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TDR BASELINE LATTICE FOR SOLEL II UPGRADE PROJECT

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Abstract

Previous TDR (Technical Design Report) studies for the SOLEIL upgrade project (SOLEIL II) have converged towards a lattice alternating 7BA and 4BA HOA (Higher Order Achromat) type cells providing an ultra-low natural horizontal emittance value in the 85 pm·rad range at an energy of 2.75 GeV. The new TDR lattice is an evolution that keep the insertion devices based photon source points at their present location, allows a better relative magnet positioning and more space for accommodating photon absorbers, BPMs (Beam Position Monitor) and other mandatory diagnostics. This last evolution includes a better modelling of all the bend magnets based on their realistic field profiles and the accommodation of height super-bends for beam-lines as well as for beam size diagnostics. In addition an exhaustive investigation of the systematic and especially the cross-talk multipoles as well as the phase 1 portfolio of insertion devices impacts has been carried out. This paper reports the linear and the non-linear beam dynamic optimizations as well as future directions for performance improvement.

INTRODUCTION

SOLEIL is the French third generation synchrotron light source routinely operated for external users since 2008 with a low electron horizontal beam emittance of 4 nm·rad at an energy of 2.75 GeV in high intensity (500 mA, 416 bunches) and temporal structure (e.g. 8 bunches) modes [1,2]. After 16 years of SOLEIL successful operation and in order to remain competitive worldwide, a new storage ring lattice with a significantly higher photon beam brightness has been designed. The financing of the SOLEIL II project has been approved in December 2023 and the construction phase will start in early 2025. The existing booster and storage ring will be renewed with much lower ring emittances of respectively 5 nm·rad and 85 pm·rad at an energy of 2.75 GeV. The storage ring commissioning phase, including the 29 beamlines, is planned for 2030.

SOLEIL II LATTICE LAYOUT

Alternating 7BA and 4BA cells was then identified during the Conceptual Design Report (CDR) [3] phase as the natural solution to best fit the current beamline (BL) positioning and leave the tunnel shielding wall unchanged. The TDR reference lattice is then composed of 20 HOA cells alternating 7BA and 4BA cells (Fig. 1), giving a natural horizontal emittance of 85 pm·rad at an energy of 2.75 GeV [4]. In addition, the optical β-functions are focused down to low values (~1.5 m) in the short and medium sections for insertion devices (ID). The comparison of the main parameters are listed in Table 1.

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Table 1: Comparison of the Main Bare Lattice Parameters

	Present	SOLEIL II
H-Emittance (2.75 GeV)	4 nm.rad	85 pm.rad
Circumference	354.10 m	353.96 m
Straight section number	24	20
Long straight length	12.00 m	8.07 / 9.00 m
Medium straight length	7.00 m	3.71 / 4.21 m
Short straight length	3.80 m	3.14 m
Straight length ratio	46 %	25 %
Betatron tunes H/V	18.16 / 10.2	54.2 / 18.3
Mom. comp. factor	$4.18 10^{-4}$	$9.9\ 10^{-5}$
RMS energy spread	0.102 %	0.095 %
Energy loss per turn	917 keV	477 keV
Damping times s/x/z (ms)	3.3/3.3/6.6	7.4 /13.5 /12.1
RMS Nat. bunch length	15.2 ps	8.9 ps
RF main cavity voltage	2.8 MV	1.7 MV

LATTICE MODELLING

To accommodate high field superbends for specific BLs and diagnostic stations, the long bends have been split into 3 distinct parts giving the possibility of changing only the central part according to the desired peak fields [5]. The realistic field profiles then differ noticeably from the initial hard-edge model. The SOLEIL II lattice being based on permanent magnets dipoles and quadrupoles, any mismodelling may critically increase the needed correctors strengths beyond their limits. To ensure that the optical functions and the machine geometry (straight section alignments) to be as close as possible to the model, the whole lattice based on these realistic fields was refitted. Splitting all the bends into small pieces of 1 mm long, the number of elements became too large (~160000) for tracking calculations a new simplified hard-edged model was necessary. The goal was to individually fit each of these 6x6 bends with a simplified element composed of bends and drifts, for example, the long bends are now divided into 5 blocks (Fig 2). In addition, 8 superbends are planned and their positioning along the SOLEIL II lattice is shown in Fig. 3. Among these 8 superbends, 2 are dedicated to the measurement of the beam size by means of pinhole cameras. Their 6x6 matrix is also fitted with a simplified model based on 9 blocks. At this stage, and as long as the mean systematic multipoles are of the same order in the peak field region, the presence of these 8 superbends is almost transparent

