

## SOLEIL STATUS REPORT

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### Abstract

The 2.75 GeV synchrotron light source SOLEIL (France) delivers photons to 27 beamlines and 2 new ones are under construction. The commissioning of the Femtoslicing operation mode involving two beamlines is in progress. The uniform filling pattern is now available to users with a 500 mA stored beam current. The operation of the two canted and long beamlines ANATOMIX and Nanoscopium both using in-vacuum insertion devices (IDs) as a photon source has been raising challenges still under investigation. Upgrades of crucial subsystem equipment like magnet power supplies, storage ring RF input power couplers, and solid state amplifiers are continuing. New user requests for beam stability are under upgrade consideration. Other projects for the storage ring are ongoing such as the design and construction of new insertion devices, new multipole injection kicker, localised small and round photon beam production, as well as R&D on 500 MHz solid-state amplifiers. In parallel first studies for a future upgrade of the machine have been progressing.

### OPERATION

Today, 27 beamlines are opened to the users. The last two beamlines ANATOMIX and PUMA, currently under commissioning, will be available to the Users by 2016. Five electron beam filling patterns are routinely delivered during user operation in Top-up injection mode (see Table 1 and Figure 1).

Table 1: Five Different Filling Patterns for SOLEIL Users

Filling pattern	2014 user operation	Achieved ultimate performance
Uniform (416 bunches)	430 mA (one week at 490 mA)	500 mA
Hybrid (312 + 1 bunches)	425 + 5 mA	455 + 5 mA
8 bunches	90 mA	110 mA
1 bunch	16 mA	20 mA
Hybrid Low-Alpha (bunch length/bunch current)	4.7 ps RMS / 65 $\mu$ A/ bunch	2.5 ps RMS / 10 $\mu$ A/bunch

In 2014, 6370 hours of beam time have been scheduled shared in 1329 hours for Machine studies and 5041 hours for user operation. A total of 4963 hours were actually issued to the Users which correspond to an availability of the photon beam for the beamlines of 98.5 %.

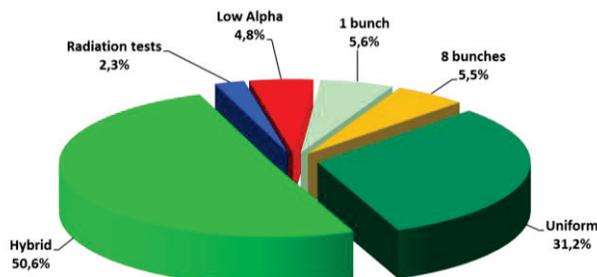


Figure 1: Time distribution of the five filling patterns delivered to Users during 2014.

Over the 35 scheduled weeks, the availability was above 99 % during 21 weeks during 5 of which it was at 100 %. In the very near future, the uniform user operation mode will be delivered with a current of 500 mA.

Operation in this mode has been tested successfully for one week at 490 mA in user operation. In addition, beam current in hybrid mode will be upgraded to 450 mA shortly. The distribution of multibunch mode beam time is different from last year [1]. The hybrid filling pattern is most common, closely followed by the uniform mode while the three other modes are almost at the same percentage as shown in Figure 1. Bunch purity is now maintained to a few  $10^{-4}$  level over a full week thanks to the upgrade of the LINAC bunch cleaner.

As has been the case for the last two years, external electrical power drops are the main source of beam interruption. The main cause is the heavy work around the construction of a new university (Paris-Saclay) nearby SOLEIL. This problem represents 35 % of the beam time lost in 2014. The second main source of beam interruption (15 %) was human errors. Fault rates of equipment are reasonably low as can be seen in Figure 2. In particular, the fraction of lost time due to power supply dysfunctions or failures is drastically reduced compared to the previous years. The Mean Time Between Failures (MTBF) has reached a new record of 75 hours and the Mean Time To Recover (MTTR) has reached 1.09 hour.

Five feedbacks (FB) are simultaneously in operation (Slow Orbit FB, Fast Orbit FB, Transverse FB, Tune FB and Coupling FB). Top-up injection allows constant beam current intensity within  $\pm 0.5$  %. The long and short term photon beam position stability is reaching the desired performance. Using global orbit feedback systems, the long term position drift (8 h) is below 1  $\mu$ m RMS and the short term (0.1 Hz – 1 kHz) vertical noise is below 300 nm RMS. Recently, a regularization of the singular values

using Tikhonov algorithm [2] has allowed for an increase of the Fast Orbit Feedback gain without adding noise. The 50 Hz line was attenuated by a factor of 2 and the integrated noise (0.1 Hz – 1 kHz) in the vertical plane has been reduced by 22 %.

