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ALBA II ACCELERATOR UPGRADE PROJECT

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Abstract

ALBA is working on the upgrade project that shall transform the actual storage ring, in operation since 2012, into a 4th generation light source, in which the soft X-rays part of the spectrum shall be diffraction limited. The project has been officially launched in 2021 and a White Paper presenting the main concepts of the upgrade will be published in 2022. The storage ring upgrade is based on a 6BA lattice which has to comply with several constraints imposed by the decision of maintaining the same circumference (269 m), the same number of cells (16), the same beam energy (3 GeV), and as many of the source points as possible unperturbed. The lattice optimization has achieved an emittance of 140 pm rad, which is a factor 30 smaller than that of the existing ring, but with a cells compactness that presents technological challenges for the magnets, vacuum, diagnostics, RF systems and injection elements designs that are being investigated through an intensive R&D program.

INTRODUCTION

The main goal of the accelerator upgrade for ALBA II is the transformation of ALBA into a diffraction limited storage ring, which implies the reduction of the emittance by at least a factor of twenty.

The upgrade has been conceived as a cost and time effective process, to be realized before the end of the decade and profiting at maximum from the existing infrastructures, in particular the building which is now hosting the facility. It has been decided that the storage ring (SR) upgrade will be done without any major modification of the shielding tunnel. Furthermore, the requirement of maintaining the Insertion Devices (IDs) as close as possible to their present position will preserve them operative for ALBA II and will imply minor modifications to the beamlines.

Another important decision has been the determination of the beam energy of ALBA II, which will be maintained at 3GeV, after having considered several factors. First, the circumference of the SR is constrained to be about 270 m in order to reuse the tunnel; and since we want to preserve also the IDs position, a sixteen-cell geometry is imposed. With these constraints the length of the arcs is too short for obtaining a substantial reduction of the beam emittance at higher beam energies, also considering that the emittance scales with the square of the energy. Another consideration is related to the injector: increasing the energy of the SR would require replacing the whole booster, which increases the cost of the project and lengthens its realization.

LATTICE

In order to fit these goals and constrains, an extremely optimized lattice design based on a six bend achromat (6BA) has been conceived [1], whose main parameters are listed and compared with the ones from ALBA in Table 1.

Table 1: List of ALBA and ALBA II Parameters

Parameter	ALBA	ALBA II
Emittance, pm rad	4600	140
Circumference, m	268.8	268.8
Energy, GeV	3.0	3.0
Number of Cells	16	16
Number of straights	4 / 12 / 8	16
Straight ratio, %	36	24
Tunes (hor, ver)	(18.16, 8.36)	(43.68, 11.67)
Mom. Comp. Factor	8.9e-4	0.8e-4
Beam current, mA	250	300
Energy loss/turn, keV	1023	845
Nat. bunch length, ps	15	6

The choice of a 6BA is the result of an optimization work, performed with a tracking code developed on purpose [2], aiming to balance the demand for both, a low emittance and a large as possible dynamic aperture and momentum acceptance, maintaining a limit to the maximum quadrupolar and sextupolar fieds in the magnets; together with the geometrical constrains due to the available space, and the fixed position of the insertion devices.

The new 6BA optics allows for a reduction of the horizontal natural emittance by about a factor 30, while keeping the current ALBA cell length. The overall ring symmetry is preserved: the lattice is composed by 16 cells organized in 4 quadrants.

All arcs have the same low-emittance lattice, but four straight sections have high-betas, see Figure 1. One of them is required for the injection, two more are for RF cavities and one is available for an ID.

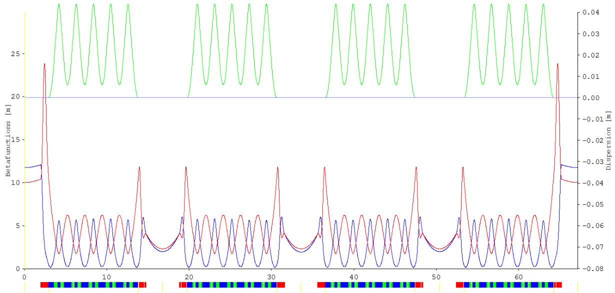

Figure 1: Dispersion (top) and β-functions (bottom) along a quadrant of the 6BA ALBA-II lattice.