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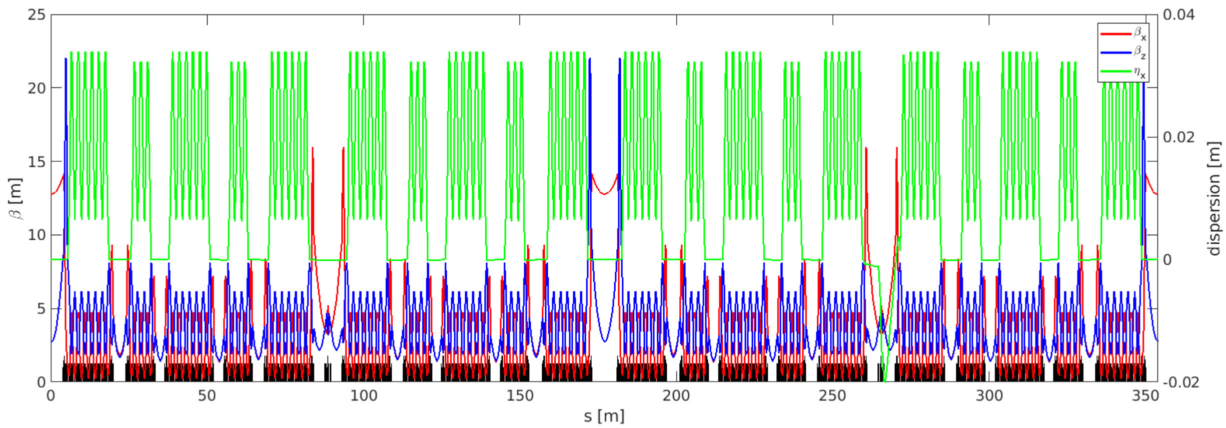

Figure 1: Optical functions of the 7BA-4BA SOLEIL II lattice producing a natural H-emittance of 85 pm·rad.

for the optics as well as the beam dynamics performance of the optimized lattice. The expected effects of these 8 superbends on emittance and energy loss per turn are finally moderate and are listed in Table 2. In addition,there is a weak vertical tune shift due to the fringe field peaks, which can be easily overcome with the nearby quadrupolar correctors.

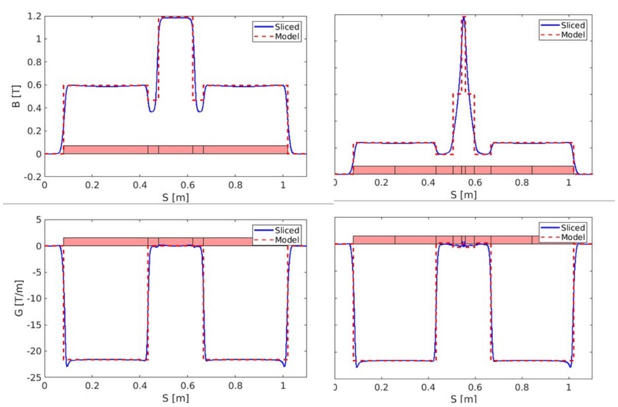

Figure 2: B-field and G-field of the normal long bend (left) and 3 T superbend (right) as well as their simplied fitted lattice models.

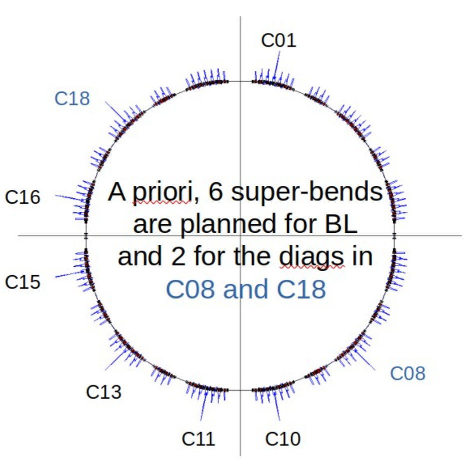

Figure 3: Positioning of the 8 superbends.

