14th International Particle Accelerator Conference,Venice, Italy JACoW Publishing
ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-WEPL003

ALBA-II FIRST TOLERANCE STUDIES

Z. Martí*, G. Benedetti, M. Carlà, U. Iriso
ALBA-CELLS Synchrotron, Cerdanyola del Vallès, Spain

Abstract

While the design of the ALBA-II is in progress, it is required to assess the consequences of realistic imperfections such as alignment tolerances and magnetic errors. Compensation of insertion device induced optics variation has been studied, and the tolerable random and systematic multipole levels is established. We demonstrate that non-linear optics is rather robust in the presence of realistic imperfections, rendering a ±6 mm dynamic aperture sufficient for off-axis injection and a large momentum acceptance that supplies more than 4 hour lifetime including errors. Moreover, studies in preceding low emittance light sources required simulating the full accelerator tuning, starting from the commissioning phase. To this end, the Simulated Commissioning (SC) toolbox has been used.

INTRODUCTION

While the ALBA-II lattice design is evolving [1] and since that latest version is still under development, we are presenting here the first feasibility tests of the last stable lattice version [2]. The effects of misalignment, magnetic errors, systematic and random multipoles, insertion devices are studied. The dynamical aperture (DA) and the lifetime are used as figures of merit. These simulations have been carried out using AT [3] Matlab® version. We have not included diagnostics nor calibration errors. The idea behind this choice is that after the commissioning phase all those errors should be mostly compensated. In addition that separates the problems and makes the overall calculations faster and simpler.

To asses the feasibility of the commissioning including also diagnostic and calibration errors the Simulated Commissioning toolbox (SC) has been used [4]. A series of pre-defined correction schemes are used: first turn (FT) orbit correction, turn by turn (TbT) beam based alignment (BBA), RF phase and frequency correction, closed orbit (CO) beam based alignment and LOCO [5].

ORBIT AND OPTICS CORRECTION SYSTEM

The ALBA-II tune will be around 43 and 15 units, in the horizontal and vertical plane respectively, and the ring has 16 arcs and 16 straight sections. Usually 2 beam position monitors (BPM) are needed to control position and angle at every straight. To sample well enough the optics 4 BPM per tune unit are usually considered. That sums up around 13 BPMs per cell. In this study up to 14 BPM per cell are considered, between sextupole pairs in the arcs and before and after the triplet in the straights (black dots in Fig. 1).

For the orbit corrector magnet (OCM), two possibilities are considered here: they are either simulated as thin elements exactly at the BPM location or sharing the yoke of sextupoles in the arc and quadrupoles in the straight. In the later case the best performance is achieved by using the first and third quadrupole in the triplet, even if the horizontal beta function gets really small at the third quadrupole.

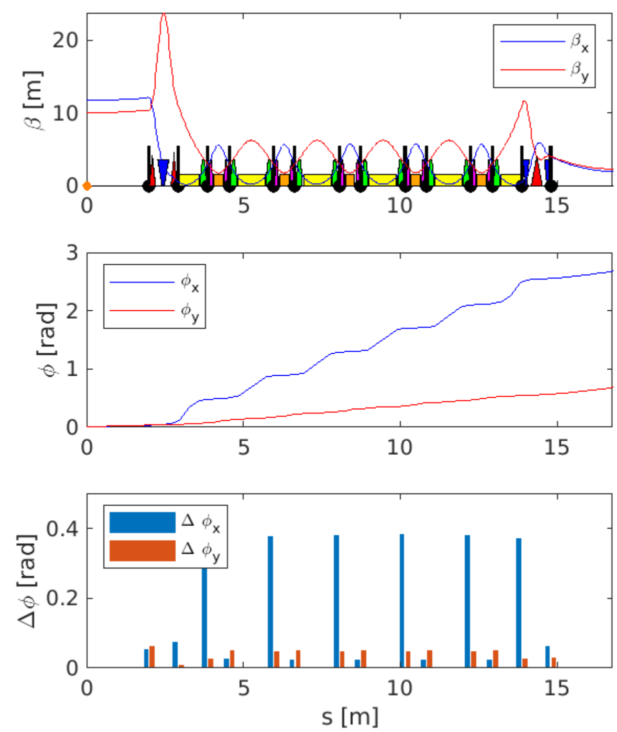

Figure 1: ALBA-II injection cell. In the upper plot, the beta functions are shown together with the lattice elements: the quadrupoles are blue and red, sextupoles green and magenta, dipoles yellow, anti-bends orange, BPM are black dots and thin OCM are vertical lines. The middle plot shows the phase advance in both planes and the lower plot the horizontal phase advance from BPM to BPM.

