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UPDATE ON SIRIUS, THE NEW BRAZILIAN LIGHT SOURCE

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Abstract

Sirius is a 3 GeV synchrotron light source that is being built by the Brazilian Synchrotron Light Laboratory (LNLS). The electron storage ring uses the multi-bend-achromat approach (5BA in this case) to achieve a very low beam emittance of 0.28 nm.rad. The 518 m circumference contains 20 straight sections of alternating 6 and 7 meters in length, to be used for insertion devices as well as injection and RF systems. The 5BA cell is modified to accommodate a thin high field dipole (for 1.4° deflection) in the center of the middle bend producing hard X-ray radiation (12 keV critical energy) with a modest contribution to the total energy loss. This high field dipole (2.0 T) will be made of permanent magnet material, whereas the low field (0.58 T) ones, responsible for the main beam deflection, will be electromagnetic. Many challenges are associated with this kind of lattice, including both in beam dynamics and accelerator engineering, that require R&D on new techniques. In this paper we discuss the main issues and achievements for Sirius in the last year.

INTRODUCTION

Over the last year the Sirius 5BA lattice design has been optimised to a robust configuration in the presence of nonlinear and perturbation effects. The 10-fold symmetric lattice configuration with alternating high and low horizontal betatron functions has been adopted and the 20-fold symmetric solution has been put aside for the moment [1]. Most of the subsystems components are under prototyping phase and the Sirius site is already being prepared. The earthwork is already concluded and the building executive design is ready. The new machine will be situated in the same LNLS campus, close to the present UVX light source as shown in Figure 1.

THE 5BA LATTICE

Linear Lattice and Beam Parameters

The lattice is a 20-cell 5-bend achromat (5BA) with natural emittance of 0.28 nm.rad at 3 GeV. The circumference is 518.4 m and there are 20 dispersion-free straight sections of alternating 7-m and 6-m in length for insertion devices and machine utilities. A quadrupole doublet is used to match the arcs to the high horizontal beta sections and a quadrupole triplet is used in the low horizontal beta ones, the optics thus has symmetry 10, as shown in Figure 2. The vertical beta function in the straight sections is always low to minimize the impact of the insertion devices on the optics. The main parameters of the Sirius storage ring are shown in Table 1.

Figure 1: The future site for Sirius and the old light source UVX (on the top right side). The earthwork is already concluded and construction should start soon.

Table 1: Sirius Main Parameters

Energy	3.0	GeV
Circunference	518.4	m
Betatron tunes (H/V)	46.18/14.15	
Natural chromaticity (H/V)	-113/-80	
Horizontal emittance (bare)	0.28	nm.rad
Natural bunch length	2.6 (8.8)	mm (ps)

Operation Scenarios

In this section the operation scenarios for Sirius from commissioning to full current and maximum insertion devices usage are described. The parameters for each phase are shown in Table 2. In the commissioning phase (Phase 0) the

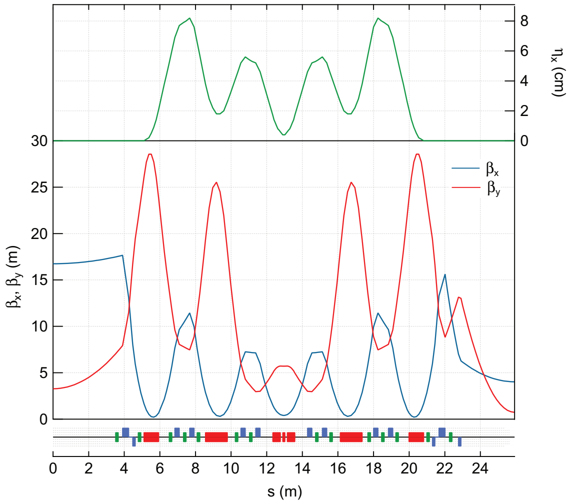

Figure 2: The lattice functions for one half of a 5BA period.

