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INJECTION SCHEMES FOR THE SOLEIL UPGRADE

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Abstract

Injection into the SOLEIL upgrade storage ring is much more challenging compared to the case of the current ring. Thanks to the experience gained in the development, manufacture and commissioning of a Multipole Injection Kicker (MIK) on the MAX IV 3 GeV storage ring, the SOLEIL pulsed magnet team is currently developing new MIK magnets that will serve as the basis for the injection schemes in the upgrade storage ring. We then propose two kinds of injections: firstly, a betatron off-axis injection that should be compatible with the full-coupling storage ring tuning, and secondly, a synchrotron on-axis injection by creating a large horizontal dispersion bump at the injection point.

INTRODUCTION

Injection into the proposed SOLEIL upgrade storage ring is much more challenging than in the current ring, mainly due to the drastic reduction of the horizontal dynamic aperture from ±15 mm to ±5 mm [1] with almost the same local betatron function. In addition, the Injection Straight Section (ISS) length is reduced from 12 m to 7.35 m in the upgrade lattice. The use of the current injection system composed of four dipole kickers and occupying the entire straight section does not therefore appear to be an optimal solution, as it might be useful to have space for the installation of other necessary devices (diagnostics, scrapers...). On the other hand, the feedback from using an injection system based on a single Multipole Injection Kicker (MIK) on MAX IV storage ring has been very positive [2]. Indeed, based on a BESSY design, SOLEIL team has designed, built and installed on the MAX IV 3 GeV storage ring an in-air MIK that is successfully and routinely used in operation for top-up injection since 2017. Together with a good injection rate, the transparency of the injection process in terms of the stored beam position stability proved to be well below the requirement of 10% of the RMS beam size. These excellent results have motivated further developments of new MIK magnets to fulfill the drastic specifications of injection into the upgrade storage ring, in terms of compactness and increasingly stringent position stability requirements for the stored beam.

MULTIPOLE INJECTION KICKER

Re-using the MAX IV type MIK magnet in the upgraded storage ring would generate a magnetic field plateau for the injected beam that is too far from the stored beam axis, typically 10 mm. Besides, under these conditions, injection in the strong field gradient part of the MIK (50 $T.m^{-1}$) would make it difficult to use a beam coming from a booster, regardless of the efforts made to reduce its emittance, because it would be far too sensitive to any injection jitter. For this reason, new developments have been carried out on the MIK by the SOLEIL pulsed magnet team, leading to several different topologies for the distribution of conductors. For each topology, the peak field is obtained at the transverse location x = 3.5 mm with a sextupole-shaped plateau, while a sextupole or octupole-shaped zero field is proposed for the stored beam. Efforts have been made to preserve the full vertical aperture of these new MIKs, which should be greater than 6.5 mm, and to improve their kick efficiency with up to 2.5 mrad/kA per meter of the magnet. Based on these performances, two top-up injection schemes were studied in the frame of the Conceptual Design Report phase of the SOLEIL upgrade project [3]: a betatron off-axis injection and a synchrotron on-axis injection (see Fig. 1), both using the MIK, associated with a thick and a thin septum with deflections of 180 and 20 mrad respectively.

BETATRON OFF-AXIS INJECTION

Principe of Injection on the Coupling Resonance

The betatron off-axis injection is the first straightforward injection scheme proposed, optimized by increasing the local horizontal β-function at the MIK position to 12 m (see Fig. 2) and by introducing the "dissonance" (see Fig. 3): the amplitude-dependent tune shifts are indeed such, that the working point is on the coupling resonance, but for the large injected beam amplitudes, tunes stay away from the resonance in order to avoid large vertical oscillations induced [1].

Injection Performance

An injected beam of 512 particles distributed at ± 3 RMS on a 6D hyper-contour is systematically considered. Figure 4 on the left shows the Beam Stay Clear (BSC) at the septum (5.5 mm) as well as the injected beam kicked by the MIK (1 mrad deviation) at the horizontal offset of x = - 3.3 mm, and then its rotation within the on-momentum acceptance of the storage ring modelled without errors. The Accelerator Toolbox code [4] has been used for the simulations.

