DESIGN OF A BOOSTER FOR THE BRAZILIAN SYNCHROTRON LIGHT SOURCE (LNLS)

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Abstract

We present the conceptual design study of a 500 MeV synchrotron booster for the 1.37 GeV electron storage ring (UVX) at the Brazilian Synchrotron Light Source. The main considerations which are relevant to the determination of the basic machine parameters are discussed. The particular conditions at LNLS lead to the adoption of some peculiar technical solutions such as the choice for long ramping cycles and the accomplishment of beam injection and ejection in the same straight section.

1 INTRODUCTION

The Brazilian National Synchrotron Light Laboratory, LNLS, operates a 1.37 GeV electron storage ring with a 120 MeV injector Linac. The storage ring has been operating routinely with users since July 1997[1] and its performance parameters have improved steadily during this first year of regular operation, reaching a maximum stored current of 170 mA at 1.37 GeV with 11 hours lifetime. These parameters already exceed those specified during design (1.15 GeV, 100 mA and 7 hours). The need for an increase in the injection energy arose with the demand for the installation of insertion devices. The present injection process at low energy (120 MeV) does not allow these devices to be installed since the reduction in the vertical aperture of the ring would decrease the injection efficiency. The upgrade of the injection energy by installing a synchrotron booster has been foreseen in the original design and space is available inside the storage ring to place it. The geometry is such that the same Linac currently used to inject into the storage ring can be used to inject into the booster.

The original idea of a full energy injector has been revised though, and a choice for an intermediate energy injector was considered as the optimum compromise between cost, injection and ramping efficiency, physical space available (since the original occupation planning was not followed), and interference with regular operation of the storage ring during the booster installation and commissioning period. A good ramping efficiency requires an injection energy greater than 300 MeV since the main current losses occur presently at the very beginning of the ramp. From the point of view of cost and space available, lower energies are favored (the dipole magnets make a big difference since they must weigh less than the crane capacity (2 tons) and the cooling needed can imply big changes in the hydraulic system). Also the cost of the rf power need to guarantee the necessary beam lifetime increases quickly with beam energy. On the other hand considerations about beam lifetime and damping time favor higher energies. A good compromise was found by setting the energy to 500 MeV.

It was also decided that the booster should be designed to operate with a long ramping cycle. In this case the magnets are powered by current controlled power supplies, similar to the ones used in the storage ring. This results in ramping cycles of at least 10 seconds, considerably longer than the achieved with the commonly used white circuits. The main advantage of this choice is to avoid the need for especial vacuum chambers and the possibility to use a power supply topology already developed at LNLS for the storage ring, thus reducing development costs. Also, beam diagnostics and commissioning of the new injector benefit from the possibility of running the booster as a storage ring. On the other hand, the lower injection rate requires more current be injected per cycle, which means we need a better vacuum than normally required for synchrotron boosters. We have estimated that about 10 minutes are needed to inject 300 mA into the storage ring with this system. An interesting byproduct of this choice is the possibility to operate the booster as a storage ring for machine experiments when it is not used as an injector.

2 MAGNET LATTICE

The booster synchrotron will be placed inside the existing UVX storage ring. The proposed geometry is shown in Figure 1 and allows the installation and commissioning of the new injection system with a minimum interference with the present operation scheme of the light source. The same Linac can be used simultaneously to inject either into the storage ring or into the booster.

The injector ring has a racetrack shape which minimizes the machine overall dimensions and provides two long straight sections for injection and ejection of the beam and for installation of the RF cavity. In the cavity section space is available for future installation of machine experiments. The injection into and ejection from the booster take place in the same straight section. This considerably minimizes the length of the transport lines. To implement this solution the injection and

