INJECTION AND EXTRACTION SCHEMES OF THE LSB BOOSTER AND STORAGE RING*

J. Campmany, M. Traveria,
Laboratori Sincrotró de Barcelona - IFAE,
Edifici Cn, Campus Universitari UAB, E08193 Bellaterra, Catalonia (Spain).

ABSTRACT

In this paper we describe the injection system designed for the new synchrotron light source in Barcelona (LSB). The LSB has a 0.1 GeV pre-injector, a booster synchrotron ramping the energy from 0.1 GeV to 2.5 GeV, and a storage ring working at least at 2.5 GeV. The injection into the booster is done by a septum and a kicker. The extraction from it follows this scheme, with two septums instead of one. The injection in the main ring is performed with two septums plus four bumper magnets that approach the stored and injected beams.

This paper is principally concerned with the injection to the storage ring.

1 INTRODUCTION

The injection process takes place in the horizontal plane. The pre-injector and the booster are installed inside the main ring. So, the injected beam comes from the inner side of the straight section. The injection utilises the multi-turn method.

Let us assume that the pre-injector produces each 0.1 s a shot of electrons with a temporal length of 100 ns (50 bunches of 2 ns).

The injection to the booster is based in a classical septum - kicker combination [1]. The entering beam is bent horizontally and placed in the central orbit by a septum (septum foil thickness 3 mm). Afterwards, to make null its divergence, the injected beam is kicked by a fast pulsed magnet. The pulse must have a flat top of 100 ns minimum and a ramping down time of 320 ns maximum, since the booster turn period is 420 ns.

The extraction from the booster is made through a combination of a fast kicker and two identical septum magnets. (See table 1). The extraction angle is 0.16 rad.

Table 1. Booster pulsed magnet characteristics.

Booster magnets	Length [m]	Field [T]	Angle [mrad]	Angle [°]
Injection kicker	0.4	0.005	6	0.34
Injection septum	0.3	0.3	270	15.47
Extraction kicker	0.4	0.108	5.2	0.30
Extraction septum	0.85	0.8	81.5	4.67

* Work supported by CIRIT and CICYT

The main ring injection septa are the same as the booster extraction septa. Four bumper magnets placed in one straigh section of the storage ring generate the orbit displacement required.

2 THE LSB MAIN RING INJECTION

To have a design open to the possibility of the topping-up injection, we have slightly modified the scheme proposed by S. Tazzari for the ESRF [2]. In it, the injection acceptance in the normalized phase-space is constrained to one σ of the whole beam cross-section, giving a maximum injection efficiency of 68%. In the injection for the LSB, we have followed the same philosophy as Tazzari, but taking into account 3σ of the real beam phase-space cross-section (99% of efficiency). Moreover, we also take into account the possible closed-orbit errors both in the stored and the injected beams. We optimized the horizontal β function at the end of the transfer line in order to achieve the optimum injection-acceptance in the main ring. The value of this optimized β was found solving:

$$\beta_{ix}^{2} + \beta_{ix}^{3/2} \cdot (A + x_{CO}) / (6\,\varepsilon_{i}^{1/2}) = \beta_{sx}^{2}/2 \qquad (1)$$

Where $A = 4\,(\varepsilon_s\,\beta_{sx})^{1/2} + D_{sx}(\Delta p/p)_s + x_{SE}$, x_{CO} is the horizontal closed-orbit maximum error (5 mm), β_{ix} and β_{sx} are the values of β-function at the exit of the transfer line, and at the storage ring injection point, respectively, ε_i and ε_s are the values of the horizontal emittance of the injected and stored beams, respectively, D_{sx} is the dispersion function of the main ring at the injection point, $(\Delta p/p)_s$ is the relative error of momentum for the stored beam, and x_{SE} is the septum foil thickness (5 mm with tolerance allowances). The injection point is placed in the middle of the straight section, where the slopes of β and *D* are null, in the absence of bump excitation. The result of (1) is $\beta_{ix} = 6.197$

To bend the injected beam at 2.5 GeV, and taking into account the constraints imposed by the limited physical space, we have chosen a combination of two identical septa. We show this scheme in Figure 1.

