OPTICS FOR THE ALBA BOOSTER SYNCHROTRON

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Abstract

The ALBA booster synchrotron is a full energy injector of 3 GeV for top-up operation installed in the same tunnel as the Storage Ring. Its large circumference of 249.6 m and the magnetic lattice with combined function bending magnets provide an equilibrium emittance as low as 9 nm rad. In this paper the lattice concept and the main features of the optics are described. The closed orbit correction scheme consists of 44 horizontal and 28 vertical correctors and 44 BPMs. A solution that requires a reduced number of BPMs has been studied as well. Chromaticity correction and dynamic aperture during the ramping have been also investigated. Finally, the injection and extraction schemes are also presented.

INTRODUCTION

In the ALBA booster the beam is injected at 100 MeV and ramped up to 3 GeV with a maximum repetition rate of 3 Hz.

The lattice layout is similar to the SLS booster concept [1], where the low emittance is achieved with a large circumference ring and a modified FODO lattice based on many alternated focusing combined function magnets. The use of combined function dipoles has the advantage of reducing the number of magnets and decreasing the natural emittance by introducing additional damping due to the field gradient, but on the other hand, this reduces the flexibility of the lattice.

In the ALBA booster instead, the introduction of both gradient bending magnets and focusing quadrupoles implies a higher flexibility and the reduction of the emittance by roughly a factor 2. Both the combined dipoles and the quadrupoles of the unit cell have a built-in sextupolar component in the iron pole profile to correct the natural chromaticity to (+1, +1). The large circumference allows to build wide arcs with relaxed optics: the maximum beta functions are 11.2 horizontal m and 11.7 m vertical, and the maximum dispersion is only 0.47 m.

LATTICE LAYOUT

The booster lattice has a four-fold symmetry, consisting of 4 arcs with 4 straight sections of 2.46 m. The basic structure of the arc is composed of 8 unit cells (FODO), each with a defocusing gradient bending magnet (BM10) and a focusing quadrupole (QH02). At each end of the arcs there is a matching cell consisting of a shorter combined function defocusing dipole (BM05) and three quadrupoles (QH01,

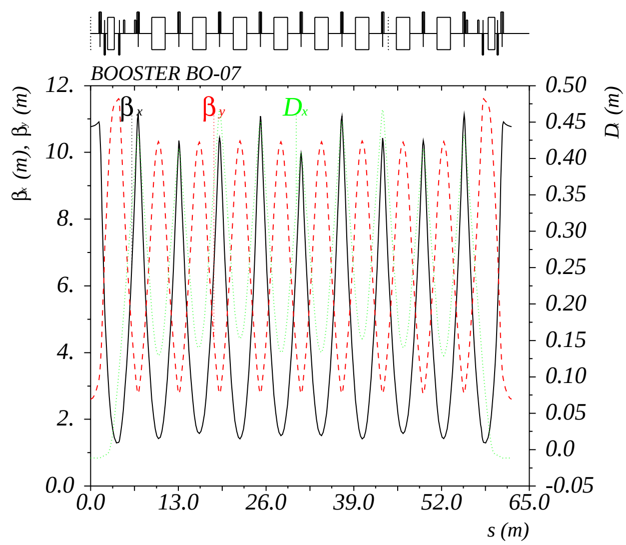

Figure 1: Booster arc: beta and dispersion functions for the nominal lattice.

QV01, QV02), which lead to zero dispersion in the straight sections where the RF-cavity and the injection elements are installed. The main lattice parameters are listed in Table 1 and the optical functions are shown in Fig. 1. Table 2 lists the dipole and quadrupole main parameters.

Table 1: Main parameters of the ALBA Booster.

Injection energy	100	MeV
Extraction energy	3.0	GeV
Circumference	249.6	m
Emittance at injection	150	nm·rad
Emittance at 3 GeV	9	nm·rad
Energy spread at injection	±0.5%	...
Energy spread at extraction	±0.1%	...
Betatron tunes Q_x/Q_y	12.42 / 7.38	...
Maximum betas β_x/β_y	11.2 / 11.7	m
Maximum dispersion D_x	0.47	m
Natural chromaticities ξ_x/ξ_y	-16.9 / -10.0	...
Momentum compaction α_c	0.0036	...
RF frequency	500	MHz
Harmonic number	416	...
Damping times at 3 GeV $\tau_x/\tau_y/\tau_t$	4.5 / 8.0 / 6.3	ms
Maximum repetition rate	3	Hz

Table 2: Design parameters of the booster dipoles and quadrupoles at 3 GeV.

Dipoles	BM05		BM10	
Number	8		32	
Magn. length (m)	1.00		2.00	
Bend angle (°)	5		10	
Field (T)	0.873		0.873	
Gradient (T/m)	-2.29		-2.29	
Sextupole (T/m^2)	-22.2		-22.2	
Quadrupoles	QH01	QH02	QV01	QV02
Number	8	36	8	8
Magn. length (m)	0.36	0.36	0.20	0.20
Gradient (T/m)	13.6	15.8	-10.3	-11.3
Sextupole (T/m^2)	...	43.9	...	...

