LINEAR AND NONLINEAR OPTIMIZATIONS OF COMBINED 7BA-6BA LATTICES FOR THE FUTURE UPGRADE OF SOLEIL

A. Loulergue, H.-C. Chao, P. Brunelle, L. S. Nadolski, M.-A. Tordeux, R. Nagaoka, A. Nadji, Synchrotron SOLEIL, Gif-sur-Yvette, France

Abstract

Previous MBA studies converged to a combination of 7BA and 6BA structures, with the target horizontal emittance in the range below 300 pm.rad, where the effect of anti-bends, dipole field values, and straight section lengths were investigated. Inspired by the successful lattice designs adopting the interleaved sextupole scheme with dispersion bumps originally developed at the ESRF, the 7BA-6BA structures adopting this scheme are studied in details in parallel to those without it. The former aims at the horizontal emittance in the 200-300 pm.rad range with on- and off-momentum dynamic acceptances sufficiently large for off-axis injection and good Touschek lifetime. The latter pursues the lower bound of the reachable horizontal emittance with quadrupole and sextupole strengths in the feasible range with maximum dynamic acceptance. The option of non-standard on-axis injection such as displacing the injected beam longitudinally is envisaged for the latter solutions.

INTRODUCTION

SOLEIL is the French third generation light source routinely operated for users since 2007 with a low electron beam emittance of 4 nm.rad at an energy of 2.75 GeV in high intensity multibunch (up to 500 mA) and temporal structure (e.g. 1 and 8 bunches) modes. After nearly 11 years of successful operation, a series of feasibility study is launched towards a possible future upgrade of the lattice with a significantly lower emittance. The approach taken is to employ whatever useful methods in lowering the emittance by fully respecting the geometric constraints such as the circumference of the ring and the available straight sections, so as not to impact the existing insertion device based beamlines.

SOLUTIONS ALLOWING OFF-AXIS INJECTION

The SOLEIL synchrotron storage ring is a fourfold symmetry lattice composed 16 double bend (DB) cells. It provides four long straight sections (SDL) of 12 m and twelve medium sections (SDM) of 7 m. In addition, a set of eight short sections (SDC) of 3.8 m have been inserted in half of the DB cells. Since 2012, one of the SDL has been split into two low vertical beta sections for two long canted beamlines by means of an additional quadrupole triplet [1].

To reach a much lower emittance, the number of dipoles must be increased. A first combination of 5BA-4BA cells [2, 3] giving an emittance of 440 pm.rad including longitudinal gradient bends (LGB) was studied. The nonlinear beam dynamics analysis [4], although not fully optimized, exhibited a rather limited on-momentum acceptance for off-axis injection. In the same philosophy, a 7BA-6BA lattice was studied giving a much lower emittance of 160 pm.rad including LGB [5]. In this latter case, the dynamic acceptance is reduced even further more.

Progressing further in the investigation of much lower emittance lattices having a large enough dynamic acceptance compatible with off-axis injection, a combination of hybrid 7BA-6BA cells based on the ESRF-EBS design [6] has been studied. As conceived elsewhere, removing the central bend of a 7BA cell, allows the 6BA cells to host the SDC [7]. The paring of the sextupoles in the dispersion bump to odd multiples of π (close to 3π in H and π in V) is very effective in compensating the driving terms as well as producing large on-momentum dynamic apertures. The optical functions producing an emittance of 220 pm.rad are plotted in Figure 1. This lattice keeps the present symmetry of the ring, but with shorter straights (sees Table 1). The circumference ratio dedicated to straights is noticeably reduced from 45 % to 32 %.

