A NEW OPTICS FOR SIRIUS

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Abstract

We report on the latest optics modifications for the 3 GeV Sirius electron storage ring presently under construction at the Brazilian Synchrotron Light Laboratory, LNLS. Although the basic parameters are set and frozen, improvements in the magnetic lattice and beam optics are still being implemented. In particular, the central dipole in the 5BA cell has been replaced by an all-permanent-magnet dipole with a thin superbend in the center with peak magnetic field of 3.2 T and the operation mode has now symmetry 5, with 15 low β_x straight sections and 5 high β_x sections. The 3 GeV ring bare lattice emittance is now 0.25 nm.rad.

INTRODUCTION

Sirius is a 4th generation storage ring based on a 5BA magnetic lattice that is presently under construction at LNLS in Campinas, Brazil. Although construction is already in advanced phase [1], the design of some components are still being improved and, in particular, the optics is still being continuously upgraded, as reported over time in various conferences [2-4]. Most of the upgrades have resulted from strong interaction between the LNLS accelerator engineering and scientific groups.

In particular, the upgrade reported in reference [4] has simultaneously reduced the horizontal and the vertical betatron functions to 1.5 m in the center of the low β sections, opening up the possibility of installing new kinds of insertion devices with small horizontal as well as vertical gaps. The initial objective was to take full advantage of the small emittance by better matching the electron and the photon beam phase ellipses, thus increasing the brightness and coherent flux from undulator beamlines. These characteristics made the 10 available low β sections very attractive and the possibility to increase their number was envisaged. Studies resulted in the proposal of a new optics where 5 of the high β sections are converted to low β, totalizing 15 low and 5 high β sections. The optics becomes 5-fold symmetric.

Another modification with a big impact on the dipole beamlines and the machine optics is the new design of the central dipole in the 5BA arc. The peak field in the central high field slice (superbend) has been increased from 2.0 to 3.2 T, providing hard X-rays of 19 keV critical energy from dipoles. The new design uses permanent magnet and combines the low and high field parts into just one piece.

A rearrangement in the positions of quadrupoles and sextupoles in the arc-to-straight matching sections resulted not only in weaker quadrupole strengths but also in a better distribution of the spaces between magnets.

Worth mentioning is also the optimization of the slow and fast orbit feedback systems that changed the number and position of BPMs and slow and fast orbit correctors.

NEW SUPERBEND DESIGN

Ever since the initial designs, the Sirius lattice already contained a thin superbend in the central dipole to provide for hard X-ray radiation source from dipoles in the machine, while keeping the total radiated power at low level. This thin superbend is enclosed with low field dipoles forming the central dipole in the 5BA arc. The longitudinal dipole field gradient obtained with this arrangement has always been exploited to reduce the beam emittance.

The design for this central dipole went through a few versions and prototypes. The previous version used electromagnets for the low field part (0.58 T), and permanent magnets for the high field part (2.0 T).

In the new design the superbend has a much stronger magnetic field, the peak reaches now 3.2 T, and the low and high field parts are joined into a single permanent magnet named BC. The low field part still keeps the transverse field gradient. Figure 1 shows the mechanical design and the longitudinal field profile for half magnet.

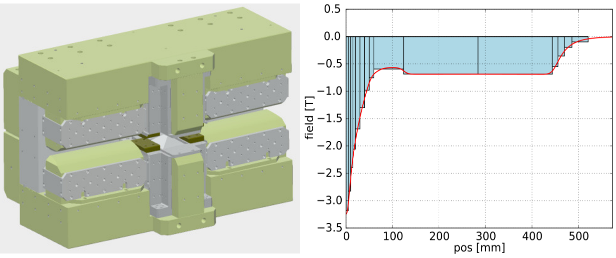

Figure 1: Design of BC dipole magnet consisting of a thin high field part (superbend) in the center and low field parts with transverse gradient. The mechanical design is shown on the left and the longitudinal magnetic field profile for half magnet on the right. The peak field reaches 3.2 T.

To take advantage of this magnetic field configuration to minimize the emittance, the *H* function is strongly focused at the dipole center, where the radius of curvature is small, following the well-known procedure to emittance minimization. The emittance was reduced by about 10% with this new dipole model, from 0.27 to 0.24 nm.rad.

The 3.2 T peak magnetic field represents a dipole source with critical photon energy of 19 keV. The small horizontal and vertical beam sizes at this point, 9 x 4 μm^2 where 1% emittance coupling is considered, makes this a high brightness dipole source. The advent of these new superbend sources made, in fact, a previously planned high field wiggler no longer necessary.

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NEW MAGNET POSITIONING

A rearrangement in the positions of quadrupoles and sextupoles in the arc-to-ID matching sections resulted in a number of advantages including the reduction of the required quadrupole strengths and the optimization of the spaces between magnets. Not only the ID straight sections became longer but also a space has been created just after the last dipole in the arc, allowing the relocation of a vacuum pumping station that, among other benefits, created a space at a high β_y position in the arc that optimizes the installation of vertical beam pick-ups, scrapers and so on. Figure 2 shows a schematic diagram comparing the previous and new magnet configurations. The lengthening of the ID sections (2x18cm) was very important to allow the implementation of the 5-fold symmetric mode since the straight section for the RF cavities changed from high to low β, which means two extra quadrupoles had to be installed in the section to turn the quadrupole doublets into triplets. Since it was very difficult to change the RF cavities to a new section due to constraints in the building service area, the increase in the length of the section was essential.