In order to test the proposed BPM and OCM layout, the orbit and optics correction is tested against a set of 100 random generated lattices with magnetic and alignment errors. the resulting breakdown of errors, after discussing with the magnets and alignment teams, is shown in Table 1.

The optics correction emulates a LOCO correction which is based on the orbit response matrix correction. In order to simplify the magnetic design of the combined function dipoles (the main dipoles and the anti-bends), each magnets will be powered by just one power supply. As a conse-

* zeus@cells.es

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-WEPL003

Table 1: Set of RMS tolerances assumed in the simulations. The alignment of the girder marks depends on the distance of each mark to the laser tracker. We assume that the alignment to the reference grid is done with just one laser tracker.

Quad strength	0.07%
magnets alignment	29 µm
girder alignment	15 µm + 6 µm/m × distance
alignment to reference grid	30 µm

quence the optics correction will produce an orbit distortion in the horizontal plane. This approach increases the overall horizontal plane OCM strength, but largely simplifies the magnetic design. We have noticed that this choice forces to correct the optics in steps, at each step a maximum of 50% of the optics correction can be applied. In total 236 normal quadrupole knobs are considered.

In this conditions, the number of BPM and OCM used meaningfully affect at the overall correction strength (see Fig. 2) but not the DA nor the lifetime. The case with 14 BPM does not follow the trend and we believe this is due to the fact that the phase varies very slightly between bending magnets, having two BPM and OCM there leads to an ineffective correction. In practice in order to extract light, the vacuum chambers will hardly be compatible with a BPM after the bending. For these reasons 9 BPM are selected, 4 before and after the straight section triplets and 5 in-between sextupole pairs before a bending magnet.

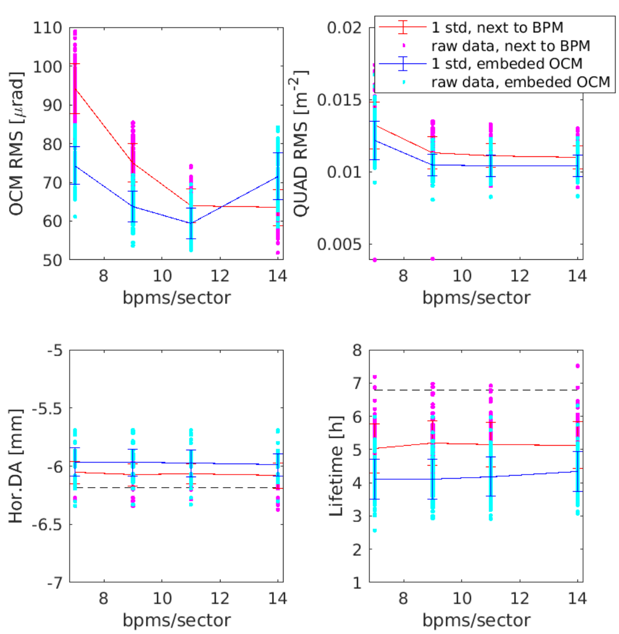

Figure 2: Mean Orbit and optics correction result for 100 different lattices with errors as a function of the number of BPMs and OCM used. Black dashed lines indicate the bare lattice value.

The skew quadrupole correction turns out to be quite relevant, without it the normal quadrupole correction is very inefficient. That could be related to the fact that the lattice working point is close to the coupling resonance. As can be appreciated in Fig. 3, above 10 skews per cell (more than one skew between bendings) there is no much gain. Again, that is consistent with the small phase advance between bending magnets.