The injection efficiency is 100% without any errors, provided that the booster natural emittance is reduced from the present value of 140 nm.rad down to 10 nm.rad (see Fig. 5 left). In addition, an emittance exchange from the horizontal to the vertical plane was found to be particularly efficient in counteracting the effect of the MIK peak field sextupolar component. Enough space remains in horizontal phase space to accept a steering error at injection, but nevertheless, the possibility of a permanent magnet thick

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septum is being considered to minimize the amplitude of the angle/position jitter at injection.

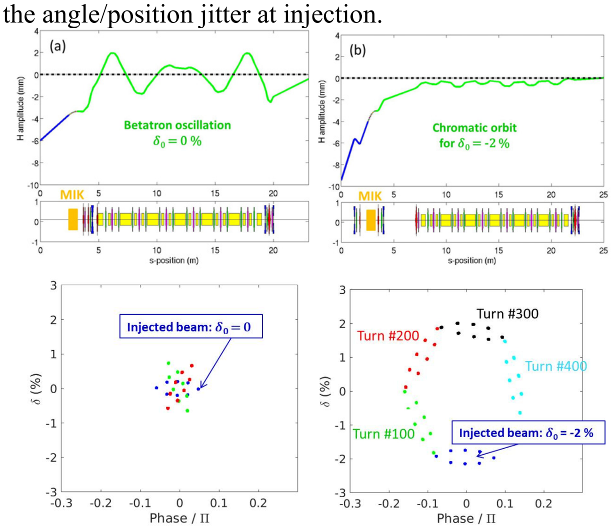

Figure 1: Injected beam trajectory at first turn and synchrotron oscillation in the longitudinal phase space using the MIK device. (a) betatron off-axis injection. (b) synchrotron on-axis injection.

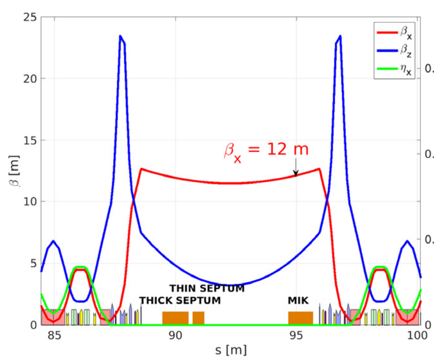

Figure 2: Optical functions of the reference lattice in injection section and injection device location (off-axis betatron injection).

SYNCHROTRON ON-AXIS INJECTION

An alternative scheme is studied to provide injection that requires small horizontal dynamic apertures and would then be less sensitive to storage ring errors. The principle consists in injecting an off-momentum beam on its chromatic orbit and in taking advantage from the zero dispersion in the straight sections to suppress horizontal amplitudes at the insertion device locations. The MIK is thus placed in a non-zero dispersion section to steer the off-momentum injected beam on its chromatic orbit, and Fig. 1b shows how the horizontal trajectory amplitude in the lattice arcs is significantly reduced compared to the betatron off-axis injection scheme.

Lattice Modification

As the dispersion function in the arcs of the reference upgrade lattice is very small [1], it is necessary to create a dedicated dispersion bump at the MIK location in the injection section, decreasing a priori the lattice symmetry from 2 to 1. A trade-off is made between dispersion value (16 cm) and energy offset (-2%) so that the beam reaches a 3 mm horizontal off-energy orbit at the MIK exit. To achieve this, the ISS is modified such as two doublets of quadrupoles and two sextupoles are added (see Fig. 6). As a result, the natural horizontal emittance is increased from 80 up to 90 pm.rad because the dispersion function in the dipole located at entry and exit of the ISS is no longer adjusted to zero. The vertical β-function at MIK is also minimized to reduce the impact on the injected beam of the magnetic horizontal field around the peak vertical-field of the MIK.

