SIRIUS (BR): A NEW BRAZILIAN SYNCHROTRON LIGHT SOURCE

L. Liu*, X. R. Resende and A. R. D. Rodrigues
LNLS - Laboratório Nacional de Luz Síncrotron, CP 6192, 13084-971, Campinas, SP, Brazil.

Abstract

We report on the status of Sirius, the new 3 GeV synchrotron light source currently being designed at the Brazilian Synchrotron Light Laboratory (LNLS) in Campinas, Brazil. The new light source will consist of a low emittance storage ring based on the use of permanent magnet technology for the dipoles. An innovative approach is adopted to enhance the performance of the storage ring dipoles by combining low field (0.5 T) magnets for the main beam deflection and a short slice of high field magnet. This short slice will create a high bending field (2.0 T) only over a short longitudinal extent, generating high critical photon energy with modest energy loss from the complete dipole. There are several attractive features in this proposal, including necessity for lower RF power, less heating of the vacuum chambers and possibility to reduce the beam emittance by placing the longitudinal field gradient at a favorable place.

INTRODUCTION

In order to satisfy the future demand for synchrotron radiation in Brazil, a proposal for a new ring is being developed to replace the existing 1.37 GeV UVX light source, a facility that is being operated for users since July 1997 in Campinas, São Paulo. The proposed new source, Sirius, is a 3rd generation 3.0 GeV low emittance synchrotron light source facility to be built in the same LNLS site, as shown in Figure 1.

Many alternative lattices have been analysed in the last year, including the 2.5 GeV, 16 cell TBA lattice presented at PAC09 [1]. That design was based on the use of low field (0.45 T) permanent magnets for the storage ring dipoles. The use of permanent magnets can reduce both the investment and operation costs of the project with the elimination (or significant decrease) of power supplies and cooling systems. The low dipole field also favors emittance reduction by wigglers. There is however the considerable drawback of excluding hard x-ray bending magnet sources, which can have substantial demand from users since the beam size is naturally very small at dipole sources and some experiments do not need the high brightness of the insertion devices.

In the second half of 2009 a new idea came up that would allow the implementation of hard x-ray dipole radiation sources but would still preserve the benefits of low overall dipole radiation power. The idea is to combine the low bending field for the main beam deflection with a high magnetic field which extends over only a very short longitudinal length (a slice magnet, for 1° deflection) so that the hard x-ray radiation is produced only at the beamline exit. In addition, this high field slice could be used to create a longitudinal bending field profile designed to help reducing the emittance. The idea was implemented in the new lattice design and, together with further considerations on the need to produce high brightness radiation up to about 100 keV, led to a modification of the project to a 3.0 GeV electron storage ring with 20 TBA cells. The permanent magnet dipoles now combine a low bending field of 0.5 T for the main beam deflection with a 2.0 T slice to produce hard x-ray bending magnet photons of 12 keV critical energy.

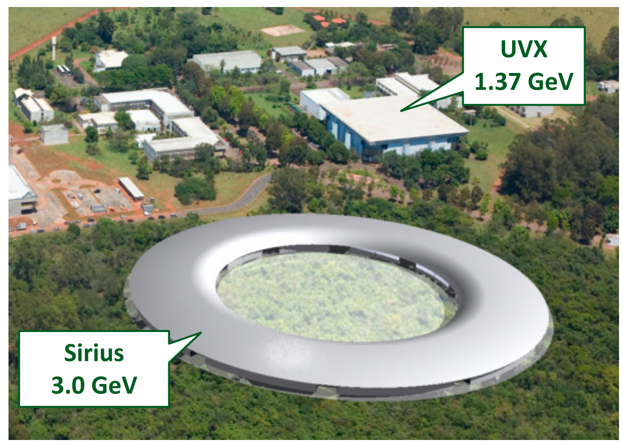

Figure 1: Aerial view of the LNLS site with the planned new Sirius light source.

THE STORAGE RING LATTICE

Linear optics – emittance optimization

The 3.0 GeV low emittance Sirius lattice structure is of a modified TBA type, with the middle dipole split to accommodate the high field slice in its center, as shown in Figure 2. Concerning emittance reduction, the center of the middle dipole is the most favourable position to place the high field slice since this is where the so called H function is small [2]. In addition, this is also a proper position for the dipole synchrotron light port. Besides the longitudinal field variation, we also resort to other known recipes to reduce the emittance, specifically, the use of transverse field gradient in the dipoles to increase the horizontal damping partition number, the allowance of slightly positive values for the horizontal dispersion at the straight sections (thus breaking the achromat condition), and the increase in the inner bending angle in the TBA cell with respect to the outer angles [3].

Based on the above guidelines along with the obvious (and conflicting) requirements of a low emittance lattice with large dynamic aperture and limited circumference, we propose a 20-cell modified TBA structure for Sirius. The total deflection per cell of 18° is divided into 5º for each outer dipole and 8º for the middle one. The latter, in

*liu@lnls.br

turn, is split into a central 1° deflection by the high field slice and two lateral deflections of 3.5° each. The space created to fit the slice is such that the same integrated field would be obtained if it were filled with the same bending field of the adjacent dipoles. See Figure 2.

