DESIGN CONSIDERATIONS OF A 7BA-6BA LATTICE FOR THE FUTURE UPGRADE OF SOLEIL

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Abstract

The paper reports on the studies on the low emittance lattice design using a combination of 7BA and 6BA cells in the SOLEIL ring, made within the context of a future upgrade of SOLEIL. With the aim of lowering the excessively large natural chromaticities in magnitude and the strong quadrupoles resulted in the previous studies, several design strategies are adopted in the linear optics optimization. The obtained results are presented and discussed. First attempts are made on the nonlinear lattice designs with respect to chromaticity correcting sextupoles in terms of betatron phases and amplitudes at their locations. On-momentum dynamic apertures are evaluated with preliminary sextupole configurations and the foreseen subsequent steps are discussed.

INTRODUCTION

SOLEIL is the French 3rd generation light source routinely operated for users since 2007 with a low emittance electron beam in high intensity multibunch and temporal structure (e.g. 8 bunches) modes (Table 1) [1].

Table 1: Main SOLEIL Parameters as of Today

Energy	2.75 GeV
Circumference	354.097 m
Nominal current	500 mA (multibunch mode), 8×12 mA (8-bunch mode)
Horizontal emittance ε_x	3.91 nm·rad
Adjusted emittance ratio	1%
Betatron tunes (ν_x, ν_z)	(18.174, 10.232)
RF frequency f_{RF}	352.2 MHz

A particularity of SOLEIL is the short straight sections (SDCs) created between the dipoles in half of the 16 double-bend (DB) cells, providing 8 additional straight sections for users. Hereafter the cells without and with SDCs are referred to as SDL-SDM and SDM-SDC-SDM, respectively. Previous studies (IPAC 2015) indicated that adopting a combination of 7 and 6BA cells in the existing SOLEIL ring makes it possible to reach the target range of the horizontal emittance below 200 pm·rad as expected, in contrast to fewer dipole solutions such as a combination of 5 and 4BA studied earlier [2,3]. However, the obtained 7BA-6BA lattice resulted in having unacceptably strong gradients in quadrupoles and dipoles (see Figs. 3). Besides, the natural chromaticities were as large as (-13, -8.5) in the SDL-SDM cell and (-16.3, -6.4) in SDM-SDC-SDM cell.

In the present study, the following attempts shall be made to seek for an improvement of the undesired aspect above: 1) Lengthen the magnetic structure by shortening the free straight sections by one or two meters. 2) Lower the dipole fields. 3) Incorporate anti-bends into the lattice as proposed by A. Streun [4]. In particular, the solution using the anti-bends shall be compared with the one without them to evaluate exclusively the effectiveness of the latter scheme. Preliminary nonlinear optimizations shall be made on the obtained linear solutions introducing chromaticity correcting and harmonic sextupoles.

LINEAR OPTIMISATIONS

While the two types of DB cells SDM-SDL and SDM-SDC-SDM are both nearly 22 m long, the magnet section lengths are merely 12.5 m and 2×5.73 m respectively (Table 3 and Figs. 2), resulting in SOLEIL's record availability (46%) of free straight sections w.r.t. its circumference. To probe the dependence of the linear optics on the magnet section length, that of the SDM-SDL cell was tentatively increased by 2.5 m and those of SDM-SDC-SDM by 2×1.5 m (Table 2). It must be noted, however, that in reality the allowed reduction of ID straights is expected to be more stringent.

Table 2: Modifications in the magnet and straight section lengths tentatively introduced in this study.