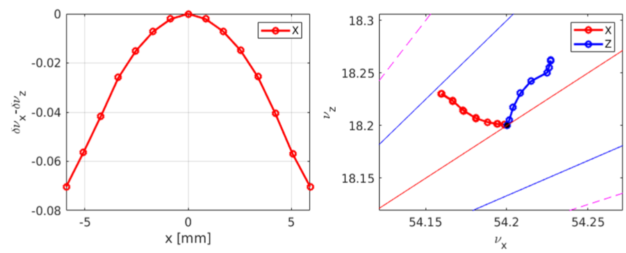

Figure 3: Betatron tune dissonance optimized at large horizontal amplitudes for the reference lattice.

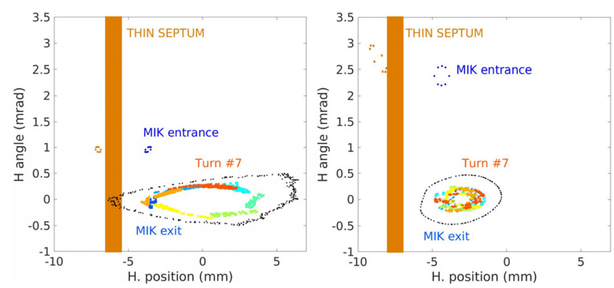

Figure 4: First turns of the injected beam in the horizontal phase space and horizontal dynamic acceptance of the storage ring w/o error at MIK exit. (left) on-momentum betatron injection. (right) synchrotron injection, energy offset = -2 %.

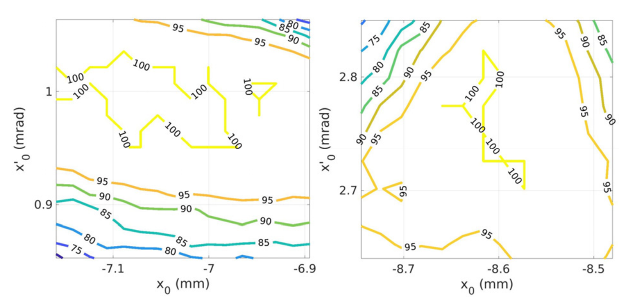

Figure 5: Scan of injection rate in horizontal phase space at thin septum exit, injected beam defined by a ± 3 RMS 6D correlated hyper-contour, w/o error (left) betatron injection, εx0 = 1 nm.rad, εz0 = 9 nm.rad, injected bunch length = 25 ps RMS, using C type MIK (right) synchrotron injection, εx0 = 9 nm.rad, εz0 = 1 nm.rad, injected bunch length = 35 ps RMS, using D type MIK.

The MOGA-Bmad code [5] was used to optimize nonlinear dynamics, using the same sextupole and octupole implementation as the reference lattice. The first objective is the maximization of the on-momentum dynamic aperture, respecting zero total chromaticities and

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containing the energy-dependent tune shift in the half integer around the working point. The second objective is the maximization of the energy acceptance at a few judicious locations around the ring. The resulting performance is presented in Figs. 7 and 8, with a 3 hours Touschek lifetime without bunch lengthening, calculated under the same conditions as the reference lattice [1].

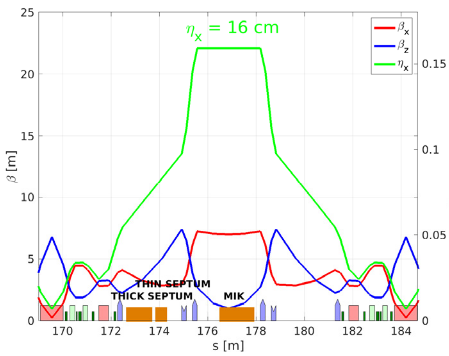

Figure 6: Optical functions in injection section for the modified lattice and injection device location (synchrotron on-axis injection).