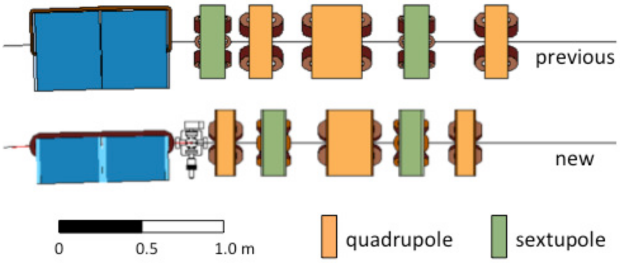

Figure 2: Schematic drawing (to scale) comparing the magnet configurations for the previous and the new arc-to-ID matching section.

The new lattice configuration including BPMs and orbit correctors is shown in Figure 3.

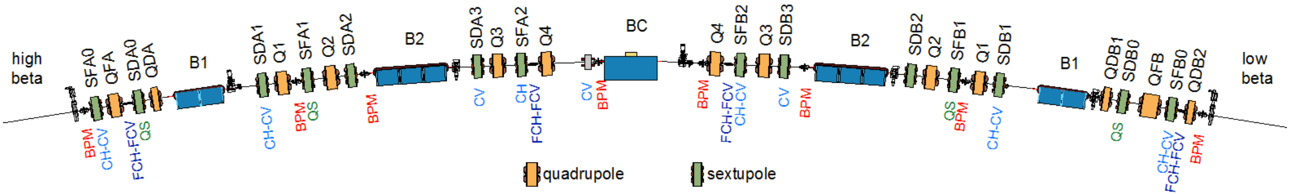

Figure 3: Arc of the Sirius storage ring lattice with new permanent magnet dipole BC with low and high field parts joined together. The peak field reaches 3.2 T. The matching sections consist of quadrupole doublets in the high straight β_x sections and quadrupole triplets in low β_x sections. The previous mode was 10-fold symmetric with alternating high and low β_x straight sections. In the new 5-fold symmetric mode, a high β_x section is followed by three low β_x sections, adding up to 5 high and 15 low β_x sections in total.

NEW 5-FOLD SYMMETRIC OPTICS

The Sirius nominal optics is designed with alternating high *(A)* and low *(B)* horizontal betatron functions for its 20 straight sections. The vertical betatron function is always low, although even lower in *B* sections. A quadrupole doublet is used to match the optical functions in the high β sections and a quadrupole triplet in the low β sections. The optical functions along the machine have symmetry 10. In the low β sections both the horizontal and vertical betatron functions have been reduced to 1.5 m [4], in a recent upgrade to improve the matching of the electron and photon beam emittances. This opened up another interesting possibility for the low β sectors, the opportunity to install IDs with small horizontal as well as vertical gaps, allowing a whole new class of IDs to be considered. In this way alternative symmetries with increased number of low β sectors started to be studied for Sirius. Since we need at least one high β sector for beam injection and off-axis accumulation in the storage ring, the alternatives that preserve the already existing low β sections can be symmetries 1, 2 or 5. In the symmetry 5 option, 5 of the high β sections are converted to low β, making a total of 15 low β sections. This mode has been chosen because it seems a good compromise for the number of low β sectors and the present non-linear dynamics optimization status. Figure 4 compares the optical functions for the previous 10-fold and the new 5-fold symmetric modes, where half of the *A* sections (high β) are converted to *B* sections (low β), and Table 1 compares the main parameters.

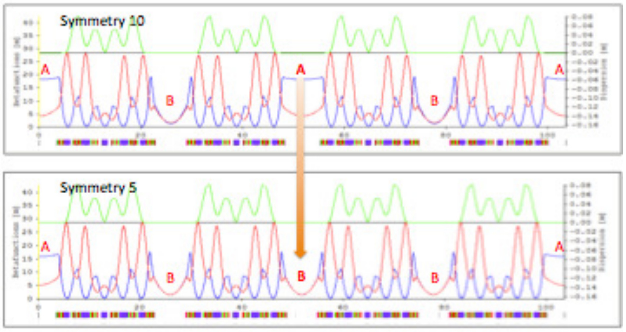

Figure 4: Optical functions for the previous 10-fold symmetric mode with alternating *A* (high β) and *B* (low β) straight sections (top) and the new 5-fold symmetric mode with half of the *A* sections converted to *B* sections (bottom).

The beam-stay-clear calculations in Figure 5 show that it is possible to install small horizontal gap devices.