On the other hand, new demands of faster switching the polarization of the VUV electromagnetic undulator (HU640) (200 ms instead of 40 s) and faster undulator gapscan (8 mm/s instead of 1 mm/s) affect the beam size stability of the newly commissioned long beamlines, Nanoscopium and ANATOMIX (150 to 200 m length), that have the most stringent specifications on the beam size variation ( $\pm 2$  % during 8 hours!). Investigations including a possible upgrade of the coupling feedback, a coupling feedforward or local compensation are envisaged.

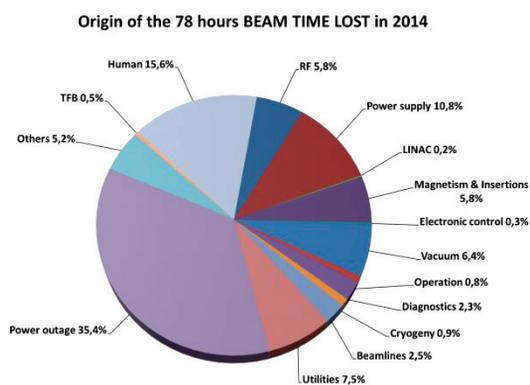


Figure 2: Pie chart of the distribution per domain of the beam loss origin during 2014.

### Femtosing Commissioning

This project based on the interaction in a wiggler of an external laser with the electron beam [3] aims at delivering very short pulses of photons (100-200 fs) to two beamlines in phase 1, namely CRISTAL and TEMPO, for diffraction studies and time-resolved photoemission respectively. After commissioning of the different diagnostics, alignment and optimization, the THz signal showing that the interaction has occurred was observed for the first time on September 29<sup>th</sup> 2014 and it is now well reproducible (Figure 3). The first photons from the sliced electron beam were observed on the CRISTAL beamline on February 9<sup>th</sup> 2015. Commissioning is continuing in order to maximize the number of photons and to characterize the pulses [3]. A dedicated electromagnetic chicane made of three magnets is currently under construction to enable the steering of the femtosliced beam directly at the center of the entrance mirror of the TEMPO beamline.

### Canted Undulators Straight Section Issues

Two canted 5.5 mm minimum gap in-vacuum undulators are installed in a 12 m long straight section, with a 6.5 mrad separation angle achieved with a chicane

of four permanent dipole magnets [4]. To provide low vertical  $\beta$  functions at the middle of each undulator, an extra triplet of quadrupoles is added in the middle of the section.

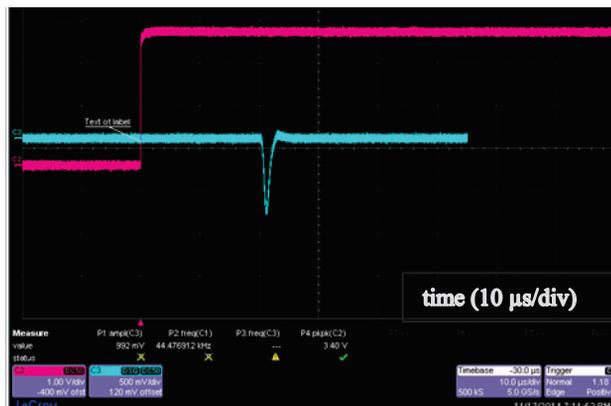


Figure 3: THz radiation intensity from a Bolometer at AILES beamline, resulting from the laser-electron interaction in the Femtoslicing commissioning.

During the first tests performed with a stored beam current of 500 mA, with both undulators simultaneously closed at their minimum gaps, strong vertical instabilities and a vacuum pressure and radiation dose increase in the downstream undulator have been observed. When the undulator was removed from the tunnel and opened during the following shutdown, it was observed that the lower liner sheet (Copper sheet plated with Nickel) was covered with photon beam impacts and had melted in some spots. Further investigations showed also some magnet demagnetization. In fact, a significant part of the off axis radiation of the upstream undulator is heating the downstream undulator magnetic system. After several investigations, it appeared that the most likely cause would be the liner vertical profile imperfections due to vertical position of magnets and poles after tuning correction. Simulations taking into account the real shape of the liner have shown that at a local deformation of the liner (bump), the power density deposited can be larger by a factor of 40 reaching a local peak power density of 400 mW/mm<sup>2</sup> for a 500 mA beam current. This behavior was not anticipated since the first calculation was performed with a perfect liner. In addition to a newly developed beam angle interlock, a photon absorber with the adequate vertical opening and situated at the entrance of the downstream undulator is under study to protect the latter from the upstream photon beam.

