LOW HORIZONTAL BETA OPTICS FOR ALBA

G. Benedetti, Z. Martí, J. Campmany
ALBA-CELLS Synchrotron, Cerdanyola del Vallès, Barcelona, Spain

Abstract

The ALBA insertion device beamlines have horizontal and vertical rms electron beam size $\sigma_x = 130\ \mu$m and $\sigma_y = 5.5\ \mu$m. Protein crystallography beamlines (BL13-Xaloc) would benefit from a reduction of the horizontal beam size, to gain spatial resolution. A modified lattice with horizontal and vertical beam size of 75 and 9 μm has been setup and tested, breaking the ring symmetry, with different setting of the six quadrupoles at each side of the BL13 insertion device. Such configuration keeps the nominal emittance. The lattice settings have been tested with promising results for the beamline, but the broken symmetry and the present sextupole arrangement limited the lifetime, the injection efficiency and the maximum stored current. For this reason, the option of making a 4-fold symmetric low beta optics and increasing the number of sextupole families, to recover the original dynamic aperture and guarantee an optimum injection efficiency, has been studied and is proposed in this paper.

INTRODUCTION

The ALBA storage ring was commissioned in 2011 [1] and is now operating at the design working point (18.15, 8.36) with an emittance of 4.55 nm [2]. The design lattice has 12 medium straight sections (5 m long) where the insertion devices are located.

A modified optics with β_x reduced from 2.05 m to 0.85 m in one of the medium straight sections was studied and tested for the protein crystallography beamline BL13, which works in the range of 6-16 keV [3]. The beamline would benefit from a smaller σ_x to improve its horizontal resolution. With this purpose, we have designed a lattice with smaller effective emittance at the BL13 straight section, that compensates the decrease of photon flux due to larger σ'_x. In addition, since the beamline has little sensitivity in the vertical plane, it is not affected by an increase of σ_y, but benefits from a decrease of σ'_y.

One of the main problems, when introducing a local optics modification, is the breaking of the lattice symmetry, not only because of the stronger effect of the resonances, but also because the sextupoles are not powered individually but grouped in 9 families. For this reason, we decided to create a first low horizontal beta lattice breaking the symmetry in BL13. The introduction of a low beta section increases mainly the horizontal phase advance by $\Delta\phi_x = +0.20$, while $\Delta\phi_y = -0.05$. The original working point can be recovered with small distributed quadrupole changes in all the matching cells. This way, in the 1-fold low β_x lattice the tunes are kept as the present ones and the new optics can be tested and set up very easily with a smooth transition of the quadrupole settings from the nominal to the low beta lattice.

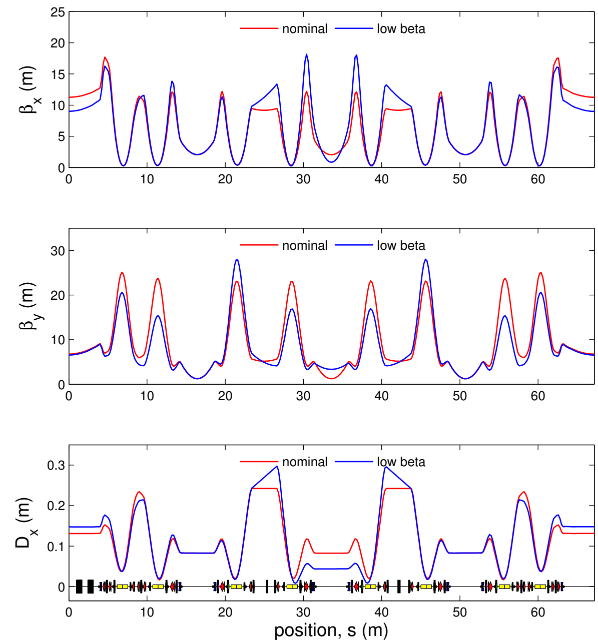

Figure 1: Change of the optics functions in one quarter of the ring. The low β_x medium straight section is located at the centre of the quadrant ($s = 33$ m). The other two medium straight sections ($s = 17$ m and $s = 51$ m) are unvaried.

