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STUDY OF UPGRADE SCENARIOS FOR THE SOLEIL STORAGE RING

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Abstract

The SOLEIL storage ring, commissioned in 2006, is a 2.75 GeV third generation synchrotron light source with a horizontal emittance of 3.9 nm·rad for a circumference of 354 m. Within the scope of a future major upgrade towards a Diffraction Limited Storage Ring (DLSR), the present paper presents and discusses lattice design and magnet lattice arrangement, under the constraint of making the upgrade in the same existing machine tunnel. Two scenarios were presented earlier in this context, which both preserved all the existing 24 straight sections hosting insertion devices, injection and RF-cavities, though the bending magnet positions were not strictly conserved. The purpose of the extended studies is to explore, in particular, the range of horizontal emittance that can be reached.The dependence of the nonlinear properties of the magnet lattice on the linear optics is simultaneously investigated.

INTRODUCTION

Today's SOLEIL Lattice

The present optics of the SOLEIL third generation light source is based on a Double Bend (DB) lattice (Fig. 1). With an energy of 2.75 GeV and a 354 meter-long circumference, the horizontal emittance provided is 3.9 nm·rad with a dispersion leakage of 17 cm to 22 cm in the three types of straight sections (SS): 4 × 12 m, 12 × 7 m, and 8 × 3.6 m. This emittance value is twice the Theoretical Minimum Emittance (TME) with dispersion leakage (Tab. 1).

Table 1: Emittance invariant and effective emittances for the SOLEIL storage ring using a DB lattice given for the 3 types of straight sections (SS).

Emittance	Value	Remarks
ϵ_x^{TME}	5.5 nm·rad	No dispersion in SS
$\epsilon_{x,\eta_x}^{TME}$	1.8 nm·rad	Dispersion leakage in SS
ϵ_x	3.9 nm·rad	17 cm to 22 cm
Horizontal effective emittance $\sigma_x \times \sigma'_x$		
Long SS	**Medium SS**	**Short SS**
5.8 nm·rad	6.5 nm·rad	5.5 nm·rad

Upgrading the SOLEIL optics can be separated into two sub-tasks 1/ the DB-split achromat cell including the short and two medium SS, namely the SDM-SDC-SDM cell; 2/ the DB full achromat with the long and medium SS, namely the SDL-SDM cell. Both cell types are very compact with a distance of 15.0 m and 12.4 m between their first and last magnetic elements. The goal to reach an emittance reduction of at least a factor ten includes different ingredients and options to be discussed in the following sections. The starting point of the present study is the linear optimization proposed in [1, 2].

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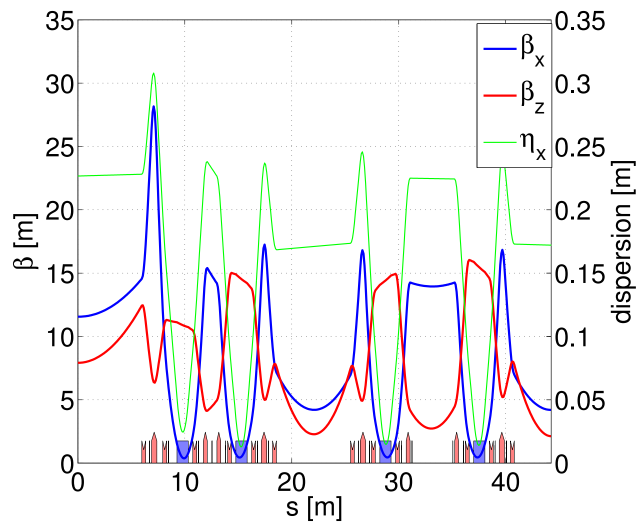

Figure 1: Optics for the 3.9 nm·rad nominal lattice of SOLEIL ($1/8^{th}$ of the circumference).

Optimization Tools

The present work relies on AT [3]; it makes use of new AT-based optimization routines [4]; the TRACY-III code [5] is used for long-term tracking.

SDM-SDC-SDM LATTICE DESIGN

Linear Optics

The baseline optics presented in [2] consist of a 4BA lattice where the two inner dipoles enclose the short SS. This compact design including combined dipoles was pushed further down resulting in a reduction of the emittance from 586 to 540 pm·rad lowering the vertical beta function of the short SS to 2 m long to host in-vacuum insertion devices.

