IV
Variable polarisation and other exotic Insertion Devices

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A bifilar Superconducting Helical Undulator was used in 1972 for the first FEL at HEPL, Stanford known since 1950s Fixed Helicity

$$B_\perp = \frac{4\pi}{10\lambda_0} \left[ \left( \frac{2\pi a}{\lambda_0} \right) K_0 \left( \frac{2\pi a}{\lambda_0} \right) + K_1 \left( \frac{2\pi a}{\lambda_0} \right) \right]$$

Almost never used in synchrotron Sources:
- small horizontal aperture
- low field at room temperature
- no variation of polarisation

See L.R. Elias, J.M.J. Madey, Rev. Sci. Instrum. 50(11), Nov. 1979
• Beamline scientist are asking for variable polarization insertion devices which can produce:
  – Circular polarisation (left or right)
  – Linear polarisation (horiz, vertical, inclined)
  – Slow or fast switching of polarisation
  – High brilliance (=> preferably undulators)
Crossed Undulator (K.J. Kim)
Fast Switching of Polarisation

- polarisation varies over a narrow wavelength range.
- strong depolarisation by emittance and energy spread.
- can only be used at very low energy.
Two Orthogonal Permanent Magnet Planar Undulators

Variable Polarization Undulator (circular, elliptical, linear)
Inefficient in terms of gap and period, suitable for low energy


Electro-magnet Helical undulator (Ophelie at LURE)
ESRF Helios Type Undulator

- Simple to build & low magnetic forces
- Lower field than the Apple II
- Generates closed orbit distortion $\sim 1/E^2$
Apple II (Sasaki) Linear/helical Undulator

Very popular:
- High magnetic field (at given period and gap)
- Generates any polarization (linear, elliptical, ..)
- The field error correction is now mastered even though delicate

Symmetric Motion : $\varphi_2 = \varphi_1 = \varphi$

$$[B_z(s), B_x(s)] = \begin{bmatrix} 4B_{z0}\cos\left(\frac{\varphi}{2}\right)\cos(2\pi\frac{s}{\lambda_0} + \frac{\varphi}{2}) \\ -4B_{x0}\sin\left(\frac{\varphi}{2}\right)\sin(2\pi\frac{s}{\lambda_0} + \frac{\varphi}{2}) \end{bmatrix}$$

$\varphi = 0 \Rightarrow [B_z(s), B_x(s)] = \begin{bmatrix} 4B_{z0}\cos(2\pi\frac{s}{\lambda_0}) \\ 0 \end{bmatrix}$ : Vertical

$\varphi = \pi \Rightarrow [B_z(s), B_x(s)] = \begin{bmatrix} 0 \\ -4B_{x0}\sin(2\pi\frac{s}{\lambda_0}) \end{bmatrix}$ : Horizontal

$\varphi = \arctan\left(\frac{B_{z0}}{B_{x0}}\right) \Rightarrow [B_z(s), B_x(s)] = 4B\begin{bmatrix} \cos(2\pi\frac{s}{\lambda_0} + \frac{\varphi}{2}) \\ -\sin(2\pi\frac{s}{\lambda_0} + \frac{\varphi}{2}) \end{bmatrix}$ : Helical

$[B_z(0,0,s), B_x(0,0,s)] =$

$$\begin{bmatrix} B_{z0}\cos(2\pi\frac{s}{\lambda_0} + \varphi_2), B_{x0}\cos(2\pi\frac{s}{\lambda_0} + \varphi_2) \\ B_{z0}\cos(2\pi\frac{s}{\lambda_0}), -B_{x0}\cos(2\pi\frac{s}{\lambda_0}) \end{bmatrix} + \begin{bmatrix} B_{z0}\cos(2\pi\frac{s}{\lambda_0} + \varphi_1), B_{x0}\cos(2\pi\frac{s}{\lambda_0} + \varphi_1) \\ B_{z0}\cos(2\pi\frac{s}{\lambda_0}), -B_{x0}\cos(2\pi\frac{s}{\lambda_0}) \end{bmatrix}$$

