MODELING RESULTS FROM MAGNETIC AND BEAM BASED MEASUREMENTS OF THE ALBA GRADIENT DIPOLES

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Abstract

The ALBA lattice is a DBA-like structure where most of vertical focusing is provided by gradient dipoles. In the first year of machine operation, the model parameters describing the focusing strength of the 32 dipoles have been calibrated by fitting the measured closed orbit response matrix. The mean k-value obtained from this analysis differs by -0.22% with respect to the value taken from the magnetic measurements previous to the magnet installation, while the k variation within the 32 dipoles is of the same order of magnitude. The optics results (tunes, beta beating) obtained with the beam based model are compared with the predicted ones from the magnetic measurement model.

INTRODUCTION

ALBA is a 3^{rd} generation light source with nominal operating energy of 3 GeV. The ALBA storage ring presents a 4-fold symmetry and consists of 16 sectors: 8 unit cells and 8 matching cells. Each unit cell accommodates 6 quadrupoles and 2 dipoles, while each matching cell has 8 quadrupoles and 2 dipoles. The ALBA lattice is based on a double bend achromat-like (DBA-like) structure [1], i.e. a cell containing two bending magnets, where the first builds up dispersion and the second one minimizes it again without becoming zero to avoid affecting the emittance value of the lattice, making the whole structure achromatic-like (Fig. 1).

The dipoles used in ALBA are combined-function magnets. These dipoles have the advantage of reducing the space taken up by the magnets maximising the space available for insertion devices and decreasing the natural emittance by introducing additional damping due to the field gradient. On the other hand, the fact that most of the vertical focusing takes place in the dipoles reduces the flexibility of the ALBA SR lattice, in particular in the vertical plane, and enhances the sensitivity to the gradient errors of the dipoles, as well as to the edge focusing due to the pole face rotations.

Studies carried out during the accelerator design phase pointed out that a careful characterization of the combined functions dipole focusing properties including the edge effects was crucial to obtain the designed optics and in particular the vertical tune and betatron functions [2]. This was confirmed during the storage ring commissioning: the vertical tune was found to be 0.12 lower than the expected with the quadrupole settings based on the model calibrations, and to correct the symmetry of the ring changes in the defocusing quadrupoles up to ±2% were needed, much higher than the quadrupole magnetic measurement errors, while the changes in the focusing quadrupoles were only ±0.5%, in agreement with the magnetic measurement errors.

In the next sections, the values of the focusing strength k of the 32 dipoles calculated from the magnetic measurements before the installation are compared with the k values fit with the beam based measurements (LOCO) taken after the storage ring commissioning. Afterwards, the agreement between the beta beating expected from the magnetic measurements and reconstructed with LOCO is discussed.

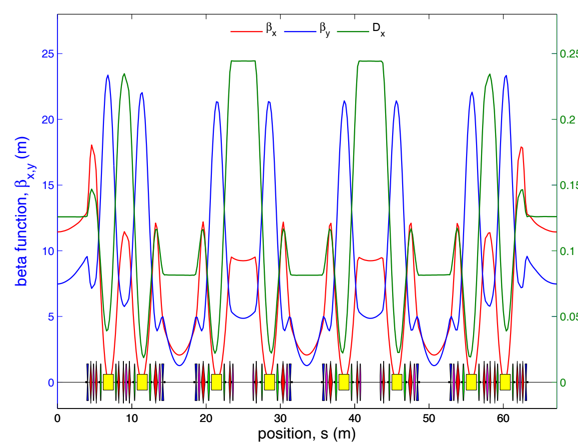

Figure 1: ALBA optical functions for one of the 4 superperiods.

DIPOLE MODEL

In the ALBA lattice model, the dipole was represented using the hard edge model approach: a single block of constant field and gradient embedded in two thin lenses that reproduce all the focusing effects in the edge region. In this model, a dipole is described by the bend angle α, the effective length L_{eff}, the entrance and exit pole face rotation angles and, in the case of combined dipoles, the focusing strength k.