Table 1: Straight Section Length Comparison

	Actual	Upgrade
Emittance (2.75 GeV)	4 nm.rad	220 pm.rad
Circumference	354.1 m	354.1 m
Number of cells	16	16
Long straight (SDL)	12 m	9 m
Medium straight (SDM)	7 m	5 m
Short straight (SDC)	3.8 m	2.8 m
Circumference ratio dedicated to straights	45 %	32 %

The dipole fields are rather low with 0.6 T combined with a transverse gradient of 30 T/m. The maximum gradient of quadrupoles reaches 70 T/m and the three sextupole family gradients are limited to 700 T/m^2 over 200 mm bore length. The beam dynamics optimization (by means of simple fits) on each of the individual cells (7BA or 6BA) with only 3 sextupoles families exhibits

on-momentum horizontal aperture of ±15 mm (@β_x=8 m) together with an off-momentum acceptance of ±4%. The use of anti-bend [8] in the dispersion bump region improves the off-momentum optimization. Once merged together to build the full super-cell lattice, the on-momentum acceptance is reduced to about ±12 mm (Fig.

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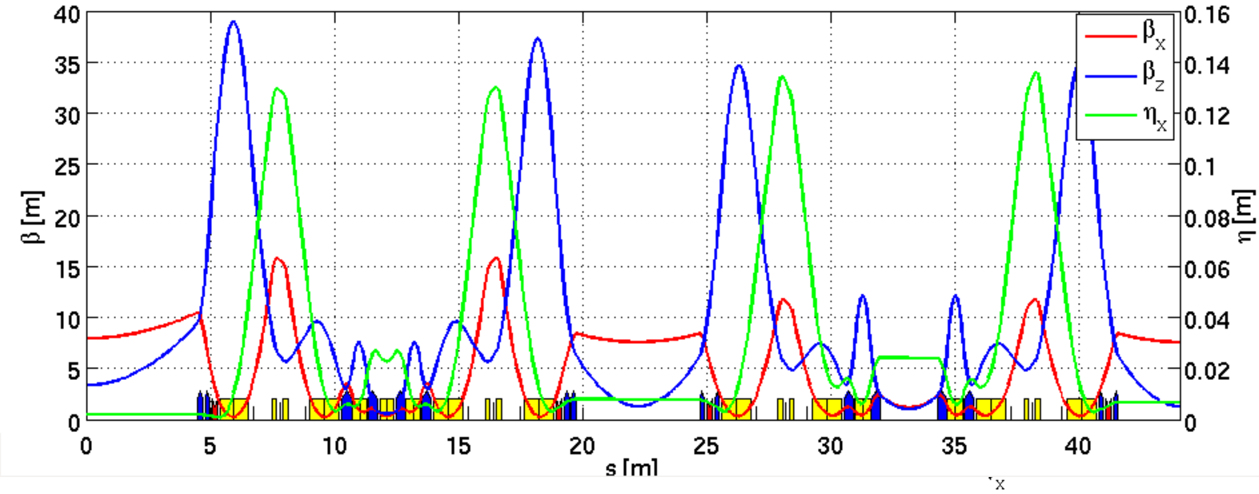

Figure 1: Optics over a half of a SOLEIL 7BA-6BA super-cell for the upgrade lattice with an emittance of 220 pm.rad.

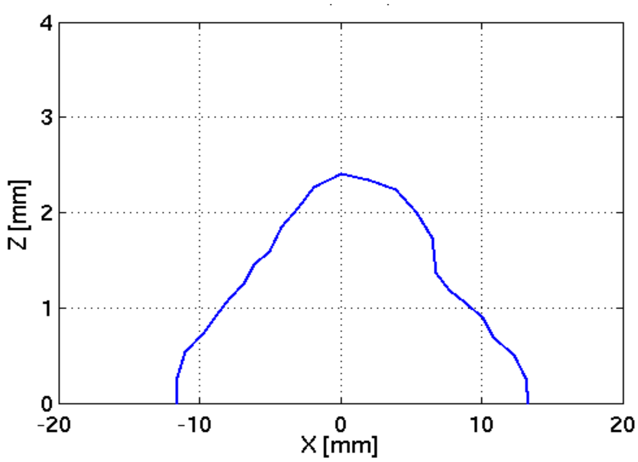

Figure 2: On-momentum dynamic aperture at injection point (β_x = 8 m and β_z = 3.5 m) for the 220 pm.rad optics.