Optics Flexibility

Despite the use vertical focusing gradient dipoles, some flexibility is allowed in the horizontal plane by varying up to 5% the focusing quadrupoles of the unit cell with changes of the beta functions in the range of 20%. In addition, three families of quadrupoles located in the matching sections provide a tuning range of about ±0.5 in the horizontal and vertical direction, without perturbing too much the beta functions. With these quadrupoles we can compensate gradient random errors in the combined function dipoles up to about ±1% [2].

Two additional families of sextupoles (SH, SV), with two pairs of magnets per arc, are installed in the matching sections to vary the chromaticity and correct the sextupole component induced by the eddy currents in the vacuum chamber during ramping of the dipole field.

Modeling of the Gradient Bending Magnets

Careful modeling of the gradient dipoles has been carried out to reproduce the real edge focusing and chose the best end chamfer cut of the magnets. Studies about this topic have been presented in [3]. Figure 2 shows a comparison of the tune changes as a function of the horizontal end chamfer angle of the booster short dipoles that was done in order to chose the best chamfer for the magnet production.

CLOSED ORBIT CORRECTION

Simulations have been performed [4] assuming the accuracy for the initial alignment of all booster magnets will be about 0.200 mm rms for the horizontal and vertical diplacement, and 0.10 mrad rms for the roll angle. This leads to closed orbit rms deviations of about 3.1 mm horizontally and 2.1 mm vertically.

A pair of horizontal and vertical correctors and one beam position monitor (BPM) is placed in each unit cell. One additional correctors-BPM block is placed in each matching section. The total number of blocks is then 44. Nevertheless, because of the lower amplification factor and integer tune in the vertical plane, the number of vertical correctors to be installed is reduced to 28. The required maximum correctors strength is 0.5 mrad in both planes. The number of installed BPMs is 44, but also a configuration with only 28 BPMs has been studied to save the costs of the electronics. Table 3 resumes the simulation results, before and after the orbit correction, for the booster correction scheme with 44 and 28 BPMs. At present it is forseen to use only 28 BPMs.

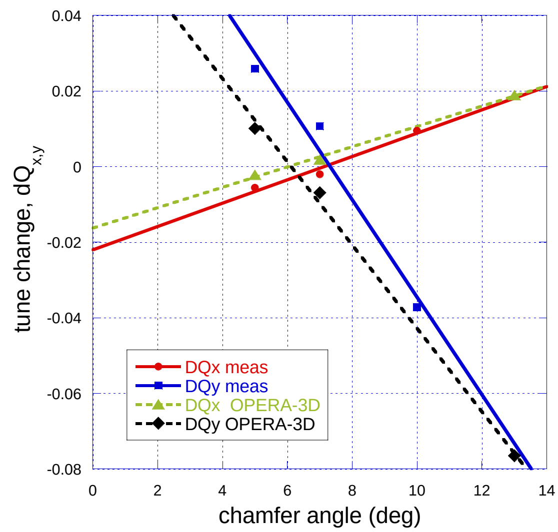

Figure 2: Tune changes as a function of the horizontal end chamfer angle in the short dipoles. Data points calculated, both from simulations (OPERA-3D) and measurements on the pre-series, with different chamfer cuts, are compared. The chosen chamfer angle of 7.5° gives almost the nominal tunes.

Table 3: Closed orbit correction rms values with 44 and 28 BPMs with Gaussian alignment error distribution.

	Horizontal	Vertical
Uncorrected orbit		
distorsion around ring (mm)	3.13	2.10
distorsion at BPMs (mm)	2.22	1.88
Corrected with 44 BPMs		
residual around ring (mm)	0.46	0.44
residual at BPMs (mm)	0.17	0.23
corrector strength (mrad)	0.15	0.17
Corrected with 28 BPMs		
residual around ring (mm)	1.47	0.83
residual at BPMs (mm)	0.36	0.41
corrector strength (mrad)	0.08	0.12

BEAM APERTURE REQUIREMENTS

The half beam stay clear allowances all along the magnetic lattice are chosen as:

$$BSC_{x,y} = max[(3 \cdot \sigma_{x,y} + 3 \cdot u.c.o.)]; \quad (1)$$

with $\sigma_{x,y}$ rms beam envelopes at the injection and u.c.o. the uncorrected rms closed orbit given in table 3 [5].

Therefore, the vacuum chamber of the ALBA booster has been chosen to have a round cross section with half apertures equal to $A_x = A_y = 15.5$ mm all around the ring but in the dipoles, where it has an elliptical cross section with $A_x = 23$ mm and $A_y = 8.8$ mm. The reduced physical dimensions of the vacuum chamber allow designing low consuming magnets with narrow gap.