Nowadays we are working on the optimization of the high-beta sections by replacing the quadrupole triplet by a doublet, so that more space shall be available for the injection elements and for the RF cavities.

Full Coupling Operation

Lifetime is expected to be dominated by the Touschek scattering due to the small emittance, in particular the vertical emittance is foreseen to be of the order of only a few pm rad.

To limit beam losses and increase lifetime, a solution under investigation consists on leaking part of the horizontal emittance on to the vertical plane by exploiting the coupling resonances. By matching the horizontal and vertical tune is thus possible to obtain full coupling with an effective horizontal and vertical emittance of 90 pm rad; improving substantially the lifetime, and allowing almost round beam at the ID positions, where both beta functions are very similar. Studies at ALBA are being carried out to assess its viability [3].

MAGNETS

Up to nine different types of magnets are needed to fulfil the requirements imposed by the 6BA lattice. In total, ALBA II will be equipped with 592 individual magnets, whose main parameters are listed in Table 2.

Table 2: Characteristics of the Different Types of Magnets for ALBA II Storage Ring

Magnet description	Types	Length [m]	Field [T]	Gradient [T/m]	Gradient [T/m2]
Bending with transversal gradient	QD	0.867	1.009	-15.41	
	QDS	0.631	0.819	2.03	
Antibending with transversal gradient	QF	0.297	-0.394	70.05	
	QFS	0.297	-0.425	70.05	
Quadrupoles	Q1	0.200		-31.54	
	Q2	0.350		83.16	
	Q3	0.200		-109.83	
Quadrupoles (injection)	IQ1	0.200		89.71	
	IQ2	0.350		-69.61	
	IQ3	0.200		44.70	
Sextupoles	SH	0.297			4936
	SV	0.631			-4084

As a baseline all the magnets are considered electromagnets since, due to the compactness of the ALBA II lattice and, for a proper lattice and orbit correction, it is required to have all of them tuneable.

However, since the upgrade it is not foreseen until 2029, a R&D program has been started [4] in order to investigate the possible options for implementing permanent magnets (PM) into the ALBA II magnets, either with full PM design, or in hybrid configuration: with PM and coils for tuneability, see Figure 2.

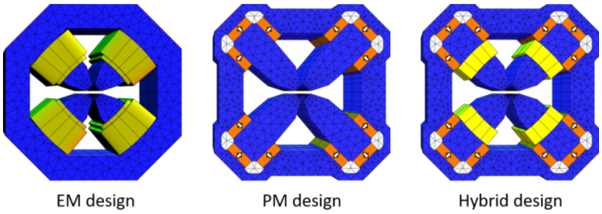
EM design PM design Hybrid design

Figure 2: Technological choices for the magnets depending on the source of the magnetic flux: electromagnets (EM), pure permanent magnets (PM) or hybrid designs.

VACUUM SYSTEM

Initial considerations assume that the smallest magnet aperture is 20 mm. In order to leave space for the magnets and chambers tolerances and drifts, a clearance of 1 mm between chamber wall and the magnets yokes is foreseen. Assuming 1 mm chamber wall thickness, the effective inner diameter of the vacuum chamber is about 16 mm.

Preliminary vacuum chamber layout shows that the tightest segments are the intersection between QD dipoles where there are four sextupoles and the anti-bending magnet. These intersections spaces will not allow for lumped pumps or many chamber size transitions, being the longest and smaller vacuum chamber segment.

So, NEG coated vacuum chambers is a must to ensure proper pressure level. We consider that the chambers will be coated all along the ring, with possible small (75 l/s) lumped pumps at bending magnet antechambers.

Simulations with the Synrad+ and Molflow+ [5] have been done with NEG coating yield at the irradiated surface and a sticking factor at the rest, assuming a negligible thermal desorption with this treatment. The results are shown in Figure 3, where the vacuum profile is computed considering a global sticking coefficient of 0.01, and considering 100 Ah of conditioning. In these conditions, an average pressure of about 1e-9 mbar will be achieved for 300 mA.

