BEAM OPTICS MEASUREMENTS DURING THE COMMISSIONING OF THE ALBA BOOSTER

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Abstract

The first phase commissioning of the Booster for the synchrotron light source ALBA has taken place in December 2009-January 2010. In this paper, the beam optics measurements performed during two weeks of commissioning are described, including the main problems found and a comparison of the measured parameters to the design.

INTRODUCTION

The ALBA booster synchrotron is a modified FODO lattice structure based on unit cells consisting of defocusing combined dipoles and focusing quadrupoles and matching cells with three families of quadrupoles [1]. The large circumference of 249.6 m and the use of combined function magnets provide a nominal emittance at 3 GeV as low as 9 nm·rad 1. The nominal working point, $Q_x = 12.42$, $Q_y = 7.38$, was chosen to provide good dynamic aperture and small closed orbit distorsion. Theoretical simulations of the lattice showed that the tunes can be changed in a broad range (±1 in the horizontal plane, ±0.5 in the vertical) with several solutions preserving the dynamic aperture and emittance below 10 nm·rad.

MODES OF OPERATION

The booster commissioning [2] started in DC operation at the linac energy of 105 MeV (mode 1), storing the beam with the RF at 100 W and 50 kV [3] and performing the orbit correction. Afterwards, the booster operated in ramping mode at 3.125 Hz, first to 600 MeV (mode 2) and then to 3 GeV (mode 3) with sinusoidal waveforms in the digital power supplies [4] and linear ramp from 100 W to 35 kW in the RF. Finally, we went back to DC mode to perform more beam measurements (mode 4).

SOFTWARE TOOLS

An extensive use of the Matlab Middle Layer (MML) was done for the booster commissioning. MML has been indispensable for all the applications related with the BPM measurements: closed orbit, response matrix, global orbit correction, tunes based on turn-by-turn data, dispersion function. In particular two applications for the tune measurements, one for the DC operation and another for the ramping operation, have been developed with MML during the commissioning shifts.

Table 1: Design 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	$\pm0.5\%$	...
Energy spread at extraction	$\pm0.1\%$	...
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	...
Maximum repetition rate	3.125	Hz

CLOSED ORBIT MEASUREMENTS

The orbit correction system comprises of 44 horizontal and 28 vertical correctors and 44 BPMs of which only 28 were equipped with the Libera reading electronics [5].

The first closed orbit in DC operation (mode 1) was obtained setting several correctors. The global orbit correction with an SVD algorithm was then performed using a measured orbit response matrix, but the orbit was not corrected to better than ±4 mm in the horizontal plane and ±2 mm in the vertical.

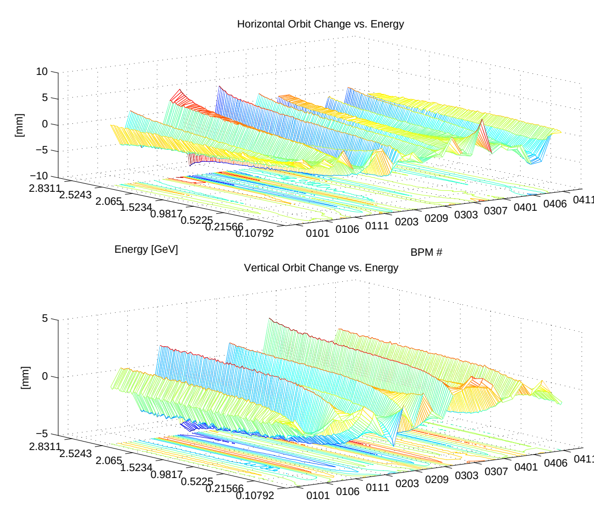

Figure 1: Horizontal and vertical orbit during ramp to 3 GeV corrected only at injection energy.

In ramping operation the orbit was corrected only at injection energy without ramping the correctors. An example taken when ramping to 3 GeV (mode 3) is shown in Fig. 1. The orbit increases up to ± 8 mm horizontal and ± 4 mm vertical due to both the energy increase and the tune drift.

TUNE MEASUREMENTS AND SEARCH FOR THE WORKING POINT

Integer Tune

The integer part of the betatron tunes was inferred from the measured orbit response matrix. In the horizontal plane, due to the undersampling of the 12 betatron oscillations, the orbit response at 28 BPMs to a single corrector (a column of the matrix) is not sufficient to determine the integer tune (Fig. 4), but we overcame this problem considering the response at a single BPM to all the 44 correctors (a row of the matrix), even if this measurement takes much longer than changing a single corrector.

