ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPML034

BASELINE LATTICE FOR THE UPGRADE OF SOLEIL

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Abstract

Previous MBA studies converged to a lattice composed of 7BA-6BA with a natural emittance value of 200-250 pm.rad range. Due to the difficulties of non-linear beam dynamics optimization in targeting lower emittance values, a decision was made to symmetrize totally the ring with 20 identical cells having free straight sections longer than 4 m. A 7BA solution elaborated by adopting the sextupole pairing scheme with dispersion bumps originally developed at the ESRF-EBS, including reverse-bends, enabling an emittance of 72 pm.rad has been defined as the baseline lattice. The on-momentum dynamic aperture obtained allows considering off-axis injection. The linear and non-linear beam dynamic properties of the lattice along with the expected performance in terms of brilliance and transverse coherence are presented. In particular, the beta functions tuned close to 1 m.rad^{-1} in both transverse planes at the center of straight sections allow matching diffraction limited photons up to 3 keV.

INTRODUCTION

SOLEIL is the French third generation light source routinely operated for users since 2007 with a low electron beam emittance of 4 nm·rad at an energy of 2.75 GeV in high intensity, up to 500 mA, multibunch and temporal structure (e.g. 8 bunches) modes. After nearly 11 years of successful operation, a series of feasibility studies is launched towards a possible major upgrade of the storage ring with a significantly lower emittance lattice. The approach taken is to employ whatever useful methods in lowering the emittance providing at least 17 straight sections and 4 high field dipole-based beamlines.

BASELINE UPGRADE LATTICE

The present SOLEIL synchrotron storage ring is a four-fold symmetry lattice composed of 16 double-bend (DB) cells. It provides four 12 m long straight sections (SDL) and twelve 7 m medium sections. In addition a set of 8 short sections have been inserted in half of the DB cells. Lately, since 2012, one of the SDLs has been split into two parts having low vertical beta function source points for long canted beam-lines by means of an additional quadrupole triplet [1]. A combination of 7BA-6BA [2] giving an emittance of 220 pm.rad based on the ESRF-EBS [3] design has been studied. By the end of 2017, to push further down the emittance as well as to maximize the soft X-rays photon flux, a new full symmetric lattice with a number of cells jumped from 16 to 20 has been investigated. It is still a 7BA lattice with paired sextupoles in the dispersion bump enabling a natural horizontal emittance of 72 pm.rad (Fig. 1).

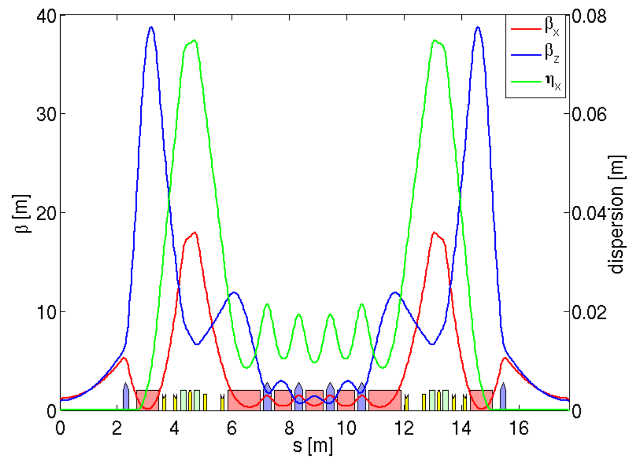

Figure 1: Optical function of the SOLEIL baseline lattice.

A special attention has been paid to get low beta values at straight section centers, they are of the order of 1 m.rad^{-1} in both planes. The main lattice parameters comparison are listed in Table 1.

Table 1: Main Lattice Parameters

	Present	Upgrade
Emittance (2.75 GeV)	4 nm.rad	72 pm.rad
Circumference	354.1 m	353.1 m
Cell Number	16	20
Straight Lengths	12/ 7 /3.8 m	4.4 m
Straight Number	24	20
Straight Ratio	45 %	25 %
Working Point	18.16 10.23	54.3 18.3
Natural Chrom.	-53 -19	-120 -127
Mom. Comp. Factor	4.4 10^{-4}	1.5 10^{-4}
Energy Spread	1 10^{-3}	8.6 10^{-4}
Energy Loss per Turn	904 MeV	310 MeV
Damping Times	3.3/3.3/6.6	10/21/24 ms

The bending magnet fields are rather low with 0.52 T combined with transverse gradient of 38 T/m. The maximum gradient of the quadrupoles reaches 95 T/m and the sextupole gradients are limited to 2000 T/m^2 over 100 mm yoke length. The beam dynamics optimization is based on four sextupole families, two octupoles families as well as phase advances in between the dispersion bumps. The dynamic aperture reaches few millimeters in both planes but with an important reduction for on

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momentum particles due to the combined large path lengthening and synchrotron motion (Figs. 2 and 3). The single particle dynamics is performed using AT.2.0 tracking code [4].