The distance between the septum and central orbit at injection point is determined using the expression:

$$d_{SE\text{-}CO} = 4\,(\beta_{sx}\,\varepsilon_s)^{1/2} + D_{sx}(\Delta p/p)_s + x_{CO} + x_{SE} \qquad (2)$$

where symbols have been defined previously. The bump amplitude is then determined by:

$$x_{bump} = 2x_{CO} + x_{SE} + 6\,(\varepsilon_i \beta_{ix})^{1/2} + 2D_{sx}(\Delta p/p)_i \qquad (3)$$

where, ε_i is the value of the emittance of the injected beam, and $\beta_{ix,}$ D_{sx} , $(\Delta p/p)$, x_{CO} and x_{SE} have been defined above.

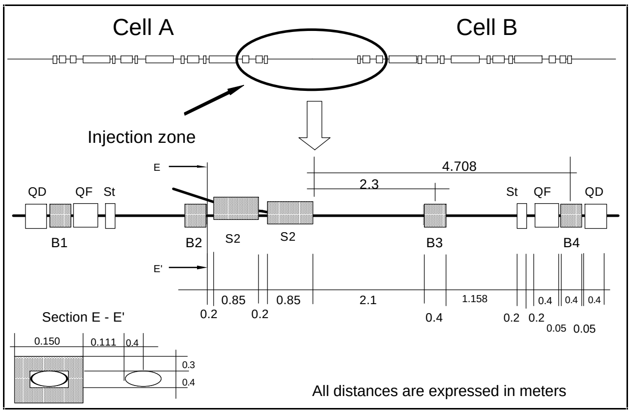

Figure 1. Injection scheme for the LSB storage ring.

During the design of the injection, however, we have noticed that the optical functions slightly change (±10%) when the injection bump is switched on (Figure 2). Therefore, we have performed the calculation of injection parameters in an iterative way, taking this variation into account. The ring parameters used in the injection calculations are shown in Table 2.

Table 2. Parameters used for injection in Storage ring.

Septum foil thickness, x_{SE}	[mm]	3±1
Injected beam emittance, ε_i	[m rad]	$1.987 \cdot 10^{-7}$
Injected momentum error, $(\Delta p/p)_i$		$7.28 \cdot 10^{-4}$
Horizontal β at transfer line end, β_{ix}	[m]	6.197
H dispersion at transfer line end, D_{ix}		0.033
V dispersion at transfer line end, D_{iY}		0.000
Horizontal closed orbit error x_{CO}	[m]	0.005
Injected beam H diameter, $2 \cdot 3\sigma$	[m]	0.0067
Stored beam emittance, ε_s	[m rad]	$8.3 \cdot 10^{-9}$
Stored momentum error, $(\Delta p/p)_s$		$9.6 \cdot 10^{-4}$
Horizontal β at injection point, β_{sx}	[m]	14.439
Vertical β at injection point, β_{sY}	[m]	4.929
H dispersion at injection point, D_{sx}		0.033
V dispersion at injection point, D_{sY}		0.000
Stored beam H diameter, $2 \cdot 4\sigma$	[m]	0.0056
Bump amplitude, x_{bump}	[m]	0.021
Distance from SE to central orbit, d_{SE}	[m]	0.027
Pulse lenght of bumper magnets	[s]	$6.62 \cdot 10^{-6}$

3 BUMP DESIGN

The bump of the closed orbit is done by 4 bumper magnets placed in the straigth section between cells A and B (see Figure 1). The bump has been designed symmetric, in order to reduce the number of power supplies and control items. The length (L), maximum angular deviation (θ) and maximum field (B) for the kicker magnets are shown in Table 3. With such bumper magnets, we obtain the evolution of the stored beam in the normalized phase-space diagram shown in Figure 2.