Magnetic measurement model

The characteristics of each one of the 32 dipole magnets were measured with a Hall probe bench in the ALBA

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magnetic measurement laboratory [3]. The magnetic field was evaluated at the nominal field of 1.43 T calculating the multipolar coefficients in the magnet mid plane along the direction r perpendicular to the particle trajectory:

$$B(r) = B_0 + b_1 r + \frac{b_2}{2} r^2 + \frac{b_3}{3!} r^3 + ... \quad (1)$$

Using the gradient method, the different multipolar terms b_i were previously calculated by comparing the values of the magnetic field at each point in the nominal trajectory with those corresponding to the inner and outer adjacent trajectories. That is to say, a polynomial fit of the transversal dependency of the magnetic field was carried out for each value of the coordinate s.

$$\frac{d^i B}{dr^i} = b_i(s) \quad (2)$$

Afterwards, the terms b_i were integrated along the path of the electron in order to obtain the integrated multipoles:

$$\tilde{b}_i(s) = \int_0^s b_i(s) ds \quad (3)$$

The magnetic field B_y profile of the dipole was obtained along the nominal trajectory and compared with the gradient profile in the body to subtract the peak contribution from the edge focusing.

The parameters for the hard edge model are the bending angle of 11.25° perfomed by the nominal trajectory, the effective length L_{eff} estimated by taking the total field integral and dividing it by the field in the homogeneous region:

$$L_{eff} = \frac{\int_{-\infty}^{+\infty} B_y(s)\, ds}{B_0} \quad (4)$$

the focusing strength k estimated in the homogeneous region and the entrance and exit pole face rotation angle of the particle trajectories estimated from the peak contribution to the gradient profile in the edge region.

Table 1: Parameters of the Gradient Dipoles Based on the Magnetic Measurements. The maximum variation within the 32 dipoles is indicated for the parameters used in the model to calculate the beta beating due to the dipoles.

Parameter	Value	max variation
Length (m)	1.3837	±0.1%
Angle (°)	11.25	
Bend radius (m)	7.047	
Field (T)	1.4300	
Gradient (T/m)	5.685	
Energy (GeV)	3.0	
Strength k (1/m^2)	0.5680	±0.4%
Entry edge angle (°)	5.945	±5%
Exit edge angle (°)	5.945	±5%

The analysis was perfomed on each of the 32 dipoles and the mean value of each parameter was assumed for the lattice model. The beta beating due to the errors could be calculated introducing in the model the variations with respect to the mean of the focusing parameters. The parameters of the magnetic measurement model are summarised in Table 1.

Beam based measurement model

The parameters data used in this model are the same of the magnetic one, except the focusing strength k values obtained from LOCO [4]. This code is used at ALBA and at other synchrotron light sources as a calibration method of the magnet parameters [5, 6]. The LOCO analysis consists of fitting the beam position monitor (BPM) orbit response matrix of the model over the measured response matrix, that is, to reduce the χ^2 between the model results and the real results. The resulting lattice model is equivalent to the real machine lattice as seen by the BPMs and the dipole correctors.

Many parameters of the storage ring model are fit with LOCO, but the parameters describing the gradient bendings are only the 32 k values of each single dipole, while the effective lengths and the pole face rotations are not varied.

LOCO found a k value in the dipoles on average -0.22%, lower than the estimated with the magnetic measurements, and variations within the 32 dipoles in the range of ±0.3% (Table 2).

Table 2: Parameters of the Gradient Dipoles fit with LOCO.

Parameter	Value	max variation
Strength k (1/m^2)	0.5667	±0.3%

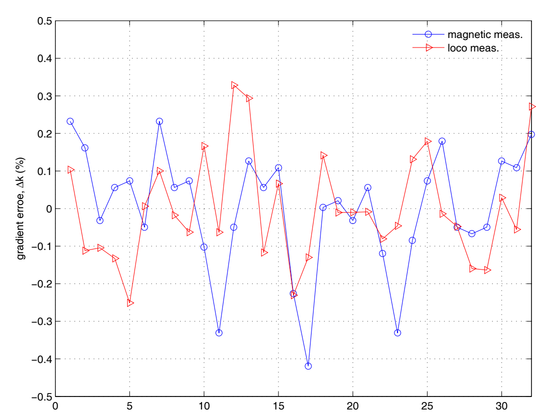

Figure 2: Comparison between the focusing strenght errors Δk for each dipole estimated from the magnetic measurements and from the beam based measurements.

