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# TDR BASELINE LATTICE FOR THE UPGRADE OF SOLEIL

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*Abstract*

Previous CDR studies for the SOLEIL Upgrade project have converged towards a lattice alternating 7BA and 4BA HOA type cells providing a low natural horizontal emittance value in the 80 pm.rad range at an energy of 2.75 GeV. This lattice adapts to the current tunnel geometry as well as to preserve as much as possible the present beamline positions. The TDR lattice is an evolution of the CDR one including longer short straight sections, better relative magnet positioning, and the replacement quadrupole triplets by quadruplets for improving flexibility of optics matching in straight section. The SOLEIL upgrade TDR lattice is then composed of 20 HOA cells with a two-fold symmetry, and provides 20 straight sections having four different lengths of 3.0, 4.2, 8.0, and 8.2 m. This paper reports the linear and the non-linear beam dynamic optimization based on intense MOGA investigations, mainly to improve the energy acceptance required to keep a large enough Touschek beam lifetime. Some future directions for performance improvement are discussed.

## INTRODUCTION

SOLEIL is the French third generation light source routinely operated for external users since 2008 with a low electron beam emittance of 4 nm·rad at an energy of 2.75 GeV in high intensity (500 mA, multibunch) and temporal structure (e.g. 8 bunches) modes [1,2]. After 15 years of successful operation, a series of feasibility studies were initiated for a possible upgrade of the storage ring with a significantly lower emittance. The approach taken is to employ all useful methods to reduce the emittance while respecting the geometric constraints such as the circumference of the ring and the available straight sections, in order to limit the impact on the existing beamlines and the building costs.

## LATTICE LAYOUT

The current lattice of the SOLEIL storage ring is composed of 16 modified two-bend achromat cells, 8 of which have short straight sections between the dipoles, altogether giving a total of 24 straight sections covering up to 46% of the 354.1 meter long circumference [3] with 3 different lengths: 4×12, 12×7, and 8×3.8 m. This compact lattice provides a natural horizontal emittance of 4 nm.rad at an energy of 2.75 GeV.

Alternating 7BA and 4BA cells was then identified during the Conceptual Designe Report phase (CDR) [4,5] as the natural solution to best fit the current beamline (BL) positioning and leave the tunnel shielding wall unchanged [3, 4]. The TDR reference lattice is then composed of 20 HOA cells alternating 7BA and 4BA cells (Fig. 1), giving a natural horizontal emittance of 84 pm.rad at an energy of 2.75 GeV. 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 main comparison parameters are listed in Table 1.

Table 1: Main Lattice Parameters

| | Actual | Upgrade |
|---|---|---|
| Emittance (2.75 GeV) | 4 nm.rad | 84 pm.rad |
| Circumference | 354.1 m | 353.5 m |
| Straight section number | 24 | 20 |
| Long straight length | 12 m | 8.00 / 8.35 m |
| Medium straight length | 7 m | 4.20 m |
| Short straight length | 3.8 m | 3.00 m |
| Straight sec. length ratio | 46 % | 25 % |
| Betatron tunes | 18.16 10.23 | 54.2 18.3 |
| Mom. comp. factor | $4.4\ 10^{-4}$ | $1.05\ 10^{-4}$ |
| RMS energy spread | 0.1 % | 0.091 % |
| Energy loss per turn w/o IDs | 917 keV | 458 keV |
| Damping times (ms) | 3.3/3.3/6.6 | 7.7 /14.4 /12.2 |
| RMS Nat. bunch length | 15.17 ps | 8.5 ps |
| RF Voltage | 2.8 MV | 1.8 MV |

## EVOLUTIONS FROM THE CDR

The first evolution was to change the matching sections from triplet to quadruplet of quadrupoles and to significantly rearrange their implantation for a much better mechanical integration of magnets, BPMs and crotches. In addition, all these quadrupoles became pure permanent magnets. The TDR lattice is then fully based on permanent magnets for all dipolar and quadrupolar main fields. Other magnets (sextupoles and octupoles) are naturally kept electromagnetic. To preserve optics tuning capabilities, 196 auxiliary thin air-cooled quadrupolar electromagnets were added along the arc cells. Added to the quadrupolar fields available in all the octupoles leading to a total of 412 quadrupolar correctors. In parallel, the nominal working point was shift away from the coupling resonance (Fig. 2). In terms of risk analysis, a coupling value of 30% with white noise excitation was finally preferred to the non-linear dissonance condition during injection process.