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Table 1: Comparison of Main Parameters

	Previous	New Mode
Symmetry	10	5
Low / high β sections	10 / 10	15 / 5
Emittance (bare) [pm.rad]	270	250
Emittance (with IDs)	→ 190	→ 150
Tunes (H/V)	48.13/13.11	49.11/14.16
Nat. chrom. (H/V)	-126/-79	-119/-80
rms energy spread	0.76×10^{-3}	0.85×10^{-3}
En.loss/turn (bend) [keV]	456	475

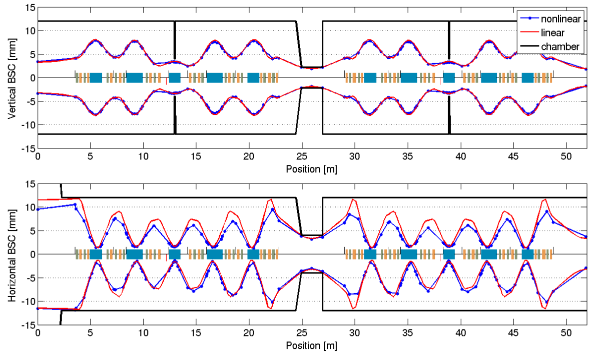

Figure 5: Vertical (top) and horizontal (bottom) beam stay clear calculated from tracking simulations for linear (red) and nonlinear (blue) optics. The black curves represent the vacuum chamber limitation.

Nonlinear Optimization

As expected, the optimization of the nonlinear dynamics behaviour in this reduced symmetry mode is more challenging and very time consuming. The process adopted for Sirius begins with the optimization of the lattice unit cell without errors, in order to produce a good starting point for the next phase, the multi-objective genetic optimizer. The results are then checked with all perturbations included. The whole process, described in [5], is an on-going work. The partial results, however, already qualify the 5-fold symmetric mode as a feasible one, as can be seen in Figure 6.

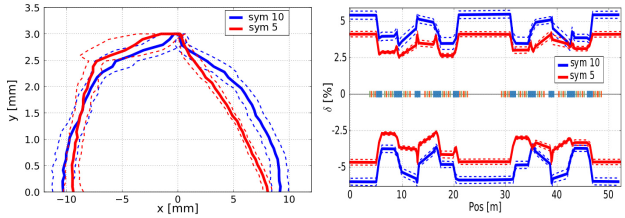

Figure 6: Comparison of dynamic aperture and momentum acceptance for the previous 10-fold (blue) and the new 5-fold (red) symmetric modes. Simulations include all perturbations and the dashed curves indicate one rms deviation from the average (solid curve) over 20 random machines.

The dynamic aperture in the negative horizontal side at the injection straight section is in excess of the target 8 mm and is sufficient for the off-axis injection process. On the other hand, the momentum acceptance is still smaller for the new mode affecting mainly the Touschek lifetime, which is reduced from about 28 hours to about 9 hours for the same current and beam size parameters. The total lifetime is reduced from about 12 to 6.5 hours, which is nevertheless still acceptable. One possibility to enlarge the lifetime is to operate at a higher emittance coupling level. Increasing the coupling coefficient from 1% to 3% improves the total beam lifetime to about 9 hours while still keeping the vertical emittance bellow diffraction limit for 10 keV photons.

ORBIT CORRECTION

The Sirius slow (SOFB) and fast (FOFB) orbit feedback systems were revised after a few technical definitions for the subsystems, such as slow correctors located in sextupole magnets as additional coils, and air coil fast correctors combining horizontal and vertical corrections at the same location with a special vacuum chamber. The orbit feedback system will consist of 160 BPMs, 120 horizontal and 160 vertical slow correctors, and 80 fast correctors in each plane. Two fast correctors per plane are installed upstream and downstream of all photon sources, that is 20 straight sections and 20 superbends. 80 out of the 160 BPMs are also installed so as to surround every photon source point. In order to enable simultaneous operation of the SOFB and FOFB systems without conflicts, the solution adopted at other laboratories [6] will be implemented. The SOFB system corrects the orbit to a reference orbit and the FOFB system corrects at a much faster rate to the SOFB residual closed orbit. In order to improve the vertical orbit correction, an extra vertical corrector has been added to a place with no sextupole. The configuration of BPMs and correctors is shown in Figure 3. Figure 7 shows the residual orbit after SOFB correction.

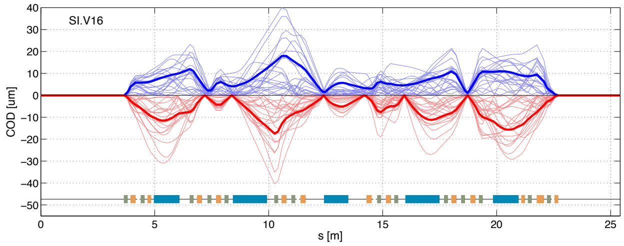

Figure 7: Horizontal (blue) and vertical (red) residual orbit after SOFB correction to a reference orbit. 20 random machines are simulated including errors. Bold curves represent one rms value.

CONCLUSION

The Sirius optics has gone throguh major changes recently as a result of interaction with beamline scientists. The critical energy from dipole BC increased from 12 to 19 keV with an increase in the peak field from 2 to 3.2 T; and the number of low β sections increased from 10 to 15, reducing the lattice symmetry from 10 to 5. Studies show that all these modifications can be implemented with re-optimization of the linear and nonlinear optics.

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