Case Study
ALBA – Magnet

Introduction

D. Einfeld
CELLS/Barcelona
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Schematic of an accelerator complex for a synchrotron light source

Pre-Accelerator

Linac: To produce 4 to 10 mA pulse electron beam with an energy of 100 to 150 MeV, a pulse width of 1 to 2 nsec and a frequency of 500 MHz.

Transfer Line (Li-Bo)

Booster

Linac: To produce 4 to 10 mA pulse electron beam with an energy of 100 to 150 MeV, a pulse width of 1 to 2 nsec and a frequency of 500 MHz.

Booster: To accelerate the energy of the electron beam (coming from the linac) from 100 MeV to 3 GeV.

Transfer Line (Bo-St)

Storage Ring: To accumulate the electron beam and store it over a long time with a small emittance and provide a high quality photon beam to the experiments.

Front Ends: To transfer the photon beam to the experimental hall.

Front Ends
### Layout of Linac

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Single-bunch</th>
<th>Multi-bunch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>3 GHz</td>
<td>3 GHz</td>
</tr>
<tr>
<td>Bunch length</td>
<td>&lt; 1 ns (FWHM)</td>
<td>0.3 to 1 μs</td>
</tr>
<tr>
<td>Charge</td>
<td>≥ 2 nC</td>
<td>≥ 4 nC</td>
</tr>
<tr>
<td>Energy</td>
<td>≥ 100 MeV</td>
<td>≥ 100 MeV</td>
</tr>
<tr>
<td>Pulse to pulse (δE)</td>
<td>≤ 0.25 % (rms)</td>
<td>≤ 0.25 % (rms)</td>
</tr>
<tr>
<td>Energy spread (ΔE/E)</td>
<td>≤ 0.5 % (rms)</td>
<td>≤ 0.5 % (rms)</td>
</tr>
<tr>
<td>Norm. Emitt. (1σ_{x,y})</td>
<td>≤ 30 π mm mrad</td>
<td>≤ 30 π mm mrad</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>3 to 5 Hz</td>
<td>3 to 5 Hz</td>
</tr>
</tbody>
</table>

**Smaller emittance and higher transmission as at other Linacs**
Exit conditions Linac:
\[ \varepsilon_{\text{norm}} = 30 \, \pi \, \text{mm*mrad}, \, \varepsilon_{(100)} = 150 \, \pi \, \text{nm*mrad}, \, \beta = 2 \text{ to } 10 \, \text{m/rad}, \, \alpha = -2 \text{ to } 0, \, \Delta E/E = 0.005 \]

Design is similar as to other light sources.
ALBA design:
defocussing bending magnets and focussing quadrupoles
$\varepsilon_x = 10 \text{ nmrad}$
smaller emittance, higher flexibility and lower costs

Sextupole components within the bendings and quadrupoles
Layout of the Booster Storage Ring Transfer Line

- Storage Ring
- Injection Straight
- Transfer Line
- Booster Synchrotron
- Quadrupoles
- Bending magnets
- Septum
- Kicker

Design is similar as to other light sources
For the lattice design one has to make pretty soon the decision to use combined bending magnets or not. The usage of combined bending magnets has two advantages: 1.) reduction of the emittance by roughly 30 % because of Jx and 2.) building a more compact machine and therefore having more space for insertion devices (for a 3 GeV machine and a circumference of 300 m it is roughly 10%).
Booster Design Criteria

- Full energy Booster
- Small emittance and beam cross section
- Top-up injection
- In the same tunnel as the S.Ring

✓ Share shielding
✓ Share engineering services

✗ No independent access to both rings
   But if top-up is running there is no access in any case
✗ Installation and commissioning require good organisation
✗ What happens to stray fields?
   Do some calculations to find acceptable distance between both rings.
   Take maximum magnetic field into consideration

D. Einfeld, CELLS
CAS, Bruges, June. 2009
### Parameters of Booster Synchrotron

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>GeV</td>
<td>3</td>
</tr>
<tr>
<td>Emittance (natural)</td>
<td>nmrad</td>
<td>9.0</td>
</tr>
<tr>
<td>Tunes ((Q_x / Q_y))</td>
<td></td>
<td>12.42 / 7.38</td>
</tr>
<tr>
<td>Natural Chromaticities ((\xi_x / \xi_y))</td>
<td></td>
<td>-17.0 / -9.6</td>
</tr>
<tr>
<td>Momentum Compaction Factor ((\alpha_t))</td>
<td></td>
<td>3.6x10^{-3}</td>
</tr>
<tr>
<td>Energy Spread ((\delta E/E))</td>
<td></td>
<td>9.6x10^{-4}</td>
</tr>
<tr>
<td>Revolution frequency ((f_0))</td>
<td>MHz</td>
<td>1.202</td>
</tr>
<tr>
<td>Damping Times ((\tau_x / \tau_y / \tau_s))</td>
<td>ms</td>
<td>4.6 / 8.0 / 6.4</td>
</tr>
<tr>
<td>Partition Numbers ((J_x / J_y / J_s))</td>
<td></td>
<td>1.75 / 1.0 / 1.25</td>
</tr>
<tr>
<td>Energy Loss per turn ((U_0))</td>
<td>keV</td>
<td>625</td>
</tr>
<tr>
<td>Harmonic Number ((h))</td>
<td></td>
<td>416</td>
</tr>
</tbody>
</table>
Gradient within the bending magnet and sextupole components within the bendings and quadrupoles
Beam size at injection ($1\sigma$)