with $B_{z0}, B_{x0}$ function of the magnetic gap.
Antisymmetric Motion: $\varphi_2 = -\varphi_1 = \varphi$

$$[B_z(s), B_x(s)] = \begin{bmatrix} 4B_{z0} \cos^2\left(\frac{\varphi}{2}\right), -4B_{x0} \sin^2\left(\frac{\varphi}{2}\right) \end{bmatrix} \cos\left(2\pi \frac{s}{\lambda_0}\right): \text{ Linear}$$

$\varphi = 0 \implies [B_z(s), B_x(s)] = [4B_{z0}, 0] \cos\left(2\pi \frac{s}{\lambda_0}\right): \text{ Vertical}$

$\varphi = \pi \implies [B_z(s), B_x(s)] = [0, -4B_{x0}] \cos\left(2\pi \frac{s}{\lambda_0}\right): \text{ Horizontal}$
Radiation Pattern from Apple II

Apple II on the ESRF
Period: 88 mm
Gap: 16 mm,
Power density @ 30m

Vertical Field
Horizontal Traj. & Polar.

Horizontal Field
Vertical Traj. & Polar.

Vary \( \varphi \), with \( \varphi = \varphi_1 = -\varphi_2 \)
Linear incline Field & Polar.

Vary \( \varphi \), with \( \varphi = \varphi_1 = \varphi_2 \)
Helical Field
Helical Traj. & Circul Polar.

Vertical
2\textsuperscript{nd} Order Tune Shift of an Apple II at the ESRF

Horizontal Tune shift vary with phase => must be compensated on low energy rings

Period = 88 mm
Gap = 16 mm
Length = 3.2 m
Energy = 6GeV
Betax,z = 35, 2.5 m

Apple II may reduce the dynamic aperture
Spring8 type Linear/Helical Undulator

- Produces: helical radiation or linear at 45 degrees but no vertical or horizontal.
- Technological difficulties to hold the blocks in the middle raw.
Fast Switching
electromagnet/permanent magnet
helical undulator

Field : 0.2 T
Period : 80 mm
Gap : 16 mm
Current : 250 A
Designed for 10 Hz flipping

Fast Switching by Electron Beam Deviations

Induces perturbations to all other beamlines if not tuned precisely!
Fast Switching using Chopper

- No perturbation to the electron beam
- Requires very high quality optics
- Adequate only for low/medium energy ring (length of the bending magnets)
Wiggler Sources of Circular Polarisation

- The radiation from wigglers is less brilliant than helical undulators but the only way to produce circularly polarized radiation at high energy.

- Based on the bending magnet radiation right (left) circularly polarized when observed below and above the orbit plane.

- Two types of devices are used
  - Asymmetric wigglers
  - Ellipsoidal wigglers
Asymmetric Wiggler

Horiz. Angle [mrad]
Vertic. Field [T]

High Field Source Points
Low Field Source Points
N turns
Direction of Observation

Ellipsoidal Wiggler

High Vertical Field
Low Horizontal Field
Same period but
Phase shifted by 90 deg

\[ K_x \sim 1 \]
\[ K_z \sim 5 - 20 \]

Radiation from Ellipsoidal Wiggler

Period = 150 mm
Kz = 8
Kx = 0.8
ELETTRA / SLS Helical Undulator/Wiggler
Ellipsoidal Wiggler vs Asymmetric Wiggler

- An ellipsoidal wiggler has two source points per period (one for asymmetric wiggler).

- Ellipsoidal is used on-axis => no multiple source points.

- Radiation from ellipsoidal wigglers is used on a maximum of flux => less sensitivity to closed orbit distortion.

- An asymmetric wiggler is simpler mechanically but much more delicate magnetically => can generate large field integrals.