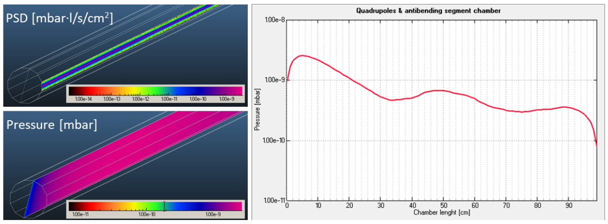

Figure 3: Left: Molflow+ PSD Desorption map and Dynamic pressure map. Right: Pressure profile (with NEG).

RF SYSTEM

The main RF system of ALBA will be reused for ALBA II, since its operation parameters will be very similar. The nominal frequency will be kept at 500 MHz.

In the case of ALBA II the use of a 3rd harmonic system (3HS) is mandatory for increasing the bunch length in order to meet the lifetime specifications and to reduce the Intra Beam Scattering transverse blow-up. For this purpose, a RF system operating at 1.5 GHz will be installed in ALBA II. A prototype of the 3rd harmonic cavity has been designed and prototyped by ALBA [6], and it's being tested in collaboration with DESY and HZB [7].

In summary, ALBA II will have six cavities working at the fundamental frequency of 500 MHz, and four 3rd harmonic cavities at 1.5 GHz. Both will be active normal conducting HOM damped cavities. Table 3 shows the main parameters of both systems.

Table 3: Main RF Parameters for the ALBA II Storage Ring

Parameter	Fundamental RF system	3rd Harmonic RF system	Unit]
Frequency	500	1,500	MHz
Cavity Voltage	500	200	kV
Number of cavities	6	4	-
Coupling factor	2.4	0.53	-
Shunt Impedance	3.3	1.2	MOhm
Quality factor	29500	14000	-
Synchronous phase	159	-7.5	degrees
Bunch lengthening	-	2.55	-
Transmitter power	95	9	kW
Power to beam	54	-8	kW

The bunch lengthening expected with this double RF system is estimated to be 2.55, with a lifetime larger than 4 hours for a 300 mA beam current in multi-bunch mode.

INJECTION SYSTEM

The existing ALBA booster, thanks to its large circumference, delivers a beam emittance as small as 9 nmrad, already suitable for the injection into the upgraded storage ring.

Injection into the new storage ring will be more difficult compared to the existing ring, mainly due to the strong reduction of the horizontal dynamic aperture and the reduced injection straight length to 4 m.

The best scheme that fulfills these conditions is injecting with a single fast pulsed multipole kicker magnet installed in the same straight section as the septum magnet. The multipole kicker under study for ALBA II is a novel design, called Double Dipole Kicker (DDK), where 8 conductor rods are arranged in order to produce a sextupole-like behaviour around the center, resulting in zero field at the stored beam position and a field peak at the injected beam position [8].

Such topology presents the advantage that allows producing almost pure dipole field when only 4 out 8 rods are powered, so that it can be used for on-axis injection during the commissioning.

PHOTON SOURCES

One of the aims of the ALBA II upgrade project is to keep all the Insertion Device (ID) beamlines already installed or currently under design at their present locations. Therefore, on day one ALBA II will make use of the current set of IDs.

From the point of view of the photon delivery performance, the existing IDs will benefit from the foreseen 30-fold decrease of the electron beam emittance. Figure 4 shows a comparison between the spectral brilliance calculated for the undulator-type IDs in the present and the upgraded machines. It can be seen that the expected brilliance increase will depend strongly on the photon beam energy: from a factor 6 at 100 eV, passing through a factor 13 at 1 keV, and up to a factor 20 at 10 keV.