Nevertheless a hard limit was reached making the use of the longitudinal variable dipole field mandatory. The gain in term of emittance is promising leading to an emittance of 433 pm·rad (reduction of 100 pm·rad) with a similar linear optics as illustrated by Fig. 2. Each dipole was split into 8 parts for this purpose: it appears that 3 or 4 parts should be enough to obtain a similar emittance value. The drawback of this solution may be the quite high combined dipole field and the 2.2 T field for one of the slice (see magnet parameters in Tab. 2 and 3), which needs further investigations. With this lattice design keeping natural chromaticities low

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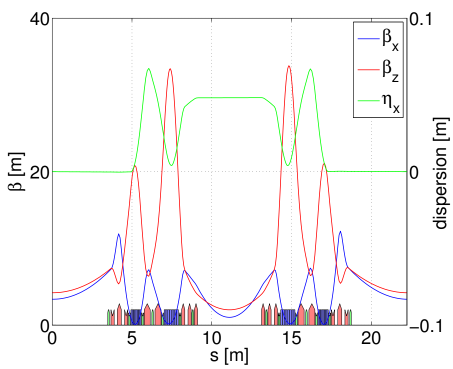

Figure 2: Optical functions for the 433 pm·rad SDM-SDC-SDM cell.

is in conflict with the low-emittance requirement. The chromaticity wall is −6.4/−6.0 per cell. A large reduction of the short SS effective emittance is prevented by the horizontal dispersion of 4 cm to 5 cm due to the lattice compactness.

Table 2: Parameter Table for Quadrupoles and Sextupoles

SDM-SDC-SDM		SDL-SDM	
b_2^{max}	b_3^{max}	b_2^{max}	b_3^{max}
63 T/m	6000 T/m^2	63 T/m	7000 T/m^2

Non-linear Optics

The non-linear optimization for this optics remains very challenging. To allow for off-axis injection, the dynamic aperture should be of the order of $\frac{x}{\sqrt{\beta_x}} = 4 \times 10^{-3}\,\mathrm{m}^{\frac{1}{2}}$ with the today's booster performance. This value could be relaxed assuming an upgrade of injector for low emittance optics. The linear and nonlinear optimizations are somehow linked in order to provide the necessary constraints to preserve as far as possible the dynamic aperture (DA) and momentum aperture (MA). A first optimization based on the minimization of the first and second order sextupole resonant driving terms (RDTs) and of the tuneshifts with amplitude gave only a DA of ∼−3 mm ($\beta_x = 3.4$ m) in the horizontal plane (see Fig. 3).

It is worth noting that this DA is obtained only after looking for solutions with suitable phase advance between sextupoles, i.e. $(2k+1)\pi$ or $k\pi$ respectively in the H and V-plane. Since sextupole magnets (5 chromatic and 2 harmonic like families) are modeled as of 0.1 m-long thick elements, they render the phase conditions not exactly satisfied. In fact this condition cannot be reached within a single cell but rather after two cells. Moreover the tuneshifts with amplitude are kept under control. All particle tracking have been made using the symplectic code Tracy-III for 1026 turns for an ideal lattice (no magnetic or alignment errors) at this stage of the work. The obtained momentum aperture of

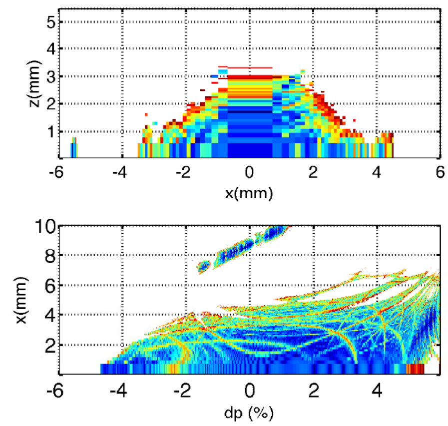

Figure 3: On-momentum dynamic aperture at cell entrance (up) and off-momentum horizontal aperture (down) for the 433 pm·rad SDM-SDC-SDM cell.

more than ± 3 % is naturally large without any specific optimization; the local momentum acceptance is mainly limited in the short SS (Fig. 3 and 4).

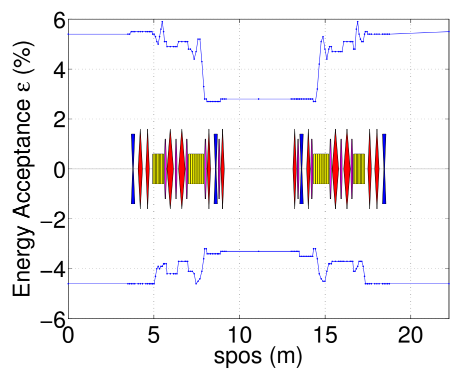

Figure 4: Local momentum acceptance for the 433 pm·rad SDM-SDC-SDM cell (4D-tracking).