Table 2: Super-bend Impact on the Lattice

	W/o SB	+ 8 SB	Diff
Emit. [pm·rad]	84.7	90.5	+5.8
U0 [keV/turn]	477	485	+8
Frac. Tunes	0.2/0.30	0.2/0.31	+0/0.01

LATTICE EVOLUTION

The continuous evolution is still to improve the matching sections according to the engineering integration requirements. It mainly concerns the rearrangement of their implantation for a much better mechanical integration of the BPMs blocks, the crotch photon absorbers being located just downstream of the dipoles. In addition, the magnet bore radius and the median pole gap have to be large enough to allow the vacuum chamber cooling channel as well as the safe photon power extraction. Special attention has been paid to the canted region, where larger magnet bore diameters (and weaker field) are mandatory to safely extract off-axis photon beams. With the constraints of large gradient fields, not too tight orbit interlock and limited space to accommodate insertion devices, the new number of sextupole and quadrupole families is quite large. For example, we can have up to 9 different sextupole families. In addition, all sextupoles and the octupoles are now paired in positions to facilitate the planned and necessary beam-based alignment of the strong sextupoles. The short straight sections had to be kept to a minimum of 3.10 m free length to accommodate the in vacuum undulators.

BEAM DYNAMICS

Multipoles Impacts

The initial magnet design provided rather low systematic higher order multipoles. With relative field variations well below 0.1% at a radius of 5 mm, they had a moderate impact on beam dynamics performance. The need for safe vacuum chamber cooling and photon extractions lead to larger magnet pole gaps with thinner poles width in sextupole magnets, resulting in much

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larger systematic multipoles, up to a few percent at a radius of 5 mm. The effect on beam dynamics is then relevant with a Touschek beam lifetime reduction of the order of 40% (from 4.6 down to 2.8 hrs at 500 mA in 416 bunches w/o bunch lengthening). The natural way to limit these performance reductions is to include all these systematic multipoles in the optimization process, restoring the lifetime up to 3.3 hours. At this stage, the effects of the pipe limits become negligible and the effect of the transition from symmetry 2 to symmetry 1 (setting on the canted chicane) is also moderate. With a very compact lattice having a typical inter-yoke distance of 50 to 60 mm, the magnetic field crosstalk may not be negligible. An intensive campaign of these cross-talk field simulations (magnets taken 2 by 2) has been undertaken.

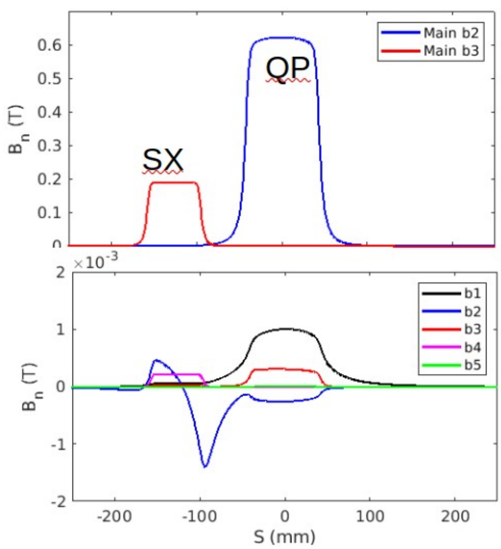

Figure 4: Example of cross-talk multipoles (bottom) between a quadrupole and a sextupole (top).

In the bend side, the presence of end plates to limit the fringe field extension and naturally almost cancels out most of the cross-talk effect. On the other hand, in the matching sections with quadrupole, sextupole and octupole magnets, these simulations show a non-negligible cross-talk field from dipolar to decapolar and negligible beyond (Fig. 4). The addition of all these new cross-talk multipoles hopefully shows a really moderate impact on the beam dynamic performance (Fig. 5).

Insertion Devices Impact

An ID portofolio composed of 19 insertion devices is now defined both for the first and second phases of the upgrade. The phase 1 will utilize the majority of the existing undulators and wigglers closed to lower gap values. New undulators are designed to fulfil photon beam user requirements together with implementation constraints [6]. The linear and non-linear effects of IDs are simulated using AT code and RADIA kick maps [7], and 4 modes of polarisation are studied for each helical type undulator. As a first step, LOCO algorithm [8] is used to correct the linear perturbation (horizontal and vertical beta-beatings can reached ±5% and ±10%).