In addition to the ID beamlines, the ring must provide high magnetic fields for BLs on dipoles even if their number and location are not yet completely decided. To be more flexible, the second evolution was to split the 76

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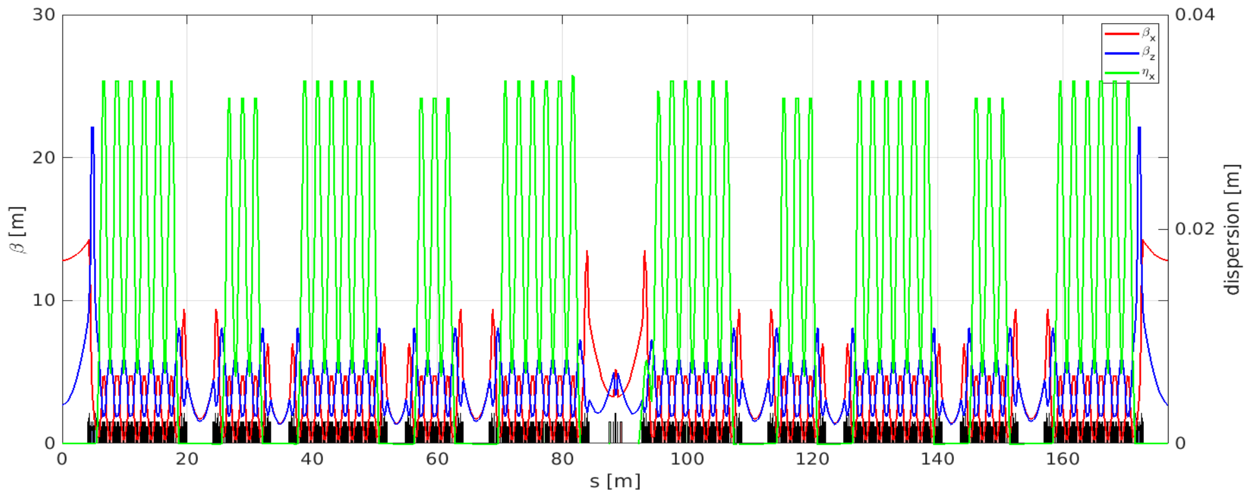


Figure 1: Super period optical functions of the 7BA-4BA SOLEIL upgrade lattice producing an emittance of 84 pm.rad.

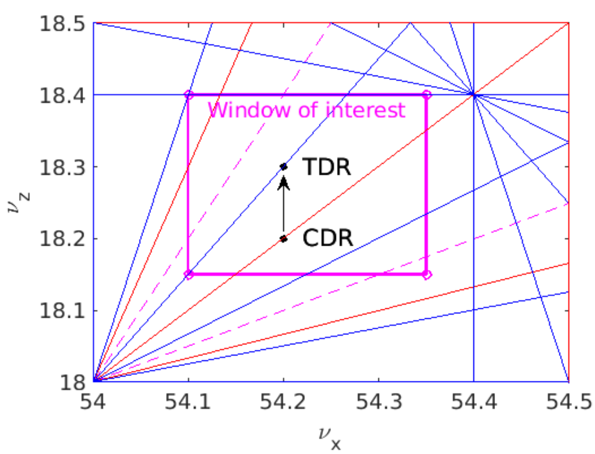


Figure 2: Evolution of the working point in the tune diagram from CDR to TDR lattice.

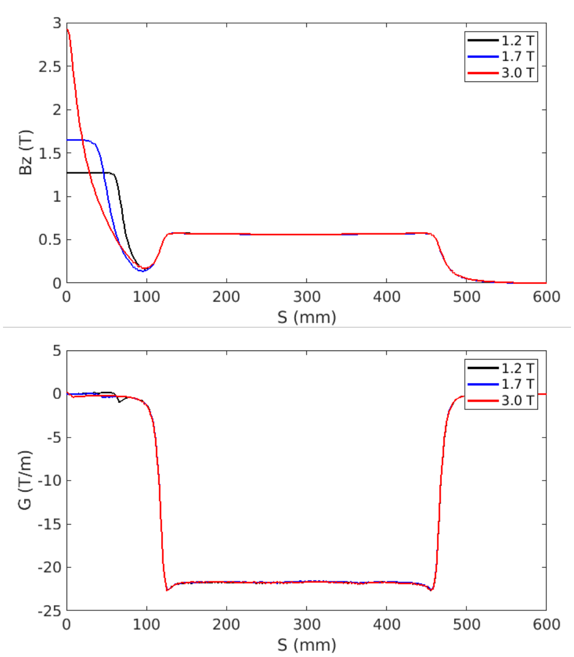


Figure 3: Longitudinal variation over half long bending magnet: main field (up) and gradient (down).