Focusing strengths k comparison

Figure 2 shows the comparison between the focusing strength errors Δk for each dipole from magnetic and beam based measurements. There should be a certain degree of agreement between the two lines in the plot, but the Δk are of the same order of magnitude that the measurements precision, so that it is difficult to state if the two plotted distributions of Δk could be similar.

However, the agreement between the two models can be evaluated comparing the effect on the beta beating produced by those errors in the 32 dipoles as discussed in the next section.

BETA BEATING RESULTS

Introducing the k values of each single dipole in the model, the contribution to the beta beating due to the gradient dipoles was estimated with both the magnetic measurement model and the LOCO model. The effect on the horizontal plane is negligible, below 1%, because the horizonta beta function are minimum at the dipole locations. Hence, we focus the discussion on the vertical beta function.

Figure 3 shows the comparison of the vertical beta beating all along the ring expected from the magnetic measurements and recostructed with LOCO: the agreement in this plot is much more clear. The peak to peak beta beating value is $\pm 20\%$ in both models and the phase of the oscillations are also very similar. This means that the real machine reconstructed with the LOCO analysis is reasonably similar to the predicted by the model based on the Hall probe test bench measurements.

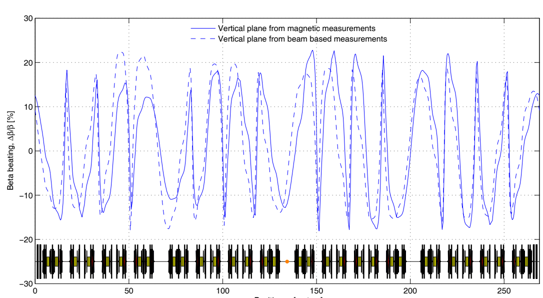

Figure 3: Vertical beta beating extimated introducing the Δk errors measured with the magnetic measurements and reconstructed with LOCO.

CONCLUSIONS

A comparison of the beta beating, i.e. the degree of lattice asymmetry, due to the dipoles in both magnetic and beam based measurements models has been carried out.

The introduction of a variation in the focusing strength, the effective length, the entrance and pole face rotation and the combination of all them affects the optical functions around the ring was considered.

The comparison of the mean focusing strength k values of the magnetic and beam based measurements showed a relative difference of 0.22%, maybe due to a small systematic error in the magnetic measurements. Even if this relative difference is within the technical specifications and the precision of the magnetic measurements, its effect was observed on the measured vertical tune Q_y, lower by 0.12 with respect to the expected one on the basis of the magnetic calibrations.

The vertical beta beating due to the dipoles resulted to be in the same range in both magnetic and beam based lattice models ($\pm 20\%$), which suggests that the model predicted by magnetic measurements was reasonably similar to that reconstructed through the beam orbit response matrix analysis. Moreover, the phases of this beta beating comparison are the same. This result shows that the errors introduced in the two model cases produce the same beta beating values and the Δk obtained with the LOCO analysis are the effective k values including the effect of L_{eff} and the strengths of the dipoles.

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REFERENCES

[1] M. Muñoz, D. Einfeld, "Optics for the ALBA Lattice", Proceedings of PAC2005, Knoxville, US.

[2] D. Einfeld et al., "Modelling of Gradient Bending Magnets for the Beam Dynamics Studies at ALBA", Proceedings of PAC2007, Albuquerque, US.

[3] J. Marcos, "Measurements of ALBA Storage Ring Bending Magnets using Hall probe bench: point-to-point vs on-the-fly measurements mode", ALBA internal note.

[4] X. Huang, J. Safranek, G. Portmann, "LOCO with constraints and improved fitting technique", ICFA Beam Dyn. Newslett. 44, 2007.

[5] G. Benedetti et al., "LOCO in the ALBA Storage Ring", Proceedings of IPAC2011, San Sebastián, Spain.

[6] G. Benedetti, J. Campmany, D. Einfeld, Z. Martí, M. Muñoz, "Beam Optics Measurements during ALBA Commissioning", Proceedings of IPAC2012, New Orleans, US.

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