MBA studies for the ALBA upgrade

G. Benedetti on behalf of:
M. Carlà, Z. Martí, G. Benedetti

8th LER Workshop – 26-30 October 2020
• The current ALBA lattice
• First study (2019): a dispersion bump H7BA cell for ALBA
• Second study (2020): an extensive search for a distributed sextupoles MBA cell
• A preliminary look at the magnets (preliminary)
Present ALBA Storage Ring Lattice

- Energy = 3 GeV
- Circumference = 268 m
- Symmetry = 4 fold

- 8+8 DBA-like cells, 17 m long

Straight sections:
- 12 medium straights (4.0 m)
- 4 long straights (7.8 m)
- 8 short straights (2.3 m)
Current ALBA lattice

One quarter of the storage ring lattice:

- Matching
- Unit
- Matching

Circumference 268 m, energy 3 GeV, emittance 4.6 nm·rad
• What is the ideal **number of bends**?

• Chromaticity correction:
  
  – Double **dispersion bump** (ESRF-EBS)
  
  – **Distributed sextupoles** (MAX-IV)
  
  – **Bump-less** with a couple small bore **super-strong sextupoles**
  
  – **Exotic ideas:**
    
    • Vertical dispersion to **easy vertical chromaticity correction**
    • Moebius-strip to **avoid vertical chromaticity correction**

**Given all the technological constrains, which is the best solution for an upgrade?**
• Energy = 3 GeV, C = 528 m, $\varepsilon_x = 328$ pm·rad
• 20 7BA cells, 26 m long $\rightarrow$ 20 straights: 4.6 m
- Energy=6 GeV, C=844 m, $\varepsilon_x=134$ pm·rad
- 32 Hybrid 7BA cells, 26 m long

- Large dispersion for chromatic sextupoles
- Only 2 sext families with phase advance = $\pi$ ("$\pi$ trick")
- **longitudinal gradient dipoles**
- Long and strong dipoles are used to create dispersion bumps:
  - Emittance is mostly driven by those dipoles
  - Bumps take up a significant space
Specific constraints for ALBA

- Keep beam energy 3 GeV
- Tunnel (SR with similar compact circumference)
- Existing ID beamlines (preserve 16 cells and source points)
- Straight sections longer than 4 m, $\beta_x = \beta_y = 1-1.5$ m
- Reduce emittance at least by a factor 10
- Keep injector (present $\varepsilon_x^{\text{booster}} = 10 \text{ nm} \cdot \text{rad}$)
- Keep infrastructures, as much as possible
Following SOLEIL’s IPAC2018 example, in 2019 we started testing a H7BA cell:

8 unit + 8 matching cells → 12 medium straights 4.0 m + 4 long straights 7.8 m

16 hybrid 7BA with anti-bend identical cells → 16 straights 4.35 m

7 transversal gradient BENDS (no longitudinal gradient)
6 focussing QUADS (< 90 T/m)
2 ANTI-BENDS: knob to minimise dispersion in BEND 2 and 6
3 families of paired SEXT with “π trick” (<2000 T/m²)
“First study for an upgrade of the ALBA lattice”, IPAC 2019

ε_x = 160 pm·rad **without longitudinal gradient in bending magnets**
(with longitudinal gradient ε_x = 140 pm·rad)
The 3 sextupole strengths were found with MOGA to optimise lifetime, DA and MA.

Dynamic aperture quite small and momentum aperture even much smaller.
Over the source points of the present 12 Medium Straight Sections:
- 8 would be preserved
- 4 radially shifted by 68 mm

The present 4 Long Straight Sections (currently not used yet for BLs):
- All radially shifted by 240 mm

Any other layout based on 16 identical cells gives very similar shifts for the BLs source points.
A compact cell with double dispersion bump (H7BA) for ALBA gives small dynamic and momentum aperture:

... is there any better solution for ALBA?