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Table 2: Sirius Scenarios for Beam Lifetime and Instability Calculations

	Phase 0 Commissioning	**Phase 1** Initial user mode	**Phase 2** Final user mode	
Total current	100	100	500	mA
Current/bunch (uniform fill)	0.116	0.116	0.579	mA
Single bunch current (SB)	-	-	2	mA
RF cavities	3 NC	3 NC	2 SC + HC	
Horizontal emittance (zero current/IBS)	0.28/0.30	0.22/0.23	0.19/0.21/0.26 (SB**)	nm.rad
Vertical emittance* (zero current/IBS)	2.8/3.0	2.2/2.3	1.9/2.0/2.2 (SB)	pm.rad
Energy spread (zero current/IBS)	0.083/0.091	0.093/0.099	0.091/0.098/0.109 (SB)	%
Bunch length (zero current/IBS)	3.2/3.5	3.7/3.9	12.7/13.2/13.9 (SB)	mm
Total lifetime	11.4	8.3	9.2/4.2 (SB)	

* Considering 1% coupling equivalent via dispersion waves.
** IBS effects for a single bunch with 2 mA.

energy loss is due only to dipoles and no insertion device is restricting the vertical acceptance of the machine. Although the final design for Sirius includes 2 superconducting (SC) cavities it is likely that during the commissioning phase the RF voltage will be provided by 3 normal-conducting cavities (NC). The stored current considered for this phase is 100 mA, distributed in a uniform filling pattern. In the initial users mode (Phase 1), the first 13 beamlines, 8 from IDs and 5 from bending magnets, are included. The IDs beamlines include 4 in-vacuum undulators with 4.5 mm minimum gap (IVU19), 2 in-vacuum undulators with 8.0 mm minimum gap (IVU25), 4 elliptically polarizing undulators (EPU) and 1 superconducting wiggler (SCW) transferred from the present storage ring. All those insertion devices add about 200 keV to the energy loss/turn and cause a reduction in the natural emittance from 0.28 to 0.22 nm.rad. The same RF cavities and stored current of the commissioning phase are assumed. The IDs for the final scenario (Phase 2) are not defined yet and it is therefore harder to estimate their impact on the beam parameters. It was then considered doubling the number of IVUs and EPUs adding 150 keV to the energy loss/turn. In this case, to reach 500 mA with reasonable lifetime, it is necessary to use 2 SC cavities and a 3rd Harmonic Cavity (HC) is also necessary to increase the bunch length. For Phase 2, the current of 500 mA is used only to dimension the sub-systems and in the calculations of lifetime and instability thresholds [2] (as a worst case scenario); the nominal current in the final user phase of Sirius will be 350 mA. The effects of the 11 insertion devices of Phase 1 on the beam equilibrium emittance and energy spread are shown in Figure 3. The effect of a hypothetical set of Phase 2 insertion devices, where the Phase 1 devices are doubled with the exception of the SCW, is also shown in Figure 3.

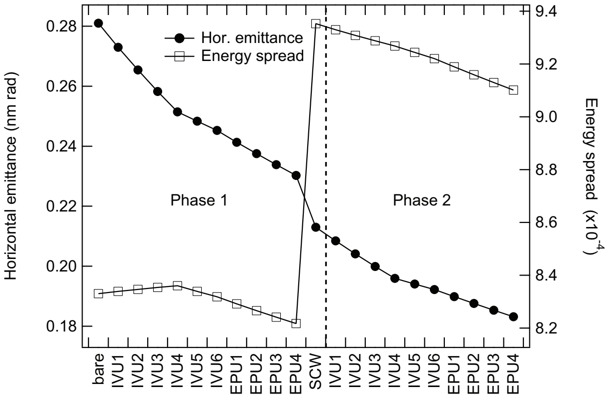

Figure 3: Effect of insertion devices on the Sirius natural emittance and energy spread. The big jump in emittance and energy spread is due to a 4 Tesla superconducting wiggler.

Error Tolerances

The main error tolerances relevant to the orbit correction system are listed in Table 3. In order to minimize coupling, a correction system will use 40 independently excited skew quadrupoles whose fields are realized with as additional pole-winding coils at one family of sextupoles in the dispersive section. With such correction system, the coupling, defined as the ratio between vertical and horizontal emittances, can be controlled to the 0.1% level. Ultimately, for beam lifetime purpose, the vertical beam size can be set to an equivalent 1% coupling level by the introduction of vertical dispersion-function waves [3].

Table 3: Main Error Tolerances

Alignment error*	40	μm
Roll angle error*	0.2	mrad
Excitation error*	0.05	%
Dipole ripple	20	ppm
Quadrupole vibration amplitude**	6	nm

* Gaussian distributions truncated at 1 σ.
** Integrated residual vibration amplitude.

