OPERATION STATUS AND PERFORMANCES UPGRADE ON SOLEIL STORAGE RING

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Abstract

SOLEIL is the French 2.75 GeV third generation synchrotron light source delivering beam to Users since January 2007. As of June 2008 up to 14 beam-lines are taking beam, 7 from insertion devices (IDs), 2 from IR ports, and 5 from dipole ports. Users have full control of their IDs. With 300 mA maximum stored beam current in multi-bunch filling pattern, and position stabilities in the few micron range, the main target performances have been reached. A beam of 50 mA in 8 bunches was delivered to Users for the first time in December 2007 for time structure experiments. Operation and performance status are given, namely subsystem behaviour (RF, vacuum,…), beam optics, orbit stability, beam lifetime, and operation statistics. Then the main objectives for 2008 will be reviewed: delivery of 4000 hours of beam to the beamlines, installation and commissioning of a second cryomodule for reaching the 500 mA current target, construction and installation of 3 new IDs, improvement of the orbit stability with a fast orbit feedback complementary to the slow orbit one, and preparation for top-up operation.

INTRODUCTION

Following the successful commissioning of the SOLEIL accelerator systems in 2005 (Linac and Booster) and 2006 (Storage Ring [1]), SOLEIL has started regular operation for the beamlines and their Users from January 2007 onwards. During the first year of operation, 2640 hours of beam have been delivered to the beamlines, while 1800 hours were still devoted to machine studies. This enabled to further improve the storage ring performances, and to perform the commissioning of the numerous insertion devices installed on the ring. Since then, the optimization of the SR is going on in order to reach the ultimate performances in brilliance, beam lifetime and beam stability.

STORAGE RING PERFORMANCES

The performances of the storage ring as of June 2008 are summarized in table 1.

Beam current

Since March 2008, the machine is routinely operated in **multibunch mode** at 250 mA for the beamlines, and at 300 mA during the shifts dedicated to radiation control of the beamline hutches. The lifetime reaches 16 hours at 300 mA. With the recently installed 2nd RF cryomodule, it is planned to raise the current up to 500 mA by the end of 2008.

A bunch by bunch transverse feedback combats very efficiently the transverse instabilities [2] and the beam is kept stable up to the maximum current of 300 mA with zero chromaticities in both planes, which keeps the injection efficiency > 90%. The feedback is routinely used during Users operation, with chromaticities set at 2 in both planes.

The demand for the time structure modes is arising and the beam was delivered a few times in **8 bunch mode** at 50 mA. The purity (ratio of the parasitic bunches to the main bunches) was measured with a pin diode in the range of a few 10^{-5}, which demonstrates the good control of the Linac gun emission.

Table 1: Achieved results as of June 2008

Parameter	*Design*	*Achieved/measured as of June 2008*
Energy (GeV)	2.75	2.74
RF frequency (MHz)	352.2	352.197
Betatron tunes (H/V)	18.2 / 10.3	18.199 / 10.299
Natural chromaticities (H/V)	-53 / -23	-52 / -19
Momentum compaction $\alpha 1$, $\alpha 2$	$4.5\ 10^{-4}$ $4.6\ 10^{-3}$	$4.55\ 10^{-4}$ $4.30\ 10^{-3}$
Emittance H (nm.rad)	3.73	3.70 ± 0.2
Energy spread	$1.016\ 10^{-3}$	$1.0\ 10^{-3}$
Coupling, $\varepsilon v/\varepsilon h$	<1%	0.3% natural 0.1% with correction
Max current (mA)	500	300
Average pressure (mbar)	10^{-9} (500 mA)	$1.6\ 10^{-9}$ (300 mA)
Beam lifetime (h)	16	16 (300 mA)
Current in single bunch (mA)	12	20
H Beam position stability (µm)	18 (rms)	4 (rms)
V Beam position stability (µm)	0.5 (rms)	1.1 (rms)

Beam lifetime

In **multibunch mode** the total beam current of 250 mA is achieved by filling 312 bunches (out of 416 buckets). At this beam current, the present mean pressure is around $1.1\ 10^{-9}$ mbar and the vertical coupling varies between 0.6% and 1.2% depending on the machine IDs configuration. Without IDs, the measured beam lifetime is 19 h with a 0.6% coupling and a 2.4 MV RF voltage, which is in good agreement with the 6D tracking predicted value of 19,1 h calculated with the same parameters. The total beam lifetime is still dominated by the gas scattering effect (24h) but Touschek lifetime is not negligible (63h). This value corresponds to an energy acceptance of [-4.3% , +3.5%]. Non-linear effects of some IDs can significantly reduce the beam lifetime because of dynamic aperture and energy acceptance reductions [3]. A more robust working point with IDs is being studied using extensive FMA measurements [4]. As expected, the lifetime in **8 bunch mode** is completely dominated by

Touschek effect. To reach 12h for a total beam current of 50 mA, the coupling has been increased to 6.5% by enlarging the vertical beam size via the vertical dispersion rather than exciting the linear coupling resonance.