Fractional Tune

The first measurements of the fractional tunes in DC mode were performed using the residual oscillations of the injection and taking the FFT of the BPM turn-by-turn data.

The search of the first working point was done trying to optimize the beam transmission [2] and the measured tunes were 12.64 and 7.43 (DC mode 1) instead of the nominal 12.42 and 7.38.

In ramping operation the beam was excited with two striplines [5]. The fractional tunes could be measured taking the FFT of the turn-by-turn data all along the ramping (160 ms, 192300 turns) either at a couple of stripline BPMs or at any of the BPMs used for the orbit correction.

In the operation at 600 MeV, the tunes at the injection energy were 12.46 and 7.43 (AC mode 2) and drifted within a range of ± 0.3. In the operation at 3 GeV, the tunes at the injection energy were 12.65 and 7.39 (AC mode 3) and drifted in the range of ± 0.4, resulting in beam loss at 2.7 GeV probably due to a resonance crossing (Fig. 2).

Finally, in the last days of commissioning, the booster operated again in DC mode in order to perform further beam measurements and studies. The magnet settings at injection energy of AC mode 3 were tried to be reproduced in DC mode, nevertheless, the measured tunes were 13.27 and 7.39 (DC mode 4). In fact we realized only after the commissioning that in ramping operation, due to a error in the timing, the beam was not injected at the minimum of the waveform [2] and the lattice was different from what was actually expected.

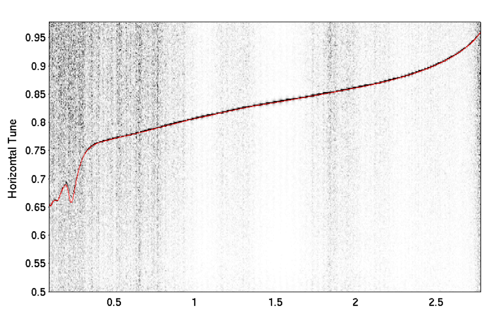

Figure 2: Horizontal tune measurement ramping to 3 GeV: the beam is lost at 2.7 GeV touching an integer resonance.

Agreement with the Model

In general, the model and measured tunes agree within 0.2 and, in order to match the measured values, the calibrations of the quadrupole families at injection energy must be corrected by 1-2%, while the gradient of the bendings seems miscalibrated by -1%. The magnetic measurements are now being reviewed and cross-checked with LOCO.

DISPERSION AND CHROMATICITY

The dispersion function was measured in DC mode 1 and 4 varying the master oscillator by ± 1 kHz. A comparison with the model is shown in Fig. 3.

A measurement of the chromaticity was attempted both in DC and AC operation. The results have still to be investigated since the values are reasonable (ξ_x, ξ_y) = (-1, +2), but no effect of the sextupole families was observed.

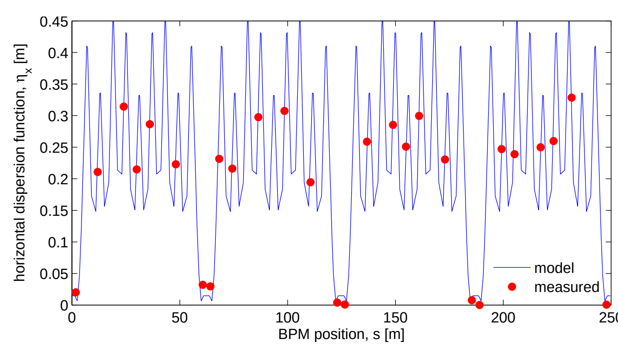

Figure 3: The dispersion function in DC mode 4 measured by changing the frequency by ± 1 kHz is in good agreement with the model.

LOCO AND LATTICE MODEL

Two orbit response matrices were measured in DC operation (modes 1 and 4) and analysed with LOCO to infer the beta functions and the symmetry of the lattice. The quality of the data is very good and a coupled analysis was performed by fitting the gradient calibrations and the BPM gain and coupling factors.

Figure 4 reports an example of the model orbit response to a corrector before and after the LOCO analysis compared with the measurements at the BPMs.

The ALBA booster is the first machine applying LOCO in a lattice with combined dipoles and one family of quadrupoles with sextupole integrated in the pole profile.