A 4-fold low horizontal beta lattice with optimum dynamic aperture has been also studied to be proposed for a possible machine upgrade. In this case the nominal working point cannot be recovered with the matching cells and Q_x must be changed by more than half a unit. As a consequence this optics would require a longer commissioning since the beam cannot undergo a transition of the quadrupole settings from the present to the low beta. In this 4-fold option, the only hardware change is represented by the increase of the present 9 sextupole families that are split in 15.

LOW HORIZONTAL BETA OPTICS DESIGN

Three lattices for the low horizontal beta optics have been developed: one breaking the periodicity 4 of the ring and two fulfilling the four fold symmetry (respectively called 1-fold, 4-fold and 4-fold* in Table 1). The low β_x optics is designed by readjusting six quadrupoles, up and downstream of the BL13 medium straight section (Fig. 1). The optics in the adjacent medium straight sections is not varied, while the working point is adjusted using the quadrupoles of the matching cells. The natural emittance of the modified

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Table 1: Comparison of the main optics parameters at BL13 of the low β_x lattice solutions with respect to the nominal design. The coupling is assumed to be 0.5%.

Lattice	β_x (m)	β_y (m)	D_x (m)	σ_x (μm)	σ_y (μm)	$\epsilon_x^{\mathrm{eff}}$ (nm)	ϵ_x (nm)	(Q_x, Q_y)
Nominal	2.05	1.20	0.083	130	5.5	6.10	4.55	(18.15, 8.36)
1-fold	0.85	3.70	0.040	75	9.0	5.45	4.45	(18.15, 8.36)
4-fold	0.85	3.30	0.045	77	8.5	5.55	4.45	(18.84, 8.36)
4-fold*	0.95	3.70	0.050	80	8.5	5.20	3.95	(19.15, 8.36)

lattices is decreased to 4.45 nm and 3.95 nm, while the effective emittance at BL13, $\epsilon_{x,\mathrm{eff}}^2 = \epsilon_x^2 + \mathcal{H}_x \epsilon_x \sigma_e^2$, is reduced by 10-15% with respect to the present value as it is shown in Fig. 2.

To preserve the 4-fold symmetry, the local low beta optics can be repeated in one medium straight section in each quadrant. In this case the tune change is four times larger and the design working point cannot be readjusted with the matching cells. Two candidate lattices with higher Q_x have been developed, considering that the best values for the injection are with a horizontal fractional tune in the ranges [0.12, 0.24] and [0.76, 0.88]. The parameters are similar except the working point that is (18.85, 8.36) and (19.15, 8.36) respectively.

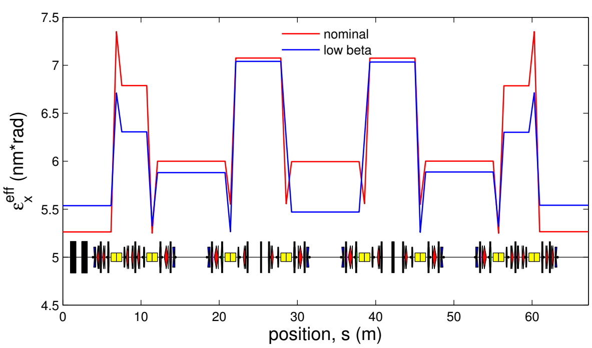

Figure 2: Effective emittance of the 1-fold low β_x lattice (blue line) compared with the nominal lattice (red line). In the low β_x lattice the effective emittance in BL13 (s = 33 m) is lower than in the other two lateral medium straight sections (s = 17 m and s = 51 m).

NON LINEAR BEAM DYNAMICS

Sextupole families settings were calculated both for the 1-fold lattice (9 families), and the 4-fold and 4-fold* versions (15 families). In the first case, several single core simplex downhill dynamic aperture (off and on momentum included) optimization were performed. Recently an ESRF-like approach [4] has been implemented at ALBA on our new 216 cores cluster. Similarly to ESRF the genetic algorithm NSGA-II Matlab implementation [5] has been used to optimize the sextupole settings in the 4-fold 15 families case. For both lattices, on and off momentum, "number of turns" (NoT) are used as objective functions (±3% and on energy). The NoT are the total number of turns successfully tracked for a set of starting points, which may consist in a rectangular or cylindrical mesh. Usually the objective function is constructed so that the central tracked points have up to two times more weight in the NoT sum.