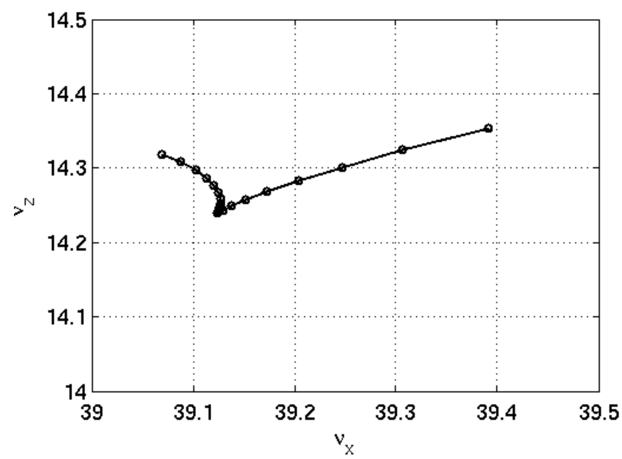

Figure 3: Off-momentum tune footprint over ±4 % at zero chromaticities.

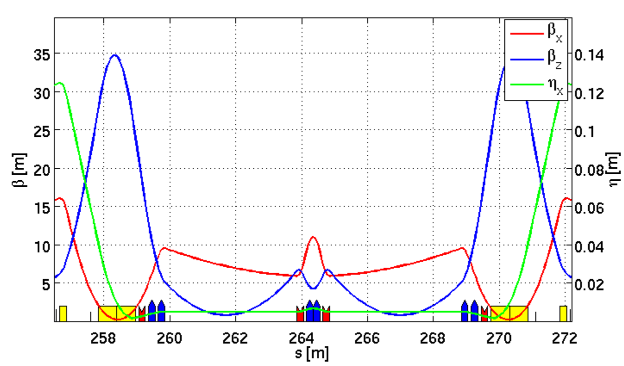

Figure 4: Modified 9 m long straight section with an additional quadrupole triplet to host the double low vertical beta sections.

2) and the off-momentum acceptance is kept to ±4 % (Fig. 3). Further optimization using MOGA, limited here to sextupoles, did not show any major improvement. With such lattice, the natural bunch length is rather short, about 2.6 mm RMS with an RF voltage of 3 MV at 352 MHz. Touschek beam lifetime estimation (OPA code [9]) with 1.2 mA per bunch exhibits about 2 hours with 4% coupling and a constant pipe diameter of 20 mm. With the same bunch parameters, the Intra Beam Scattering (IBS) effect is not negligible and raises the horizontal emittance from 220 to about 300 pm.rad with the vertical one fixed to 40 pm.rad. To cope with these two effects, a bunch lengthening by means of harmonic cavities is foreseen. Typically, a five times larger bunch length should relax the Touschek beam lifetime and almost cancels the IBS emittance increase.

Up to this point of the analysis, the double vertical low beta sections (Fig. 4) hosting the two presently existing long beam lines was not included. Its insertion, along with minor retuning, leaves the on-momentum dynamics almost unchanged, while the off-momentum dynamics get somewhat affected. The Touschek beam lifetime is then reduced from 2 to 1 hour only.

SOLUTIONS ANTICIPATING ON-AXIS INJECTION

To pursue the horizontal emittance in the 100 pm.rad range and below, lattice solutions that do not employ the (-*I*) transformation between the chromaticity correcting sextupoles have been explored. The absence of the above constraint allows increasing the flexibility of matching.