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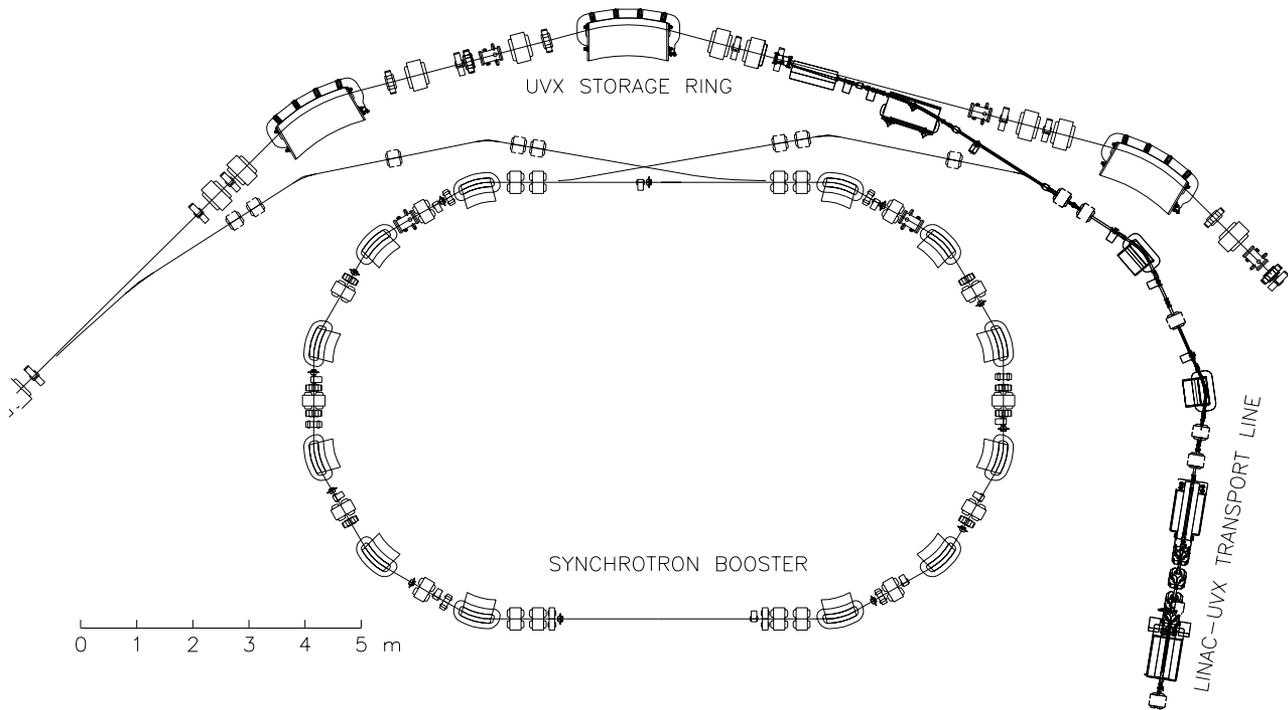
Figure 1: Lay-out of the new injector for the LNLS UVX storage ring.

ejection lines have to cross each other, as shown in Figure 1. During the booster commissioning period, two UVX straight sections will be used at the same time for injection, one for the 120 MeV beam from the Linac and another for the 500 MeV beam from the booster.

2.1 Beam Optics

The magnet lattice for the injector ring is composed of two 180° achromatic arcs and two long straight sections. The achromatic arcs are composed of FODO cells with strong dipoles. As a result all quadrupoles in the achromat are focusing in the horizontal plane. The focusing in the vertical plane comes from the dipole edges. There are three quadrupole families which focus the dispersion function to zero outside the achromat and determine its maximum value within it. We have optimized the lattice for a maximum dispersion of 1.45 m corresponding to a lattice-limited energy acceptance of 1.6 %. In the long straight sections we have used quadrupole doublets to match the betatron functions. In total the injector is has 12 dipoles and 18 quadrupoles. The natural chromaticity is compensated with two families of sextupoles in the achromatic arcs. The main parameters are shown in Table I and the optical functions in Figure 2.

The nominal operation point, ν_x=2.27 e ν_y=1.16, corresponds to a natural emittance of 284 nm.rad at 500 MeV and the dipole bending radius correspond to a magnetic field of 1.63 T at this energy. A pair of skew quadrupoles will be installed to control the emittance coupling factor and consequently the Touschek lifetime.

2.2 Orbit correction

Orbit correction is attained with 12 beam position monitors, 10 horizontal and 6 vertical correctors. Simulations have been performed for 40 machine configurations generated with random errors for magnet positioning and excitation. Gaussian distribution of errors truncated at 2 standard deviations have been assumed with rms values of 0.1 mm for alignment errors, 0.17 mrad for roll angle errors and 0.1% for excitation errors. The results show that even without any corrections the orbit distortions are within a few millimeters and can be corrected to about 0.5 mm in the horizontal and 0.06 mm in the vertical plane. The corrector strengths are always less than 2.5 mrad
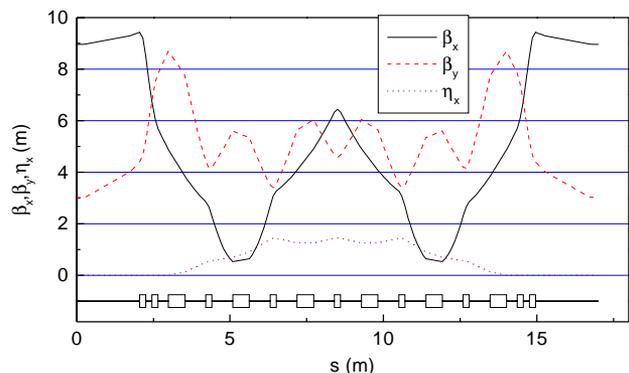
Figure 2: Optical functions for one booster superperiod. Maximum horizontal betatron function=9.4 m, maximum vertical betatron function=8.7 m, maximum dispersion function=1.45 m.