In all the cases, the chromaticity has been constrained to (+1, +1). That constrains the solution space in two degrees of freedom less by means of a linear transformation that is calculated for every lattice before the optimization.

1-fold Low β_x Lattice

In this case the NoT for the three different energies are averaged to construct a single objective function to be used with the simplex downhill algorithm.

Figure 3 shows the frequency map for the optimum solution. The calculated dynamic aperture, without errors nor coupling, is about 16 mm in the horizontal plane and 5 mm in the vertical one, leaving no room for sextupole adjustments to increase the chromaticity.

4-fold Low β_x Lattice*

In the second case, the three objective functions are considered. Figure 4 shows the frequency map for the optimum solution. The improvement due to the symmetry is very clear. The calculated dynamic aperture, without errors nor coupling, is enlarged to about 25 mm in the horizontal plane and 10 mm in the vertical one.

Our final goal is to implement the Touschek lifetime and the injection efficiency objective functions for the optimization, however, taking into account on and off energy tracking is enough for our case since we are not very dynamic aperture limited.

EXPERIMENTAL TESTS

The 1-fold low β_x lattice obtained with a local optics adjustment at BL13 was tested with beam. The quadrupole and sextupole settings were varied from the present values to the new ones in small steps allowing the beam to survive during the transition. The beta beating was corrected to 1% with the standard orbit response matrix analysis. Despite the higher vertical beta function, during the injection no losses were observed at the BL13 location. The dynamic aperture allowed to inject with good efficiency only at low chromaticity (+1, +1), achieving a maximum stored current of 60 mA. To increase the intensity, higher vertical chromaticity was needed, but the stronger sextupole settings did not allowed

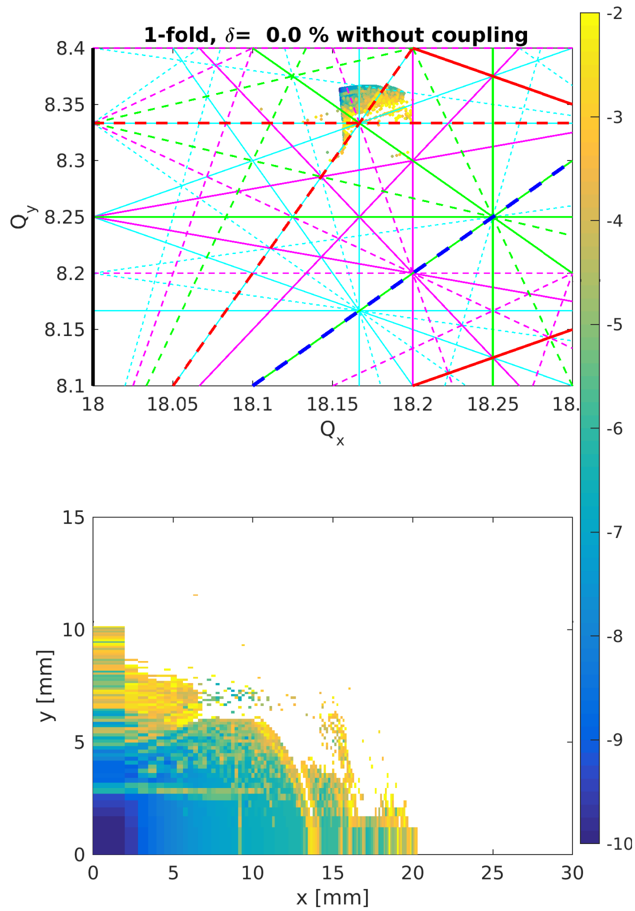

Figure 3: Simulated frequency map for the optimized 1-fold lattice (9 sextupole families single core simplex optimization). Calculations are on energy and without errors.

