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A NEW BOOSTER SYNCHROTRON FOR THE SIRIUS PROJECT

F. H. Sá[#], L. Liu, X. R. Resende and A. R. D. Rodrigues
Brazilian Synchrotron Light Laboratory (LNLS), Campinas, SP, Brazil

Abstract

The design for the Sirius full energy booster has been modified after the decision to change the storage ring lattice from TBA to 5BA in July 2012. In the new design the booster is concentric with the storage ring and shares the same tunnel. The achieved emittance of 3.7 nm.rad at 3 GeV for this large booster (496.8 m circumference) is better matched to the 5BA storage ring emittance of 0.28 nm.rad. Good nonlinear behaviour and efficient closed orbit correction in the presence of realistic errors are shown. Injection and extraction schemes and eddy current effects during ramping are also discussed.

INTRODUCTION

In June 2012 a decision was taken to significantly change the Sirius project, from a 3 GeV, 1.7 nm.rad emittance storage ring to a much brighter one with the same energy but with much lower emittance of 0.28 nm.rad [1]. The lattice structure was changed from a 20 TBA cell to a 20 5BA cell, with 518.4 m circumference. The new lattice requires considerably stronger quadrupole and sextupole focusing strengths, leading to the use of smaller bore radii for the magnets and for the vacuum chamber. The small beam aperture also requires a low emittance booster to assure high efficiency in the injection process, especially if the pulsed multipole magnet injection is adopted. In this injection scheme, a single pulsed nonlinear kick is applied to reduce the injected beam oscillation amplitude without perturbing the stored beam [2]. To optimize efficiency in this scheme, it is important to reduce the kick nonlinearity seen by the injected beam. A small injected beam size can, thus, significantly increase injection efficiency in the pulsed multipole magnet injection scheme.

In this way, the booster was redesigned to share the same tunnel as the storage ring. This concept was already being considered even in the previous design to save construction costs, and, with the requirements for the new storage ring design, was definitely adopted. The achieved new booster emittance of 3.8 nm.rad at 3 GeV is considerably smaller than the 37 nm.rad of the previous small booster design [3]. Figure 1 shows the layout of the injection system with storage ring and booster in the same tunnel.

THE LATTICE

The booster lattice consists of 50 modified FODO cells with combined-function magnets suitable to provide low emittance. The main difference from other booster designs is that this one contains only arc sections: no long dispersion-free straight sections are provided. In fact, with a total circumference of 496.8 meters, plenty component-free straight sections within the arcs in excess of 4 m in length are available. This means that injection and extraction, as well as the Petra 5-cell RF cavity, are located in these dispersive straight sections. With this concept a very high lattice symmetry for the booster is obtained and only a few magnet families are necessary. A high lattice symmetry is not only beneficial for beam dynamics but also to maximize the radial distance between the storage ring and the booster beams, minimizing the variations in the size of the passage corridor between the two concentric rings.

The lattice is composed of three main families of magnets: combined function dipoles (BD), with defocusing quadrupole and sextupole field components, focusing quadrupoles (QF) and focusing sextupoles (SF). Together, they define the working point and set the chromaticities to +0.5 in both planes. The achieved natural emittance at the extraction energy of 3 GeV is very low, 3.8 nm.rad, providing a potentially clean injection process into the storage ring, even if the pulsed multipole magnet injection process is adopted.

The families of 50 focusing quadrupoles QF and the defocusing quadrupolar component in the 50 dipoles BD set the nominal horizontal and vertical tunes to 19.19 and 7.32, respectively. In order to allow for flexibility in tune adjustment, an extra family of 25 weak corrector quadrupoles QD is added to the lattice. These QD quadrupoles are placed beside every other dipole. In the same way, the chromaticities are set to +0.5 in both planes by the family of 25 sextupoles SF and the defocusing sextupolar component integrated in the dipoles BD; and to allow flexibility for chromaticity adjustment, an extra family of 10 corrector sextupoles SD is introduced. There is one sextupole corrector SD just upstream every other 5^{th} dipole in the lattice.

Figure 1: Layout of Sirius injection system with a 150 MeV Linac and a 3 GeV booster in the same tunnel as the storage ring.

[#] fernando.sa@lnls.br

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The booster main parameters are summarized in Table 1, its optical functions are shown in Figure 2 and a schematic diagram of the lattice is shown in Figure 3.