Table I: Injector ring main parameters.

Maximum energy	500	MeV
Injection energy	120	MeV
Circumference	34.0098	m
RF frequency	476.0	MHz
Horizontal tune	2.27	
Vertical tune	1.16	
Horizontal natural chromaticity	-2.1	
Vertical natural chromaticity	-2.5	

2.3 Dynamic Aperture

The program Patpet[2] has been used to simulate the dynamic aperture of the ring. We have used the same tolerances for magnetic multipolar field components in dipoles and quadrupoles as the UVX magnets. The results show that dynamic aperture is almost the size of the physical aperture, thus, sufficiently great both to allow for injection at low energy (even if the accumulation process is used) and to guarantee an adequate beam lifetime. The simulations performed include systematic and random multipole errors, and alignment and excitation errors in all dipoles and quadrupoles.

2.4 Collective effects and beam lifetime

The demands for this injector ring with respect to coherent and incoherent collective effects are stronger than for most synchrotron boosters. This is a consequence of the choice for a slow ramping cycle operation (injection of only a few pulses per minute into the storage ring). Consequently it is necessary to capture and ramp a large current in the booster at each cycle (about 100 mA). This means we have to fill about 2 mA per bunch and collective effects may be relevant at this current level. In addition, a reasonable lifetime is also required to guarantee a high ramping efficiency in the injector. We have used the code ZAP[3] to estimate the instability thresholds and the effects on bunch dimensions. We have assumed a broad-band impedance of 2 Ω and the same higher order modes as the storage ring cavity. The transverse instability thresholds are always higher than the corresponding longitudinal ones, and since the longitudinal instability is not destructive but only lengthens the bunch decreasing the peak current to values below the threshold, we conclude that single bunch transverse instabilities are not relevant in this case. The longitudinal instability thresholds are 0.13 mA and 28.6 mA for 120 MeV and 500 MeV, respectively, assuming an RF voltage of 100 kV for both energies.

The most important contribution to beam lifetime comes from elastic scattering of electrons on the residual gas molecules, particularly at low energy. This lifetime also depends on the booster betatron acceptance, which is limited, in our case, by the dipole gap in the vertical direction. The chosen value of 35 mm for the dipole gap gives a minimum total lifetime of 5.5 minutes at injection energy for a vacuum pressure of 10 nTorr. We considered a 6 mm allowance for the vacuum chamber and 5 mm for orbit distortions.

3 SUBSYSTEMS

The booster magnets will be laminated and laser cut from 1.5 mm thick low carbon steel sheets and assembled without welding by using tie rods. This technique already proved to produce good quality magnets due to the very high flexibility in changing the lamination profile during prototyping phase. The design for the dipole magnet has been concluded and we are starting the production of the first prototype. The choice for a slow ramping speed for the booster results in projects for the subsystems which are very similar to the ones used in the storage ring, including the power supplies and the vacuum chambers. The former will be current controlled with slow ramping cycle and the later ones will be fabricated from 1.5 mm wall thickness stainless steel since eddy currents induced during ramping are negligible. On the other hand, a better vacuum pressure (10 nTorr) is required to maintain a good lifetime. The basic requirement for the RF system is to produce a 100 kV gap voltage to accelerate a beam of 100 mA to 500 MeV. A first estimate shows that a 3 kW power is necessary to supply the voltage (this value can increase in case we want a longer lifetime for operation as storage ring). The instrumentation and control system components will be duplicated, whenever possible, from the ones developed for the storage ring.

4 CONCLUSIONS

The design of a synchrotron booster to upgrade the UVX injection energy from 120 MeV to 500 MeV has been presented. The main considerations involved in the determination of the parameters have been discussed. The proposed machine satisfies the geometrical constraints and fits the main requirements using techniques which are already available at LNLS. With this upgrade we will be able to increase the accumulated current in the storage ring to 300 mA and allow the installation of insertion devices.

Funding for the booster will be allocated partially from the LNLS budget and partially from external funding agencies. We expect to finish the design project and to have the prototypes for the main sub-systems (magnets, vacuum chambers, power supplies, pulsed magnets) by the end of this year. Another two years are scheduled for the production and installation of all components.

REFERENCES

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