SDL-SDM LATTICE DESIGN

Linear Optics

This SDL-SDM cell structure is based on a 5BA lattice [2] with strictly zero horizontal dispersion in the straight sections (see Fig. 5, Tab. 2 and 3). An emittance of 440 pm·rad is reached with natural chromaticities per cell of −5.2/−4.6 respectively in the H and V-plane. Quadrupole triplets are introduced to keep the flexibility for optics matching. The vertical focusing in mainly provided by the combined dipoles; the focusing quadrupoles in the achromat are split into two for inserting focusing sextupoles at large dispersion value. Defocusing sextupoles are located upstream and downstream the dipoles where the vertical beta function is large. For injection purpose, the horizontal beta function of the long SS reaches 8 m. All dipoles have the same magnetic field but different lengths.

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Table 3: Parameter Table for Dipoles for Cells SDM-SDC-SDM (I) and SDL-SDM (II) and Reached Emittances

Cell	ρ^{min}/ρ^{max}	$\theta^{min}/\theta^{max}$	B^{min}/B^{max}	b_2^{min}/b_2^{max}	Emittance
I	0.464/6.272 m	0.018/0.240 rad	0.163/2.202 T	−17.4/−21.7 T/m	433 pm·rad
II	1.767/2.471 m	0.095 rad	0.869 T	−8.8/−20.2 T/m	440 pm·rad

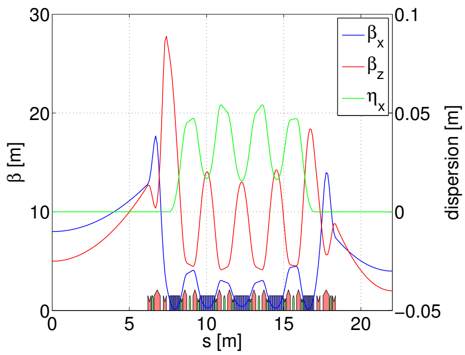

Figure 5: Optical functions for the 440 pm·rad SDL-SDM cell.

Non-linear Optics

A total 3 + 1 sextupole families are optimized in order to enlarge the dynamic aperture as for the previous cell. Matching the phase advance between sextuples was not possible in this flavor of the lattice. Nevertheless a DA of –4 mm was obtained together with an momentum acceptance of ± 3 to 4 % (Fig. 6 and 7). Matching the sextupole phase advance and reducing RDTs need to be pursued by increasing the number of sextupole families.

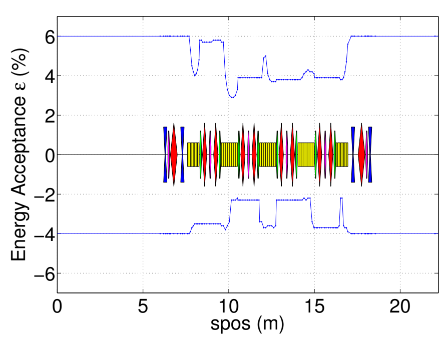

Figure 6: Local momentum acceptance for 440 pm·rad SDL-SDM cell (4D-tracking).

CONCLUSIONS AND PERSPECTIVES

This early work opens a promising perspective in reducing the SOLEIL horizontal effective emittance by more than a factor 10 (440 pm·rad) except for the short SS. Other solutions based on hybrid lattice composed of 6BA and 7BA cells are also under consideration. The compactness of the existing ring makes not surprisingly this work very challenging without exception. As for most other projects the

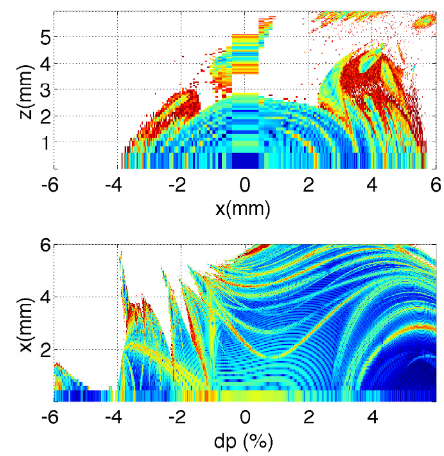

Figure 7: On-momentum dynamic aperture at cell entrance (up) and off-momentum horizontal aperture (down) for 440 pm·rad SDL-SDM cell.

on-momentum dynamic aperture remains very small. This work is in progress and will continue by including more realistic spacing for diagnostics and feasible magnet parameters. The use of genetics based algorithm is also foreseen.

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