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CDR BASELINE LATTICE FOR THE UPGRADE OF SOLEIL

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Abstract

Previous MBA studies converged toward a lattice composed of 20 7BA solution elaborated by adopting the sextupole pairing scheme with dispersion bumps originally developed at the ESRF-EBS providing a low natural horizontal emittance value of 70-80 pm rad range at an energy of 2.75 GeV. Due to difficulties to accommodate such lattice geometry in the SOLEIL present tunnel as well as to preserve at best the beamline positioning, alternative lattice based on HOA (Higher-Order Achromat) type cell has been recently investigated. The HOA type cell, being more modular and possibly exhibiting larger momentum acceptance as well as low emittances, a solution alternating 7BA and 4BA cells was then identified as the natural solution to best adapt the current beamline positioning and leave the tunnel shielding wall unchanged. The SOLEIL CDR upgrade reference lattice is then composed of 20 HOA cells alternating 7BA and 4BA structures giving a natural horizontal emittance of 80 pm rad. In addition, with a two-fold symmetry, it provides four different straights sections of 2.73, 4.15, 7.35 and 7.65 m. In particular, the beta functions nearly tuned to 1 m in both transverse planes at the center of the short and medium straight sections allow matching diffraction limited photons up to 4 keV. The linear and non-linear beam dynamic properties of the lattice along with the possibility of horizontal off-axis injection at full betatron coupling are presented.

INTRODUCTION

SOLEIL is the French third generation light source routinely operated for users since 2007 with a low emittance electron beam of 4 nm rad at an energy of 2.75 GeV in high intensity, up to 500 mA, multibunch and temporal structure (e.g. 8 bunches) modes [1]. After 14 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 respecting the geometric constraints such as the circumference of the ring and the available straight sections, so to limit the impact on the existing beamlines.

LATTICE LAYOUT

The current lattice of the SOLEIL storage ring is composed of 16 modified two-bend achromat cells, 8 of which have introduced short straight sections in between the dipoles, altogether providing 24 straight sections [2]. There are three types of straight sections with the lengths of 12, 7 and 3.8 m covering up to 46% of the total length. With a circumference of 354.1 m, this lattice provides a natural horizontal emittance of 4 nm rad at an energy of 2.75 GeV.

In the scope of a storage ring upgrade [3] having a natural horizontal emittance below 100 pm.rad (i.e.: 40 to 50 times lower), the use of Multi-Bend Achromat (MBA [4]) lattice has been investigated. A first attempt was done by alternating the hybrid 7BA ESRF-EBS [5] cell type with another hybrid consisting of a 6BA with a split in the middle as that developed for DIAMOND-II [6], allowing lattice geometry very close to the current one. But still with only 16 cells, the emittance reduction was limited at the level of 220 pm rad. Furthermore, no good matching of the electron beam phase space ellipses was attained with those of the photon beam over the photon energy range of interest. To further reduce the emittance value, the best way out was to increase the number of cells from 16 to 20. During the last few years, two solutions with 20 identical cells: 7BA ESRF hybrid and 7BA HOA (Higher-Order Achromat [7]) types giving about 75 pm rad have been investigated. Despite being competitive, their geometry ends up producing non-parallel beamlines and requires reconstruction of up to 8 ratchet walls. To keep the beamlines parallel, the lattice geometry has to include both 22.5° deflection cells and half deflection cells 11.25°.

Table 1: Main Lattice Parameters

	Actual	Upgrade
Emittance (2.75 GeV)	4 nm rad	80 pm rad
Circumference	354.1 m	353.5 m
Straigth section number	24	20
Long straight length	12 m	7.35 / 7.65 m
Medium straight length	7 m	4.15 m
Short straight length	3.8 m	2.73 m
Straight sec. length ratio	46 %	25 %
Working point	18.16 10.23	54.2 18.2
Mom. Comp. Factor	$4.4\ 10^{-4}$	9.1210^{-5}
RMS energy spread	0.1 %	0.09 %
Energy loss per turn	917 keV	490 keV
Damping times (ms)	3.3/3.3/6.6	7.3 /13.1 /11.7
RMS Nat. bunch length	15.17 ps	9.18 ps