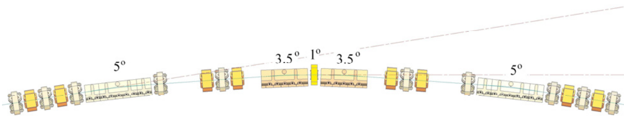

Figure 2: Layout of the modified TBA arc with the high field slice in the center of the middle dipole.

The circumference of 460.5 m contains 20 ID straights with alternating lengths of 5 m and 9.4 m. The lattice has distributed dispersion function and provides a beam with 1.7 nm.rad natural emittance. The slightly positive dispersion function at the ID straights increases the effective emittance to 1.9 nm.rad. Care has been taken to limit the dispersion function value so that the inclusion of IDs in the lattice still reduces the emittance. Figure 3 shows the evolution of natural and effective emittance as potential user IDs are installed in the ring. We consider 2 types of IDs that are presently in operation at UVX: SCW, a 1 m long, 4 T superconducting wiggler, and MPW, a 2.7 m long, 2 T hybrid wiggler.

The main parameters of Sirius are shown in Table 1 and the optical functions for one superperiod in Figure 4.

Table 1: Main parameters of Sirius.

Energy (GeV)	3.0
Beam current (mA)	500
Circumference (m)	460.5
Nat. emittance (nm.rad)	1.7
Effective emittance (nm.rad)	1.9
Cell / symmetry / structure	20 / 10 / TBA
Main dipole field (T)	0.5
Slice dipole field (T)	2.0
Total deflection by main dipoles	340°
Total deflection by slice dipoles	20°
Critical energy, main dip. (keV)	3.0
Critical energy, slice dip. (keV)	12.0
SR loss/turn, all dipoles (keV)	417.7
SR power, all dipoles (kW)	208.8
Betatron tune (h/v)	24.2 / 13.2
Synchrotron tune	9.3×10^{-3}
Nat. chromaticity (h/v)	-53.4 / -48.0
Nat. energy spread (%)	0.079
Momentum compaction	6.9×10^{-4}
Harmonic number	768
RF frequency (MHz)	500
RF voltage (MV)	3.2
Bunch length (mm)	4.3
Damping time (ms) (h/v/s)	16.3 / 22.1 / 13.4
Straight sections	10*9.4m +10*5.0m
Beam size (k=0.5%) @ slice (μm^2)	50 x 7
Beam size (k=0.5%) @ SS (μm^2)	246 x 4

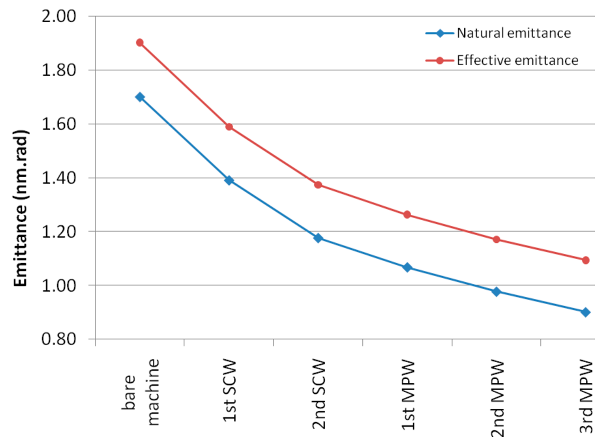

Figure 3: Evolution of natural and effective emittance as user IDs are installed in the ring. SCW is a 1 m, 4 T wiggler and MPW is a 2.7 m, 2 T wiggler.

Even though permanent magnets are routinely used in many synchrotron sources in wiggler and undulator insertion devices, its large scale use in lattice magnets is much less common. Several engineering issues remain to be analyzed and R&D in this field is crucial to the success of this choice of dipole design. First prototypes for the low and high field permanent magnet dipoles have been designed and will be ready to be tested soon [4].

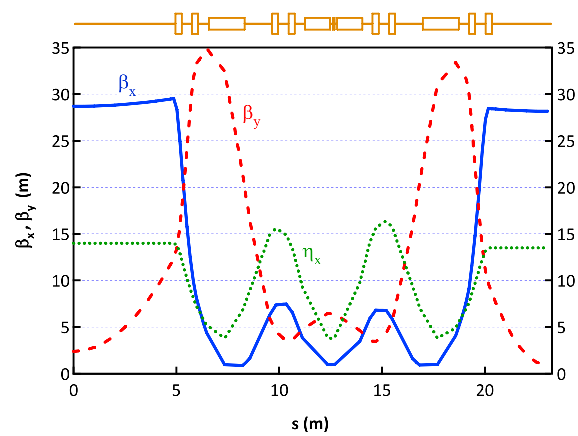

Figure 4: Optical functions for one Sirius TBA superperiod.