Magnetic section lengths [m]			
SDL-SDM		SDM-SDC-SDM	
Original	Modified	Original	Modified
12.5	15.0	5.73	7.23

Straight section lengths [m]					
SDL		SDM		SDC	
Org	Mod	Org	Mod	Org	Mod
12	9	7	5	3.8	2.8

Out of several possibilities for the use of the additional space so obtained for the magnet sections, here we have chosen to allocate them for dipoles, in view of the dependence of the key optics functions on their length in approaching the TME (Theoretical Minimal Emittance) condition, as shown in Eqs. 1 below:

$$\beta_{x0}^{TME} = \frac{L_{dipole}}{2\sqrt{15}}, \qquad (D_x)_0^{TME} = \frac{(L_{dipole})^2}{24\rho}, \qquad (1)$$

$$(\beta_x)_{entrance}^{Achromat} = \frac{6}{\sqrt{15}} L_{dipole},$$

where L_{dipole} denotes the dipole length and ρ is its radius of curvature. This choice already makes a significant change over the previous design where the current dipole field of 1.71 T was kept, rendering the MBA dipoles short. The dipoles are lengthened by more than a factor of two with a lower field of 0.8 T. The linear optics solutions found in the new configuration giving comparable values

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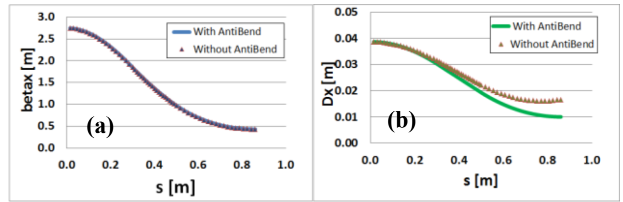
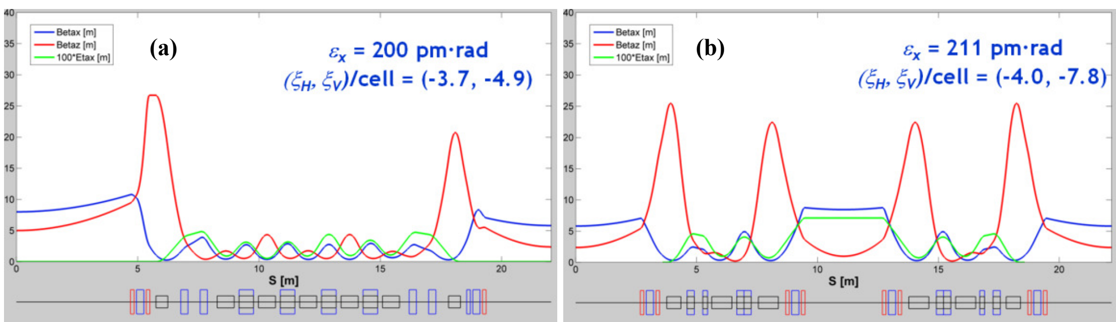
of emittance have, as expected, notably better properties for the focusing strengths and chromaticities (referred to as solution A in Table 3 and as "No AB" in Figs. 3).

In addition to increasing the dipole lengths, we now introduce anti-bends (ABs) in the lattice, following the scheme proposed by A. Streun [4]. The idea is based upon the observation that the optics solutions surrounding the TME are not symmetric in β_x and D_x, and that there are more margins for β_x to deviate from its TME value than for D_x. One can thus relax the quadrupole focusing and use AB that selectively focuses D_x. We shall also follow his idea to integrate ABs in focusing quadrupoles (QFs), to gain space and in addition lower the horizontal emittance further via increasing the damping partition number J_x. The known drawback here is that it leads to an increased energy spread and lower momentum compaction.



Figures 1: Effect of an anti-bend (-1° at 0 m position) on β_x (left *a*) and D_x (right *b*) at the center of an adjacent dipole (at 0.8 m position).

To see a visible effect, ABs each having a deflecting angle of -1° were tentatively integrated in the four central QFs in the SDL-SDM cell and likewise in the SDM-SDC-SDM cell in the present study. The expected behaviour of β_x and D_x with such AB is numerically confirmed (Figs. 1). Optics solutions found under the described lattice are shown in Figs. 2.