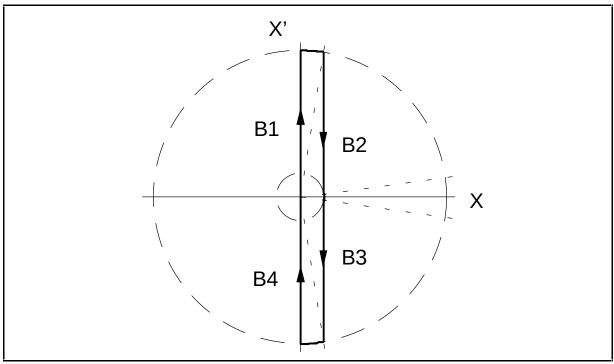

Figure 2. Evolution of the close orbit in the phase-space X-X'. X is defined as $x \cdot \beta_i^{1/2}$ and X' as $x' / \beta_i^{1/2}$.

Regarding to the temporal constraints of the injection, we have chosen the time in which the bump is 'on' to be equal to 8 main ring revolutions (f_{rev} = 1.2 MHz), giving a pulse of 6.62 µs. Moreover, the switch between the 'on' and 'off' status follows a sine function. The synchronized variation of the bumper strenghts gives 4 closed orbit displacements, one for each turn, as shown in Figure 3.

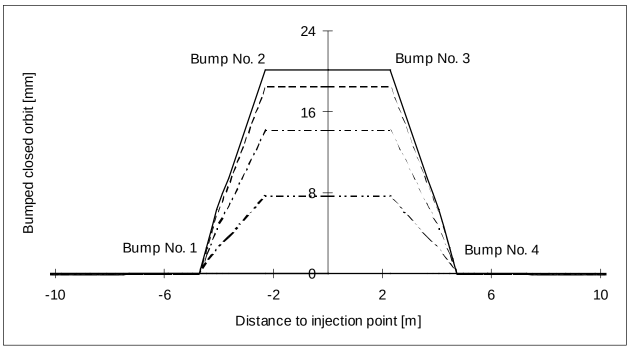

Figure 3. Bump amplitude during the 4 first turns. Positive Y axis points towards the center of the ring.

Table 3. Bumper magnets characteristics.

Bumper no.	B [T]	L [m]	θ [mrad]	θ [°]
1, 4	0.210	0.4	10.37	0.59
2, 3	0.160	0.4	7.84	0.45

4 INJECTION DYNAMICS

Equation (1) assumes that the injection efficiency is 99% if the switching off of the bumpers is instantaneous. However, because of power supply constraints, we have to design the switching off of the bumpers as slow as possible. This implies that the stored beam, with the injected beam describing betatronic oscillations around, will remain bumped on during several turns.

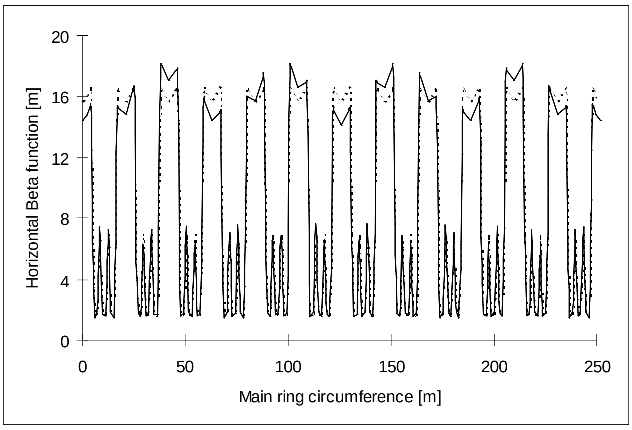

Figure 4. Change of β along the ring when switching the bump from 'off' (dashed) to 'on' (continous curve).

