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PROGRESS ON THE 6BA LATTICE FOR ALBA-II

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Abstract

The ALBA-II upgrade lattice to a diffraction limited soft X-rays storage calls for an emittance smaller than 200 pm · rad in a 269 m circumference at an energy of 3 GeV. In this paper we report on progress of the 6BA lattice with distributed chromatic correction. This lattice relies on transverse gradient dipoles and reverse bends to suppress the emittance. Several modifications to the lattice presented in 2021 have been introduced in order to easy the injection with high horizontal beta function and a longer section for the septum magnet, make more efficient the chromaticity correction with the sextupoles and provide room for the orbit correctors in the straight sections. The optimisation of the dynamic aperture is still ongoing and the last performances of the linear and non-linear beam dynamics are presented in this paper.

INTRODUCTION

The result of the previous lattice studies for the ALBA upgrade was a ring composed of 16 six bend higher order achromat (6B-HOA) cells providing an emittance as low as 140 pm · rad at an energy of 3 GeV [1]. Such a lattice fitted the existing tunnel and preserved the positions of the insertion device beamlines. The non-linear dynamics was there optimised with only two families of chromatic sextupoles in the arcs. The orbit correctors were integrated in the arc sextupoles and in the matching quadrupoles of the straight sections. Errors studies performed on that first upgrade lattice have demonstrated that its non-linear optics was robust in the presence of realistic imperfections, rendering a dynamic aperture (DA) and momentum acceptance (MA) sufficient for off-axis injection and long lifetime including errors [2].

However, when the design of the magnets has started [3], it has became clear that the strong gradients of the matching quadrupoles made it unfeasible integrating orbit correctors in such a magnets. In addition, the injection straight section was only 4 metre long, making it very difficult avoiding interference between the septum and the first matching quadrupole. Eventually, the first vacuum engineering studies pointed out that the vertical aperture of the first sextupole of the cell, downstream the first dipole, was too narrow to allow the soft X-ray radiation from the undulators being extracted.

The consequence of including new constraints to optimise the linear beam dynamics was that the sextupole strengths were achieving the limit allowed by the magnetic design (5000 T/m^2 with an inner aperture of 24 mm) with a consequent reduction of the DA and no room to further optimise it. The solution has been found reconsidering an arrangement of the sextupole next to the anti-bend QF, more efficient in terms of sextupole strengths and already adopted in other HOA lattices, which however, for the short dimensions of the ALBA-II cell, provides a 20% larger emittance.

This new unit cell shows promising performances in terms of DA and lifetime and is currently under further development to be integrated with a matching cell with high beta functions to allow off-axis injection.

Table 1: 6B-HOA Lattice Main Parameters

Parameter	Value	Unit
Emittance	185	pm·rad
Energy	3	GeV
Circumference	268.8	m
Number of cells	16	
Straight length	4.0	m
Betas at straights	2.0, 1.6	m
Working point	45.15, 14.37	
Chromaticity	-89, -57	
Momentum compact factor	$1.0{\cdot}10^{-4}$	
Energy spread	$1.1{\cdot}10^{-3}$	
Energy loss per turn	1025	keV
Damping times	3.1, 5.2, 4.1	ms
RF voltage	2.4	MV
Bunch length (w/o HC)	6.8	ps

LATTICE EVOLUTION

The ALBA-II ring consists of 16 6B-HOA cells fully based on electromagnets [4] with beam energy of 3 GeV and circumference of 269 m. With respect to the last lattice version, in the straight sections the separation between magnets has been increased to make room for two pairs of independent orbit correctors, while in the arcs some spaces between magnets had to be increased to avoid coil-to-coil interference. In addition, the first vertical sextupole of each cell has been removed to facilitate radiation extraction, all the anti-bends QF have been split in two and the horizontal sextupoles rearranged and placed in between two half anti-bends (change from a SH-QF-SH to a QF-SH-QF sequence). The number of sextupoles in the new cell has been reduced from 20 (10 vertical SV and 10 horizontal SH) to 14 (9 SV plus 5 SH).

The resulting unit cell (Fig. 1) has a natural emittance of 185 pm · rad. The maximum quadrupole gradients are still below 100 T/m and the sextupoles are now kept below 5000 T/m^{-2}.

