with respect to the Low-Alpha (α) mode, which was delivered three beamlines (AILES, TEMPO and CRISTAL) users over two sessions in 2012. The first one was a block of 48 hours of $\alpha/25$ operation in April, and the second one in November consisted of 48 hours of $\alpha/25$ and 20 hours of $\alpha/100$ operation. The $\alpha/100$ operation was intended to fulfill the request of the beamlines carrying out time-resolved experiments, providing a less than 3 ps RMS bunch length. Together with the effort of minimizing the beam losses particularly enhanced in this mode, the Top-Up injection was realized in April, as it can be seen in Figure 2.

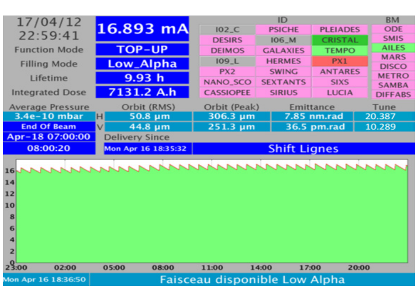

Figure 2: Machine status panel showing successful Top-Up operation in the Low-Alpha mode ($\alpha/25$) achieved in April 2012. The photon beams are delivered to 3 beamlines: AILES, TEMPO and CRISTAL.

The bunch current strongly impacts the THz photon spectrum stability in terms of amplitude and shape, via high sensitivity to the electron bunch length and profile. The current variation at each beam refill was therefore limited to ± 3 µA over 65 µA per bunch for the $\alpha/25$ mode, and even ± 0.5 µA over 15 µA per bunch for the $\alpha/100$ mode, thanks to special Linac and Booster injector tunings. Thanks to the two (slow and fast) orbit feedback systems, the stability at radiation source points was maintained at a level of 10 µm (horizontal) and 1.4 µm (vertical) for the 0.01 to 1 kHz frequency range in the $\alpha/100$ mode. Apart from optimisation of the fast orbit feedback gains and the refined granularity of RF-frequency correction (0.1 Hz), the principle of the correction remained unchanged compared to the nominal Alpha operation, in terms of interaction between fast and low feedback systems. Within the frame of improving the beam stability, a decision was made to replace the existing 352 MHz RF-master oscillator by one providing much reduced time jitter. In the concerned range of frequency between 10 Hz and 1 MHz, the phase noise of the new oscillator was measured to be 0.051 ps RMS, giving nearly a factor of 50 of reduction as compared to the old one. As a consequence, the beam in the Low-Alpha mode turned out to be significantly more stable longitudinally, as measured by a streak camera [3]. In addition to the improvement confirmed and appreciated by the beamline AILES in terms of the Signal/Noise ratio of the THz spectrum, an interesting shift toward higher bursting threshold current of the Coherent Synchrotron Radiation is currently under investigation.

Towards 500 mA Operation

The operation at the maximum current of 500 mA in a uniform filling pattern with IDs closed to their minimum gap (mechanic) or powered to their maximum current (electromagnetic) has been validated during a continuous shift of 8 hours without any problem and with good performances in terms of beam lifetime and injection efficiency. Regarding the multibunch operation with the hybrid filling pattern, machine studies performed in 2012 indicated that a 500 mA beam in the ¾ filling pattern is still under a severe influence of the fast-beam-ion instability (FBII), which eventually blows up the beam leading to a complete beam loss in typically 10 minutes after the final current is reached. The instability threshold is expected to lie somewhere in between 430 and 500 mA. The on-going studies pursue the possibility of destructive reactions of the fast bunch by bunch transverse feedback as implied by the post-mortem analysis, in the hope of finding preventive measures against FBII-induced beam losses.

FEMTO-SLICING PROJECT

During 2012, the shutdown periods kept being very busy with the first stage of the installation of the femto-slicing [4] equipment in the SR tunnel. Especially a dedicated new dipole vacuum chamber (see Figure 3) will allow injection of the femtosecond laser that will co-propagate with the electron beam in the modulator wiggler installed in the following medium straight section; the CRISTAL beamline frontend was modified and first diagnostics and vacuum equipment have already been installed. Four roof beams of the SR tunnel have been modified allowing a penetration hole suitable for the passage of the laser coming from the CRISTAL beamline, 80 m far away from the modulator. A small radiation safety shielded box making the transition between the experimental hall and the tunnel was also installed on the roof; it hosts two mirrors to guide the laser inside the tunnel. The installation has been following the planned schedule and the commissioning with beam is foreseen by the end of this year.