## SUBSYSTEM MAINTENANCE AND UPGRADES

Maintenance and upgrades are a critical consideration for our facility since the injector complex is already 10 years old and most of the storage ring equipment is approaching the same age.

## Power Supplies

To solve the problem encountered in 2013 [1], all the regulation cards (about 180, including the spare cards) of the storage ring quadrupoles power supplies were reprogrammed with a corrective firmware in mid-2014 by the SOLEIL power supply team. It has to be noted that other synchrotron facilities equipped with the same kind of hardware have been facing similar problems with their power supplies. And thus they also take advantage of the aforementioned work. The upgraded design of the 3Hz 2Q power converter [1] has been generalized to all 16 racks of the Booster's Dipole and Quadrupole power supplies, including some improvements decided after temperature measurements. This important upgrade on the main Booster PS results in a very significant reliability improvement. In 2015, the efforts to improve power supply reliability and to meet the operational goals will continue. Priority will also be given to equipment availability with the in-house construction of a spare power supply for the Storage Ring sextupoles and TL2 dipole, and a spare power supply for the electromagnetic insertion devices.

## RF System Solid State Amplifiers

The arrival of the so called 6<sup>th</sup> generation transistors (50 VDC) and the expertise acquired at SOLEIL on Solid State Amplifiers (SSA), has allowed the development of new modules which can deliver up to 700 W at 352 MHz and 500 MHz, with much better performance in terms of gain and efficiency, while reducing the thermal stress. These modules were tested on the 150 kW - 352 MHz amplifiers, designed by SOLEIL for the ESRF; after 3 years of operation on the ESRF Booster (4 amplifiers) and 1 year on the Storage Ring (3 amplifiers), their yearly failure rate is much lower than 1 %. An upgrade of the SOLEIL Storage Ring SSA's was also planned in order to profit from using 6<sup>th</sup> generation transistors. It started in 2013 with the replacement of all the preamplifier transistors (1<sup>st</sup> and 2<sup>nd</sup> stages of our 4 amplifiers); it will now continue with the 3<sup>rd</sup> stage modules, at a rate of one or two 45 kW towers a year. In July 2014, the first fully upgraded tower was implemented in Amplifier\_1, where it operates alongside 3 "old" towers without any problems. The electrical power savings, resulting from the improved efficiency shall compensate for the upgrade investment costs after about 3 years of operation. At the end of 2013, a license of transfer of know-how concerning our SSA technology was granted to the French company, SIGMAPHI Electronics (SPE). In September 2014, SOLEIL and SESAME, the light source under construction in Jordan, concluded an agreement of collaboration for realizing the first of the four 80 kW - 500 MHz SSA's needed for the SESAME Storage Ring. SPE, as SOLEIL licensee, will supply the 3 other ones. In addition, a 50 kW - 500 MHz SSA has been built at SOLEIL for ThomX, the Compton X-ray source under construction at Orsay. It is currently under testing, as can be seen in Figure 4.



Figure 4: ThomX 50 kW, 500 MHz SSA constructed at SOLEIL and presently under testing.

## ONGOING PROJECTS

A total of 27 very diverse IDs are now installed in the Storage Ring. Others are under construction, such as the second U18 cryogenic in-vacuum undulator for the ANATOMIX long beamline and a spare U20 in-vacuum undulator for high photon energy beamlines. Two other IDs designed at SOLEIL are being constructed, in the frame of the collaboration between SOLEIL and MAX-IV laboratories: an aperiodic in-vacuum wiggler (WSV50) and a 3m-long U15 in-vacuum cryo-ready undulator with a 3 mm gap.

In the framework of the same collaboration, a Multipole Injection Kicker (MIK) that can inject without disturbing the stored beam is under construction together with its pulsed power supplies.

A study of the adaptation of a long straight section to produce a small and round photon beam is underway.

Finally, we are continuing very preliminary investigation studies of a new lattice for the storage ring upgrade, aiming to reach ultra-low horizontal emittance by using Multi Bend Achromat structures [5].

## PERSPECTIVES

The transition to a stored beam current of 500 mA will be offered to users very soon. Maintenance and upgrades of equipment will continue to assure the highest availability and reliability for the accelerators. First user operation in Femtoslicing mode is foreseen before the end of the year.

## REFERENCES

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