Dynamic aperture optimization

Five families of sextupoles are used to correct the chromaticity and optimize the nonlinear beam dynamics in Sirius. In order to lower the strength of the chromaticity correction sextupoles, a space in the center of the arc quadrupole is created by splitting it into a pair of quadrupoles. The space created is ideal to place a sextupole since this is where the betatron functions are more separated. In this way we succeeded in finding a relatively robust lattice configuration with fairly large dynamic aperture. The sextupole families were optimized using the program OPA [5] and the dynamic aperture is calculated by tracking particles with the code MAD [6]. Figure 5 shows the dynamic aperture for on-energy and off-energy particles, with and without systematic multipole errors, at the center of the long straight section. The systematic multipole errors considered do not affect the dynamic aperture. The tune diffusion analysis shown in Figure 6 is calculated using a program developed in-house which incorporates a numerical algorithm for Fourier analysis by J. Laskar [7]. Further dynamic aperture optimization in presence of insertion devices is an ongoing work. The five sextupole families used in this preliminary optimization can be further subdivided into a total of 8 families.

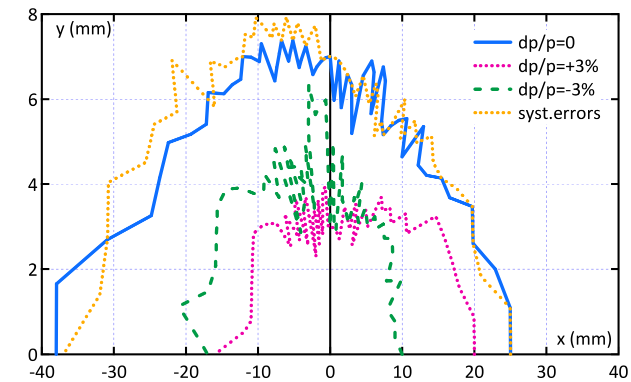

Figure 5: Dynamic aperture tracking for 4096 turns in the middle of the long SS (β_x=28.7m, β_y=2.4m) with MAD.

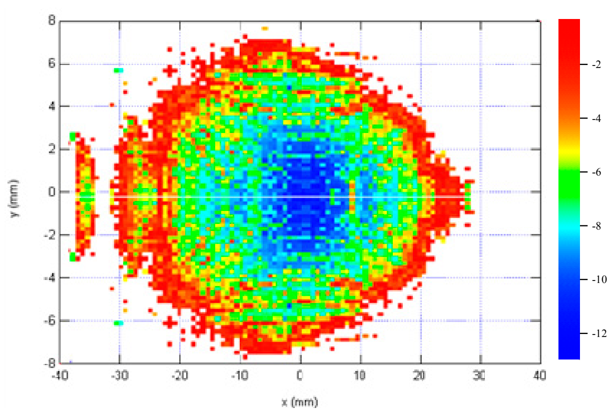

Figure 6: Tune diffusion analysis for on-energy particles.

BRIGHTNESS, LIFETIME, TOP-UP INJECTION, BEAM STABILITY

Figure 7 shows the calculated brightness for some IDs in Sirius, assuming 0.5% coupling and 500 mA.

The low emittance and expected low coupling (~0.1%) of the ring combined with the large stored current result in a total beam lifetime limited by Touschek effect to less than 5 hours. To optimize the performance of the ring, an injection system is designed for top-up operation, including a 150 MeV linac and a full energy synchrotron booster concentric with and sharing the same tunnel with the storage ring.

A big concern of the project is the beam stability. Efforts are being made at the design stage to minimize possible sources of beam instability. In particular, options for the storage ring building and floor are being analysed.

Closed orbit correction schemes are also being studied to provide optimized parameters for the slow and fast orbit feedbacks.

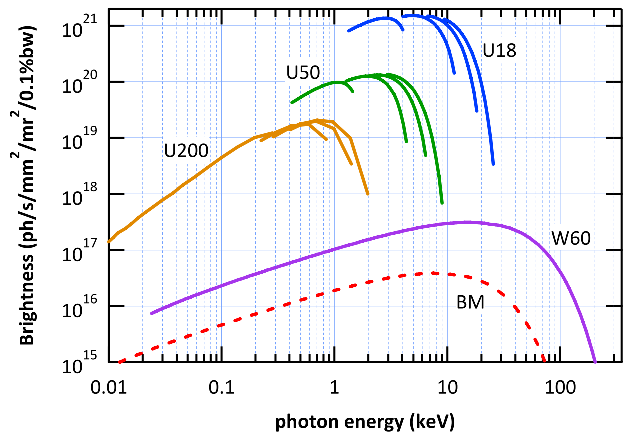

Figure 7: Brightness for Sirius for 0.5% coupling, 500 mA and some selected IDs. IDλ=(N_λ,K): U18=(194,2.2), U50=(54,2.5), U200=(30,10.3), W60=(17,22.4).

CONCLUSIONS

A low emittance lattice for the new proposed light source at LNLS, Sirius, has been presented with special attention to providing cost effective solutions regarding both the construction investment as well as the operation of the facility. In particular the large scale use of permanent magnet technology for lattice magnets is being studied. The design combines a low main bending field with a short high field slice which allows hard x-ray bending magnet synchrotron light ports while keeping modest overall emitted radiation power.

With the major parameters and the basic lattice design defined, detailed studies of the various subsystems, including prototype work on the dipoles, are now in progress.

ACKNOWLEDGEMENTS

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