STUDY OF LOWER EMITTANCE OPTICS USING MULTI-BEND-ACHROMAT LATTICE AT SOLEIL

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Abstract

In the scope of a possible future upgrade, the use of MBA (Multi-Bend-Achromat) lattice is attempted in exploring new optics with the horizontal emittance in the sub-nanometer range for SOLEIL. With a combination of 4 and 5BA cells, a solution reaching 0.52 nm·rad emittance is found, achieving more than one order of magnitude of reduction in the effective emittance as compared to the present optics. Steps and considerations in developing the lattice, as well as some of the linear properties of the obtained optics are discussed.

INTRODUCTION

SOLEIL is the French third generation light source routinely operated for users since 2007 with a low emittance electron beam of 3.91 nm·rad in high intensity multibunch and temporal structure (e.g. 8 bunches) modes (cf. Table 1) [1]. After nearly 7 years of successful operation, a series of feasibility study is launched towards a possible future upgrade of the lattice with a lower emittance.

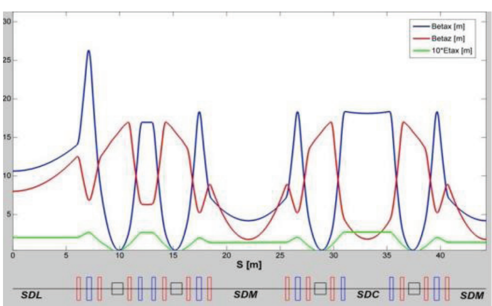


Figure 1: Original SOLEIL optics and the DB (Double Bend) lattice over 1/8th of the ring, showing long (SDL), medium (SDM) and short (SDC) straight sections.

The approach taken is to make use of whatever effective methods in lowering the emittance, but to fully respect the geometric constraints such as the circumference of the ring and the available straight sections, in order not to impact the existing insertion device beamlines.

Table 1: Current Standard SOLEIL Parameters

Energy	2.75 GeV
Circumference	354.097 m
Nominal current	430 mA (multibunch mode), 8×11 mA (8-bunch mode)
Horizontal emittance	3.91 nm·rad
Adjusted emittance ratio	1%
Betatron tunes	(18.174, 10.232)
RF frequency	352.2 MHz

As a first of such study, the use of longitudinal field variation of superbends was attempted [2] in view of the growing interests at SOLEIL in the dipole-based beamlines for such dipoles as means to raise the photon energy. A zero dispersion solution having 0.98 nm emittance was obtained in a 4BA structure by assuming a 7 T superbend at the centre of inner dipoles, which however resulted in markedly enhanced chromaticities and energy spread. The present paper reports on a second study investigating the applicability of MBA lattices for SOLEIL, those employed successfully in ultra-low emittance rings.

STEPS TAKEN AND CONSIDERATIONS

As a first step towards exploring the good use of MBAs at SOLEIL, the number of dipoles per achromat to introduce was deduced from the spatial availability. To maximise it, the dipoles were all assumed to be combined functions focusing vertically. Thus only horizontally focusing quadrupoles were considered in between them, which were furthermore split in two as in the Sirius design [3] to increase the flexibility of matching as well as to place a sextupole in between to make use of the dispersion function being maximal at those locations. The length of this unit in between two dipoles was assumed to be constant (named *LC*). At both ends of an achromat, a unit (named *LD*) composed of a Q-triplet was assumed instead of a doublet, again to leave more flexibility of matching in the straight sections, which is found important at SOLEIL to cope with occasional modifications of the optics. With *N* dipoles per achromat, the total achromat length *Lmag* is therefore decomposed into $2LD+(N-1)\,LC+\sum_{i=1}^{N} LBi$, where *LBi* is the length of *i*-th dipole (Fig. 2). In this study, *LD* and *LC* were tentatively set to 1.6 and 1.3 m, respectively.

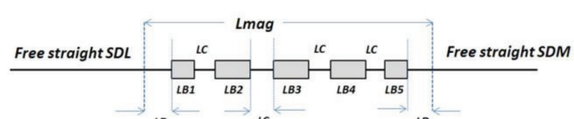


Figure 2: Schematic MBA structure considered in a SDL-SDM cell (5BA in this example).

The dipole length was varied between the outer dispersion suppressors and the inner ones such as to better balance the contribution to the emittance of each one as well as the amplitude of the dispersion at quadrupoles. The outer dipoles were chosen to be shorter than the inner ones by roughly 30%.

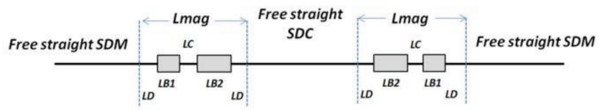


Figure 3: Schematic 4BA arrangement in a SDM-SDC-SDM cell.

