# Storage Ring Design with Beam Optics Program

Chitrlada Settakorn Chiang-Mai University, Thailand School on Synchrotron Radiation April 22- 26, 2002 ICTP, Trieste, Italy

### **Storage Ring and Synchrotron Radiation**

Highly relativistic electrons are stored in a circular path. To keep the electron circulate in the ring, dipole magnets are used to guide the electron to a circular trajectory. Transverse acceleration from the magnetic forces causes the electron to radiate. Insertion devices (undulators, wiggler magnets, and wavelength shifters) are often added to the straight section to generate radiation which specific characteristics.



#### **Storage Ring components**



#### **Bending magnet**

A bending magnet of *B* Tesla and length l (m) deflects a charged particle beam with a bending angle  $\varphi$  given by

$$\varphi = \frac{l}{\rho} = \frac{eB}{cp}$$
 or in practical unit  $\varphi = 0.3 \frac{B(T)l(m)}{E(GeV)}$ ,

where *E* is the particle energy.

Example:

For a bending magnet of 1 Tesla, 1 m long and a particle energy of 3 GeV, the deflecting angle is 0.1 rad.

Bending magnets are distributed along the beam path. With appropriate deflection angles, the beam therefore travels in a close orbit(total deflection angle of 360 degree,  $2\pi$ ).

#### Beam focusing from quadrupole magnets



Quadrupole magnets act in particle beam optics like lenses in light optics.

Deflection angle to the focal point  $\alpha = x/f = klx$ , where k is the quadrupole strength given by

$$k(m^{-2}) = 0.3 \frac{g(T/m)}{cp(GeV)}$$

The focal length of the quadrupole is 1/f = kl where *l* is the length of the quadrupole

#### **Magnet Lattice or Lattice**

The arrangement of magnets (bending, quadrupole, sextrupole magnets) along the beam path is called magnet lattice or lattice. Most of storage ring consists of a repetitive sequence is called *periodic magnet lattice*.

## **FODO lattice**

Equidistant sequence of focusing and defocusing quadrupole



A quadrupole is called focusing if it focus the particle beam in the horizontal plane. The opposite is true for the vertical plane.

A focusing quadrupole in the horizontal plane is defocusing in the vertical plane and vice versa.



#### Sequence of FODO cells:



- Periodic cells can be used to construct arbitrary long transport lines.
- To make a ring, insert bending magnets between quadrupoles.

Example of FODO lattice modified to provide magnet free straight sections:



Beam Emittance:

$$\epsilon_{\rm FODO} \approx 100 {\rm x} \ 10^{-13} {\rm E}^2 {\rm \phi}^3$$

E: beam energy(GEV)

φ: deflection angle per bending magnet(degree)

### **Double Bend Achromat (DBA) lattice**

DBA lattice provides dispersion free straight section.



DBA lattice of LNLS, Campinas, Brazil

Beam Emittance :

$$\varepsilon_{\text{DBA}} \approx 5 \times 10^{-13} \text{ E}^2 \phi^3$$

E: beam energy(GEV)

φ: deflection angle per bending magnet(degree)

### **Triple Bend Achromat (TBA) lattice**

TBA lattice can be used to reduce the ring circumference. Used usually for smaller, low energy rings.



TBA lattice of ALS, California, USA

### **Beam Energy and Critical Photon energy**

The synchrotron radiation spectrum from bending magnets is determined by the particle energy and the magnetic field strength. The useful spectrum extends from low photon energy up to a few times of the critical energy.

Critical photon energy of synchrotron radiation from bending magnet,

 $\varepsilon_c$  (keV) = 0.665 $E^2$ (GeV<sup>2</sup>)B(T).



Synchrotron radiation from a 1 Tesla bending magnet and a 3 GeV beam.

The desired <u>maximum photon energy</u> and the <u>bending field strength</u> determine the required particle energy.

# Storage Ring Design using Particle Beam 2002

# **Optics and Design Program**



(The program is available to download at http://coherent.stanford.edu/He-Web/PC-programs.html)

• Start by creating a new lattice.



• Add elements to compose a lattice. Once completed, click done.

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• Edit properties of each element e.g. length, quadrupole strength, curvature of dipole magnets, etc.

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• Select the <u>Beam Line Edit Mode (BL edit mode)</u>, for editing several elements at once.

• A special feature for the quadrupole magnet editing is <u>scroll quad</u>, in which the quadrupole strength can be adjusted using a scroll bar. This scroll quad will become handy for optimizing the lattice and the quadrupole doublet design exercise.

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- To obtain a periodic solution for the lattice, select <u>look for periodic solution</u> under the <u>optics</u> menu.
- If exist, the periodic solution of β<sub>x</sub> (red), β<sub>y</sub> (green) and dispersion(η) function (blue) will be displayed.



• Select <u>ring design</u> to compose a ring from the periodic lattice.

<mark>O</mark> design a storage ring	
Eile Exit	
geometry beam optics tracking	rf life time vacuum lists
ring geometry	
# of superperiods 4 (full ring: 4 cells)	Confirm
ring circumference = 51.520 m revolution frequency = 5.81895 MHz rf frequency MHz 488 79205	To close ring, you may change all dipole strengths by -20.000 % [Yes] or [No].
harmonic number is 84.000	<u></u>
now total defi.angle is 360.000 deg	
perfect ring with integer narmonic number:	Confirm
✓ study full ring?	harmonic number is not yet integer. Adjust rf-frequency ?
✓ study superperiod?	<u>Yes</u> <u>N</u> o

• To get a completed circular path, it is required a total bending angle of 360 degree. The RF frequency should be an integer multiple of the revolution frequency for the beam to gain energy from the RF-cavity. (this integer multiple is called harmonic number)

- Selecting <u>beam parameters</u> under the <u>beam optics</u> menu will show the ring parameters. <u>Resonance diagram</u> can also be viewed under this menu.
- Parameter lists can be chosen under the <u>lists</u> menu.
- More features in the ring design are tracking, rf-cavity, vacuum system and beam lifetime.

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