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SOLEIL STORAGE RING UPGRADE PERFORMANCE IN PRESENCE OF LATTICE IMPERFECTIONS

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Abstract

The design for the upgrade of the SOLEIL third generation light source is progressing. At the present stage, different lattices are evaluated as possible candidates for the storage ring upgrade and an important factor for the comparison of their performances is the robustness against lattice imperfections. The strategy for this study consists in defining a set of misalignments of the lattice elements and field errors of the magnets that are expected to be attained after the commissioning, applying them to the lattice models and correcting them using response matrix based techniques. A dedicated algorithm was developed in Accelerator Toolbox in order to accomplish this procedure and compare the different lattices. In this paper the results of this study at the current state are presented, including the considered lattice imperfections, the correction method applied and the final performance of the lattices.

INTRODUCTION

Synchrotron SOLEIL officially started the works for the preparation of the Conceptual Design Report (CDR) of the SOLEIL Upgrade, to be published at the end of 2020. The project includes considerable changes to the accelerator complex and especially to the storage ring. The goal of the project is to reach a beam horizontal emittance below 100 pm rad conserving most of the filling patterns and the operation modes currently employed. The energy will also remain at 2.75 GeV, as today. The different lattices considered for the storage ring upgrade are compared in view of the final choice. To evaluate their robustness against lattice imperfections, the alignment and field errors introduced into the model lattices are chosen to simulate the residual lattice errors remaining after commissioning. The simulation of the commissioning will be realized in a second moment. The tested lattices up to this point, including the allocation of correctors and BPMs for the correction procedure, will be discussed below, and then a list of the errors applied to the models will be given, followed by a description of the correction procedure applied with the results obtained. The work presented in this paper is realised using Accelerator Toolbox (AT) 2.0 [1].

STUDIED LATTICES

The lattices considered for the Upgrade consist of Multi-Bend Achromat (MBA) periodic cells of 2 different types. In the “Hybrid” cell type, sextupoles are located in the 2 dispersion bumps at both sides of the cell, with sextupoles of each family separated by a –I transformation of the coordinates, in order to cancel part of their nonlinear effects. The other type considered is the Higher Order Achromat (HOA), where the local corrections of nonlinearities give rise to a more uniform distribution of sextupoles along the cell. The first lattice considered is composed of 20 cells of Hybrid type, while the second one is composed of 20 HOA cells. A plot of the layout and optics of the Hybrid cell is given in Fig. 1, while in Fig. 2 the same plot for the HOA cell is presented. Some parameters of the 2 lattices are reported in Table 1.

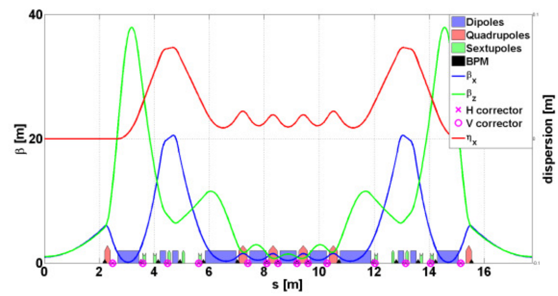

Figure 1: Layout and optics of the Hybrid cell.

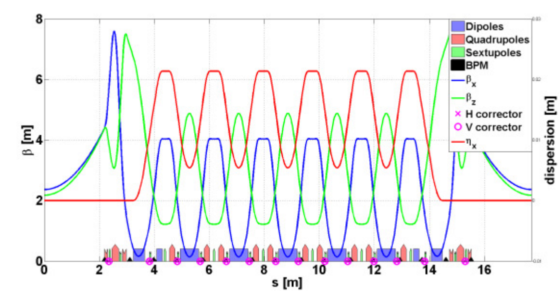

Figure 2: Layout and optics of the HOA cell.

Table 1: Some Features of Hybrid and HOA Lattices

Lattice	Hybrid	HOA
Circumference	355.8 m	354.2 m
N. of cells	20	20
Nat. emittance	72.2 pm	76.3 pm
Nat. energy spread	$8.63\ 10^{-4}$	$7.75\ 10^{-4}$
Nat. bunch length	3.7 mm	2.5 mm
Betatron tunes	55.2 , 18.2	65.2 , 23.2
Chromaticity	1.6 , 1.6	1.6 , 1.6

Recently, in the effort of better fitting the Upgrade lattice to the constraints coming from the beamlines, new lattices have been taken under consideration. One of those is created by grouping together 5 Hybrid cells and applying the necessary changes generating a new periodic cell.