Vacuum system and conditioning

As already mentioned [1], the storage ring vacuum system makes intensive use of NEG coated aluminium vessels. The pressure is monitored by reading the currents of the sputter ion pumps (SIP) which are distributed all along the ring. After having cumulated an integrated current of 890 A.h, the average pressure in the ring reaches now 1.6 10^{-9} mbar at 300 mA. In fact this value is artificially enlarged by the too large weight given to the 3 in-vacuum undulators in the computation: Their 3x8 SIP show the highest pressures in the ring and represent 12% over the 200 SIP of the ring in the computation, to be compared to their contribution in length (9 m over 354 m i.e. 2.5%). A computation taking into account the lengths ratio gives a more realistic 1.1 10^{-9} mbar average pressure at 300 mA. Figure 1 shows the conditioning of one typical cell of the ring. The average pressure in such a cell reaches 0.9 10^{-9} mbar at 300 mA [5].

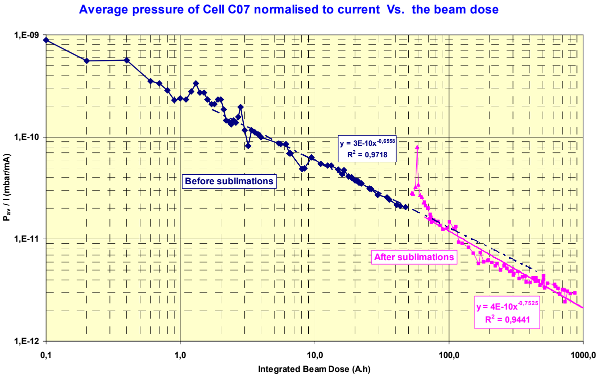

Figure 1: Vacuum conditioning: Normalised pressure (in mbar/mA) in a cell versus integrated dose (in A.h)

BEAM POSITION STABILITY

The SOLEIL beamlines cover a very wide range of photon energies from VUV (few eV) to hard X-ray (30 keV). As a consequence, the effective photon beam emittances vary from one beamline to another. Table 2 shows the photon beam emittances (ε_{totalH} , ε_{totalV}) calculated for different beamlines, by convoluting the single electron photon emittance (ε_{single}) at the relevant energy, with the effective electron beam emittances (5.5 nm.rad in H, taking into account the contribution of the dispersion, and 15 pm.rad in V). It appears that the photon beam emittances are comparable to the electron beam emittances only for the hard X-ray beamlines, which therefore are more sensitive to beam position stabilities.

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 [6].

Table 2: Photon beam emittances at different beamlines. The source types and the location of the IDs are indicated: long (LSS), medium (MSS) or short (SSS) straights, HUxx=helical undulator, U20= in vacuum undulator.

Beamlines	Photon Energy	ε_{single} (nm.rad)	$\varepsilon_{total\ H}$ (nm.rad)	$\varepsilon_{total\ V}$ (nm.rad)
DESIRS (HU640 on LSS)	40 eV	2.5	14.7	2.5
TEMPO (HU80 on MSS)	1.6 keV	0.062	6.15	0.099
PROXIMA1 (U20 on SSS)	18 keV	0.0055	5.8	0.027
DIFFABS (Bend)	35 keV	0.0028	-	0.821

Table 3 summarizes the position stability achieved in both planes. "Slow motion" corresponds to measurements performed during an 8 hour Users shift, whilst "fast motion" corresponds to the noise levels integrated in a range from 1 Hz to 1kHz.

Table 3: Position stability achieved at different source points. σ_{ph}/10 indicates the tolerance relative to the photon beam size.

	Horizontal plane (µm)			Vertical plane (µm)		
Source point	σ_{ph}/10	Slow motion (rms)	Fast motion (rms)	σ_{ph}/10	Slow motion (rms)	Fast motion (rms)
LSS (VUV)	32	4	≈ 3.7	6	1.6	≈ 1.6
MSS (Soft X-rays)	18.3	3	≈ 3.2	6.5	1.4	≈ 1.4
SSS (Hard X-rays)	39	3	≈ 3.4	0.55	1.1	≈ 1.1
Bend (Hard X-rays)	4.3	4	≈ 4.4	1.5	1.4	≈ 1.4

In most cases, the values are below the 10 % tolerance of the photon beam size, except for the hard-X ray beamlines (either bends or in vacuum undulators installed on short straight sections). However this stability can be degraded at time, due to the imperfect compensation of the effects of the IDs variations, or to other external perturbations such as motions of the overhead cranes.

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 remaining drifts with temperature (SR-tunnel temperature regulation) and the perturbations induced by ID changes, and to make the feedback as reliable as possible [6].

A global « Fast Orbit FeedBack » system is presently being tested and will allow further reducing this noise level all around the machine in a frequency range from 1 to 150 Hz [7]. It will also suppress the transitory effects observed during the changes of the insertion devices magnetic field values.