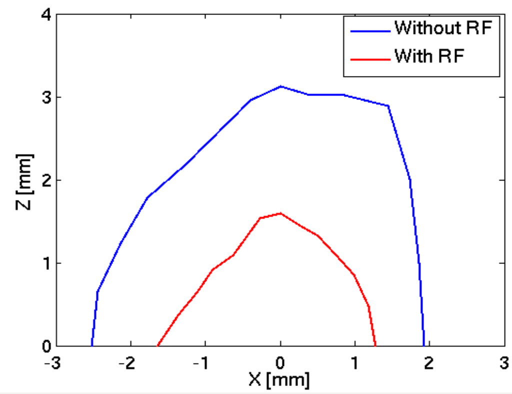

Figure 2: On-momentum dynamic aperture at straight center section with β_x=1.3 and β_z=1.0 m.rad^{-1}.

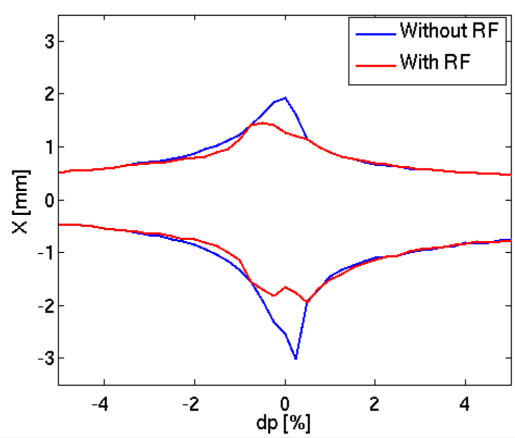

Figure 3: Horizontal dynamic aperture versus energy deviation at straight section center with β_x=1.3 m.rad^{-1}.

The natural bunch length is rather short, about 3.7 mm RMS with an RF voltage of 1.1 MV at 352 MHz. The Touschek beam lifetime estimation with 1.2 mA per bunch (500 mA with uniform filling pattern) exhibits about 1.5 hours with 10 pm.rad emittance in the vertical plane. Figure 4 exhibits the local momentum acceptance. At full betatron coupling, the emittances reached are about 50 pm.rad in both planes. The beam lifetime is increased from 1.5 to about 3 hours. Under the same bunch conditions, the Intra Beam Scattering (IBS) effect is not negligible and raises both emittances from 50 to about 67 pm.rad and relative energy spread from 8.6 10^{-4} to 1.1 10^{-3}. To cope with these two effects, a bunch lengthening by means of harmonic cavities is foreseen. Typically a factor of five lengthening should relax the Touschek beam lifetime as well as limiting the IBS emittance increase from 50 to 55 pm.rad.

PHOTON BEAM PERFORMANCE

At full betatron coupling, the reached emittances are about 50 pm.rad in both planes. They are very comparable to diffraction limited photon emittance (65 pm.rad) at 3 keV emitted from an undulator. The matched beta function (L_{und}/π) over a 4 m long undulator is in the order of 1.3 m very close to the present lattice values. Figure 5 illustrates the two matched ellipses taken at the undulator center at 3 keV photon energy.

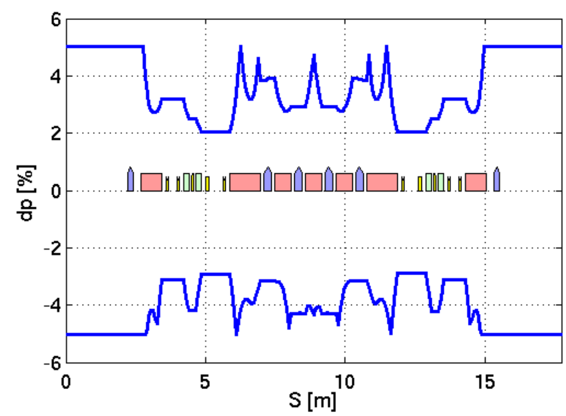

Figure 4: Touschek relative energy acceptance along a single cell.

