A PROPOSED BOOSTER SYNCHROTRON FOR THE LSB

F.Pérez and M.Pont
Laboratori del Sincrotró de Barcelona - IFAE
Edifici Cn, Universitat Autònoma de Barcelona, E-08193 Bellaterra (Spain)

Abstract

The design of a booster synchrotron for the LSB machine is presented. It should take the electrons from the energy of 100 MeV at the exit of the pre-accelerator to the nominal energy of the storage ring, that is 2.5 GeV. The main requirement for the booster is that it should provide a good injection efficiency to the storage ring. This requires a booster with a relatively low emittance, relatively small beam size at extraction (low β_x and β_y, and zero dispersion) and an adequate harmonic number. A booster that fulfils the above requirements and that allows space for injection, acceleration and extraction will be presented. Detailed designs of the booster magnets: dipoles, quadrupoles and sextupoles; as well as of the RF system will also be presented.

1 INTRODUCTION

The LSB complex will be composed of three main parts [1], a pre-injector at 0.1 GeV, a Booster to accelerate the electrons from 0.1 GeV to 2.5 GeV; and an Storage Ring at 2.5 GeV from which synchrotron light is extracted to the experimental hall.

In this paper a FODO based booster for the LSB is presented. The magnet lattice is introduced in the next section. In section 3 we present the dynamic performance through the ramping in order to be sure that the injection to the storage ring will be correct. Finally, the magnet and RF designs are also presented.

2 MAGNET LATTICE

The magnetic lattice is a separated function FODO lattice with missing magnets to suppress the dispersion in the straight sections. A three fold symmetry with three straight sections: one for injection, a second one for acceleration and the third one for extraction, has been adopted. With this structure the booster becomes compact with a reasonable circumference of 126 m. At extraction, a maximum quadrupole gradient of 14.8 T/m is found. A length of 2.58 m in each of the dispersion free half-period will suit the accommodation of the RF cavity and the magnets for injection and extraction. The main parameters of the booster are listed in Table 1. Figure 2 shows the lattice structure of one cell and the optical functions along a cell.

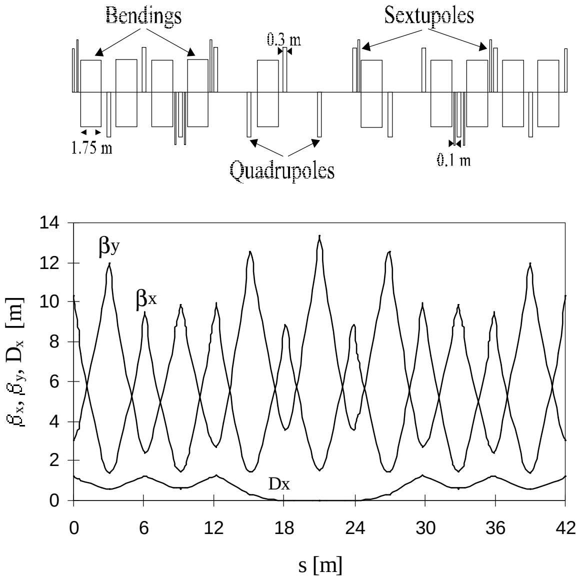

Figure 1 Lattice structure and optical functions of one super-cell of the Booster

Table 1 Booster Parameters

Maximum Energy	GeV	2.5
Injection energy	GeV	0.1
Type of lattice		FODO
Number of superperiods		3
Number of straight sections		2 x 3
Length of the straight sections	m	2.58
Circumference	m	126.0
Revolution frequency @ 2.5 GeV	MHz	2.379
Repetition rate	Hz	10
Natural Emittance @ 2.5 GeV	nm rad	198.7
Horizontal tune		6.22
Vertical tune		3.69
Natural chromaticity Q'_x		-6.3
Natural chromaticity Q'_y		-5.4
Momentum compaction factor		0.034
Energy loss per turn @ 2.5 GeV	MeV	0.41
Natural energy spread @ 2.5 GeV		7.3E-04
Long. damping time @ 2.5 GeV	ms	2.4
Trans. damping time @ 2.5 GeV	ms	5.5
	ms	5.1
Maximum β_x	m	10.30
Maximum β_y	m	13.36
Maximum Dispersion, D_x	m	1.26
Minimum Dispersion, D_x	m	0.001

3 BOOSTER PERFORMANCE

3.1 Aperture requirements

We have chosen a cylindrical vacuum chamber of 30 mm of radius everywhere except at the dipoles where the chamber will become elliptical with half horizontal axis of 30 mm and half vertical axis of 15 mm.