long combined bending magnets into three parts. The central part, which houses the peak field without transverse gradient, is interchangeable and can provide a standard field of 1.2 T as well as higher fields of 1.8 T and up to 3 T. The two-side field plateau, providing the transverse gradient, remains unchanged regardless of the central peak field value (Fig. 3). This superbend will also be very valuable for the dedicated diagnostics stations. Overall, the 3 T field magnet has a negligible impact on the various equilibrium synchrotron parameters if their number is limited to 6.

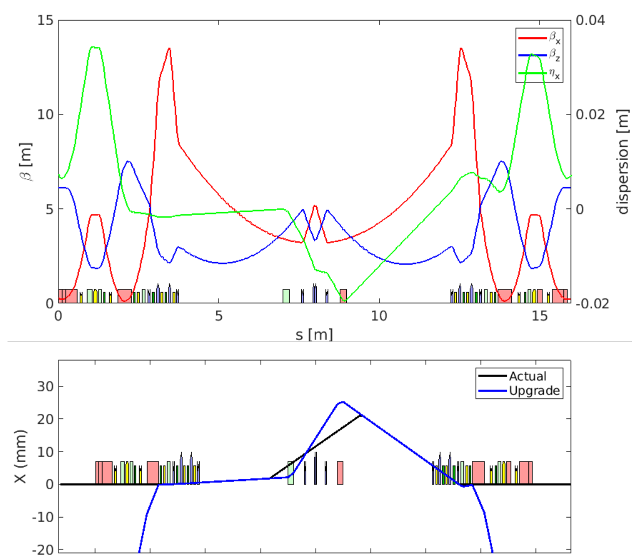


Figure 4: Double low beta optics for the two canted long beamlines (up) and comparison of the horizontal trajectory with the actual one (down).

The last evolution consisted in perfectly setting up and aligning the two long canted beamlines as well as the double low vertical beta functions by means of an additional triplet of quadrupoles (Fig. 4). With an overall straight section length shorter than the actual one and the need to control the dispersion function, we also had to modify the adjacent arc bends in order to completely fit the geometry as well as the optical functions. The

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resulting optics is very similar to today's and provides a vertical beta function of about 2 m at the center of each in-vacuum undulators.

## BEAM DYNAMICS

The main proposed injection scheme is based on the horizontal on-momentum and off-axis scheme [6]. Using Multipole Injection Kicker (MIK) [7] as key component should make the Top-up injection quasi transparent for the users with a field-free region along the path of the stored beam. The MIK generates over one turn a flat top deflection maximized at x = -3.5 mm from the central axis. To enlarge the horizontal Dynamic Aperture (DA), larger β functions ($\beta_x = 12.7\,m$ and $\beta_z = 2.7\,m$) are provided in the injection section. A third or fourth harmonic cavity system will be installed half of long straight section [6] in order to lengthen the beam by a factor of 3 to 4, increase the Touschek beam lifetime as well as to reduce the Intra Beam Scattering (IBS) effect. We must respectively achieve an on-momentum DA of at least 5 mm at injection location as well as at least 3 hours of Touschek beam lifetime without any bunch lengthening. These target values must be satisfied in the presence of all possible errors (alignment errors, magnet systematic and random errors, insertion devices, injection magnet jitters, etc.).