Both the low electron emittances and the photon matching attained enabling to increase the brilliance up to 2 orders of magnitude in the SOLEIL region of interest between 1 and 3 keV (Fig. 6). It exceeds an average value of the brilliance of 10^{22} photons/s/mm^2/mrad^2/0.1%b.w. while it is still above 10^{20} at 40 keV. The photon transverse coherence is also largely increased. With this new baseline lattice, the photon beam coherence will exceed 41% at 1 keV and reaching 14% at 3 keV.

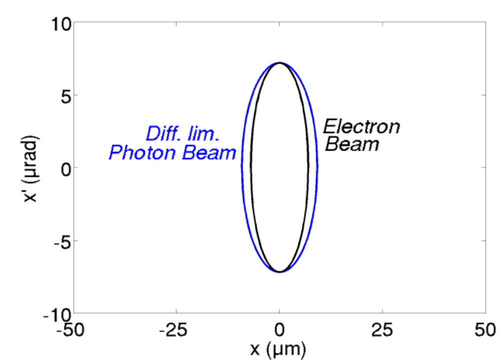

Figure 5: Matched phase space between the 50 pm.rad electron beam and the 65 pm.rad photon (3 keV) beam over 4 m long undulator.

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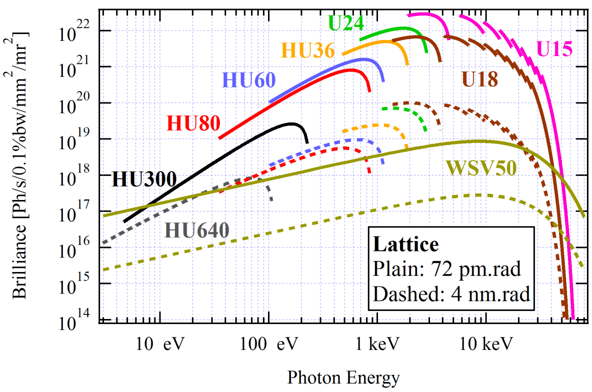

Figure 6: Photon beam brilliance comparison of between upgraded and present SOLEIL storage ring.

SOLEIL is also presently operating several bending magnet beamlines at a magnetic field of 1.71 T. The ugrade lattice having a larger number of dipoles, the peak field is limited to about 0.52 T with a consequent reduction of the critical photon energy (from 8.6 to 2.6 keV). To cope with this reduction it is foreseen implementing local peak fields in the central magnet of 3 T in four equally spaced cells and 1.8 T in the other cells (Fig. 6). In parallel, to prevent from an emittance increase due to this higher peaked field, the adjacent focusing quadrupoles are shifted ($\Delta x \sim 1.3$ mm) providing a beneficial reverse-bend effect [5]. The natural emittance is then kept in the 70 pm.rad region enabling 48 pm.rad in both planes at full coupling. The energy spread is however inevitably increased from 8.6 10^{-4} to 1.0 10^{-3} in presence of these larger magnetic fields.

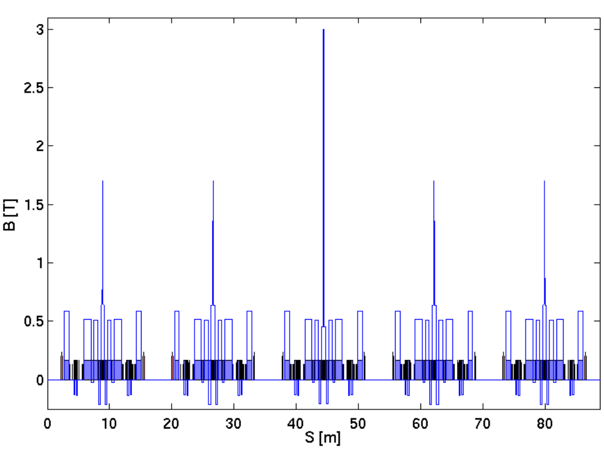

Figure 6: Dipolar magnetic field profile along 5 cells of the upgraded lattice with peak fields of 1.8 and 3 T.