INJECTION AND EXTRACTION

The injection take place in one the free dispersion straight sections. The beam is injected on axis through a 12.6° septum and a fast kicker of 32.5 mrad.

The extraction is performed in a dispersive region. The beam is first deflected by a 3.5 mrad fast kicker upstream one of the defocusing bending magnets that increases the beam displacement from the axis, and then extracted through a 4.9° septum into the booster to storage ring transfer line.

The septum plates, both at the injection and at the extraction, are placed at a distance of 13 mm from the booster axis and do not affect the beam stay clear.

CHROMATICITY AND DYNAMIC APERTURE

The natural chromaticities of the booster lattice are ξ_x = -16.9 and ξ_y = -10.0 and the strength of the built-in sextupoles in the dipoles and quadrupoles provide corrected chromaticities of ξ_x = +1 and ξ_y = +1.

Eddy currents induced in the dipole vacuum chamber give rise to a sextupole component that changes the chromaticity of the machine. The maximum sextupole strength, reached at 200 MeV, $K_2 \approx 1.1\ \mathrm{m}^{-3}$, is comparable with the sextupole in the dipoles $K_2 = -2.22\,\mathrm{m}^{-3}$, and produce a change in the vertical chromaticity of 7 units. Therefore, the two families of sextupoles, SH and SV, are varied during the ramping in order to keep constant the chromaticity [6].

Dynamic aperture simulations with the design sextupole values have been performed in two scenarios, first with $\xi_x = \xi_y = +1$, and with $\xi_x = \xi_y = +5$. Figure 3 shows the dynamic aperture calculated on-energy and ±2% off-energy at 200 MeV corresponding to the peak value of the eddy currents and sextupole families strengths, respectively in the $\xi_x, \xi_y = (+1, +1)$ and in $\xi_x, \xi_y = (+5, +5)$ scenario.

New dynamic aperture calculations with multipole values from the first measurements on the real dipole and quadrupole families with integrated sextupole component are now in progress, and the use of frequency map analysis to optimize the booster working point at different chromaticities is under test.

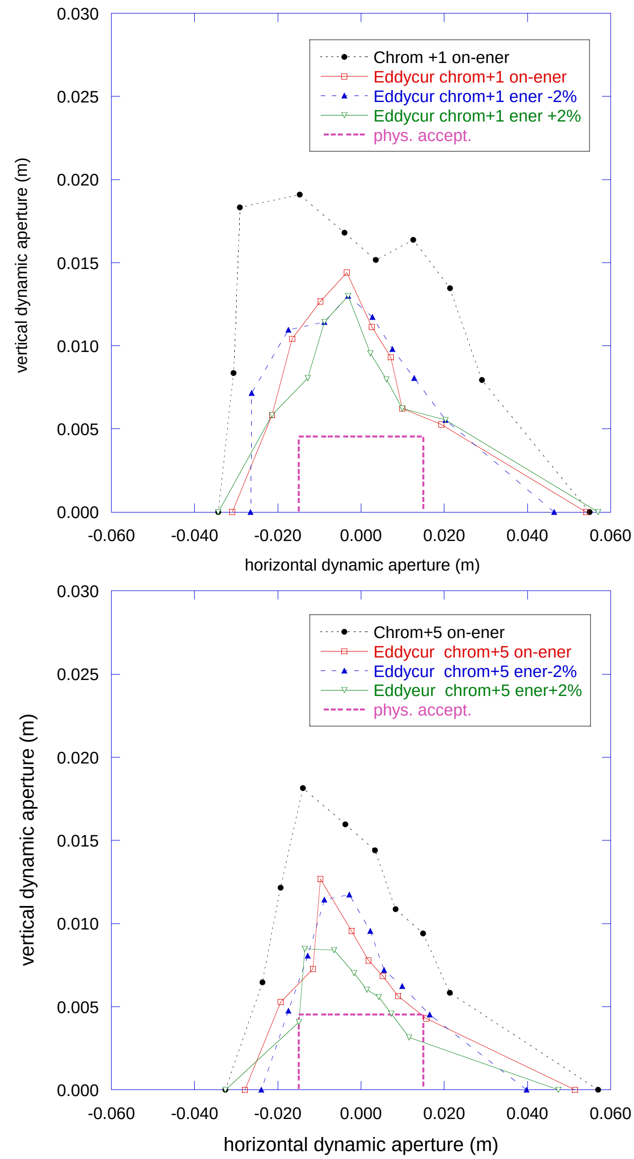

Figure 3: Dynamic apertures at the injection point at 200 MeV, where the eddy current effect is strongest, calculated for 1028 turns with chromaticity $\xi_x, \xi_y = (+1, +1)$ (top) and $\xi_x, \xi_y = (+5, +5)$ (bottom).

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