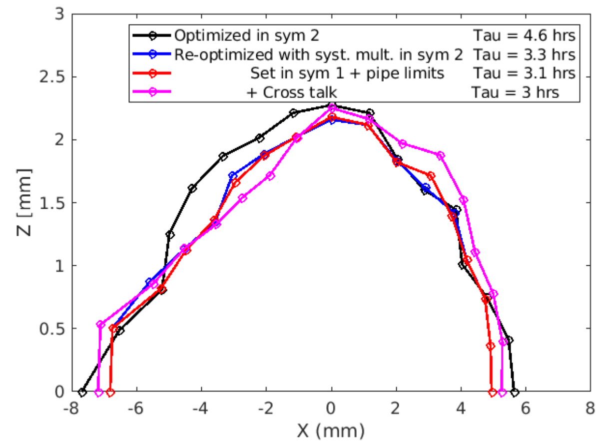

Figure 5: Dynamic aperture and Touschek beam lifetime versus the lattice settings.

A lattice without any errors is used. The effect of IDs on on-momentum dynamic aperture is acceptable and the physical aperture effect remains small in the presence of IDs. The Touschek lifetime can be significantly reduced, especially for the linear tilted mode of helical undulators where some betatron coupling is generated even by the perfect ID magnetic field (Table 3). The LOCO correction is mandatory to recover a reasonable Touschek lifetime of 2.5 hrs (500 mA in 416 bunches, without bunch lengthening). The effects of IDs for phase 1 and phase 2 configurations are found to be very similar.

Table 3: Phase 1 ID Configuration. Effect on Touschek Lifetime (hrs) Versus Polarisation Mode (all the helical undulators are set in the same polarisation mode)

	Lin H	**Lin V**	**Circ**	**Lin T**
No lin. corr.	2.3	2.4	2.4	1.5
W/ lin. corr.	2.6	2.5	2.7	2.5

CONCLUSION

The new SOLEIL II baseline lattice achieves a low natural horizontal emittance of 85 pm·rad. The brilliance at 500 mA and 30% coupling (25 pm·rad V-emittance) increases by up to 2 orders 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 4 keV. After a series of evolutions, the ring lattice reaches a stage where mechanical integration including safe photon beam extraction is feasible, all magnets are also feasible together with reasonable beam performance.

Work will continue on the beam dynamics optimisation including the IDs of phase 1 and phase 2. Others important priorities include the robustness and commissioning stage modelling as well as beam collimation studies and machine protection that have also been initiated.

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REFERENCES

[1] Synchrotron SOLEIL, `https://www.synchrotron-soleil.fr`

[2] L. Nadolski, “Operational status of synchrotron SOLEIL”, presented at the IPAC'24, Nashville, TN, USA, May 2024, paper TUPG48, this conference.

[3] “SOLEIL upgrade conceptual design report”, CDR, 2021, `https://www.synchrotron-soleil.fr/fr/file/13803/download?token=OUzsp46P`

[4] A. Loulergue *et al.*, “TDR baseline lattice for SOLEIL II upgrade project”, in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 1054-1056. `doi:10.18429/JACoW-IPAC2023-MOPM031`

[5] C. Kitegi *et al.*, "Magnet Design Status of SOLEIL II," in *IEEE Trans. Appl. Supercond.*, Apr. 2024, `doi:10.1109/TASC.2024.3375294`

[6] J. Susini, *et al.*, “A brief introduction to the Synchrotron SOLEIL and its upgrade programme”, *Eur. Phys. J. Plus*, vol. 139, no. 1, p. 80, 2024. `doi:10.1140/epjp/s13360-024-04872-2`

[7] P. Elleaume, “A New approach to the electron beam dynamics in undulators and wigglers”, in *Proc. EPAC'92*, Berlin, Germany, Mar. 1992, pp. 661-664.

[8] J. Safranek, “Experimental determination of storage ring optics using orbit response measurements”, *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 338, no. 1, pp. 27-36, 1997. `doi:10.1016/S0168-9002(97)00309-4`