Table 1: Main Parameters for the Sirius Full Energy Booster Synchrotron

Maximum Energy	3.0	GeV
Injection energy	0.15	GeV
Circumference	496.8	m
Revolution period	1.657	µs
Repetition rate	2	Hz
Betatron tunes (ν_x, ν_y)	19.19 / 7.32	
Momentum compaction factor	7.0 x 10^{-4}	
Natural chromaticities (ξ_x, ξ_y)	-33.6 / -13.9	
Nominal chromaticities (ξ_x, ξ_y)	+0.5 / +0.5	
Emittance @ 3 GeV	3.8	nm.rad
Energy spread @ 3 GeV	8.8 x 10^{-4}	
RF frequency	499.654	MHz
Harmonic number	828 = 4·9·23	
Bending field @ 3 GeV	1.1	T
Energy loss/turn @ 3 GeV	782	keV
Current	2	mA
Injected beam emittance	170	nm.rad
Injected beam energy spread	0.5	%

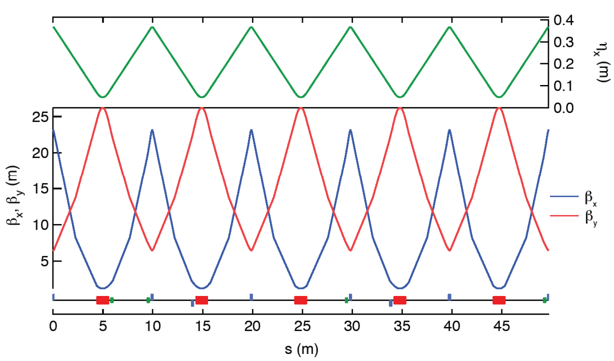

Figure 2: Optical functions for 1/10th of the Sirius booster lattice.

The physical aperture requirements for the booster are defined by the injected Linac beam size and energy variation from pulse to pulse, by the closed orbit distortions and by a tolerance for beam oscillations after injection. The adopted values of 23.4 mm inner diameter in the dipoles and 36.1 mm inner diameter in the straight sections allow for ±4σ at injection energy, ±1.5% Linac energy variation from pulse to pulse, oscillations after injection of ±4.5 mm and ±1.5 mm in the horizontal and vertical planes, respectively, and ±1.0 mm for closed orbit distortion in both planes. During acceleration the beam size shrinks as well as the oscillations due to mismatched energy, position and angle of the injected beam. The booster vacuum chambers will be made of 1 mm thick stainless steel cylindrical tubes.

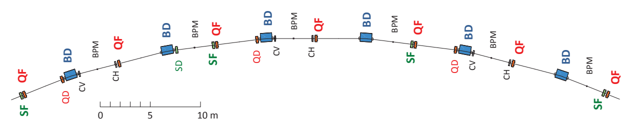

Figure 3: Schematic diagram of the Sirius booster lattice.

The chromaticity correction sextupoles, multipole components in dipoles and quadrupoles, and alignment errors reduce the dynamic aperture to about ±12 mm in the horizontal and ±4 mm in the vertical plane at the injection point. This is sufficiently large for an efficient on-axis injection and for beam lifetime. Figure 4 shows the dynamic and momentum apertures for 20 machines with random multipole, alignment and excitation errors in all magnets. The Gaussian distribution of the random errors is truncated at ±2σ.

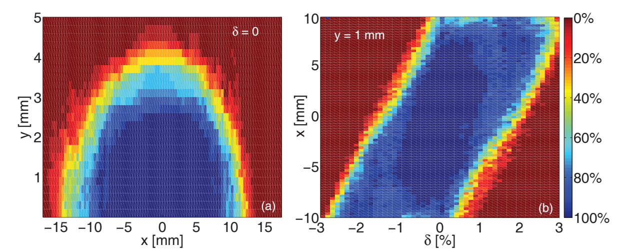

Figure 4: Dynamic (left) and momentum (right) apertures at the injection point for 20 machines with random alignment and multipole errors. The color scale represents the percentage of simulated machines for which a given particle initial condition survives in 5000 turns.

CLOSED ORBIT CORRECTION

The closed orbit correction system for the Sirius booster consists of 50 BPMs, 25 horizontal (CH) and 25 vertical (CV) corrector magnets, distributed as shown in Figure 3. The system is used for orbit correction during the energy ramp from 150 MeV to 3 GeV at a repetition rate of 2 Hz. To calculate corrector kicks and estimate residual orbit displacements, we have simulated static orbit distortions due to random alignment and excitation errors in all magnets in the lattice. The errors have Gaussian distribution with a cut-off in two sigmas. The assumed rms errors are: horizontal and vertical misalignments of 100 µm and roll angle errors of 0.5 mrad for all magnets and 500 µm misalignment for BPMs. The excitation errors are 0.2% for all quadrupoles and sextupoles and, in the case of combined-function dipoles, 0.1%, 1.5% and 12% for, respectively, the dipole, quadrupole and sextupole components, estimated from

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mechanical tolerances for pole fabrication. These are relaxed error tolerances, we expect better results for the real machine. The implicit safety margin that is assumed should account for the dynamic effects during energy ramping that were not taken into account in these calculations.

