COMMISSIONING AND PERFORMANCE OF SOLEIL

A. Nadji, J.C. Besson, F. Bouvet, P. Brunelle, A. Buteau, L. Cassinari, M.E. Couprie, J.C. Denard, J.M. Filhol, C. Herbeaux, J. F. Lamarre, P. Lebasque, V. Le Roux, M.P. Level, A. Loulergue, P. Marchand, L. Nadolski, R. Nagaoka, B. Pottin, M.A. Tordeux,
Synchrotron SOLEIL, Gif-sur-Yvette, France

Abstract

The French 3rd generation synchrotron light source, SOLEIL, was successfully commissioned in 2006. The Linac and the Booster are operational at their performance design. During the early phase of storage ring commissioning, essential designed parameters were reached very quickly even though the project incorporates some innovative techniques such as the use of a superconducting RF cavity, solid state RF amplifiers, NEG coating for all straight parts of the storage ring and new BPM electronics. Prior to the start of the commissioning, most of Insertion Device low gap vacuum vessels, including 10 mm inner vertical aperture vessels, were installed on the ring. The main results of one year commissioning and achieved performances are summarized in this paper.

INTRODUCTION

The very successful commissioning results of the SOLEIL 100 MeV Linac and the 2.75 GeV Booster have been extensively reported in [1] and [2], respectively. Both accelerators are now operating with very good performance and have never slowed down the progress in Storage Ring (SR) commissioning. The different steps of the first part of the SR commissioning were described in [3]. The achievement of the first turns and the storing and accumulation of the first beam were extremely fast. The optics was measured close to the model value. The natural closed orbits with correctors switched off, as well as the very low betatron coupling have demonstrated the excellence of the magnet alignment and magnetic centering. In July 2006, one month after the beginning of the commissioning, a current of 100 mA in 312 bunches was achieved. In September 2006, the maximum possible current of 300 mA was reached for the first time, after an integrated dose of only 30 A.h. Since then, the commissioning of the SR is progressing in order to reach the ultimate performances in brilliance, beam lifetime and beam stability.

LATTICE CALIBRATION

Beam Based Alignment and Orbit Correction

Beam based alignment (BBA) measurements have been performed, to calibrate the BPMs offsets with respect to the magnetic centres of adjacent quadrupoles. The horizontal (vertical) offset distribution is fitted by a Gaussian shifted by 132 µm (-150 µm) with a standard deviation of 153 µm (170 µm). These offsets have been included in the SVD based global orbit correction using 120 BPMs and 56 correctors in each plane. In the horizontal correction, path-length effects are corrected with the RF frequency. The rms residual orbits after correction are around 44 µm horizontally and 78 µm vertically. This is achieved with small corrector strengths (typically ~0.9 A rms H and ~0.5 A rms V), *i.e.* below 10% of their maximum capability. Further iteration of BBA is needed to improve the result in the vertical plane.

Optics

The four-fold symmetry of the lattice has been restored by using a new version of LOCO code including additional constraints on quadrupoles gradient variations [4]. The rms beta-beats were reduced from 6% (H) and 8% (V) down to 0.8% (H) and 1% (V). The reduction in horizontal dispersion function error after correction is shown in Figure1.

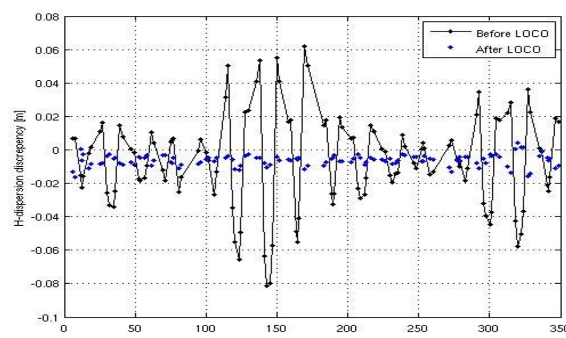

Figure 1: Horizontal dispersion function error before and after correction with LOCO.

The amplitude of gradient variations of the 160 individually powered quadrupoles is within a few ‰. The operational working point is the one targeted at the design. It allows a high injection efficiency (above 90%) and good lifetime. The tuning range is large (0.01 to 0.49) in both planes and the beam can be set on the non systematic 3rd order resonance ($3\nu_x = 55$) without loss though with lower a lifetime. The variation of tunes with momentum deviation is in excellent agreement with the model as shown in Figure 2.

The measured natural total chromaticities (-52 and -19) are close to theory (-53 and -23). The main difference in the vertical plane is due to the fact that the energy dependence of the dipole fringing field effect is not taken into consideration in our numerical model.

First measurements of transverse acceptances of the machine of 5 mm (V-plane) and –15 mm (H-plane) are in

agreement with the size of the smallest vertical chamber and the horizontal position of the injection septum.
The main results of the commissioning of the presently installed 10 Insertion Devices are reported in [5].

