PROGRESS STATUS FOR THE 10-YEAR-OLD SOLEIL SYNCHROTRON RADIATION FACILITY

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Abstract

Synchrotron SOLEIL has just turned 10 years since its commissioning. The 2.75 GeV facility is now delivering very stable photon beams to 29 beam lines. A total of 5 operation modes are available in top-up. Maintaining and updating the key performance metric remains a daily work facing both aging of components and tighter operation requirements. Low-alpha operation is attracting more beam lines leading us to an upgrade of the Booster (BOO) radiofrequency (RF) system in order to increase the injection efficiency into the storage ring (SR). The femtoslicing experiment is now in production for a hard X-ray beam line; a dedicated chicane has been installed for a second beam line in the soft X-ray regime. The two long canted beam lines can operate simultaneously at minimum gaps since May 2016 thanks to the introduction of a dedicated photon absorber and a fast angle interlock. R&D work in several areas will be reported. In parallel lattice design are in progress both for short term and long term evolution of the ring performance.

OPERATION STATUS

Introduction

The SOLEIL [1] facility (Tab. 1) has seen its first beam eleven years ago. Today, a total of 27 beam lines (BLs) are open to external users. Two other BLs are under partial commissioning and shall get their first users between the end of 2017 and 2018. In daily operation, 27 insertion devices (IDs) are freely controlled by the user with the exception of an out-of-vacuum wiggler (W164) and an in-vacuum wiggler (WSV50) operating at fixed gap values due to their impact on the horizontal emittance. Five feedback systems (slow, fast orbit, transverse bunch-per-bunch (FBT), tune, coupling) are running 24/7, all in top-up injection for the 5 modes of operation whose distribution is given by Fig. 1.

Table 1: SOLEIL SR Main Parameters

Parameters	Values
Energy [GeV]	2.75
Circumference [m]	354.097
Natural Emittance [nm.rad]	4.0
Symmetry	1
Tunes (H/V)	18.155 / 10.229
Natural chromaticities (H/V)	-53/-19

SOLEIL continues to extend its panel of filling patterns and user modes with the introduction of more beam lines using low-alpha mode [2] and the new femtoslicing mode (see thereafter).

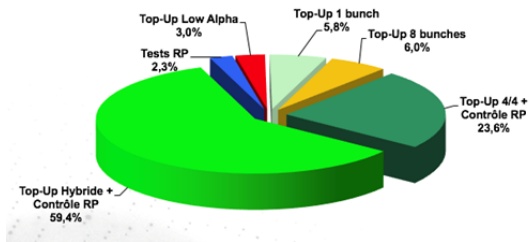

Figure 1: Distribution of the filling pattern for the Year 2016. Radiation Safety control are referred as RP.

Performance

The year 2016 has been the worse in terms of operation due to one major cryogenic incident resulting in a forced shutdown period of 2 weeks. The overall beam availability was 98.3 % (94.2 %) with a MTBF of 82.7 h (80h) MTTR of 1h22 (5h24) where bracket numbers include the two weeks forced shutdown. Top-up availability was 99.54 %.

One of the two LINAC Klystron failed during a site voltage sag, which forced us to switch to an injection degraded mode in the Booster with a beam of 66 MeV instead of 110 MeV without impacting the quality of the top-up mode beam delivered to the users.

Cryogenic System Breakdown

End of May 2016, a beam trip occurred due to a nitrogen pre-cooling fault on the cryogenic system operating the two superconducting cavities of the storage ring. Investigations revealed a loss of efficiency on the first exchanger of the Helium liquefier due to water deposition on the Helium side. An emergency meeting concluded that the situation could likely lead to a turbo expander destruction. Experts advised us to take immediate actions to dry up the system. The water pollution revealed more significant than expected. In total, 12 days were devoted to this operation involving large amount of human resource: 20 man-weeks during the drying critical phase (cold box up to the compressor room with replacement of the activated charcoal). With the help of expert consultants, we come to the conclusion that water accumulation can reach critical levels despite the close loop operation. A desiccation system shall be installed in

the close future and maintenance period of the full system has been completely revised.

Simultaneous Operation of Canted IVUs

Since May 2016 the two long BLs, ANATOMIX and Nanoscopium, operate simultaneously. They take their beam from two canted 5.5 mm in-vacuum undulators (IVUs) installed in a 12 m long straight section [3]. To operate safely a dedicate photon movable asymmetrical absorber (Fig. 2) has been designed and installed at the entrance of the downstream undulator in order to prevent any radiation to hit the CuNi sheet damaged severely in 2011 and assuring the electric continuity for the machine impedance. A fast multi-input interlock system has been added including a new vertical angle interlock of ± 25 µrad [4]. Details are reported in Ref. [5].

