MAX IV Lattice Design:
Multibend Achromats for Ultralow Emittance

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Brief Overview of the MAX IV Facility

- New site, replacement for present MAX-lab and MAX I, II, III rings
- Funding granted April 2009, construction starts in 2010, commissioning of the 3 GeV storage ring in 2014, user operation 2015

- 3 GeV linac (SPF, FEL) ~ 300m
- 1.5 GeV SR (IR/UV) 12 DBAs \( \varepsilon = 6 \text{ nm rad} \)
- 3 GeV SR (X-ray) 20 MBAs \( \varepsilon < 0.3 \text{ nm rad} \)
Multibend Achromats

- Damping ring community...
- EPAC ’94: W. Joho et al., “Design of a Swiss Light Source”
- PAC ’95: D. Einfeld et al., ”Design of a Diffraction Limited Light Source (DIFL)”
- PAC ’95: D. Kaltchev et al., “Lattice Studies for a High-brightness Light Source”
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**Design of a Diffraction Limited Light Source (DIFL)**

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Abstract:

Three synchrotron light source of the third generation have been commissioned (ESRF, ALS and ELETTRA). All machines have reached their target specifications without any problems. Hence it should be possible to run light sources with a smaller emittance, higher brilliance and emitting coherent radiation. A first design of a Diffraction Limited

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2. Obtaining a Low Emittance

The optics influences the emittance via the partition number $J_X$, which is unity for a pure dipole field and via the $H$-function:

$$H = \gamma^2 + 2\alpha' + \beta''^2$$

which is determined by the shape of the horizontal...
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LATTICE STUDIES FOR A HIGH-BRIGHTNESS LIGHT SOURCE

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Abstract
A number of lattices have been studied for use in a high-brightness Canadian synchrotron light source. In particular we have investigated some designs similar to the proposed 1.5 - 2.1 GeV Swiss Light Source, which incorporates superconducting dipoles in multi-bend achromats, but providing 8 or 10 rather than the original 6 straight sections. Similar emittances to those machines have reached their target specifications without any problems. Hence it should be possible to run light sources with a smaller emittance, higher brilliance and emitting coherent radiation. A first design of a Diffraction Limited H-function: 

\[ H = \gamma \eta^2 + 2\alpha \eta' + \beta \eta'^2 \]

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\[ \varepsilon_x = C \frac{E^2}{N_d^3} \]

Abstract

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Evolution of the MAX IV 3 GeV Storage Ring

- MBA challenge: compact lattice $\rightarrow$ combined-function magnets, narrow apertures, ...
- Tarawneh et al., NIMA 508 (2003) 480 $\rightarrow$ 3 GeV (285 m), 12 MBAs, $\varepsilon = 1.2$ nm rad
- Eriksson et al., PAC '07 $\rightarrow$ 3.0/1.5 GeV rings stacked, $\varepsilon = 0.83 / 0.4$ nm rad
- Leemann et al., PRST-AB 12 120701 (2009) $\rightarrow$ 3 GeV, 528 m, 20 MBAs, 5 m long straight sections, $\varepsilon < 0.3$ nm rad, gradient dipoles, discrete sextupoles & octupoles, fully integrated magnet design
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**THE MAX-IV DESIGN: PUSHING THE ENVELOPE**

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Hamed Tarawneh, Sesame, Amman, Jordan

Abstract

The proposed MAX IV facility is meant as a successor to the existing MAX-lab. The accelerator part will consist of three storage rings, two new ones operated at 3 and 1.5 GeV respectively and the existing 700 MeV MAX III ring. The two new rings have identical lattices and are placed on top of each other. Both these rings have a very short bunches for the generation of short pulses of spontaneous X-ray radiation and can also work as an electron source for Free Electron Lasers (FELs).

A more detailed description of the MAX IV facility can be found in ref. [1] and since the MAX III ring is described earlier [2], it will not be treated here.