Dynamic and Momentum Aperture

For Sirius, the target dynamic aperture (DA) to assure a safe and high efficiency injection process is about 8 mm in the inner horizontal side of the ring at injection point. A good beam lifetime is achieved when the momentum aperture (MA) is larger than ± 4%. The main steps on the DA optimisations are discussed in [1, 4]. Figure 4 (a) and (b) shows the simulated 6D dynamic and momentum apertures for 20 machines with all IDs planned for Phase 2 (EPUs in horizontal polarization mode), physical limitations, random alignment, excitation and multipole errors and orbit and tune correction. It is possible to notice that the vacuum chambers are not limiting the dynamic aperture, which means that we still have room for DA improvement. However, the negative horizontal aperture, which is the relevant parameter for beam injection, is already approaching the physical aperture. Other corrections schemes, such as coupling and symmetrisation, are also being studied for DA and MA improvement. Figure 4 (c) and (d) shows the DA and MA of the same machines as Figure 4 (a) and (b) with additional coupling correction and symmetrisation of the linear optics. Before correction, coupling has an average value of 12%, dropping down to 0.1% after correction. Beta-beating before symmetrisation has standard deviations of approximately 5% and 10% in the horizontal and vertical planes, respectively, and can be corrected to less than 1%.

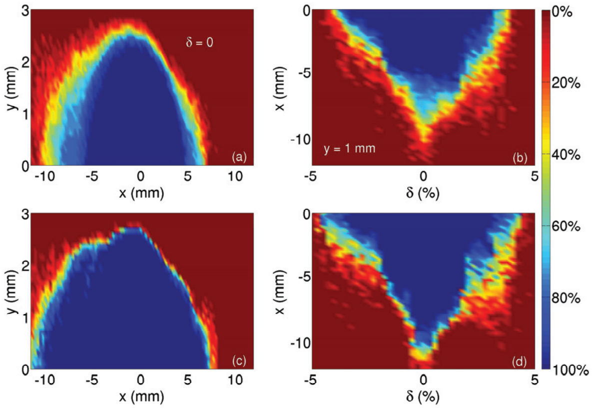

Figure 4: Dynamic (left) and momentum (right) apertures at the center of the 7-m straight section for 20 machines with random alignment and multipole errors, orbit and tune corrections (top and bottom) and additional coupling and beta-beating corrections (bottom). The color scale represents the percentage of simulated machines for which a given point of the grid corresponds to a stable initial condition.

IBS Effects and Lifetime Calculations

Given the beam scenarios presented it is important to calculate the impact of intra-beam scattering (IBS) on the beam emittances. To estimate the final parameters of the single bunch distribution, such as the emittance and energy spread, the IBS growth times calculated using the CIMP formalism [5], are iterated until convergence. The results for all scenarios are shown in Table 2. With the final values for the equilibrium beam sizes it is possible to calculate the lifetime for each phase (also in Table 2) and in all phases the total lifetime is ≈ 10 hours.

MAIN SUBSYSTEMS

The booster magnets have been contracted to a Brazilian motor company (WEG) and are under production. A digital PWM power supply controller has been tested and approved. The storage ring vacuum chambers will be made of copper with 24 mm inner diameter and pumping will be based mainly on NEG coating (more than 90% of the ring circumference). Most of the components have been prototyped and approved. The chambers will be produced in-house using the cleaning and NEG deposition system already in operation. The RF system will consist of two 500 MHz superconducting RF cavities driven by solid-state amplifiers. A 5 kW amplifier has been exhaustively tested and approved. The BPMs for the storage ring have been prototyped and approved. An open source BPM electronics has been designed and is under test. The booster extraction kicker has been assembled and is under test. The design of the accelerator and experimental hall floor has been defined after prototyping and vibration measurements. The earthworks at Sirius site has been completed and the building executive design is ready. Construction is being contracted.

CONCLUSION

The lattice design and beam dynamics optimization for Sirius was presented. The calculations show that the machine design is robust in the presence of realistic, although demanding, tolerances. The optimized lattice allows for top-up operation with conventional off-axis injection and the optimized energy acceptance allows for a total beam lifetime of 10 hours. Most of main subsystems had passed the prototyping phase and are moving towards production. The construction of the building should start soon.

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