Using the MAD code [3], we have simulated the injection dynamics in the first 5 turns, assuming that the variation of the field in the bumpers is a half-sine wave with a pulse length of 6.62 μs. The computed evolution of the injected beam in the horizontal normalized phase space is shown in Figure 5.

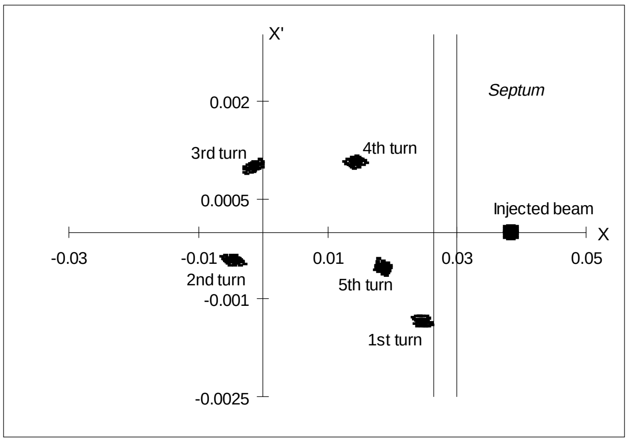

Figure 5. Position of the injected beam in the horizontal normalized phase-space during the 5 first turns. The injected beam diameter is assumed to be 6σ.

From this result, assuming a zero error in the positioning of the injected beam, the injection efficiency after the first five turns is 95%. Since we have chosen the injected beam as 3σ (99%) of the septum-entering beam, we can therefore consider a global efficiency of the injection at the main ring of 94%. Once the bump is switched off, the injected beam describes betatron oscillations around it. Even in the worst case, the injected beam is separated from the septum wall by at least x_{CO}, ensuring that it is not lost before damping.

5 BOOSTER-TO-MAIN RING TRANSFER LINE

The transfer line between the booster and the main ring has been designed taking into account the start and ending optical parameters of the booster extraction-point and main ring injection-point. In this last case, however, we use the β_{ix} obtained when solving the equation (1), in order to minimize the injection acceptance.

We propose a line with 2 dipoles and 7 quadrupoles. The line has been designed using the MAD program, with the simplex algorithm in order to minimize its length (total length = 27.205 m) and the maximum of β function (max. β_x=50.3 m, max. β_y= 50.16 m). Figure 6 shows the beam envelope along the transfer line.

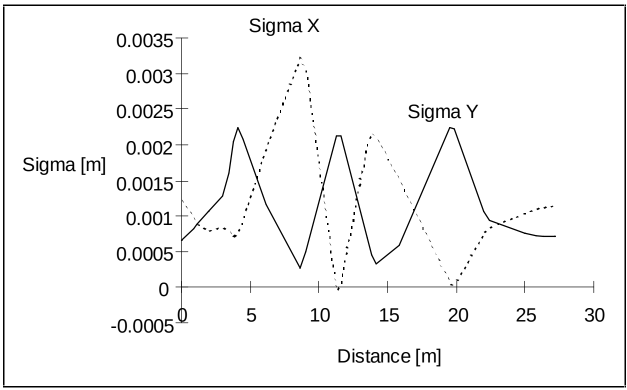

Figure 6. Beam envelope (σ) along the transfer line

6 CONCLUSION

We have presented the design of the injection for the LSB. It is based on classical expressions but improving the expressions to increase the injection efficiency.

We have also taken into account some effects caused by the variation of optical functions in the main ring when the bumper magnets are switched on, along with the finite time of the posterior on-off pulse transition. The final design shows a theoretical injection efficiency from the booster to the main ring of 94%.

REFERENCES

[1] G.H.Rees, 'Injection', in 'CERN accelerator School', CERN 85-19, p. 331.

[2] S.Tazzari, 'Apertures for injection', ESRP-IRM-4/83.

[3] H.Grote, F.C.Iselin, 'The MAD Program. User's Reference Manual', CERN/SL/90-13 (AP) (Rev. 3).