However, the resultant dynamic acceptance, in particular the on-momentum dynamic aperture, is expected to be severely limited, obliging on-axis injection. Two such schemes are presented below: The first is an extension of the 7BA-6BA lattice developed previously [10], in which SDL and SDM both were shortened to 5.5 m, while SDC was kept to its original value of 3.8 m. The gained space (of nearly 5.5 m) was redistributed to the two magnet sections of 6BA, each being merely 5.75 m long initially. All dipoles and focusing quadrupoles in the achromat integrate transverse gradient and antibends, respectively. Solutions with the emittance in 100 pm.rad range are found with zero dispersion and low betas (~2.5 m) in the straights. Integrating further moderate LGBs (Longitudinal Gradient Bend) in the dipoles allows lowering the emittance by 10-20 %, as shown in Fig. 5.

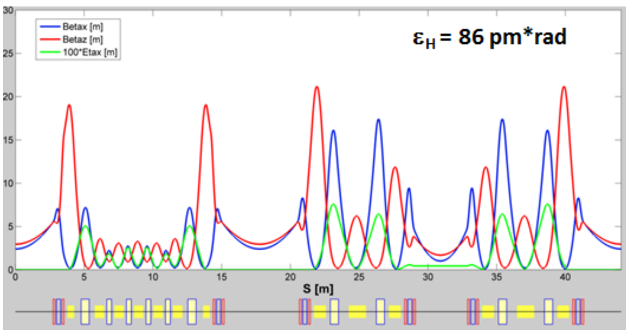

Figure 5: A 7BA-6BA lattice without employing the (-*I*) transformation giving the emittance of 86 pm.rad. See text for the description of the lattice.

The second solution constitutes a ring composed of 16 identical cells with 5.5 m long straight sections in between. A 10BA lattice composed of eight FODO cells having the phase advance of 150º and 90 º horizontally and vertically and two dispersion suppressing dipoles at two ends was developed, giving an emittance of 45 pm.rad (Fig. 6). The lattice consists of combined dipoles having 0.65 T and 49 T/m and focusing quadrupoles of maximum 95 T/m in between the dipoles.

As regards the nonlinear optimisation, both solutions tentatively distributed chromaticity correcting sextupoles in quadrupoles, and in dipoles as well in the latter, the technical feasibility of which yet remains as an open question. As anticipated, the horizontal on-momentum dynamic aperture has difficulties exceeding ±1 mm range for both solutions, while the momentum aperture extends roughly to ±4 % for the first case and to more than ±6 % in the second case. MOGA optimizations of sextupoles including the tune dependence and octupoles are underway.

In parallel, symmetry 16 solutions adopting the (-*I*) transformation for the chromaticity correction are also studied with an aim of building a lattice with the emittance in the 100 pm.rad range or below and keeping the possibility of off-axis injection.

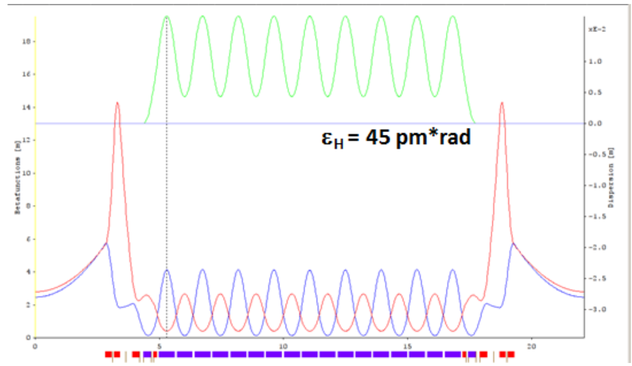

Figure 6: A 10BA lattice giving an emittance of 45 pm.rad. The ring is composed of 16 identical cells with 5.5 m of straight sections in between.

CONCLUSION

Keeping the three types of straight sections existing at SOLEIL as well as off-axis injection appears feasible with the 7BA-6BA solution adopting the (-*I*) transformation *à la ESRF* hybrid lattice [6,7] as shown in this paper, provided that the target emittance is in 200 pm.rad range. Linear solutions preserving the same number of straight sections are found in the 100 pm.rad range, however requiring on-axis injection. Symmetrizing the ring to 16 identical cells would allow off-axis injection with emittances much lower than 200 pm.rad or would allow targeting a lattice giving a two digit emittance.

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