The proposed injection solution, based on a horizontal on-momentum off-axis scheme, will employ a novel pulsed multipole kicker currently under design [5] that will allow also on-axis injection for the ring commissioning. As in the previous baseline lattice, to enlarge the DA, higher beta functions are provided in the injection straight section. As a new

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feature, in this lattice the higher betas are obtained replacing the matching quadrupole triplet with a simpler doublet (Fig. 3) and the space cleared by the removed quadrupoles makes the injection straight section longer by around 20 cm, that is very useful to relax the field of the injection septum magnet.

The main parameters of the lattice are listed in Table 1.

BEAM DYNAMICS OPTIMISATION

The optimisation process has been broken down into several steps. Each step targets a different aspect, such as linear optics of the unit cell, injection cell and so on. However, each step is carried out in a similar fashion. The fitness of a candidate solution is evaluated through a scalar cost function which adds up with proper weights the contribution of the different metrics that need to be optimised at that particular step (e.g., emittance, DA, etc.). The optimisation is obtained by minimising such a cost function. Due to the non-linear nature of the problem, the minimisation requires the use of a robust algorithm, it was found that an evolutionary strategy algorithm was able to provide satisfactory results within a few days of run-time. More advanced techniques such as genetic algorithms (i.e., NSGA2) were also tried, but after an initial test the idea was abandoned due to the higher complexity that made the debugging of the optimisation process excessively complicated. The evaluation of the lattice parameters relies exclusively on the UFO code [6, 7], a GPU code developed in-house specifically to support the optics design process of ALBA-II. While this code is not particularly accurate, its speed allows to run the optimisation requiring only moderate hardware resources. In fact the entire optimisation was executed on a single machine equipped with one high-end GPU.

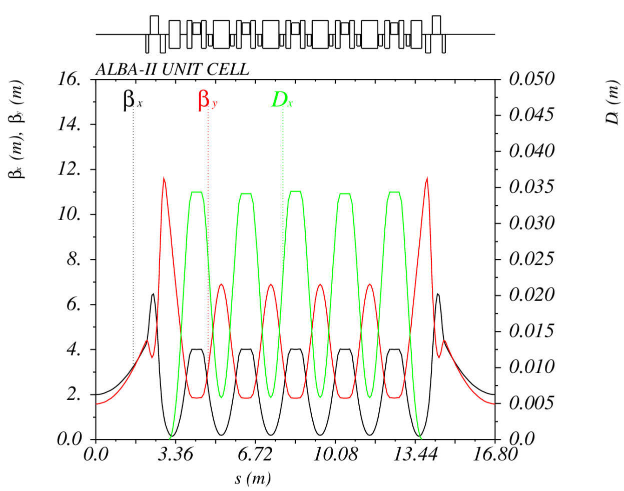
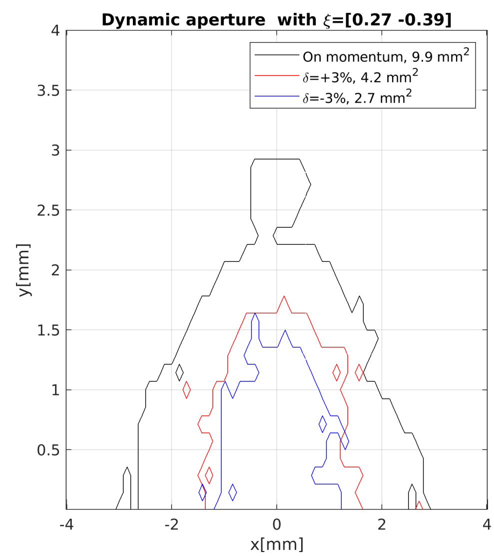


Figure 1: Unit cell with QF-SH-QF arrangement in the arc.

UNIT CELL LINEAR OPTICS

The first step aims to optimise the linear optics of the unit cell, the optimisation parameters include the magnets strength and the length of many elements. The cost function target mainly the minimization of the natural emittance and try to match the beta functions at 2 m at the insertion devices. To limit below the allowed maximum sextupolar strength required for chromaticity correction, a penalty proportional to the sextupolar strength excess is added to all those solutions which exhibits at least one sextupole above a given threshold. A similar approach is used to penalise solutions with momentum compaction factor below $1 \cdot 10^{-4}$. Figure 1 shows the linear optics functions for the obtained unit cell. The beta functions are focused to $\beta_x = 2.0$ m and $\beta_y = 1.6$ m in the straight sections for insertion devices. The resulting bending magnets field is 1.22 T combined with a maximum defocusing gradient of 26 T/m (the previous design was 1 T and 15 T/m). The anti-bend magnets have a 0.22 T field and a 70 T/m focusing gradient (it was 0.4 T and 70 T/m).