Alternating 7BA and 4BA cells was then identified as the natural solution to best adapt the current beamline positioning and leave the tunnel shielding wall unchanged. The HOA type cell, being more modular and exhibiting potentially larger momentum acceptance, has

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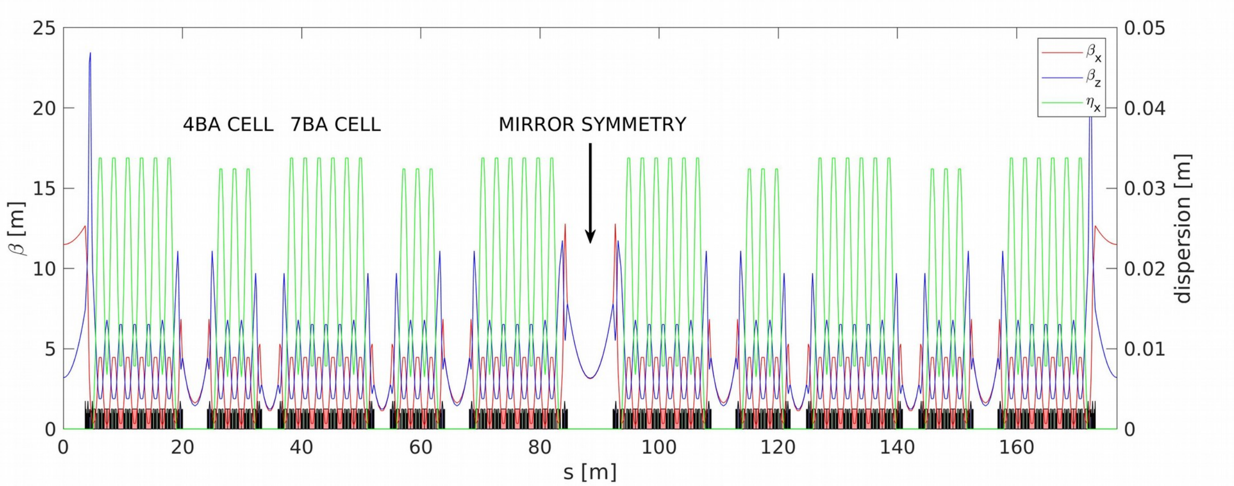

Figure 1: Super cell optical functions of the 7BA-4BA SOLEIL upgrade lattice producing an emittance of 80 pm mrad.

therefore been chosen. The CDR upgrade reference lattice is then composed of 20 HOA cells alternating 7BA and 4BA (Fig. 1), giving a natural horizontal emittance of 80 pm rad at an energy of 2.75 GeV. The main parameters are listed in Table 1. In addition, to perfectly align the two long canted beamlines as well as to minimize the radial offset for the others, the lattice has a two-fold symmetry with four different straight section lengths [8].