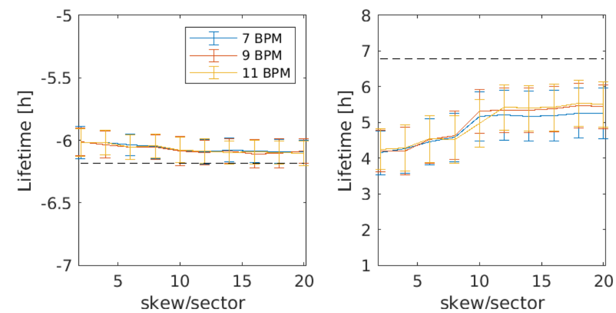

Figure 3: Mean lifetime and horizontal DA as a function of the number of skew per cell.

The girders mechanical design is under study and the last studies indicate that 3 or 5 girders per cell are optimum to achieve high resonant frequency and low deformation. We have checked that from the point of view of the required OCM strength, 3 or 5 girders is quite equivalent (see Fig. 4). Two different girder alignment strategies are compared: either each girder is aligned independently (standard girder alignment), or the laser tracker is placed in-between two girders aligning only the nearby marks of each girder (two girder alignment). Avoiding far away marks allows to get rid of the girder length dependence and would be our preferred girder alignment method.

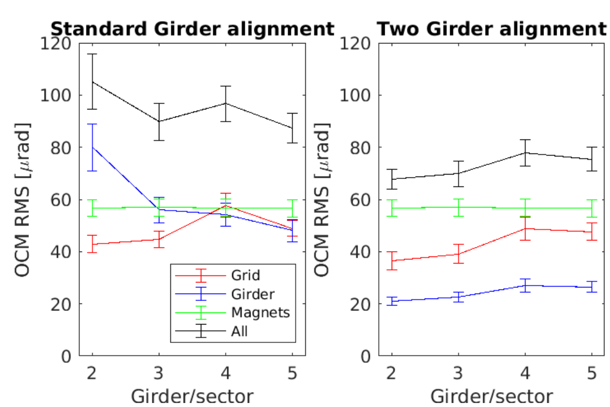

Figure 4: RMS OCM strength as a function of the number of girders. The lines in color represent the result only including one of the three misalignment components of Table 1 The black lines correspond to the result including all misalignment components.

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-WEPL003

MULTIPOLE EFFECTS

Both systematic and random multipole limits have been established in order not to reduce the lifetime and the DA by more than 5%. Since the DA is around 6 mm, that is also the assumed reference radius for the multipoles definition. In this simulations we include calculations up to the 10 th order.

To asses the random multipole tolerance, the maximum field at the reference radius is scaled from 0 to 3 mT. For each value of the maximum field, and for each magnet, that maximum field it is distributed among the different multipoles in 100 random lattices. As shown in Fig. 5 a field error below 1 mT ensures a reduction below 5%.

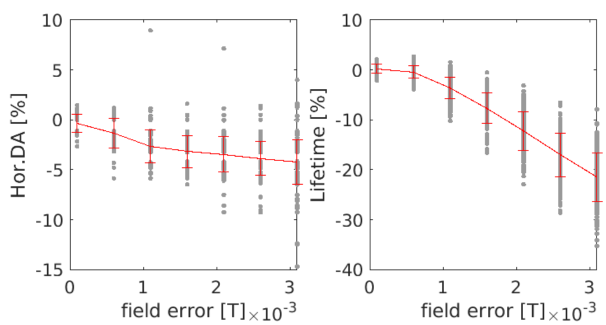

Figure 5: DA and lifetime reduction as a function of the field error at the reference radius in red lines. Raw data corresponding to 100 random cases are shown as gray dots.

Regarding the systematic multipoles, the 6-th and 10-th pole are allowed in the quadrupoles, the 9-th pole in the sextupoles and from the 3rd pole (sextupole) to the 10-th pole in the combined function bends, anti-bends and OCM. For ALBA-II that makes a total of 72 different possible systematic multipole components. In the case of the OCM, the multipoles are assumed to be proportional to the dipole setting and hence different for each family member. In this case the mean effect of 100 random distributions of orbit OCM settings is considered.