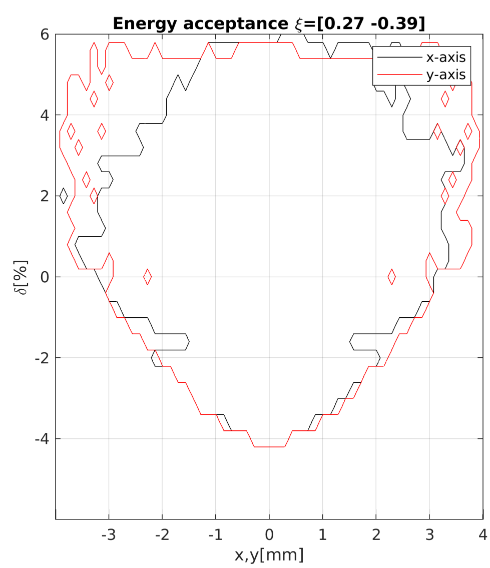


Figure 2: Dynamic and momentum apertures calculated at the insertion device straight section with low betas $\beta_x = 2.0$ m and $\beta_y = 1.6$ m, without errors.

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NON-LINEAR OPTICS PERFORMANCES

In this step, a ring made of 16 identical unit cells is considered. Each sextupole is assigned to a family resulting in 14 independent families. Each family is allowed to vary in the range 0 to 5000 T/m^2, while the linear optics is maintained fixed except for some minimal fluctuation in quadrupoles strength just to allow for same freedom of the working point. In this case the cost function is defined as a combination of on and off energy DA aiming to optimise off-axis injection and lifetime. Figure 2 shows the DA and MA for the best found solution. Subsequently an accurate Touschek beam lifetime estimation was obtained with the code Elegant (which was cross-checked with the Accelerator Toolbox code). For a total current of 300 mA in 448 bunches, it achieves a value of 0.8 hours for a coupling of 0.5% and 5.5 hours when considering a round beam as the one produced when operating the optics in full coupling [8, 9]. A substantial increase in lifetime above these values is to be expected from the longitudinal bunch stretching produced by the third harmonic RF system [10].

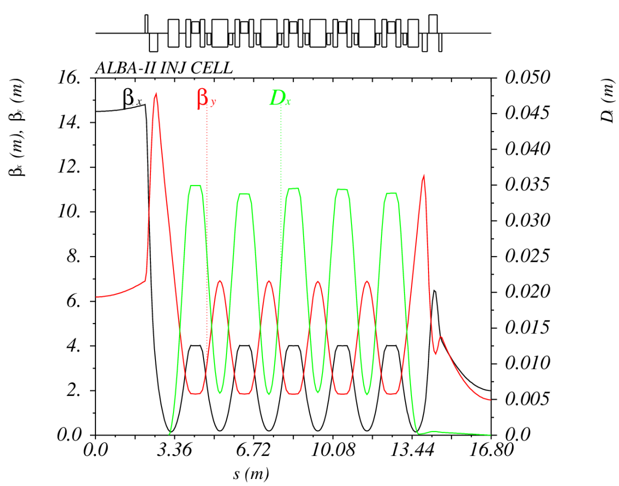

Figure 3: Injection cell with high betas in the injection section (on the left) where the triplet of quadrupoles is replaced by a simple doublet.

INJECTION CELL

While the simulated lifetime is considered satisfactory for operation, the DA provided by the unit cell is far from sufficient for off-axis injection. A horizontal dynamic aperture of 6 mm is required for the off-axis injection system under study for ALBA-II. To magnify the dynamic aperture at the injection point, a special cell with higher horizontal beta function is included ($\beta_x = 15$ m, $\beta_y = 4$ m, Fig. 3).

The modification of the phase advances due to the introduction of the injection cell results in a break down of the first order resonant driving term correction scheme. Therefore a last optimisation step is required to recover the performances of DA scaled with the high beta. In a first attempt the sextupoles of the two cells surrounding the injection section are decoupled from the ones of the unit cell introducing 14 new families. The optimisation, still in progress, is being carried out by varying the new sextupoles families in the range 0 to 5000 T/m^2, while the rest of the machine parameters are kept fixed.

CONCLUSION

The study to develop a ring based on a 6B-HOA cell is going to lead to a second version of the the ALBA-II baseline lattice that addresses many problems encountered in the process of mechanical integration of the accelerator design. The work we are still carrying out is mainly aimed at improving the DA to provide an efficient injection.

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