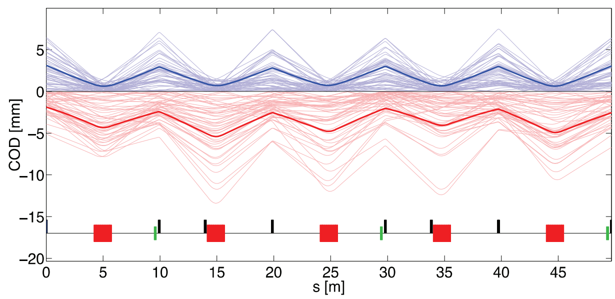

Figure 5: Horizontal (blue) and vertical (red) uncorrected closed orbit for 50 random machines. The bold curves represent one rms value.

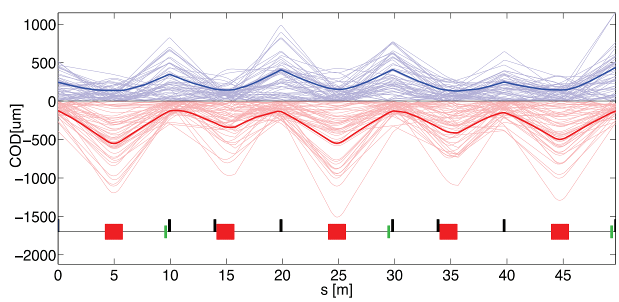

Figure 6: Horizontal (blue) and vertical (red) corrected closed orbit for 50 random machines. The bold curves represent one rms value.

INJECTION AND EXTRACTION

The injection and extraction process will take place at dispersive straight sections within the arcs. The on-axis injection of the 150 MeV beam from the Linac will use a 21.75° septum and a 22 mrad fast kicker. The injection process is shown in Figure 7.

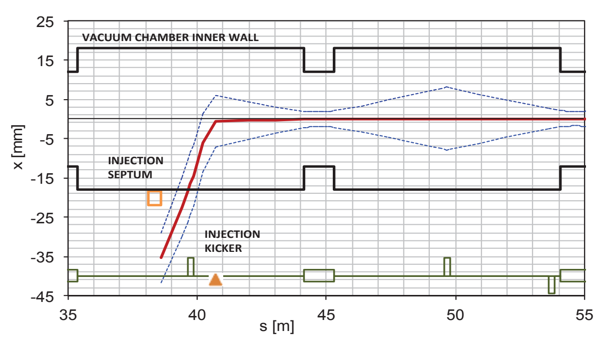

Figure 7: Booster injection scheme with the injected beam horizontal trajectory (red) and ±4σ envelope of the injected beam (blue).

The booster beam extraction at 3 GeV will employ one fast kicker that will deflect the beam by 1.1 mrad towards a 7.2° septum. Both, the kicker and the septum will be split into two halves to relax the requirements on the pulsed electronics. Figure 8 shows the extraction process.

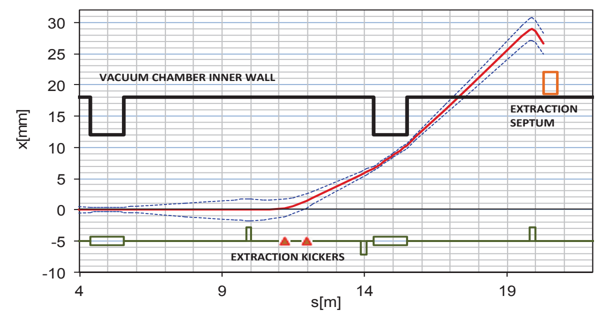

Figure 8: Booster extraction scheme with the extracted beam horizontal trajectory (red) and ±4σ envelope of the extracted beam (blue).

ENERGY RAMP EFFECTS

We have simulated the effects due to induced eddy currents in the vacuum chamber during the booster energy ramping [4]. A sinusoidal energy ramping has been assumed for the calculations. The main effect is an induced sextupole component that shifts the chromaticity, as shown in Figure 9. The lattice sextupoles can be tuned to compensate this effect.

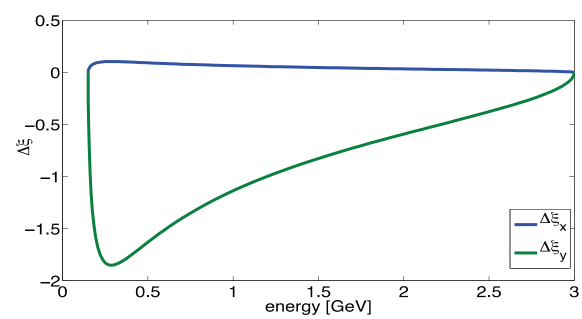

Figure 9: Chromaticities induced by eddy currents due to the ramping process.

CONCLUSIONS

A new full energy booster sharing the same tunnel with the storage ring has been designed for Sirius. A very low emittance is achieved allowing a high efficiency in the injection process. The booster components are already in prototyping and production phase.

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