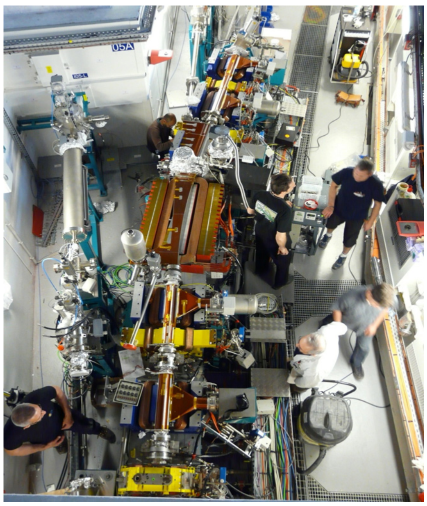

Figure 3: Installation of the new dipole vacuum chamber and first diagnostics.

BEAMLINES

A total of 24 beamlines are now available for the users among the 26 taking already the photon beams. The two remaining ones (HERMES and Nanoscopium) will be available in 2014. Three new beamlines are under construction (ROCK, ANATOMIX and PUMA) and will be available by the end of 2015, raising to 29 the number of beamlines. For the year 2012, there were 2800 users from 479 different laboratories using the facilities.

NEW DEVELOPMENTS

Built in-house Spare SR Dipole Power Supply

SOLEIL experienced many hours of beam interruption in October 2008 (48 hours) and November 2009 (24 hours), during repairs of the SR dipole power supply. To prevent this happening in the future, a new power supply has been designed and built in-house with the following characteristics: 580 A/610 V +/- 10 ppm [5]. The tests of performance qualification have been successfully performed and in the event of a breakdown of the original dipole power supply, it will take less than 5 minutes to switch to the spare power supply.

Another spare power supply for the SR sextupole families is under construction in-house.

Insertion Devices

A new electromagnetic/permanent magnet helical undulator (EMPHU) [6] for fast switching of the polarization has been installed and commissioned with beam, which brings the total number of IDs installed in the SR to 25 [7]. The in-vacuum undulator previously with SmCo magnets has been changed to another one with NdFeB magnets, for providing a higher magnetic field and filling the gap between harmonics around 4 keV. Several other state-of-the-art IDs are under design or construction such as an aperiodic in-vacuum wiggler, a cryo-ready in-vacuum undulator, or a Robinson wiggler.

High RF-power Solid-state Amplifiers

After 6 years of operation, the SOLEIL innovative design of high RF power solid-state amplifiers at 352 MHz has proved itself and demonstrated that it is an attractive alternative to the vacuum tube amplifiers, featuring an outstanding reliability (100 % operational availability) and a MTBF larger than 1 year [8]. A refurbishment of the modules of the SR amplifiers using a new generation of transistors, validated after a test run of 5 000 hours, has started at a rate of 1-2 towers a year. In addition an R&D program concerning other frequencies such as 500 MHz, 200 MHz or 176 MHz is going on. The picture 4 shows a 500 MHz 10 kW unit prototype, currently under long-term test at SOLEIL. Two 500 MHz amplifiers, based on this technology, are being built for THOMX (50 kW) and SESAME (80 kW) projects.

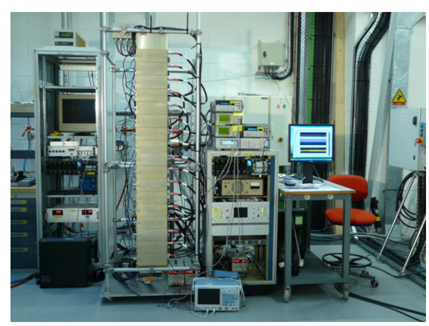

Figure 4: 500 MHz 10 kW unit prototype under long-term test at SOLEIL.

REFERENCES

[1] P. Brunelle et al., IPAC'11 Proceedings, pp. 2124–2126.
[2] N. Hubert et al., WEPME001, these proceedings.
[3] M. A. Tordeux, ESLS20 workshop, BESSY November 2012.
[4] A. Nadji et al., IPAC'10 Proceedings, Kyoto, Japan, pp. 2499-2501.
[5] F. Bouvet, Power Supplies Activities at SOLEIL, 3rd POCPA Workshop, DESY, May 2012.
[6] F. Marteau et al., Proceedings of Magnet Technology 22, IEEE 22 (3), 4102004, 2012
[7] M.E. Couprie et al., AIP Conference Proceedings 2010, 1234, pp. 519-522
[8] P. Marchand et al., IPAC'11 Proceedings, San Sebastian, Spain, pp. 376-378.

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