The first step of the optimization was performed only by targeting the on-momentum DA and limiting the off-momentum tune shifts using simple sextupole and octupole scans with the code OPA [8]. The next step involved AT [9] and MOGA [10] iterations to be able to control both DA and energy acceptance to increase the Touschek beam lifetime. The Figures 5 and 6 exhibit respectively the on and the off-momentum aperture using FMA technics for the diffusion index [11] calculated at the injection point for the ideal lattice. The energy acceptance along the lattice typically ranges from -4% to +3.5%. According to the Piwinski's model, the Touschek beam lifetime reaches 3.7 hours in the high brilliance operation mode of 500 mA (416 × 1.2 mA) before any bunch lengthening, at zero current bunch length, and with emittances of 84 and 25 pm.rad respectively in H-plane and V-plane (30% coupling). The vacuum lifetime is much larger with about 20 hours at 500 mA and a $10^{-9}$ mbar (100% nitrogen) dynamic mean pressure (expected after 100 A.h accumulated beam). The impact of the systematic multipoles and errors are still under investigations with latest results reported in [12]. In parallel, dynamics optimization with MOGA-ELEGANT [13] based on large scale high performance computer was also recently started. At present times, based on simplified constraints, gives equivalent results.

## CONCLUSION

The new SOLEIL Upgrade baseline lattice achieves a low natural horizontal emittance in the range of 84 pm.rad. The brilliance at 500 mA and 30% coupling (25 pm.rad) (30% coupling) increases by up 2 orders of magnitude, reaching $10^{22}$ photons/s/mm$^2$/mrad$^2$/0.1%b.w., pm.rad) in the SOLEIL photon energy range of interest between 1 and 4 keV. The IBS induced emittance growth

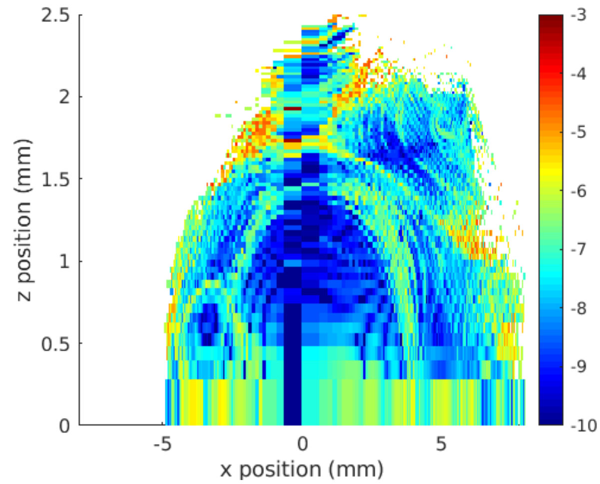


Figure 5: On-momentum DA at injection point.

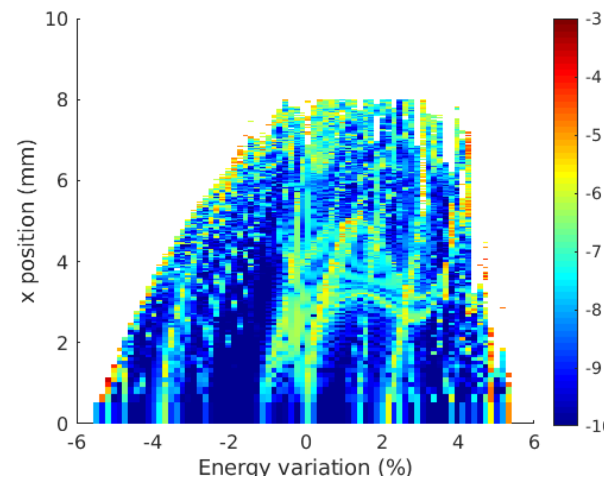


Figure 6: Off momentum horizontal DA at injection point.

and limited beam lifetimes can be mitigated to an acceptable level by means of a third (or fourth) harmonic RF cavity to lengthen the bunch.

Work will continue to focus on the dynamic aperture the momentum acceptance optimization to ease up the injection and accumulation schemes for the first day and daily operation. Another important topic is related to the impact of the magnet crosstalks due both to the compactness of the lattice and the combined magnet design. Modeling of the ID impacts on beam dynamics will continue as well as the mechanical integration of the crotch absorber and the diagnostics components. Beam collimation studies and machine protection will soon be initiated as a priority.

The SOLEIL Upgrade design remains aggressive in terms of parameters. It makes extensive use of permanent magnet technology, accommodates a small (12 mm diameter) beam NEG coated vacuum vessel, and narrow photon extractions and requires brand new a low emittance booster (5 to 10 nm.rad [14]). No critical obstacles have been encountered so far in the project.

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[1] Headings, table captions, and equations, when placed at the top of a column, do not require any preceding blank space, i.e., the 'space before' should be set to 0 pt.

2 When more than 9 references, different indentations apply to ensure their proper alignment. Further details are given in **ANNEX B**.