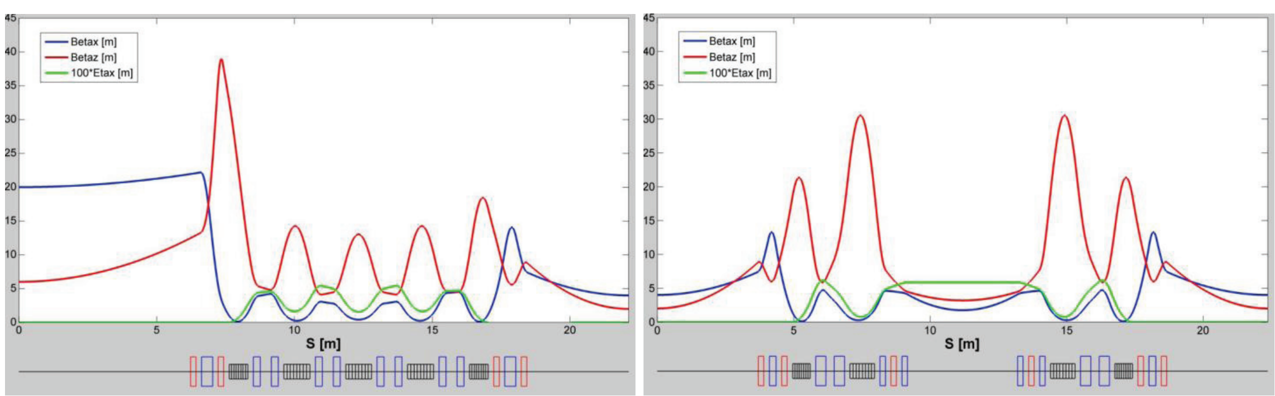
Starting from the simpler SDL-SDM cell, a 4BA lattice was firstly tried, finding well behaving solutions in the emittance range of above 0.7 nm. Since the length available for dipoles is still 4.15 m for a 5BA, the feasibility of latter was then studied with the aim of going further below in the emittance, where the emittance of well behaving solutions extended below 0.5 nm. On the other hand, for the SDM-SDC-SDM cells that have the short straight sections SDC in the middle of the achromat (Fig. 3), *Lmag* on each side is merely 5.73 m, rendering 4BA to be the only practical option. Namely, placing 3 dipoles on each side (i.e. a 6BA) leaves only 0.23 m for dipoles. With 4BA, the length available for two dipoles in each magnet section is 1.53 m. It follows that 5BA in SDL-SDM and 4BA in SDM-SDC-SDM cells appears to be the best feasible combination to minimise the emittance. However, it would inevitably create an unbalance on the emittance between the two types of cells. To compensate it, the use of longitudinal gradient in the inner dipoles of the 4BA cells may be a way as was done in Ref. 2, which is yet to be looked at.

OBTAINED RESULTS

As already stated, the combination of 5BA in the SDL-SDM and 4BA in the SDM-SDC-SDM cells was adopted as being considered optimal. With this lattice, an optics solution with a high horizontal beta at SDL for injection and low betas in the rest of straight sections was searched using the Q-triplet degrees of freedom. The solution found gives 0.52 nm·rad emittance with zero dispersion in SDL and SDM straight sections (Figs. 4). The gain in the effective emittance as compared to the original SOLEIL optics exceeds one order of magnitude in the SDL and SDM, and more than a factor of 5 in SDC straights (Table 2). Doubling of the effective emittance from 0.52 to 1.05 nm in SDC suggests that additional effort of reducing the emittance by breaking the achromat condition would not be fruitful in lowering the effective emittance, with the contribution from the energy spread dominating the former.

Table 2: Effective emittance $[\varepsilon_x(s)]_{eff} \equiv \sqrt{\varepsilon_x^2 + H(s)\cdot\varepsilon_x\cdot\sigma_{\Delta p/p}^2}$ [nm·rad] in the straight sections, in comparison with those of the original optics.

	SDL	SDM	SDC
Original optics	5.34	5.55	5.58
SOL-MBA	0.52	0.52	1.05
Ratio	10.3	10.7	5.3



Figures 4: Lattice and envelop functions for the SDL-SDM (left) and SDM-SDC-SDM (right) cells giving the emittance of 0.52 nm·rad, altogether representing 1/8th of the ring.

Table 3: Major machine parameters of the 0.52 nm solution in comparison with those of the original SOLEIL optics (in squared brackets). The values are calculated per cell.