Two sets of limits are provided for the magnet design. A first set of limits is established by scaling each individual allowed multipole component until the 5% limit is reached. The values range from 10 to 700 relative units (normalized by the main multipole and multiplied by 10^4). That limit should be understood as a strict limit in the sense that in no case the magnets multipoles should be allowed to overcome it. A second set of limits is found by combining the 72 possible multipoles in a way that their effect on DA and lifetime is the worst possible. Then scaling all the terms with the same proportion until the 5% limit is reached. In this case the values range from 2 to 100 relative units. We consider that this more restrictive limit is not required to be met in all cases but should be used as a guide whenever possible. Once all the magnetic designs are completed their systematic multipoles effect should be recalculated.

INSERTION DEVICES

The main difference between the effect of IDs in ALBA-II with respect to the present machine is that the vertical beta function at the straight center is increased from 1.2 m to 2.2 m. That almost doubles the linear effects, still, the worst configuration of the variable gap IDs (3 IVU and 3 Apple-II) only produces a 0.01 vertical tune change and a 3% beta beating. That does not include the 3 additional wigglers that keep the gap constant during operation. Those IDs produce a very similar overall effect but can be corrected statically. According to simulations, even if the optics is not dynamically corrected, the DA and lifetime do not vary significantly once the alignment errors and the orbit correction described above are included.

COMMISSIONING SIMULATION

SC assumes the standard girder alignment, so it is a bit pessimistic compared to the previous simulations. The additional calibration and diagnostic tolerance considered are reported in Table 2. According to the simulations shown in Fig. 6, in the 97% of the cases we can reach a closed orbit. To achieve that, the TbT BBA turns out to be a key step. In the few cases where a closed orbit is not found, the problem comes from a poor TbT BBA or the RF adjustments (usually due to the RF phase and frequency too far away). In both cases, a more careful manual optimization could solve the problem. As shown in the beta beating results of that Fig. 6, at the end of the correction scheme, the optics errors do not depend on the BPM offset error.

Table 2: RMS Tolerances Assumed in the SC Simulations

Magnet calib.	0.02%	OCM calib.	5.0%
OCM limit	1 mrad	BPM calib.	5.0%
BPM Offsets	500 µm	BPM TbT noise	30 µm
BPM CO noise	1 µm	BPM roll	4 mrad
Circ. error	10^{-5}	RF frequency	100 Hz
RF voltage	0.1%	RF phase	$\pi/2$ rad

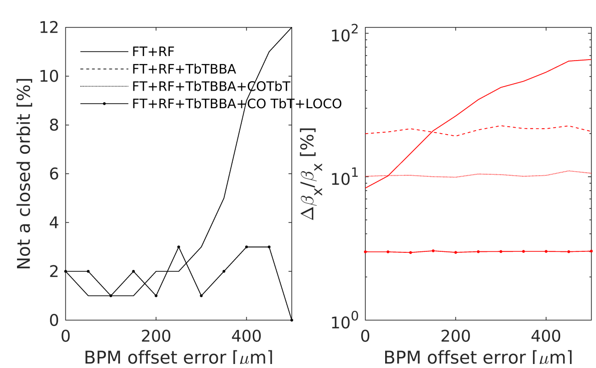

Figure 6: Simulated commissioning results as a function of the assumed BPM offset error. The data shown are extracted from 100 randomly generated lattices.

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-WEPL003

REFERENCES

[1] G. Benedetti, M. Carlà, U. Iriso, Z. Martí, and F. Pérez, "Progress on the 6BA lattice for ALBA-II", presented at IPAC'23, Venice, Italy, May 2023, paper WEPL001, this conference.

[2] G. Benedetti, M. Carlà, U. Iriso, Z. Martí, and F. Pérez, "A Distributed Sextupoles Lattice for the ALBA Low Emittance Upgrade", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 2762–2765. doi:10.18429/JACoW-IPAC2021-WEPAB074

[3] https://atcollab.github.io/at/index.html/.

[4] T. Hellert *et al.*, "Toolkit for simulated commissioning of storage-ring light sources and application to the advanced light source upgrade accumulator", *Phys. Rev. Accel. Beams*, vol. 24, p. 100702, 2019. doi:10.1103/PhysRevAccelBeams.22.100702

[5] X. Huang, J. Safranek, and G. Portmann, "LOCO with constraints and improved fitting technique", *ICFA Beam Dyn.Newslett.* vol. 44, pp. 60–69, 2007.