Figures 2: Lattice and envelop functions for (a) SDL-SDM (7BA) and (b) SDM-SDC-SDM (6BA) cells, each using the means described in the text to relax the linear focusing reduce the magnitude of natural chromaticities. The horizontal emittances are 200 and 211 pm·rad, respectively. Two cells shown represent 1/8th of the ring.

Table 3: Major Machine Parameters of Solutions A and B

Cell type	SDL-SDM		SDM-SDC-SDM	
Cell length [m]	22.03		22.23	
MBA lattice	7BA		6BA	
Solution*	A	B	A	B
ε_x [pm·rad]	115	200	189	211
Dipole fields [T]	0.8	0.8/0.9/1.0	0.8	0.942
Q_x/cell	3.107	2.443	2.878	2.368
Q_z/cell	2.225	1.832	1.651	1.720
ξ_x/cell	-8.0	-3.7	-6.1	-4.0
$\xi_z$cell	-8.8	-4.9	-9.2	-7.8
Momentum compaction (10^{-4})	1.4	1.1	1.9	0.98
Energy spread (10^{-3})	0.89	1.07	0.87	1.08

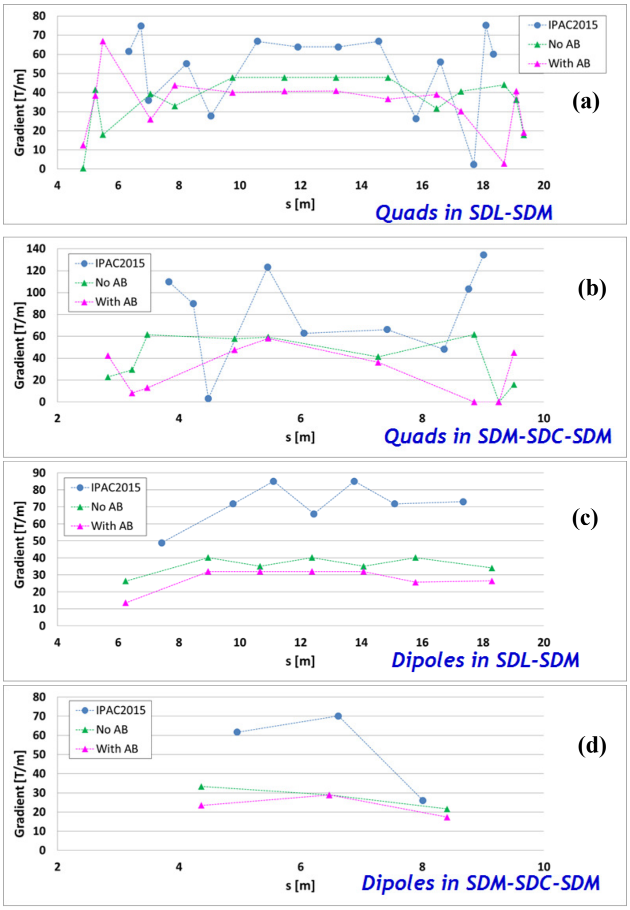
*A: Increasing the magnet section length. B: Introducing anti-bends in addition to condition A.

The properties of the obtained solution (referred to as solution B) are compared with the solution without ABs in Table 3, where we notice that chromaticities are furthermore reduced, especially in the horizontal plane. As compared to the IPAC 2015 solution, the horizontal chromaticity is reduced by a factor of 3 to 4. The focusing strengths of quadrupoles and combined function dipoles of the solution with ABs are compared with the other two solutions in Figs.4. Again, there is a clear trend that the gradients are furthermore reduced on the whole w.r.t. the solution without ABs. The majority of quadrupoles have the focusing strength of less than 50 T/m and those in dipoles are less than 30 T/m.