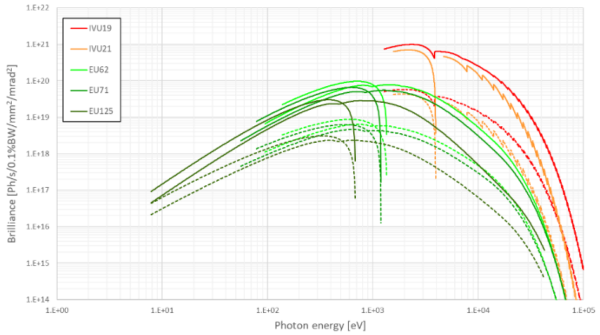

Figure 4: Comparison of the spectral brilliance for undulator-type ID sources operating in the present ALBA (dashed lines), and in the upgraded ALBA II (solid lines) storage ring.

In a similar way, the change in the transverse coherent fraction, which measures how close the source is to the diffraction limit, is shown in Figure 5. Calculations have been performed with SPECTRA [9] within Gaussian approximation.

The improvement in the coherent fraction will range from a factor 2 at low energy up to a factor 30 at high energies.

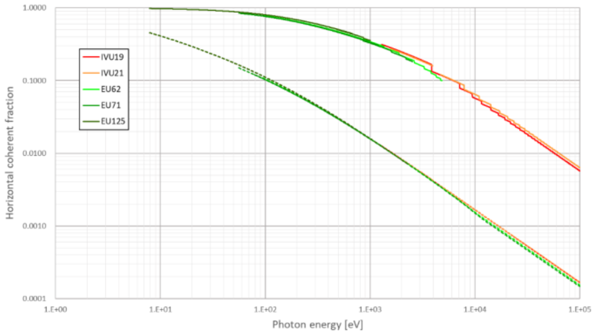

Figure 5: Horizontal coherent fraction, for the present storage ring (dashed lines) and for the upgraded ALBA II (solid lines).

In the case of wiggler-type IDs, the gain in brilliance is smaller, and strongly dependent on the effective source size as determined by the amplitude of the electron beam oscillations inside the device.

CONCLUSION

Upgrading ALBA to an ultra-low emittance, 4th generation, light source ALBA II is feasible, while maintaining the same tunnel, the same injector, and the same insertion devices source points as of today, reaching a factor 30 reduction of emittance, down to 140 pm rad.

REFERENCES

[1] 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`

[2] M. Carlà, "UFO, a GPU Code Tailored Toward MBA Lattice Optimization", presented at IPAC'22, Bangkok, Thailand, Jun. 2022, paper WEPOMS043, this conference.

[3] Z. Martí, G. Benedetti, M. Carlà, U. Iriso, and L. Torino, "Full Coupling Studies for ALBA-II", presented at IPAC'22, Bangkok, Thailand, Jun. 2022, paper WEOZSP4, this conference.

[4] "Development of Advanced Technologies for ALBA II", Ministerio de Ciencia y Tecnología, fondos del Mecanismo de Recuperación y Resiliencia, financiado por la Union Europea. NextGenerationEU#.

[5] R. Kersevan and M. Ady, "Recent Developments of Monte-Carlo Codes Molflow+ and Synrad+", in Proc. IPAC'19, Melbourne, Australia, May 2019, pp. 1327-1330. `doi:10.18429/JACoW-IPAC2019-TUPMP037`

[6] J. R. Ocampo, J. M. Alvarez, B. Bravo, F. Perez, A. Salom, and P. Solans, "Prototype Fabrication of an Active Normal Conducting Third Harmonic Cavity for the ALBA Storage Ring", presented at IPAC'22, Bangkok, Thailand, Jun. 2022, paper TUPOMS051, this conference.

[7] F. Perez et al., "3HC - 3rd Harmonic Normal Conducting Active Cavity Collaboration Between HZB, DESY and ALBA", presented at IPAC'22, Bangkok, Thailand, Jun. 2022, paper TUPOMS028, this conference.

[8] G. Benedetti, M. Carlà, and M. Pont, "A Double Dipole Kicker for Off and On-Axis Injection for ALBA-II", presented at IPAC'22, Bangkok, Thailand, Jun. 2022, paper THPOPT047, this conference.

[9] T. Tanaka, and H. Kitamura, "SPECTRA: a synchrotron radiation calculation code", J. Synchrotron Rad. (2001), 8, 1221-1228.