LATTICE WORKING POINT

In order to reduce the number of different magnet families we opt to keep the same unit arc cell in both 7BA and 4BA cells. When alternating HOA cells, the best phase advances of $(\Delta\nu_x = 3/7 = 0.427, \Delta\nu_z = 1/7 = 0.143)$ for 7BA [7] is not valid anymore to obtain good beam dynamics performance. At present times, an optimum was found with slightly lower phase advances of $(\Delta\nu_x = 0.408,\ \Delta\nu_z = 0.108)$. They still are in the lower emittance regime. With a medium electron energy of 2.75 GeV, the photon energy of interest where the brilliance gain has to be maximized, is in the soft X-ray range (i.e.: up to a few keVs). At full betatron coupling, the reached emittances are about 50 pm rad in both planes. They are very comparable to diffraction limited photon emittance $(\epsilon_{ph} = \lambda/2\pi = 50\, pm.rad)$ at 4 keV emitted from an undulator. It is then worthwhile matching an electron beam to a photon beam ellipses optimizing the emitted flux density, brilliance and transverse coherence. With small β functions at the center of the medium and short straight sections of the order of 1.5 and 1.1 m, the CDR reference upgrade lattice is then close to fulfilling the typical matched beta functions $(\beta_{x,z} \sim L_{und}/\pi \sim 1)$ for 2 to 4 m long insertion devices. Although horizontal off-axis injection is foreseen for accumulation, we also opt to operate the storage ring on full coupling in order to relax the high electron density per bunch. It will then provide larger Touschek beam lifetime and less emittance and energy spread increase from the Intra-Beam Scattering (IBS) effect. For both effects, there is a non-negligible beneficial gain of the order of 2 to 3 as compared to a 10% coupling case with only 8 pm rad in the vertical plane. Among different techniques, we opt for the most natural and simplest one sitting the tune working point on a difference coupling resonance. Altogether, the storage ring working point has been chosen to be: $(\nu_x = 54.2,\ \nu_z = 18.2)$ which then has also the advantage of exhibiting the largest region free of systematic resonances equal to or less than the order 5 (Fig. 2) in the limited two-fold lattice symmetry.

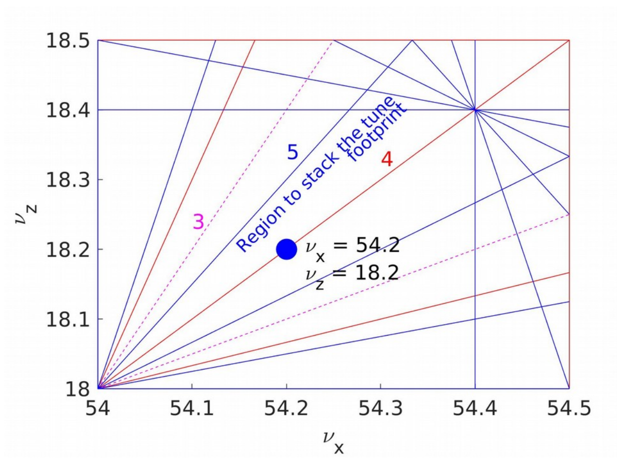

Figure 2: Tunes working point.

BEAM DYNAMICS

The main proposed injection scheme is based on the horizontal on-momentum and off-axis scheme [9]. The kick is provided by a dedicated Multipole Injection Kicker (MIK [10]) having a flat top deflection at 3.5 mm from the central axis. To enlarge the horizontal Dynamic Aperture (DA), larger β functions $(\beta_x = 11.5\, m, \beta_z = 3.2\, m)$ are provided in the injection section. We also plan to use a harmonic cavity (harmonic 4 or 3) in order to lengthen (by a factor of 3 to 4) the bunch and further relax the Touschek beam lifetime as well as to reduce the IBS effect. We need to respectively

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achieved an on-momentum DA of at least of 5 to 6 mm at injection location as well as at least 3 hours of Touschek beam lifetime without any harmonic cavity lengthening. These target values are imposed including all possible errors (lattice systematic and random, insertion devices, injection jitter etc.). To prevent or minimize the transfer of the injected beam amplitude from the horizontal to vertical plane, with a low clearance gap, one still needs to reshape the horizontal amplitude-dependent tune shift (ADTS). The dissonance *D*, the distance from the coupling resonance $D(x)=\nu_x(x)-\nu_z(x)$ which is null at the origin *x*=0, has to be large enough for the injected beam amplitude to avoid this transfer (Figs. 3 and 4).

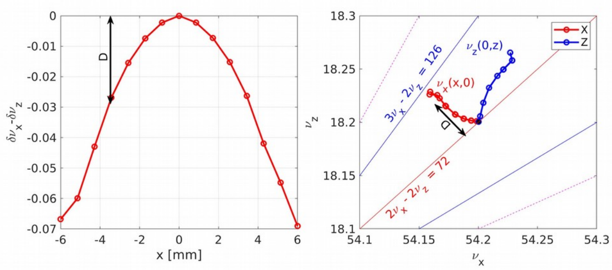

Figure 3: Left: dissonance along horizontal direction, right: on-momentum tune expansion.