To meet the requirement of the existing dipole beamlines at SOLEIL, the possibility of introducing short 2- or 3-pole wigglers as substituting radiation sources is studied, following the schemes developed elsewhere such as at the ESRF [5]. Here we need to allocate space for these devices at locations where the photons shall be emitted at the same angle as the dipole radiation utilised today. Since additional complications arise from the presence of ABs that influence the integrated angle, the optimal AB angles must be carefully determined.

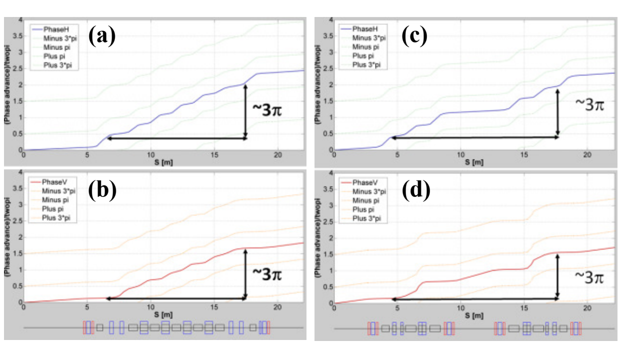
NONLINEAR OPTIMISATIONS

Thanks to the much smaller natural chromaticities obtained for the solutions with ABs as compared to the IPAC2015 solutions, the strengths of the chromaticity correcting sextupoles are reduced accordingly to reasonable values by introducing them at optimal locations optics-wise. However, the corresponding dynamic apertures are found to be severely limited and would require well-elaborated optimization schemes to be set up, such as the resonance driving term cancellations and interleaved sextupoles connected with *-I* transformations.



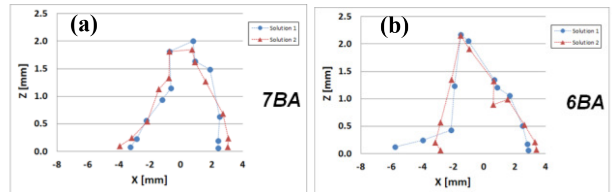
Figures 3: Comparisons of required focusing gradients in the obtained 7BA-6BA solutions described in the text.

The betatron phase advances of the solutions with ABs across the 7 and 6BA cells suggest that with some additional effort of optics matching, the outermost dispersion bumps could be utilized to establish one pair of sextupoles satisfying the *-I* transformation in both planes (Figs. 4). More studies are required to evaluate the feasibility of creating dispersion bumps with local symmetry in the optics to be able to introduce more pairs of sextupoles in an inter-leaved manner as achieved in the ESRF hybrid solution [6].



Figures 4: Betatron phase advances in the 7BA (a and b) and 6BA (c and d) cells considered. Arrows in the figures indicate the approximate *-I* relations with 3π phase differences.

Preliminary sextupole configurations adopted here have only one pair of SDs set in a pseudo *-I* relation and SFs and harmonic sextupoles distributed at locally optimal locations. The on-momentum dynamic apertures obtained for such solutions are shown in Figs. 5.



Figures 5: On-momentum dynamic apertures obtained for solution B for two different sextupole configurations. (a) 7BA and (b) 6BA.

SUMMARY

The combination of - Increasing the magnet section lengths at the cost of reducing the straight section lengths; - Lowering the bending magnet fields; and - Incorporating anti-bends in focusing quadrupoles allowed relaxing the strong focusing of the optics and simultaneously keeping 200 pm·rad range of horizontal emittance in the alternating 7- and 6BA lattice considered for SOLEIL. Under the magnet configurations considered, the quadrupole gradients are mostly below 50 T/m and the gradients in dipoles below 30 T/m. Subsequent design studies should focus on the extent to which these beneficial schemes could be integrated, which is particularly important in keeping the minimal straight section lengths necessary for the upgraded ring. Following the preliminary results obtained on the dynamic apertures of the 7BA-6BA lattice considered, a systematic study is to commence shortly in optimizing the nonlinear optics, by using genetic-algorithm-based numerical optimizers.

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