BPM interlocks

The vacuum vessels of the ring are protected against possible damage due to beam mis-steering by position stability interlocks activated on 32 over the 120 BPMs of the ring. The standard interlock threshold was set at ±1 mm in the vertical plane only.

Following the insertion of 2 uncooled slotted mirrors extracting infrared light from 2 bending magnets, a tighter interlock level (±0.3 mm) had to be set on the 2 neighbouring pairs of BPMs to avoid these mirrors being damaged by the high power X-ray fan in the median plan.

INSERTION DEVICES

Over the last 12 months, the installation of new insertion devices (IDs) and front-ends has been pursued during the shutdown periods. There are now 14 IDs installed on the ring (4 electromagnetic helical undulators, 6 APPLE II undulators with period ranging from 80 to 44 mm, and 4 in-vacuum undulators U20). Three more IDs should be installed by the end of 2008, another five in 2009 and another one in 2010, so as to complete the initial programme of 25 IDs. All these IDs are designed and built by the SOLEIL ID group. Innovative assembling and shimming techniques were developed [8], and significant Machine time is dedicated to their commissioning [9]. In parallel, an R&D programme to build a cryogenic undulator has been launched [10].

RF SYSTEM

Two cryomodules (CM), each containing a pair of 352 MHz superconducting cavities were foreseen to provide an accelerating voltage of 4 MV and a power of 560 kW to the electron beam at the maximum intensity of 500 mA and with all the insertion devices [11]. Each cavity is powered with a 180 kW solid state amplifier, while both cryomodules are cooled down by a single cryogenic plant. During summer 2006, one half of the SR RF system (CM1, 2 amplifiers, the cryogenic plant, the control and LLRF systems) was commissioned, as scheduled for the first year of SOLEIL operation with $I_{beam} < 300$ mA and a reduced number of IDs. The goal of storing up to 300 mA of stable beam, using a single CM, was quickly achieved.

The second half of the system is being installed. The CM2, manufactured by the German company, ACCEL, was delivered end of May 2008 and is in the process of RF conditioning. The objective is to increase progressively the stored electron beam intensity and reach 500 mA before the end of 2008.

Up to date, after more than 10 000 running hours, the system has proved to be very reliable and flexible in operation with only a few minor faults which led to short beam interruptions. Despite the quite challenging technological choices concerning superconducting cavities and high power solid state amplifiers, both designed in house specifically for SOLEIL, the first operational experience proved to be fully satisfactory.

OPERATION

Over the 2 815 hours of beam scheduled to be delivered to the beamlines during 2007, the beam was effectively delivered 2 640 hours which gives an overall availability of 93.8%. The main contributions of the equipment to the Machine downtime were: Power supplies 20%, Vacuum 19%, beamline interlock 12%, utilities 11%,… and RF only 3% !

The machine availability over the 5 first months of 2008 is much better with an average figure of 96.3% over 1 664 hours of beam delivered from January to May 2008.

The operation of the machine is performed by a team composed of one full time operator and one or two staff from the various technical groups. The control system based on TANGO is now fully mature, even if some developments have still to be done to provide software tools better adapted to the routine operation.

MAIN OBJECTIVES FOR 2008

During the 2nd half of 2008, it is planned to set the fast orbit feedback into routine operation, to prepare the machine operation at 500 mA, to switch to top-up mode of injection (see [12]), to install new IDS and front-ends and to compensate at best the ID's effects on the beam positions and dynamics.

REFERENCES

[1] JM Filhol et al., “Commissioning of the storage ring of SOLEIL”, ICFA Beam Dynamics Newsletter, N°44, Dec 2007

[2] R. Nagaoka et al., “Performance of the bunch by bunch transverse feedback system and studies of collective effects at SOLEIL”, these proceedings

[3] P. Brunelle et al., “Experimental characterization of the insertion device effects on beam dynamics at SOLEIL”, these proceedings

[4] LS Nadolski et al., “First frequency maps for probing the non linear dynamics of SOLEIL”, these proceedings

[5] C. Herbeaux et al., "Vacuum conditioning of the SOLEIL storage ring with extensive use of NEG coating", these proceedings

[6] LS Nadolski et al., “Transverse orbit stability status and improvement at SOLEIL”, these proceedings

[7] N. Hubert et al., “Commisioning of SOLEIL fast orbit feedback system”, these proceedings

[8] O. Chubar et al., "Compensation of Variable Skew- and Normal Quadrupole Focusing Effects of APPLE-II Undulators with Computer-Aided Shimming", these proceedings

[9] O. Chubar et al., “Observation and interpretation of dynamic focusing effects introduced by APPLE II undulators on electron beam at SOLEIL”, these proceedings

[10] C. Benabderrahmane, “Development of cryogenic undulator CPMU at SOLEIL”, these proceedings

[11] P. Marchand et al., " Operations of the SOLEIL RF Systems ", PAC 2007, Albuquerque

[12] P. Lebasque et al., "Construction of two machine study kickers and improvement on pulsed magnetic systems at SOLEIL", these proceedings