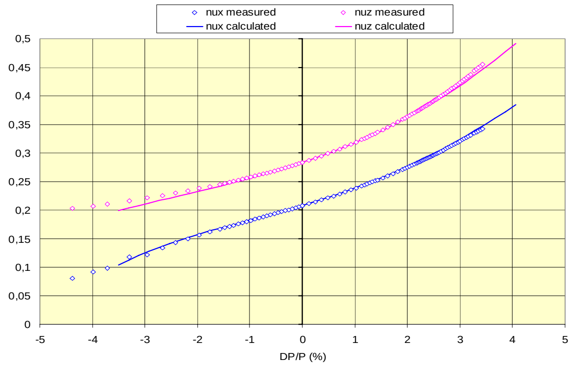

Figure 2: Tune shifts with energy: Comparison between measurement and modelling for the nominal lattice.

Emittances

The horizontal and vertical beam emittances have been measured by observing the X-part of the synchrotron radiation by means of a pinhole camera [6], (see figure 3).

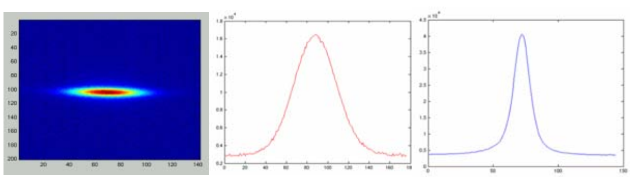

Figure 3: Image of the photon beam at its projections: horizontal (red) and vertical (blue).

The horizontal value of the emittance confirmed the design value of 3.73 nm.rad within ± 0.2 nm.rad. The use of the 5th harmonic photon spectrum of the PROXIMA1 beamline in-vacuum undulator U20 indicates also that the horizontal emittance and the energy spread are very close to the design values.
Without correction, the integrated betatron coupling was measured at 0.08%, using the closest tune approach. Thus, the 11 pm.rad measured vertical emittance corresponds to a very low 0.3% natural coupling. Using 32 skew quadrupoles, the machine could be tuned down to a very low coupling (~1‰) with a vertical emittance below 5 pm.rad, as deduced from SRW simulations [6].

BEAM CURRENT AND LIFETIME

After few problems related to overheating of some equipment (due to the stored beam current) have been resolved and with an RF-feedback, the SR is operated routinely at its 300 mA maximum current. The installation of a second RF cryomodule, in the beginning of 2008, will enable the current to reach 500 mA. Figure 4 shows an example of SR vacuum conditioning around 300 mA.
In order to provide beam stability at 300 mA, rather large normalised chromaticities are needed (+0.2, +0.5), which reduce the dynamic aperture and consequently the injection efficiency decreases (60% instead of > 90% at low chromaticities). However, the beam lifetime is not affected. No coupled-bunch instability was observed in the longitudinal plane as expected with superconducting RF cavities.

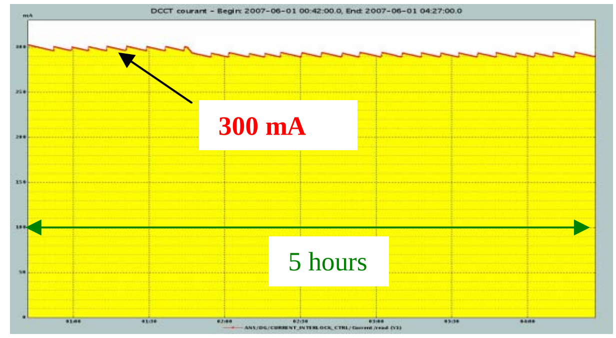

Figure 4: Frequent injection around 300 mA

Transversally, a mixture of resistive-wall and ion induced instabilities are observed in both H- and V- planes. The behaviour of the ions induced instability depends much on the beam filling pattern. The detail of these instabilities, their thresholds and the comparison with expectation are reported in [7]. Presently, a bunch by bunch transverse feedback combats very efficiently the transverse instabilities [8] and the high chromaticities are no more needed. The beam is kept stable up to the maximum current of 300 mA at zero chromaticities in both planes, which keeps the injection efficiency > 90%.
In the multibunch mode, with 300 mA in 312 bunches (out of 416 buckets); the beam lifetime reaches 8 hours. It is mainly limited by the average pressure in the ring (2.5 x 10^{-9} mbar at 300 mA). Accordingly, the beam lifetime with 100 mA in 312 bunches and an average pressure of 1.1 x 10^{-9} mbar is slightly above 20 hours. These beam lifetime values are measured at the operating natural coupling of 0.3%. They are very close to the expected value of 16h calculated with a pressure of 1 x 10^{-9} mbar (500 mA in 416 bunches) and a coupling of 1%.
In the single bunch mode, a maximum current of 20 mA is achieved without being limited by instability. The first bunch length measurements with a Hamamatsu streak camera gave 20 ps rms with 2 MV RF accelerating voltage, a value close to the expected one at very low current. The bunch length increases by roughly a factor of 2.5 with a current up to 20 mA / bunch. On the other hand, no energy spread increase has been seen up to this bunch current [7].