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A new Hybrid lattice is then generated with 4 of these superperiods. Similarly a lattice of HOA type generated by rearranging elements of the periodic cells is created. Those 2 new lattices are still under study and their robustness against imperfections will be investigated soon. Their advantage compared to the 20-cell lattices presented above is their reduced impact on the beamlines. More details about the lattices studied can be found elsewhere [2-4]; here we will discuss the errors and correction strategy considered in the study of their robustness.

ERRORS APPLIED

In our investigation we take the model lattice to be studied and apply alignment and field errors to the magnets. These errors are generated from a Gaussian distribution truncated at 2σ. In the following we refer to the value of this σ of the original Gaussian as the σ of the error. For dipoles, quadrupoles and sextupoles a horizontal and vertical misalignment with a σ = 20 μm have been selected, while for the roll error of these elements a value σ = 100 μrad is applied. The same errors have been applied also to those correctors inserted into the model lattice as independent elements. For dipolar, quadrupolar and sextupolar field errors we have chosen a $\sigma = 2.5 \cdot 10^{-4}$. Note that the bends used in both the lattices are combined function magnets, so that independent dipolar and quadrupolar errors are applied to them. To the BPMs we applied horizontal and vertical misalignments of σ = 5 μm and roll errors with σ = 25 μrad. Usually BPM offsets are known fairly well after commissioning so we choose smaller errors for them. It may be good to have them in the lattice as residual errors. For BPMs we also included gain and reading errors with $\sigma = 10^{-3}$ and σ = 1 μm. Errors on the girders are not considered at this stage but they will be implemented soon.

It is possible to increase the σs of the previous errors in order to get a realistic condition of the machine before commissioning. In this case the routines developed for this investigation need to be modified to deal with more compromised conditions of the lattice. This work may be done at a later point. Despite the errors applied being of small magnitude simulations show that the operation of the machine is dramatically compromised by their presence and in most of the cases there would be no closed orbit without a correction procedure being adopted.

CORRECTION OF ERRORS

Figures 1 and 2 show the position of BPMs and dipole correctors along the cell. All the sextupoles used for the Upgrade are supposed to be equipped with additional trim windings to be used as horizontal and vertical dipole and skew quadrupole correctors. For quadrupole corrections we can vary the current in the normal quadrupole coils, including those in combined function bends. In this case the maximum feasible correction is of few percent of the nominal field. For HOA lattices, using just sextupoles' additional coils is sufficient, since they are rather uniformly distributed along the cell. In Hybrid lattices however sextupoles are localized at the dispersion bumps at the ends of the cell, leaving uncovered 180 degrees of phase advance between them. It is then necessary to use a different type of dipole corrector in the central area of the cell. In addition, the space between elements is just few centimeters in both lattices. A solution may be to equip quadrupoles and bends with additional coils for dipole corrections. Another possibility is to shorten those elements by a few centimeters and create more space between them. For the moment in our model lattice we added dipole correctors as single elements of length 5 cm, leaving small space between the elements. An accurate study on the feasibility of our assumptions will be carried out later. The same problematic is present for BPMs installation, but with reduced impact thanks to their small size. For quadrupole corrections at this stage we are using all the quadrupoles in the lattice. This choice is made to have a first idea of the effectiveness of the correction procedure. Once completed this step redundant correctors will be eliminated. Skew quadrupole corrections are performed by the additional coils of some selected sextupoles. Table 2 presents the number of correctors per cell used up to this stage.

Table 2: Number of BPMs and Correctors in the Lattices

Lattice	Hybrid	HOA
N. BPMs per cell	16	16
N. H/V correctors per cell	14	14
N. quad. correctors per cell	17	25
N. skew quad. correctors per cell	10	14

We use a correction procedure based on matrix response similar to ones already used [5]. From the model lattice we calculate the Orbit Response Matrix (ORM) of which elements are the horizontal and vertical changes of the closed orbit measured at BPM locations divided by the change in dipole corrector field that caused them. We also calculate trajectory response matrix (changes of a particle trajectory along 1 turn when varying dipole corrector fields). The above calculations are done a first time with the sextupoles of the model turned off and a second time with them on. Then we proceed to calculating the dispersion response matrices (change of horizontal and vertical dispersion when varying normal and skew quadrupole corrector fields). For beta beating corrections we calculate a matrix response of which elements are the changes in the on-diagonal blocks of the ORM when changing quadrupole corrector fields divided by the changes in the fields. For coupling corrections the elements are the changes in the off-diagonal blocks of the ORM divided by the changes in skew quadrupole corrector fields. These matrices are calculated from the model lattice beforehand.