With these numbers and the typical errors in the bending magnets and the quadrupoles, the close orbit distortions are 3 mm, and the beam stay clear at injection and at the beginning of the cell, in each plane are,

$$\mathrm{BSC})_x = \pm 8.0\ \mathrm{mm} \qquad \mathrm{BSC})_y = \pm 3.5\ \mathrm{mm}$$

At extraction, the aperture requirements are determined by the necessary quantum lifetime. With 4 standard deviations of the beam size, the quantum life is already much larger than 50 ms. Taking an equilibrium emittance of 198.7 nm.rad, an energy spread of 7.28 10^{-4} and the same closed orbit distortions, the beam stay clear apertures become,

$$\mathrm{BSC})_x = \pm 10.0\ \mathrm{mm} \qquad \mathrm{BSC})_y = \pm 4.0\ \mathrm{mm}$$

These values should be compared to the physical apertures at the same place:

$a_x = \pm 30.0$ mm $\qquad a_y = \pm 8.0$ mm

From these calculations it can be assessed that the size of the vacuum chamber chosen fulfils the aperture requirements of the beam in the booster.

3.2 Transverse dynamics during acceleration

During acceleration the transverse emittance is damped by adiabatic damping and radiation damping while it grows by quantum excitation. Figure 2 shows the numerical solution of the differential equation obeyed by the transversal emittance during acceleration for three injection emittances, $\varepsilon_{inj}=10^{-7}$, 10^{-6} and 10^{-5} m.rad.

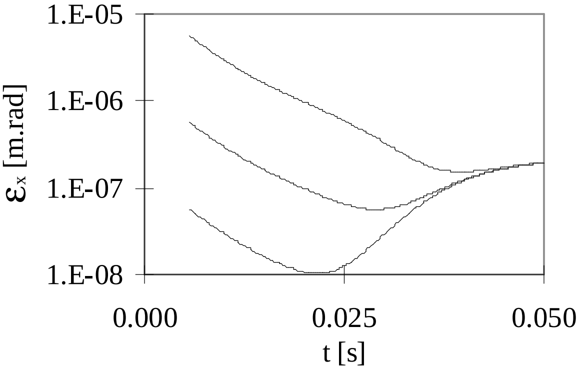

Figure 2 Transverse emittance during ramping for different initial conditions

It can be observed that at extraction the three curves collapse to the same value, the equilibrium emittance.

3.3 Dynamic aperture

We have calculated, with the BETA code [2], the dynamic aperture for dp/p=0% and ±1% and 400 turns at the beginning of the cell.

To calculate the dynamic aperture the sextupolar component induced in the bending magnets due to eddy currents has been taken into account [3]. This component is negligible at extraction but determines completely the value of the sextupoles at injection.

The results are presented in figure 3 that shows how the dynamic aperture compares with the physical aperture at injection and extraction.

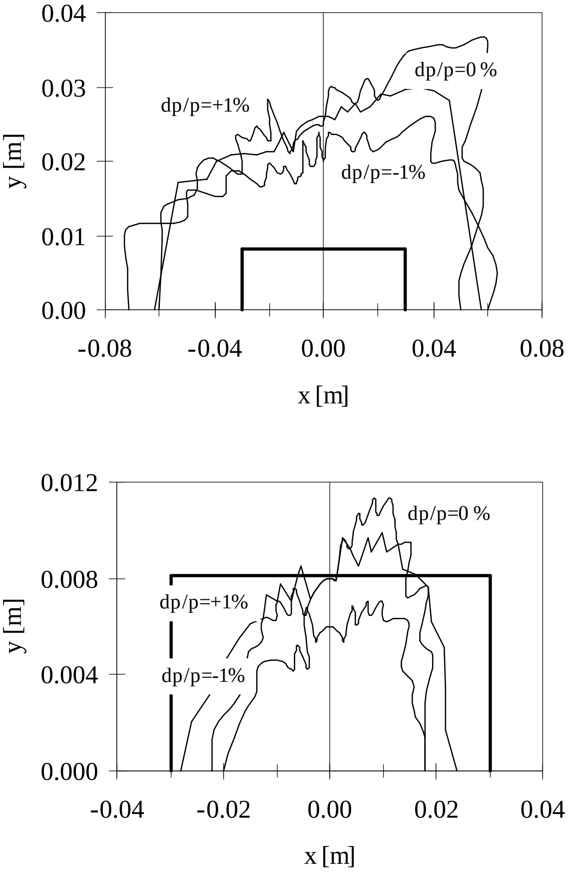

Figure 3 Dynamic versus physical aperture. The upper plot shows the results at extraction, where the sextupole induced component is negligible. The lower plot shows the dynamic aperture at injection when both the natural chromaticity and the sextupole induced component are corrected with the two families of sextupoles

At injection the dynamic aperture is smaller than the physical one, though it is still larger than the beam stay clear presented in section 3.1.