BEAM POSITION STABILITY

A slow orbit feedback (0.1 Hz), reading the high resolution LIBERA BPM electronics and using the same algorithm as for closed orbit correction is routinely used to stabilize the beam position during users operation. Figure 5 shows the beam position stability at two IDs source points during a user shift of 8 hours. One can note a position stabilisation of 2 µm (3 µm) peak to peak in the

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vertical (horizontal) plane and an angle stabilization of 0.6 µrad (1 µrad) peak to peak in the vertical (horizontal) plane. Work is still undergoing in order to minimise or to suppress the identified noise sources, such as the effect of the 3 Hz Booster power supplies, the drifts with temperature (SR-tunnel temperature regulation) and the perturbation induces by Insertion Devices changes, and to make the feedback as reliable as possible.

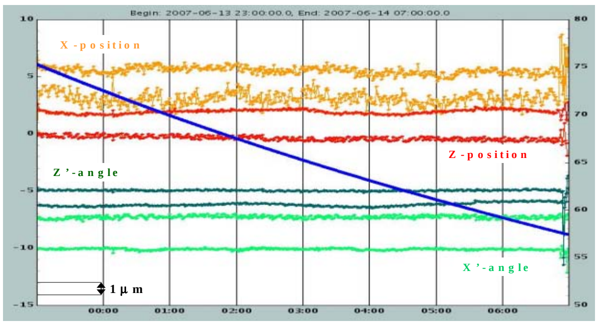

Figure 5: Angle and position evolution during an 8 hour user shift. The beam current variation is in blue.

The beam noise integrated in a spectral frequency span of 0-500 Hz is below 2 µm rms in both planes. A fast orbit feedback will be installed in order to further reduce this noise [9]. The closing of the four-kicker injection bump was worked out and presently the induced horizontal betatron oscillation amplitude is around 200 µm at maximum kick amplitude. It will be further reduced so as to make as transparent as possible the injection process during top-up operation.

EQUIPMENT

The LIBERA BPM electronics feature a resolution below 0.2 µm rms within a 100 Hz bandwidth. They provide either turn-by-turn data with 3 µm rms resolution (for a 4 mA beam), or 10 Hz data for slow orbit feedback and 10 kHz data flow for simultaneous fast orbit feedback.

Overall, the RF system is outstandingly stable. The two 180 kW solid state amplifiers are running very smoothly. A few transistor failures (18 over 1450) were observed over 1500 hours of operation but without interruption of the beam. The cryogenics plant, which maintains the cryomodule at 4 K (50 l/h liquefaction, 400 W refrigeration) is under very reliable operation [10].

The efficiency of the fast cleaner, placed just downstream the gun in the Linac, has been demonstrated by measuring the purity of stored bunches at better than 10^{-5}. Radiation measurement downstream the 10 m long NEG coated chamber (14 mm of vertical aperture) showed that Bremsstrahlung rate is negligible at 300 mA. The machine protection is fully operational and based on PLCs interconnecting vacuum system and diagnostics.

TANGO control system is used successfully to control and supervise the full facility from accelerators to beamlines. Matlab Middle Layer applications are fully integrated in the control system and have been very beneficial to the commissioning and operation.

BEAMLINES COMMISSIONING

10 (out of the 24) beamlines have already opened their front-ends (4 on bending magnets and 6 on Insertion Devices). The first one, DIFFABS, opened on September 13th 2006 and the last one, MARS, on June 14th 2007. The synchrotron beam was observed almost instantly on a beam screen. No difficulty has been encountered with the front-end equipment neither for the vacuum nor for the alignment of different absorbers and slits. These beamlines are now either under intense commissioning or finishing installation of the optics and equipment down to the optical and experimental hutches. Some of them are ready to welcome first external users in July 2007.

OPERATION

A total of 2400 hours of beam was achieved from January to June 2007. The beam time dedicated for beamlines was 1187 hours with an availability of 93 %. Operation group is now complete with 8 fulltime operators. For a 24h/24h and 7 days a week operation, part time operators coming from Machine, technical and computing divisions are participating.

MAIN OBJECTIVES FOR EARLY 2008

- 500 mA operation (with second cryomodule)
- Setting up top-up operation
- Single bunch and 8 bunches operation
- Securing beam stability with many Insertion Devices
- Fast orbit feedback.

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