An additional diagnostic (imager) shall be introduced in the front end of the beam lines in August 2017 to monitor regularly any variation of the alignment of IVUs and absorber in redundancy to the XBPM. The final cryogenic U18 undulator [6-7] of ANATOMIX shall be installed and fully commissioned during the first semester of 2018.

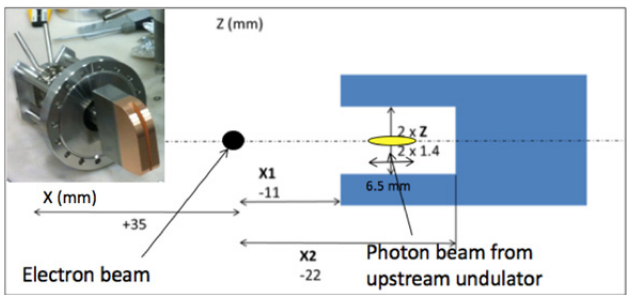

Figure 2: Dedicated movable photon absorber in 90-degree U-shape to block out any off-axis radiation from the upstream IVU.

Storage Ring RF-System.

In January 2017, the last 300 kW power coupler of the SR cavities was installed. That will open the possibility of storing 500 mA using a single cryomodule. Combining two amplifiers per cavity shall be ready by the end of 2017 [8].

The upgrade of the 180 kW solid state amplifiers (SSAs) continues at a rate of 2 towers a year (16 in total). Transistors of 6th generation much more robust and with higher performance (+10%) are implemented.

SSA technology development is an intense activity [9]: a 500 MHz 80 kW SSA has been delivered to SESAME [10], a 50 kW SSA built for ThomX. R&D work for LUCRECE project aims to build a 1.3 GHz SC-RF system with is SSA [11].

Other Equipment

The upgrade of the injection section in the SR is going to its end with the installation of new fast vertical correctors to reduce the vertical orbit distortion during injection.

The FBT has been enhanced to be able to act as a bunch cleaner on demand to improving purity.

The Multipole Injection Kicker (MIK) designed by SOLEIL in the framework of the MAX-lab collaboration shall be delivered before the end of 2017 to MAX-IV. A second version of the MIK should be installed at SOLEIL in 2018.

A major upgrade of the LINAC control shall be finished by the end of 2018. A processor for the FBT system has just been received from Spring8-TED. It will serve both ThomX and SOLEIL accelerators. The SPESO project to measure the bunch length out of the LINAC using Smith Purcell radiation is reported in Ref. [12].

Work for improving reliability and redundancy of power supplies (PSs) continues with the construction of a spare PS for SR sextupole, BOO-to-SR transfer line dipole. Another type of spare PS will be for electromagnetic IDs (HU640 and HU256). Obsolescence of the power unit for regulating SR correctors leads to the development of new power supply with Sigmaphi Electronics.

SOLEIL has passed 10 years of operation. Obsolescence, aging of components and systems require to setup a strategy in order not to penalize the overall performance of the facility.

MOGA Optimization

Multi-Objective Genetic Algorithm MOGA-ELEGANT was used for the first time to find the best settings of quadrupole and sextupole magnets in order to maximize the dynamic and momentum apertures used as proxies for the injection efficiency and the Touschek lifetime respectively. The solutions obtained after one month of computation in the high level computational cluster of SOLEIL using 200 CPUs are detailed. The improvement of the Touschek lifetime obtained with MOGA is confirmed by the beam-based experiments. The beam lifetime of the SOLEIL SR was increased experimentally by 40 % as predicted by the simulations [13].

Coupling Correction

SOLEIL operate at 1% coupling for multibunch filling patterns. Users request to maintain the beam sizes variations to a level of 5 to 10 percent over a few hours of operation. Tasks are identified to correct locally the coupling introduced by two IDs: a dedicated slow feedforward has been implemented recently for an Apple-II (HU36). A combination of local coil adjustment and fast (50 Hz) active skew quadrupole is under way for correcting the coupling introduced by the 10-meter-long EM-device (HU640) whose magnetic switching frequency shall reach up to 10 Hz in the future.

