ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB038

ROBUSTNESS STUDIES AND FIRST COMMISSIONING SIMULATIONS FOR THE SOLEIL UPGRADE LATTICE

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Abstract

Diffraction limited light sources will use very strong focusing elements to achieve their emittance goal. The beam will therefore be more sensitive to magnet field and alignment errors. The impact of errors on the lattice proposed for the SOLEIL upgrade was studied with the Accelerator Toolbox (AT) code. The performance achieved with the imperfect lattice will be presented. In particular the effect of girder misalignment was also accounted for. As the lattice uses a large number of permanent magnets for the beam bending as well as the focusing, challenges arise in terms of machine optics and orbit correction. The location of correctors and BPMs and their numbers will be investigated to maximize their efficiency, and the corrector magnet strength required to obtain a closed orbit will be studied. The commissioning strategy, and in particular the method used to achieve the first turns and a stored beam in the machine will also be presented.

INTRODUCTION

The French synchrotron light source SOLEIL operates since 2007 with a 2.75 GeV electron beam with 4 nm rad emittance. Currently 29 beamlines, with 20 of those using insertion device, are in service. An upgrade project is currently being developed [1], aiming to reduce the emittance below 100 pm rad, i.e. at least a 40-fold reduction in horizontal emittance. A reference lattice for the Conceptual Design Report (CDR) of the SOLEIL Upgrade project was designed [2]. To account for the existing beamlines geometric constraints and reach the emittance goal, a lattice alternating 7-bend achromat (7BA) and 4-bend achromat (4BA) was retained.

Because of the significantly stronger magnetic fields and much smaller beam pipes required for the CDR upgrade lattice as compared to the current accelerator, the beam sensitivity to errors of magnet alignment, magnetic field calibration and of diagnostic elements will be amplified. These errors must be compensated using dedicated corrector magnets implemented along the ring. Due to strong sextupoles in the CDR reference lattice, the residual orbit errors in sextupoles are expected to be the dominant quadrupolar errors, indicating the need of a highly performant closed-orbit correction system to minimize them. Moreover operation with full betatron coupling is required for the mitigation of IBS effects. An efficient coupling correction shall therefore be required before introducing betatron coupling in a controlled way.

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To restore linear optics, a complication adds up upon the fact that a majority of magnets with quadrupolar gradients (combined-function dipoles and reverse-bends) will be permanent magnets and therefore cannot take part in the correction procedure. To reach the performance goal of the CDR reference lattice described earlier, it is thus highly important to carefully optimize the number, locations and strengths of all types of correctors (dipolar, normal and skew quadrupolar) that must be introduced in the ring.

BPM, CORRECTORS AND ERROR ASSUMPTIONS FOR THE CDR LATTICE

A first Beam Position Monitor (BPM) configuration in the lattice was chosen. Two BPMs are placed at the entrance and exit of the matching section of each cell. In the arcs one BPM is placed next to the focusing sextupole in each Higher-Order Achromat (HOA) unit. Figure 1 shows the BPM arrangement in the 4BA cell. That in the 7BA cell follows analogously. Under this configuration, the total number of BPMs in the entire ring is 176.

Dipolar correctors for the orbit correction are located in the two sextupoles of each matching section, and in one every other defocusing sextupoles in the HOA unit. The total number of dipolar correctors in this configuration is 176 for each transverse plane. Their maximum strength is tentatively limited to 250 µrad. Figure 1 shows the dipolar corrector locations in the 4BA cell. Figure 2 shows the horizontal and vertical phase advances for the first two cells of the lattice, and highlights phases at the BPM and dipolar corrector locations in those cells.

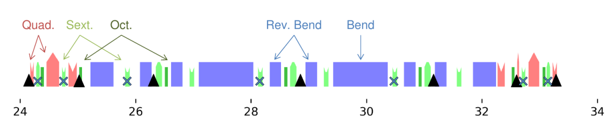

Figure 1: 4BA cell layout. Black triangles represent BPMs, blue crosses represent dipolar correctors.