	Cell SDL-SDM	Cell SDM-SDC-SDM
Horizontal emittance [nm·rad]	0.44 [3.85]	0.59 [2.67]
Energy spread	8.65×10^{-4} [1.02×10^{-3}]	9.32×10^{-4} [1.02×10^{-3}]
Momentum compaction factor	2.920×10^{-4} [4.836×10^{-4}]	1.961×10^{-4} [4.154×10^{-4}]
Betatron tunes	(2.238, 0.538) [1.110, 0.477]	(2.267, 0.695) [1.165, 0.811]
Chromaticities	(-5.33, -4.99) [-3.22, -1.15]	(-5.03, -5.84) [-3.34, -1.69]

The main machine parameters of the 0.52 nm solution are compared with those of the original SOLEIL optics in Table 3. As already said, the emittance in the SDM-SDC-SDM cell of 0.59 nm is nearly 35% higher than that of SDL-SDM (0.44 nm). Due to the use of weak dipole fields, the energy spread is found to be lower than the original optics in both cells. Reflecting the strong focusing in the horizontal plane, the betatron tune is

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roughly doubled horizontally, while vertically it remains practically unchanged. What turns out particularly positive as compared to the superbend solution in Ref. 2 is the much reduced increase of the horizontal chromaticity, not even reaching a factor of two in both cells with respect to the original optics. However, the vertical chromaticity becomes as large as the horizontal, which would require us to trace the origin and see if it could be improved, along with finding the most efficient scheme of correcting the chromaticities with sextupoles.

Since in this study we chose the dipole fields to be minimum necessary for the available length, being 0.87 and 1.18 T as compared to 1.71 T of the present ring, introduction of longitudinal gradient would be of interest in fulfilling the needs of dipole beam lines as well, in addition to our own interest in furthermore lowering the emittance as discussed earlier. Its feasibility shall be pursued along with the possibility of raising the overall dipole fields themselves. The dipole characteristics of the 0.52 nm solution are summarized in Table 4.

As a general trend in ultra-low emittance optics, the required quadrupole fields turn out to be high, some of them exceeding 50 T/m with the magnet length tentatively assigned. Statistics on the integrated gradient [m^{-1}] of the quadrupoles and dipoles are summarized in Table 5. In the Table, the magnet length required to have the (mean+rms) of the integrated strengths correspond to the field gradient of 40 T/m is shown to be roughly 0.4 m in both cells. It follows that if we envisage up to 50 T/m field gradients, the required magnet lengths remain more or less consistent with those assumed in the present study. In the subsequent studies, lattice spacing must at any cost be carefully optimized to relax the focusing strength as much as possible.

Table 4: Summary of the bending magnets used (the employed field gradients are not shown).

	Cell SDL-SDM				Cell SDM-SDC-SDM			
	L [m]	Θ [deg]	B [T]	ρ [m]	L [m]	Θ [deg]	B [T]	ρ [m]
Inner dipole	0.936	5.079	0.868	10.56	0.891	6.563	1.178	7.782
Outer dipole	0.669	3.632	0.868	10.56	0.637	4.687	1.178	7.782

Table 5: Statistics on the integrated focusing strengths [m^{-1}] of quadrupoles and bending magnets in SDL-SDM and SDM-SDC-SDM cells. As a measure, the magnet lengths indicated in the Table represent the lengths required to render the integrated strengths of (mean+rms) correspond to the field gradient of 40 T/m.

SDL-SDM					SDM-SDC-SDM				
mean	rms	max	min	magnet length	mean	rms	max	min	magnet length
[m^{-1}]	[m^{-1}]	[m^{-1}]	[m^{-1}]	[m]	[m^{-1}]	[m^{-1}]	[m^{-1}]	[m^{-1}]	[m]
1.216	0.522	1.763	0.000	0.398	1.026	0.780	2.230	0.042	0.414

SUMMARY

A preliminary study was made on the applicability of MBA in the SOLEIL ring within the frame of a possible future upgrade of SOLEIL, targeting a sub-nanometer range horizontal emittance. To evaluate the maximum number of dipoles to introduce in an achromat, certain lengths and quadrupoles were assigned for the constituent focusing units: Q-triplets at both ends and a focusing Q-doublet in between dipoles. While up to 5BA appears feasible in SDL-SDM cells, for SDM-SDC-SDM cells, 4BA seems to be the limit due to the presence of the short straight section SDC in the middle of the achromat. As a result, there appears a gap in the achievable emittance between the two cells.

Under this scheme of combining 5BA and 4BA cells, a solution giving an emittance of 0.52 nm·rad was obtained with zero dispersion in the SDL and SDM straights. The gain in the effective emittance as compared to the original SOLEIL optics exceeds one order of magnitude in the SDL and SDM, and more than a factor of 5 in SDC straights. In addition to reaching a lower emittance, the found MBA solution turns out to be superior to the superbend solution previously treated in Ref. 2 in terms of chromaticity and energy spread. The longitudinal gradient may nevertheless be used in order to compensate the gap in the emittance in between the two types of cells. Subsequent studies shall focus on the feasibility of the required quadrupole fields, magnet spacing, optics matching flexibility, optimal dipole fields, as well as the efficiency of chromaticity correction and nonlinear dynamics issues.

ACKNOWLEDGEMENT

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