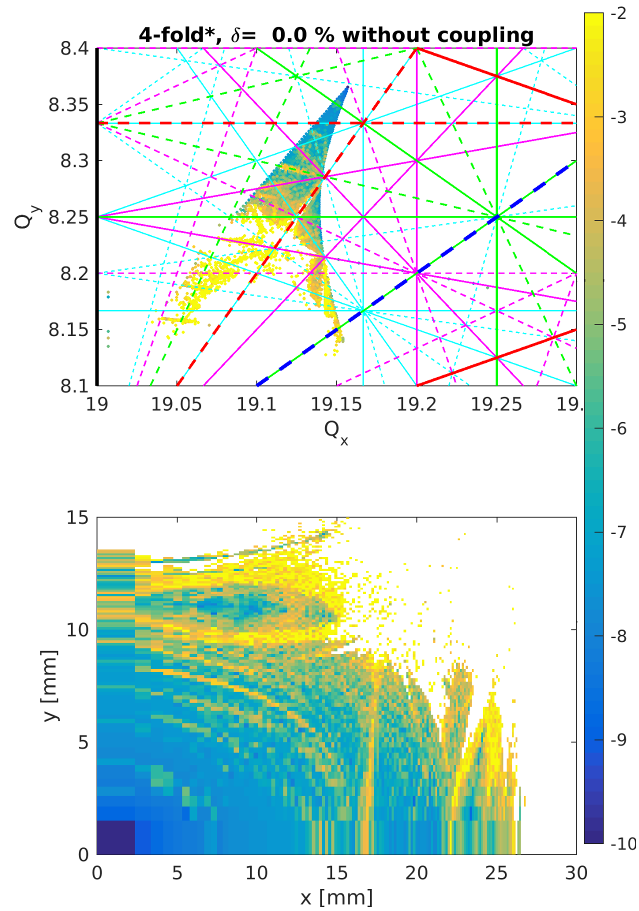

Figure 4: Simulated frequency map for the optimized 4-fold* lattice (15 sextupole families cluster NGPM optimization). Calculations are on energy and without errors.

to inject into the storage ring. The measured beam lifetime was reduced a factor two with respect to the nominal one.

A test with the beamline scientists was performed. The first results are indicating that the measured horizontal photon beam size is reduced following the expectations without any apparent decrease of the flux at the sample.

CONCLUSIONS

An optics with a horizontal beta function in one of the ALBA medium straight sections where an undulator for crystallography beamline is located has been studied and tested. The present sextupole arrangement in 9 families does not allow to efficiently correct the non-linear beam dynamics. A test with the beamline scientists was successfully performed, however the beam lifetime was reduced to 50% and the small dynamic aperture at higher chromaticity allowed to achieved only a stored current of 60 mA. These limitations could be solved by extending the local optics variation in a symmetric way in order to recover the 4-fold original symmetry of the lattice. The present 9 sextupole families should be split in 15. Dynamic aperture optimization performed with genetic algorithms indicated that a 4-fold lattice with 15 sextupoles would not affect the present lifetime and injection efficiency performances. In addition, a larger number of sextupole families will improve the flexibility of the lattice for possible future lattice upgrades and new modes of operation.

REFERENCES

[1] D.Einfeld *et al.*, "ALBA Synchrotron Light Source Commissioning", in *Proc. IPAC'11*, San Sebastián, Spain, Sep. 2011.

[2] G.Benedetti *et al.*, "Beam Optics Measurements during ALBA Commissioning", in *Proc. IPAC'12*, New Orleans, LO, USA, May 2012.

[3] J.Juanhuix *et al.*, "Development in Optics and Performance at BL13-Xaloc, the macromolecular crystallography beamline at the Alba Synchrotron", J. Synchrotron Rad. (2014). 21, p. 679-689.

[4] S.Liuzzo, "Quick dynamic aperture, lifetime and injection efficiency computations for the ESRF upgrade lattice optimization", CAoPAC Workshop, 11-13 March 2015. `https://indico.cern.ch/event/333414/contributions/775637/`

[5] L.Song, "NGPM a NSGA-II Program in Matlab", version 1.4, 2011.