Because most of the magnets with quadrupolar gradients will be permanent-magnet based, quadrupole correction coils are introduced in the 176 octupoles distributed in the ring. Skew quadrupole corrector coils are also assumed to be integrated in the 176 octupoles around the ring. Magnets and BPMs are installed on girders whose positioning errors must be accounted for. A scheme with 172 girders is currently considered for beam dynamics simulations. The plinths on which girders are installed are not simulated. A simple aperture model is added for the beam pipe: a 5 mm square aperture is assumed all along the lattice. The Acceler-

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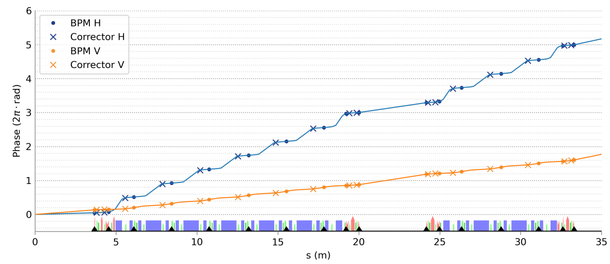

Figure 2: Phase advance in the first two cells of the upgrade lattice. Phase at the BPMs are marked with dots, phase at the dipolar correctors are marked with crosses.

ator Toolbox (AT) code [3] is used, along with the Simulated Commissioning (SC) toolbox [4,5] to integrate the assumed error model and simulate the correction procedure.

The generated errors follow a Gaussian distribution truncated at $\pm 2\sigma_{rms}$ except for the girder-to-girder misalignment limit which is an absolute value. Tables 1, 2, 3 and 4 detail the σ_{RMS} values used for the simulations, defined in collaboration with the diagnostics and alignment groups. Several effects are currently included in the model:

- BPM transverse misalignment and roll errors as well as calibration and noise errors of the electronics.
- Magnets transverse misalignment and roll errors, as well as the main magnetic field component calibration error.
- Dipolar corrector calibration errors.
- Girders misalignment and roll errors. A girder-to-girder misalignment amplitude limit is also included in the model.
- Injection errors: for one simulated machine, a random error for all injections can be applied to account for kicker magnets systematic errors (labeled "Static injection error" in Table 4). Then for each injection simulated with the toolbox, a random error can be generated (labeled "Random injection error" in Table 4).
- RF cavity frequency and voltage errors

Table 1: RMS Errors for BPMs

Type	**Level**
Misalignment x/z, before BBA	500 µm
Misalignment x/z, after BBA	10 µm
Roll	100 µrad
Calibration	10 %
Noise Turn by Turn	50 µm
Noise Closed Orbit	1 µm

FIRST TURN SIMULATION STUDIES

The combination of strong magnetic fields and small aperture will make the first beam injection into the new storage ring particularly challenging compared to third-generation light sources. Therefore full commissioning simulations using SC are being made. The commissioning steps comprise:

Table 2: RMS Errors for Magnets

Type	**Level**
Misalignment x/z	30 µm
Roll	50 µrad
Calibration	0.1 %
Dipolar correctors calibration	5 %

Table 3: Errors for Girders

Type	**Level**
RMS Misalignment x/z	100 µm / 100 µm
Girder-to-girder limit x/z	50 µm/30 µm
RMS Roll	50 µrad

Table 4: Errors for Injected Beams

Plane	**Static Injection Error**	**Random Injection Error**
x	500 µm	0 µm
x'	100 µrad	17 µrad
z	500 µm	0 µm
z'	100 µrad	0 µrad
Energy	0.5 %	0.01 %
Phase	10°	0.1°

- First turn Beam stitching with sextupole magnets off
- Multi-turn beam transmission and ramping of sextupole currents
- RF correction and beam capture
- Iterative Closed Orbit Correction
- Beam Based Alignment (BBA), with respect to quadrupoles or sextupoles to minimize orbit

A set of 50 machines were simulated for statistics. Each machine simulated 10 injections of 100 particles. The injected beam was assumed to have a 5 nm rad transverse emittance in both planes. The strong focusing in the ring creates large amplification factors in both horizontal and vertical planes as pictured in Fig. 3. Because of the large error amplification, only 6 % of the simulated machines had an injected beam make its first turn around the ring prior to steering correction. The trajectory correction over the first and second turns proved to be efficient: the beam could be transmitted in all simulated cases. The rest of the procedure (sextupole ramp, beam capture and orbit correction) was successful in every case as well.

Figure 4 shows the RMS orbit achieved in the ring for both planes. It is plotted for every element present in the lattice. The RMS level is below 100 µm in most elements for both planes. Including BPM reading and calibration errors assumed for this early stage of the machine commissioning, the RMS orbit read at the BPM is below 50 µm. It was also verified that the orbit can be corrected to zero at BPMs when removing the reading and calibration errors of the BPMs, thanks to the square BPMs-correctors configuration.