4 MAGNET SYSTEM

The magnet system of the Booster comprises 30 dipoles, 42 quadrupoles and 24 sextupoles. For the dipole magnet an H-type construction has been chosen. The magnet will be curved with parallel ends.

The main parameters of the magnets are shown in table 2. The cross section of the magnets has been determined by 2D calculations using POISSON [4]. The magnets, owing to the large currents, will have to be cooled by demineralized water circulating in the coils.

Table 2 Booster magnet parameters

Dipoles		
No. of dipoles		30
Magnetic length	m	1.747
Max. bending field	T	1.00
Bending radius	m	8.339
Magnet gap	mm	34
Field quality	$\Delta B/B_0$	$5\ 10^{-4}$
Good field region	h x v mm	40 x 30
Quadrupoles		
No. of quadrupoles		21 + 21
Magnetic length	m	0.3
Max. gradient	T/m	14.81
Aperture radius	mm	35
Field quality	$\Delta g/g_0$	$1\ 10^{-3}$
Good field region	mm	34
Sextupoles		
No. of sextupoles		12 + 12
Magnetic length	m	0.1
Max. sextupole gradient	T/m^2	141.0
Aperture radius	mm	35

5 RF SYSTEM

The RF system has to accelerate the beam from 0.1 GeV to 2.5 GeV in 50 ms, replace the energy loss by synchrotron radiation, provide large enough Quantum and Touschek lifetimes, supply a bunch length compatible with the Storage Ring and keep a longitudinal acceptance larger than the longitudinal emittance through the whole accelerating cycle.

These conditions depend on the applied peak voltage. For an injection relative energy spread of 0.3%, the voltage time dependence that fulfils these conditions is,

$$V(t) = V_{SR}+V_{acc}= V_0\ (\alpha - \cos \omega t) + T_0 (dE/dt)$$

with $\alpha = 1.17$ and $V_0 = 415$ kV. Where $\omega = 2\pi f$, and f = 10 Hz is the repetition frequency.

V_{acc} is the voltage necessary to accelerate the beam during ramping and V_{SR} is the energy necessary to replace the energy lost as well as to keep the acceptance larger than the longitudinal emittance. The time dependence of the voltage is shown in figure 4.

At extraction the bunch length is 0.09 ns and the relative energy spread 0.08% These values are adequate for the injection into the Storage Ring, which has a 2 ns bucket and a RF acceptance of 2.0%.

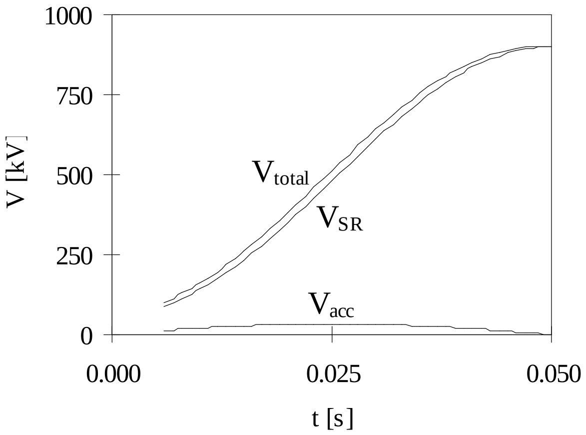

Figure 4 Time evolution of voltage

The Touschek lifetime is more than 80 h and the quantum lifetime is around 1 minute. Both are larger than the time the electrons are in the booster, 0.05 s.

The RF power system needed is mainly determined by the conditions at extraction, where 900 kV of RF peak voltage are required. In terms of power that means 112 kW. One cavity fed through one window by a 150 kW klystron at 500 MHz will be enough. Waveguides will be required to transport this high power. Commercial WR1800 are sufficient.

It is interesting to notice that all the booster RF system, from the klystron to the cavity, is exactly the same as for the storage ring. This standardization is very convenient in terms of maintenance and to reduce the cost.

6 CONCLUSIONS

A magnetic lattice based on a FODO structure has been presented for the LSB. The booster will provide the necessary small beam size for a convenient injection into the main ring, as well as an adequate harmonic number for a convenient phasing of the two rings.

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