Once the errors are randomly generated and applied to the model lattice the correction procedure is applied. The sextupoles are turned off to eliminate the nonlinearities produced by them, simplifying the convergence of the

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correction technique. The closed orbit is created (if not found) using the trajectory response matrix of the model. When the closed orbit is found it is corrected using the ORM of the model. For these operations we use the response matrices calculated with the sextupoles off. Once the measured offset of the closed orbit is reduced, we do not expect drastic changes when they are switched on again and the previous procedure is repeated. Once the closed orbit is corrected we proceed with the correction of the dispersion, and then beta beating and coupling. The last 2 operations are repeated until they produce improvements.

CORRECTION RESULTS

The following results are obtained for 100 seeds. Despite the small errors applied, before correction only for 7% of the seeds a closed orbit existed for the Hybrid lattice and 24% for the HOA one. The correction procedure succeeded 97% of times for the Hybrid lattice and 100% for the HOA and the rms closed orbit offset after corrections in neither case exceeds 32 μm. In Fig. 3 the rms closed orbit offset calculated over all cells and seeds (for which the correction was successful) for the Hybrid case is presented.

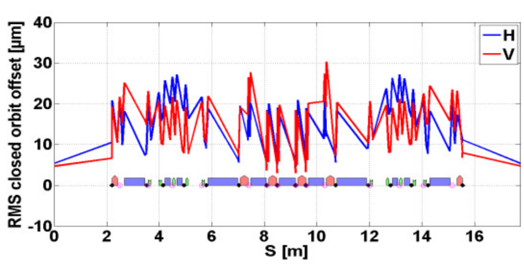

Figure 3: Rms closed orbit offset for the Hybrid lattice.

The rms value of the difference between the horizontal dispersion after correction and the one of the model is less than 1.5 mm at all positions in the ring, while the rms vertical dispersion is less than 2 mm, for both lattices. Beta beating is reduced to less than 1% which is below our tolerance. This means that we do not need to use all the quadrupoles as correctors but we can select just the most effective ones. Coupling correction is more effective for the Hybrid lattice for which horizontal and vertical emittances are smaller than 72.5 and 0.5 pm for 95% of seeds. For HOA lattice horizontal and vertical emittances are smaller than 76.6 and 2 pm for 95% of seeds. Betatron tunes and chromaticity after corrections are not changed significantly from the model values so that they do not need a specific treatment. Of great importance is the reduction of the dynamic aperture after the corrections. Figure 4 shows a comparison between the on-momentum dynamic aperture of the Hybrid and the HOA lattices after corrections evaluated with the RF cavity on. The different colours delimit the aperture of the models and areas contained in the apertures of 50, 90 and 95% of the lattices after correction. The HOA lattice suffers a bigger reduction of the dynamic aperture but it still remains competitive even considering its 2 times bigger beta function.

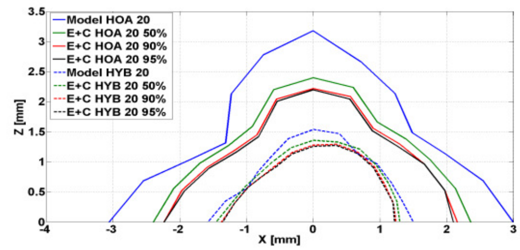

Figure 4: Dynamic apertures with RF cavity on.

Off-momentum dynamic apertures also show similar results with a larger relative reduction of the HOA aperture that remains nonetheless competitive with the one of the Hybrid lattice.

The dipole corrector strength (rms) required for the HOA lattice is 0.06 mrad, while 0.1 mrad is necessary for the Hybrid one. For normal quadrupole correctors a field increase of 2.2% (rms) of the value of the model is required for HOA and 0.4% for Hybrid, while for skew quadrupole correctors the values (rms) are 0.08 and 0.035 m^{-2} respectively. While these values should not be challenging, an accurate study will be done on the feasibility of the correction scheme.

CONCLUSION

Our study of the robustness of 2 candidate lattices for the Synchrotron SOLEIL storage ring Upgrade has been presented. The correctors seem easier to be added to the HOA lattice using sextupoles additional windings while for the Hybrid lattice other types of correctors are needed. The degradation of performance after corrections is larger for the HOA lattice but it is still competitive with the Hybrid one. Corrector strengths look more challenging for the HOA lattice. Furthermore, the HOA lattice employs many more elements, resulting in higher cost. The study of robustness will continue with more advanced designs of both lattice types including an optimization of the number of BPMs and correctors.

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