$\varepsilon_x = 140 \text{ nm.rad}$

100 % coupling

$\sigma_{x,\text{max}} = 1.3 \text{ mm}, \sigma_{y,\text{max}} = 1.25 \text{ mm}$
Beam size at extraction ($1\sigma$)

- $\varepsilon_x = 9$ nm.rad
- 10% coupling
- $\sigma_{x,\text{max}} = 0.5$ mm, $\sigma_{y,\text{max}} = 0.10$ mm
Chromaticity correction:

\[ \xi_x = -16.9 \quad \xi_y = -10.0 \]

Chromaticity is corrected to +1 in the dipoles and quadrupoles pole profile.

Bend, sext. component is 18 T/m² at 3 GeV
Quad, sext component is 44 T/m² at 3 GeV

In addition
2 families of 8 sextupoles/each add flexibility
max sext. component is 400 T/m² at 3 GeV
Dynamic aperture: Only sextupoles, no magnets errors

mid of straight section
Booster Lattice

This magnet has been chosen for the “Case Study”

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The specifications of the bending magnet are the following

1.) The deflection angle is:

$$\varphi = 10 \text{ _deg.} = 0.174533 \_rad$$

2.) The corresponding integrated flux density is:

$$\int B \cdot ds = -1.74652 \_Tm$$

3.) The integrated gradient is:

$$\int G \cdot ds = 4.58 \_T$$

4.) The integrated sextupole component is:

$$\int \frac{1}{2} B'' \cdot ds = 18 \_T / m$$
The specifications of the bending magnet are the following

6.) The good field region is:

Good field region: $X \geq 15\,\text{mm}$
The specifications of the bending magnet are the following:

7.) The size of the vacuum chamber (outer dimensions) is:

8.) The temperature and pressure drop is:

\[ \Delta \theta = 11^\circ C \text{ and } \Delta p = 7 \text{ bar} \]

9.) The repetition rate is:

\[ f(\text{rept.}) = 3 \text{ Hz} \]
The specifications of the bending magnet are the following

10.) Available space around the:

- Space for the coil ends: 150 mm
- Space for the manifold: 550 mm * 250 mm
- Space for the flowmeter: 500 mm * 200 mm
The specifications of the bending magnet are the following

11.) Sizes of the conductor:

Diameter is available with steps of 0.5 mm

A and B are available with steps of 1.0 mm
The specifications of the bending magnet are the following

12.) Shape of the magnet:

It is a so called "curved rectangular bending magnet"
The specifications of the bending magnet are the following

Some people of this course know the specification of this bending Magnet very well.

For these peoples I changed the specifications to the following:
The specifications of the bending magnet are the following

1.) The deflection angle is:

\[ \varphi = 11.25 \, \text{deg.} = 0.19634954 \, \text{rad} \]

2.) The corresponding integrated flux density is:

\[ \int B \cdot ds = -1.96528 \, \text{Tm} \]

3.) The integrated gradient is:

\[ \int G \cdot ds = 7.8279 \, \text{T} \]

4.) The integrated sextupole component is:

\[ \int \frac{1}{2} B^{'''} \cdot ds = 38 \, \text{T} / \text{m} \]
The specifications of the bending magnet are the following:

6.) The good field region is:

**Good Field Region**

- $X < 15 \text{ mm}$
- $X \geq 15 \text{ mm}$
The specifications of the bending magnet are the following:

7.) The size of the vacuum chamber (outer dimensions) is:

\[ 50 \text{ mm} \times 36 \text{ mm} \]

8.) The temperature and pressure drop is:

\[ \Delta \vartheta = 11 \text{ } ^\circ \text{C} \text{ and } \Delta p = 7 \text{ bar} \]

9.) The repetition rate is:

\[ f(\text{rept.}) = 3 \text{ Hz} \]
The specifications of the bending magnet are the following

10.) Available space around the:

- There must be full access from the positive x direction

- Space for the coil ends: 120 mm

- Space for the manifold: 250 mm over the length of the magnet

- Space for the coil ends: 120 mm
The specifications of the bending magnet are the following:

11.) Sizes of the conductor:

- Diameter is available with steps of 0.5 mm.
- A and B are available with steps of 1.0 mm.
The specifications of the bending magnet are the following

12.) Shape of the magnet:

It is a so called "curved rectangular bending magnet"
Thanks
and
I wish you a lot of success

D. Einfeld