RF-Booster Upgrade

During the low-alpha operation, the low (15-20%) injection efficiency from the booster to the storage ring is

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a strong limiting factor preventing new BLs to benefit from this mode. In order to shorten the booster bunches by almost a factor 2, the booster RF-system is being upgraded to increase the RF-voltage from 1 to 3 MV. The present SSA tower will operate at higher voltage (1.2 MV instead of 1 MV). A second cavity will be installed early 2018 with a 60 kW SSA to deliver 1.8 MV. A new digital LLRF system is also foreseen. This upgrade shall allow increasing the injection efficiency (40-45%). In addition, a full booster RF redundancy will be reached for normal operation.

FEMTOSLICING PROJECT

Commissioning and BLs

The SR optics allows naturally to generate enough effective dispersion in the horizontal plane to produce femtosliced pulses for several beam lines. The laser used produces 40 fs pulses (FWHM, measured value) of 800 nm wavelength with a repetition rate of 1 kHz. The energy per pulse is 5 mJ. Most of the power (3 mJ) makes the energy modulation inside a 3.5-meter-long wiggler W164 [14]. Five weeks of operation were scheduled between June 2016 to February 2017 during hybrid filling pattern. This was transparent for the other BLs. Ultrashort hard X-ray pulses were detected on the BL CRISTAL at 7 keV, and were successfully used in a pump-probe diffraction experiment. The measured flux reaches 1000 ph/pulse [0.8% energy bandwidth] at the exit of the CRISTAL BL optics. The beam separation is made horizontally in position (typically 2.5 mm). A major upgrade of the laser is ongoing, with the aim of increasing the frequency up to 5 kHz in year 2018 thanks to a SESAME funding by region Ile-de-France.

TEMPO Chicane

Since early 2017, a second BL in the soft X-ray domain (TEMPO) starts its femtoslicing commissioning. The trajectory originally is off-axis by 1.6 mm in position and 200 µrad in angle for an energy modulation of 19.6 MeV. In order to steer the beam to the center of the first beam line mirror, a dedicated electromagnetic chicane is necessary. The 3-magnet chicane was commissioned during spring 2016 (Fig. 3). The mirror itself is used as an extra corrector to zero the beam angle. The chicane can be switched on and off slowly during user operation allowing to adjust the strength up to a maximum energy modulation of 25 MeV.

R&D WORK

Among ID development activity, a new cryo-ready U18 IVU will be installed during the next winter shutdown period [6-7]. A 3 m-long cryo-ready U15 IVU with 3 mm magnetic gap is under construction. An aperiodic in-vacuum wiggler with spring-based self-magnetic force compensation has been delivered to MAX-IV [15].

Lastly, SOLEIL is now in capacity to perform in-house NEG coating.

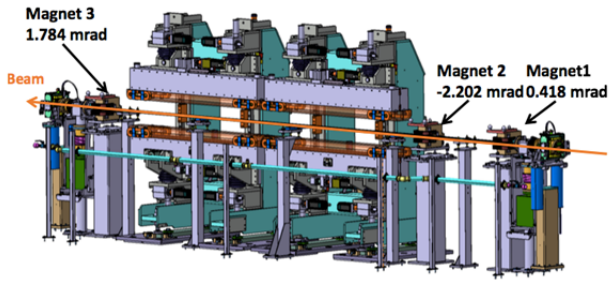

Figure 3: Electromagnetic 3-magnet chicane for the soft X-Ray BL TEMPO in order to use the femtosliced beam on axis.

SOLEIL UPGRADE

Preliminary studies for a major upgrade of the SOLEIL towards a diffraction limited light source are continuing. A tentative agenda is to write a Conceptual Design Report in 2020 and a Technical Design Report in 2021- 2022 before starting the project with the aim to have light on the horizon of 2026. A lattice with a 190-230 pm natural emittance but also more aggressive scenarios are presented in Ref. [16-17].

OTHER PROJECTS

SOLEIL participate in the OPEN SESAME H2020 project in terms of support, human resources, expertise, scientific exchange [18].

The commissioning of COXINEL has starting since 2016. This demonstrator is made of a laser plasma injector, an 8-meter long transfer line and an IVU with the goal to produce free electron laser amplification [19]. To control the large divergence of the beam 3 permanent magnet 200 T/m quadrupoles with 50 % tunability have been constructed [20].

Finally, SOLEIL has been strongly involved in the design and construction of the compact (70 m2) X-Ray source THOMX (50-89 MeV) using Compton backscattering. The commissioning shall start early 2018; using very high gain Fabry-Pérot cavity, a flux of 10^{12} to 10^{13} ph/s is expected [21].

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