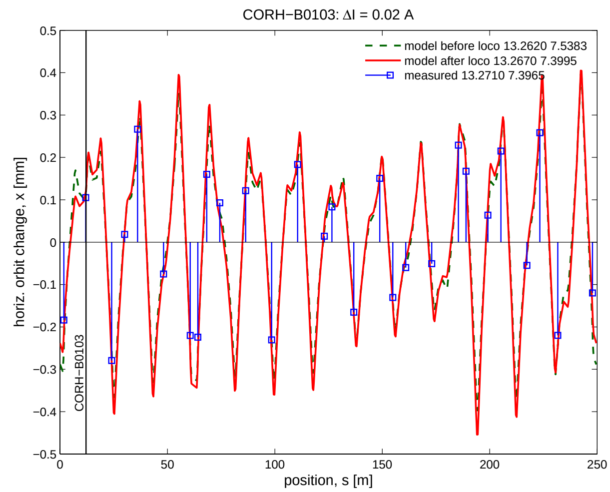

Figure 4: Comparison between the measured horizontal orbit response to a corrector taken in DC operation (mode 4) and the model before and after the LOCO analysis.

In presence of a horizontal orbit x, the built-in sextupole component k_2 generates an additional effective quadrupolar term $\Delta k_1 = x \cdot k_2$. For $x^{rms} = 2$ mm in the focusing quadrupoles, we have $\Delta k_1^{rms}/k_1 = 0.5\%$; and for $x^{rms} = 1$ mm in the combined dipoles, $\Delta k_1^{rms}/k_1 = 1\%$. This effect on the tune change is small (about 0.01), but it is not on the beta beating and had to be taken into account in the LOCO analysis by fitting individually each combined magnet, while the other quadrupoles were fitted by family.

Figure 5 shows the gradient changes reconstructed with LOCO in DC mode 4. A beta beating of up to 80% is predicted for the lattice when compared with the ideal symmetric model (Fig. 6).

Finally, the BPM calibration and coupling factors given by LOCO and predicted by 2D electromagnetic simulations of the pick up electrodes have been compared and are still under investigation.

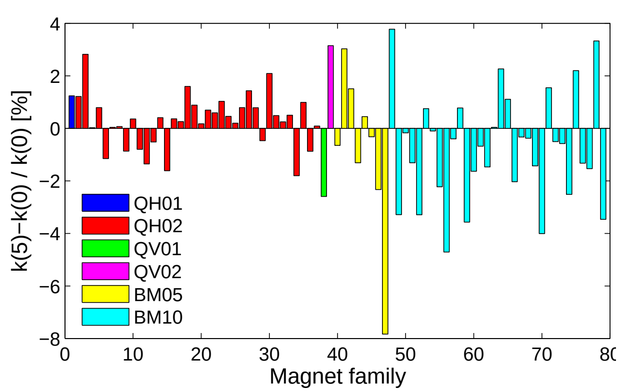

Figure 5: The gradient relative changes in DC mode 4 fitted by LOCO. The error distribution in the combined magnets with built-in sextupole QH02, BM05 and BM10 are mainly due to the orbit.

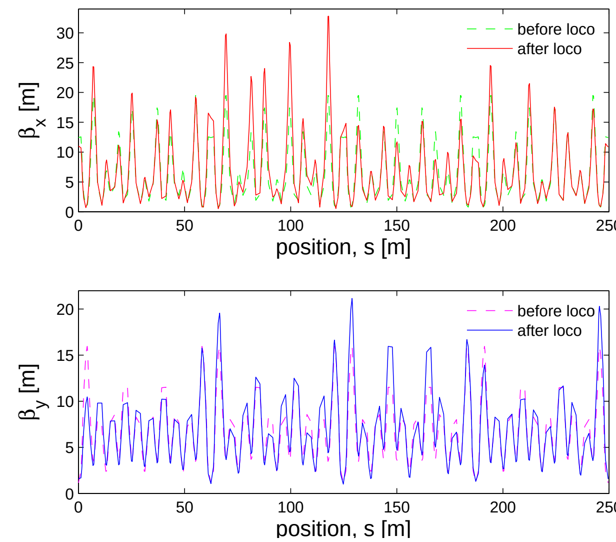

Figure 6: The beta functions reconstructed by LOCO for DC mode 4 compared with the ideal symmetric model.

CONCLUSIONS

During the first phase of the ALBA booster commissioning, all the basic optic measurements were mainly made using MML. Global orbit correction must be improved: increasing the BPM electronics units to 44 should allow correcting the orbit to 1 mm at injection energy. LOCO has proved to be a powerful diagnostic tool to analyse the real lattice and it will be used further to correct and optimize the optics. More work on the magnet calibrations at low energy is progress to set up the lattice at the design working point. The behaviour of the magnet power supplies and the optimization of the quadrupole waveforms is under investigation to reduce the tune drifts along the ramping.

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