Injection Performance

The 7 mm required BSC at the septum (see Fig. 4 on the right) is greater than that in the previous case because of the presence of horizontal dispersion, resulting in a larger deviation angle of the downstream MIK (2.5 mrad). Figure 5 on the right shows the area in horizontal phase space for which the injection rate reaches 100 %. A first study with a preliminary set of magnet systematic harmonic components proved the robustness of this injection, especially in presence of decapolar components generated by the dipolar correctors installed inside the sextupole magnets. Nevertheless, we plan to test the possibility of adjusting the phase advances of the straight section opposite to the injection section, to recover a pseudo 2-fold symmetry.

CONCLUSION AND PERPECTIVES

Two top-up injection schemes are currently under study for the SOLEIL upgrade project: a betatron off-axis injection and a synchrotron on-axis injection, both using a newly developed MIK. An in-air MIK magnet prototype of topology D has already been fabricated and magnetically measured in-house with excellent results, as a step towards proving its feasibility. Some difficulties still need to be overcome such as final mechanical integration, with great care on the conductor position tolerance or the voltage withstand of such new compact magnets. These difficulties should be resolved during the Technical Design Report phase of the project, with the early design of the final in-vacuum magnet starting this year.

Furthermore, the study of injection efficiency shows that a 100% performance requires at least a drastic reduction of the emittance of the injected beam by more than a factor of 10 from its current value. For that reason, a major upgrade of the design of the SOLEIL booster is in progress [6].

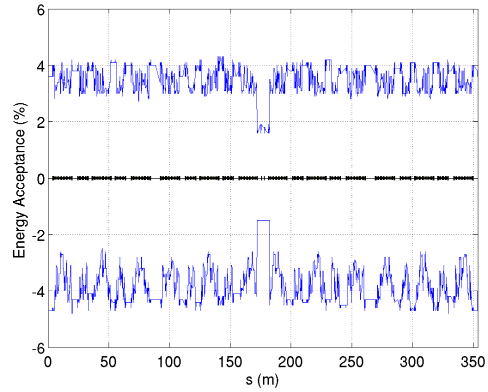

Figure 7: Energy acceptance along the ring for the modified lattice (injection section set in the middle).

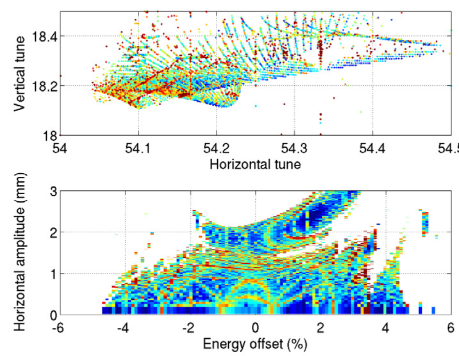

Figure 8: Frequency map (up) and horizontal off-momentum aperture versus energy (down) for the modified lattice.

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REFERENCES

[1] A. Loulergue *et al.*, "CDR Baseline Lattice for the Upgrade of SOLEIL", presented at IPAC'21, Campinas, Brazil, May 2021, paper TUPAB054, this conference.

[2] Alexandre, P. *et al.*, "Transparent Top-Up Injection into Fourth-Generation Storage Ring", *Nuclear Instruments and Methods in Physics Research, section A*, vol. 986, p. 164739, 2021. doi:10.1016/j.nima.2020.164739

[3] A. Nadji, "Synchrotron SOLEIL Upgrade Project", presented at IPAC'21, Campinas, Brazil, May 2021, paper MOPAB131, this conference.

[4] Accelerator Toolbox: a collaborative Matlab Toolbox for single particle dynamics, Github repository, https://github.com/atcollab/at

[5] M. P. Ehrlichman, "A Genetic Algorithm for Chromaticity Correction in Diffraction Limited Storage Rings", 2016. arXiv:1603.02459v2

[6] M.-A. Tordeux *et al.*, "A Low-emittance Booster Lattice Design for the SOLEIL Upgrade", presented at IPAC'21, Campinas, Brazil, May 2021, paper MOPAB113, this conference.