INJECTION INVESTIGATION

The reduced dynamic aperture naturally complicates the injection process. In the frame of beam current accumulation in the storage ring, two schemes are investigated: the first one based on large off-momentum and off phase injected beam [6, 7] and the second one, more classical, off axis in the vertical plane. Both schemes allow the preservation of the large ring symmetry avoiding a dedicated injection cell and are based on slow Non Linear Kicker (NLK) [8, 9]. They also enable injecting at full coupling working point without extra vertical excursion of the injected beam. They allow injection of one, few bunches or a long pulse of 100 bunches operated today at SOLEIL.

In the former case, the injected beam is kicked by the NLK onto a chromatic orbit in the dispersion bump region at about +6% energy deviation in between two stored bunches. An additional RF power (pulsed) is then also needed to speed the energy decrease toward +2% where the bunch is finally naturally damped and stored. The later scheme is more conventional and relies on a large vertical beta function (~20 m) present at the end of the straight section but may limit the low insertion devices gap operation.

A large part of the difficulty is here in the hands of pulsed magnets designers where short magnet of few mrad kick is mandatory at merely 3 to 4 mm only fro the axis. Another important point is to upgrade the booster as well in order to reduce its natural emittance from 110 down to 30 nm.rad and to shorten shorter the bunch length from 100 down to 35 ps RMS. A possible solution by splitting the long dipole in two, doubling the number of FODO cells, effectively reaches the desired emittance and bunch length targets.

CONCLUSION

This SOLEIL-U baseline lattice achieves a low natural horizontal emittance in the range of 70 pm.rad and 50 pm.rad in both planes at full coupling. Combined with low beta function at straight center predicts a brilliance increase up to 2 order of magnitude, reaching 10^{22} photons/s/mm^2/mrad^2/0.1%b.w., in the SOLEIL photon energy range of interest between 1 and 3 keV. At high current (500 mA), IBS emittance growth and limited beam lifetimes can be mitigated to an acceptable level by means of a third harmonic RF cavity lengthening the bunch. We believe that the radial and off-momentum acceptance are still workable for injection accumulation scheme. Nevertheless a complete upgrade of the booster shall be mandatory to reach a much lower emittance of the order of 30 nm.rad. In parallel with the magnets and pulsed elements design feasibility ongoing tasks, the modified ring geometry implies a major investigation too. The present upgraded ring tunnel accommodation enables to have all the beamlines at the cost of few (6-8) ratchet wall modifications. The long beamline building as well as the MARS beamline (hosting radio-safety infrastructure dedicated to radioactive samples) are fully preserved.

Although this SOLEIL-U lattice proposal is relatively aggressive and requiring extended modifications impacting the injector as well as the ring tunnel, no real show-stopper has been encountered at present times. In terms of time-line, the years 2017 to 2021 are dedicated to lattice investigation and equipment prototyping while the years 2022 to 2026 shall be for the implementation and restart of the machines once the funding obtained.

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REFERENCES

[1] P. Brunelle *et al.*, "New optics for the SOLEIL storage ring", in *Proc. IPAC'11*, San Sebastian, Spain, pp. 2124-2126.

[2] A. Loulergue *et al.*, "Linear and Nonlinear Optimizations of Combined 7BA-6BA Lattices for the Future Upgrade of SOLEIL", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, paper MOPIK059, pp. 659-661, doi:10.18429/JACoW-IPAC2017-MOPIK059, 2017.

[3] L. Farvacque *et al.*, "A Low-Emittance Lattice for the ESRF", in *Proc. IPAC'13*, Shanghai, China, pp. 79-81.

[4] Accelerator Toolbox, AT 2.0, https://github.com/atcollab/at

[5] A. Streun, "The anti-bend cell for ultralow emittance storage ring lattices", *NIMA*, vol. 737, pp. 148-154, 2014.

[6] M. Aiba *et al.,* "Longitudinal injection scheme using short-pulse kicker for small aperture electron storage rings", *Phys. Rev. ST Accel. Beams*, vol. 18, pp. 020701 (2015).

[7] M. A. Tordeux, "Longitudinal injection into low-emittance ring, a novel scheme for SOLEIL upgrade", Topical workshop on injection. Berlin, 28-30 August 2017.

[8] O. Dreßler and P. Kuske, USR Workshop, Huairou, Beijing, China, Oct. 30 – Nov. 1, 2012.

[9] P. Alexandre, "NLK R&D at SOLEIL" , Topical workshop on injection. Berlin, 28-30 August 2017.