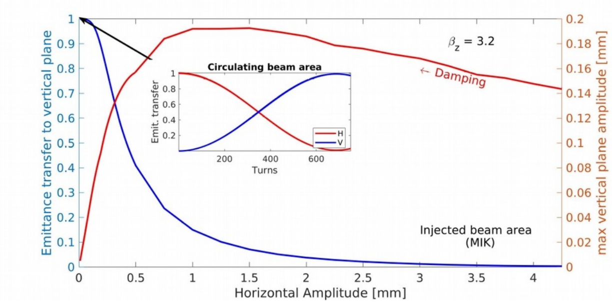

Figure 4: Coupling and vertical transfer versus horizontal initial amplitude at injection center.

The first step of the optimization was performed only by targeting the DA as well as limiting the off-momentum tune expansion by means of simple sextupoles and octupoles scans using AT code [11]. The next step involves MOGA iterations [12] to be able to control both DA and energy acceptance to enlarge the Touschek beam lifetime. Figures 5 and 6 exhibit respectively the on and the off-momentum FMA [13] obtained at the injection point for the ideal lattice.

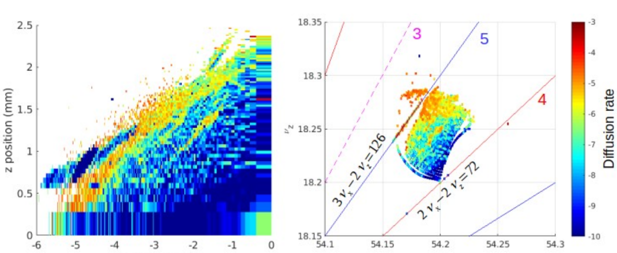

Figure 5: On-momentum FMA at injection point.

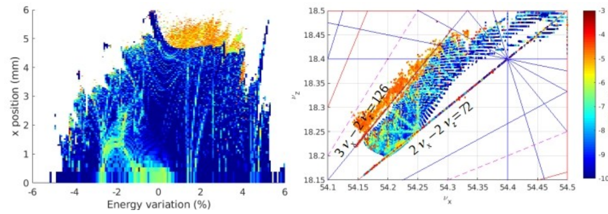

Figure 6: Off momentum FMA at injection point.

The energy acceptance ranges typically from -4% to +3.5%. Based on the Piwinski model, the Touschek beam lifetime without any bunch lengthening (at zero current bunch length) and with emittances of 50 pm rad in both planes is a little bit above 3 hours in the high brilliance operation mode of 500 mA (or 1.2 mA per bunch over 416). In parallel, the vacuum lifetime is larger with about 40 hours at 500 mA and 1.10^{-9} mbar (100% nitrogen) dynamic mean pressure (as SOLEIL today). The impact of the errors are still under investigations [14].

CONCLUSION

This SOLEIL Upgrade baseline lattice achieves a low natural horizontal emittance in the range of 80 pm rad and 50 pm rad in both planes at full coupling. Combined with low beta function at straight section center predicts a brilliance increase up to 2 order of magnitude, reaching 10^{22} photons/s/mm^2/mrad^2/0.1%b.w., in the SOLEIL photon energy range of interest between 1 and 4 keV. At high current (500 mA), IBS emittance growth and limited beam lifetimes can be mitigated to an acceptable level by means of a third (or fourth) harmonic RF cavity lengthening the bunch. We believe that the radial and off-momentum acceptances are still workable for injection accumulation schemes considered. Nevertheless a complete upgrade of the booster is mandatory to reach a much lower emittance of the order of 5 to 10 nm rad [15]. The two long canted beamlines as well as the beamline hosting radio-safety infrastructure dedicated to radioactive samples are fully preserved.

Although this proposed SOLEIL lattice upgrade is relatively aggressive requiring significant modifications of the injector, and relying on the use of large-scale permanent magnet technology, a small beam tube diameter (12 mm), and narrow photon extractions, no real obstacles have been encountered at this time.

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