In February 2020 we covered a new position only dedicated to the ALBA upgrade studies and we have restarted the quest for the best lattice solution.
The FODO is made of **quadrupoles combined with dipole and reverse dipole**
- The reverse dipole decrease the emittance by a factor 2
- Many small sextupoles are introduced in the FODO
- An exhaustive search is required to test all the possible configurations (number of bends, maximum gradient strength...)

\[ \beta_x = \beta_y = 1 \text{ m} \]
• Lattices are generated from a set of parameters: magnet length, strength... and constraints: maximum fields, gradients...
• Parameters are randomly sampled to generate lattices
• A lightweight optics solver (a simplified lattice code written in house) selects the best solutions
• Final solutions are checked against MAD-X and Elegant

Optimization was run for different **number of bends**: 6BA → 11BA and for different sets of constraints (max quad and sext gradients)
Distributed sextupoles solutions

We run the optimiser for two values of the maximum quad gradient and looking for emittance below 200 pm·rad:

- 100 T/m (blue), aperture 20 mm (state of the art of current lattice upgrades)
- 200 T/m (red), aperture 10 mm

- Each point is the best out of 5 seeds
- Each curve represents a different max sextupole strength
- For 100 T/m quad gradient: best solution would be a 7BA with $\varepsilon_x = 75$ pm·rad
- For 10 m$^{-2}$ quad strength (100 T/m), the max required sext strength is 2000 m$^{-2}$ (20000 T/m$^2$) $\Rightarrow$ sextupoles with smaller aperture (≈10 mm)
Chromaticity correction with 2 sextupoles (no bump)

7BA chromaticity correction with coupled sextupoles and no dispersion bump:

\[ \varepsilon_x = 76 \text{ pm} \cdot \text{rad} \]

- 100 T/m max quad gradient
- **Strong sextupoles** are restricted to two locations (as in the ESRF lattice) but without \( \beta_x \) and dispersion bumps
- Only 4 sextupoles required, but much stronger! (50000 T/m\(^2\))
- The vacuum chamber should have a smaller aperture (\( \approx 8 \text{ mm} \)) only at sextupole locations
Relaxing the sextupoles

A relaxed solution with 5000 T/m$^2$ sextupoles is a 5BA with $\epsilon_x = 230 \text{ pm}\cdot\text{rad}$

Dynamic aperture and lifetime larger than H7BA and optimisation has not been performed yet
Vertical chromaticity correction is harder than horizontal one: can we easy the process by introducing some **vertical dispersion**?

The added constraints results in complicated optics

- Substantial vertical emittance
- Up and down bumps in vertical orbit

...Not really promising
The rotation is obtained by means skew-quadrupoles
Phase space is rotated in the transverse plane 90° each turn
Horizontal and vertical planes are fully coupled
The machine exhibits one tune → one chromaticity
Only horizontal sextupoles are required to correct chromaticity
DOES IT REALLY WORKS? ... it was tested once in Cornell

Permanent magnets (very preliminary)

Miniaturisation issues, studying two options: iron dominated (hybrid) and Halbach arrays

NdFeB:
- Remanence: 1.4 T
- Temperature coeff: 0.1%/C
- Rad. damage threshold: $10^{15}$ n/cm$^2$

SmCo:
- Remanence: 1.1 T
- Temperature coeff: 0.03%/C
- Rad. damage threshold: $10^{19}$ n/cm$^2$

*(P.N’gotta et Al. PRSTAB 19, 2016)*

*(N.Tsoupas et Al., Physics Procedia 90, 2017)*
ESRF inspired quadrupole

First rough 2D simulation:

- Hybrid: steel + permanent magnet
- Considered 3 steel alloys:
  - AISI 1006
  - 1010 (low carbon steel)
  - Fe-Co 50-50 (Special alloy)
- Medium grade NdFeB similar to SmCo
- Bore radius: 10 mm
- Gradient:
  - 114 T/m
  - 104 T/m
  - 125 T/m
- Good field region: ~5mm
- Best gradient error ~0.3%
- Pole tip roughly optimized
- Disassembly required to install beam-pipe
The two left poles cross the zero field region (center of quadrupole)

The ideal shape for the left poles is a plane, but a 20 mm gap is added to get the beam-pipe in

No disassembly required to install the beam-pipe

Quadrupole gradient $\sim 70$ T/m

Dipolar field $\sim 0.5$ T

Pole tip needs optimization, field quality $\sim 2\%$

First rough 2D simulation:
What’s next

• Continuing the studies to define a MBA for ALBA:
  – Number of sextupole and locations
  – Clear some room in the centre of the cell to house RF cavities and diagnostics?
  – Solutions for Dipole beamlines
• Collective effects studies and apertures of the vacuum chamber
• Injection scheme
• High gradient and small aperture magnets solutions
• ...and by 2021 chose a lattice for the ALBA upgrade

ALBA has two advantages for an upgrade:
• Currently many straight sections are not used yet by beamlines
• The injector is already suitable for a low emittance SR
Thank you for your attention!

Questions?