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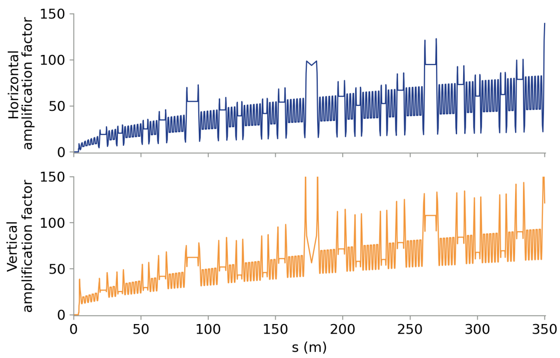

Figure 3: Beam trajectory amplification factor as a function of position along the ring. Top plot shows the horizontal plane, bottom plot shows the vertical plane.

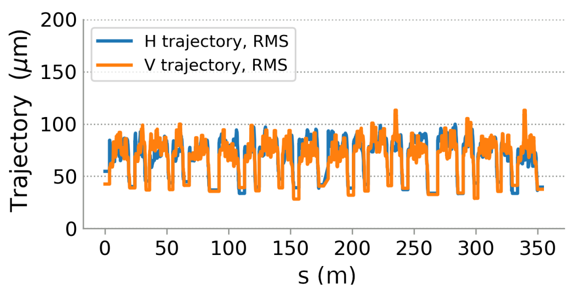

Figure 4: Horizontal (blue) and Vertical (orange) RMS orbit in all elements of the lattice obtained after convergence of the orbit correction procedure.

The absolute strength distribution of the dipolar correctors obtained with the 50 simulations is shown in Fig. 5. The median corrector strength is 50 µrad for the horizontal and 45 µrad for the vertical plane, both being well below the 250 µrad limitation specified for these correctors. Some of them however reach the limiting values.

LATTICE ROBUSTNESS AND CURRENT STUDIES

The commissioning procedure therefore appears to be robust enough to obtain a stored beam and provide a sound basis for lattice symmetrization. Beta-beating and coupling correction studies are currently being performed for the CDR reference lattice using LOCO [6]. Similar investigations were made on an earlier CDR lattice. There the residual beta-beating could be corrected below a 1 % RMS level. For the coupling correction, less than 2 % residual coupling could be achieved in 95 % of the simulated machines [7].

A correction scheme with 272 BPMs and dipolar correctors is currently being investigated. In this scheme, 96 supplementary BPMs and correctors pairs are introduced in the second defocusing sextupole of the HOA unit cell. It should provide better orbit correction and reduce the strength needed.

The beam-based alignment procedure is also being refined. For this purpose, the SOLEIL Upgrade reference lattice was

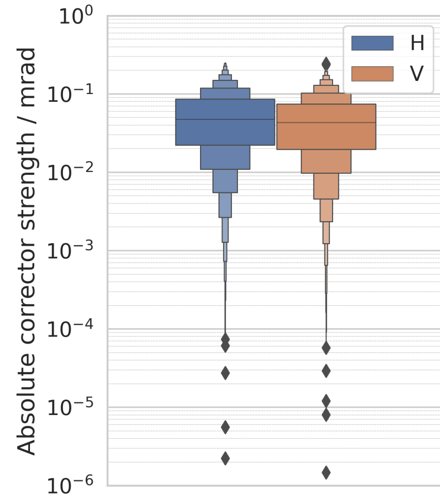

Figure 5: Distribution of the absolute strength of the dipolar correctors after the closed orbit correction procedure. In blue the horizontal corrector values, in orange the vertical correctors. For each distribution the black line shows the median value and the diamonds show extreme values.

implemented in the Matlab Middle Layer (MML) [8, 9]. It allows using the BBA routines developed for operational light sources as well as LOCO graphical user interface. A BBA procedure using sextupole magnets [10, 11] is also being investigated. This could allow reducing the orbit offset in some selected sextupoles, and therefore help restore the lattice performance.

CONCLUSION

First turn simulations including all main sources of errors have been performed for the SOLEIL Upgrade reference lattice. Beam storage could be reached with the proposed 176 BPMs and 176 dipolar correctors configuration, confirmed with statistical simulation. A satisfactory RMS orbit was obtained, providing a good basis for lattice symmetrization, most of the dipolar corrector strengths remaining within the limits.

Corrections of beta-beating and coupling are currently being investigated to confirm the numbers and locations of the BPMs, the quadrupole and skew quadrupole correctors. Further Beam Based Alignment simulations are being done in particular with the Matlab Middle Layer model of the upgrade lattice. These simulations will also be performed with updated error specifications for the magnets, diagnostics and girders after further discussions with the concerned groups.

ACKNOWLEDGMENTS

The authors would like to thank T. Hellert for the support and fruitful discussions on the Simulated Commissioning toolbox.

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