At MAX-LAB the next synchrotron light source MAX-IV is currently studied (Proceedings of the seventh European Particle Accelerator Conference, EPAC 02, Paris, France, 2002). In this paper, we present a possible lattice with
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MAX IV Multibend Achromat Lattice

- 20 MBAs → 19 ID straights
- 5 unit cells, 2 matching cells
- 5 m long straight sections
- 1.3m short straights (→RF)
- $\varepsilon_x = 0.3$ nm rad
  (4 PMDWs, LCs, and IBS)
- Rad. power: 572 keV/turn
  (with 4 PMDWs)
- Energy spread: 0.096%
  (with 4 PMDWs)
MAX IV Multibend Achromat Lattice

- 3° bends in unit cells (~0.5T)
- 1.5° soft-end bends in matching cells
- $\eta_{\text{max}} = 8 \text{ cm, } \eta^* = 0$
- $\sigma_{y^*} < 6 \mu\text{m}$
- WP: $\nu_x = 42.20, \nu_y = 14.28$
- 2 QF families (~ 40 T/m)
- QD in dipoles (~ 9 T/m)
- Quad doublet in matching cell
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- nat. $\xi_x = -50, \xi_y = -44$

- 3 SF families
  ($< 2200 \text{ T/m}^2$)

- 2 SD families
  ($\sim 1200 \text{ T/m}^2$)

- 3 octupole families
  ($< 22000 \text{ T/m}^3$)
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Integrated Magnet Design

- Compact MBA optics $\rightarrow$ highly-integrated magnet design
- Each unit cell and matching cell is machined from two solid blocks of iron (demonstrated at MAX III $\rightarrow$ NIMA 601 (2009) 229)
- Machining precision $\rightarrow$ excellent alignment (small beam size $\rightarrow$ tolerances!)
Octupole Strategy

- Large natural chromaticity + low dispersion $\rightarrow$ strong sextupoles
- Only 5 sextupole families, but many first-order sextupole driving terms
  - 2 linear chromaticities + 3 chromatic terms + 5 geometric terms
  - + second-order terms $\rightarrow$ ADTS, quadratic chromaticity, ... $\rightarrow$ tune footprint
- Not satisfied with DA and tune footprint even after extensive nonlin. optimization
- ADTS is second-order effect in sextupoles ($\rightarrow$ weak correction)
- Instead:
  - Use sextupoles to minimize first-order driving terms and correct chromaticity
  - Use octupoles to correct ADTS (first-order effect!)
- $\rightarrow$ compact tune footprint
Tune Footprint with and without Octupoles

Sextupoles only

Sextupoles + Octupoles
Dynamic Aperture

- Injection requirement: 8 mm (2.5 mm safety margin)
- Vertical: in-vac. IDs, 4 mm full-gap height
- Use octupoles to shape DA (commissioning!)
Emittance and IBS

- MAX IV 3 GeV SR is IBS-limited!
- Damping wigglers reduce emittance ($B = 2.22\ T, \lambda = 80\ \text{mm}, \ L = 2\ \text{m}$)
- DWs also increase energy spread → reduce IBS contribution
- Landau Cavities
  → reduce effect of IBS & increase Touschek lifetime

<table>
<thead>
<tr>
<th></th>
<th>$\epsilon_x$ [nm rad]</th>
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<tbody>
<tr>
<td></td>
<td>Without IBS</td>
</tr>
<tr>
<td>Bare lattice</td>
<td>0.326</td>
</tr>
<tr>
<td>Bare lattice with LC</td>
<td>0.326</td>
</tr>
<tr>
<td>Lattice with four PMDWs and LC</td>
<td>0.263</td>
</tr>
<tr>
<td>Lattice with four PMDWs, ten IVUs, and LC</td>
<td>0.201</td>
</tr>
</tbody>
</table>
Coupling Control

- Diffraction limit 1Å → need $\varepsilon_y = 8$ pm rad → 2.7% coupling (feasible)
- Beam-based BPM calibration to sextupole centers
- Corrector-based realignment of magnet cells as demonstrated at MAX III (NIM A 597 (2008) 170)
  → minimize orbit offsets in sextupoles → low betatron coupling

- Reduce coupling even further → secondary windings on all sextupoles and octupoles
  - Nondispersive skew quads (on octupoles) to correct residual betatron coupling
  - Dispersive skew quads (on sextupoles) to drive vertical dispersion bumps within achromats
    → minimize vertical beam size in IDs without sacrificing lifetime

- 0.2% coupling → $\varepsilon_y = 0.6$ pm rad → ≈ natural limit!

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