
SCHOOL ON SYNCHROTRON RADIATION

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*Synchrotron Radiation Source with
Synchrotron Radiation Program*

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School on Synchrotron Radiation
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Radiation from Bending Magnets

Radiation is emitted along the curved path of the beam. The photon characteristics depend on beam energy and magnetic fields.

Critical photon energy of synchrotron radiation from bending magnet,

$$\varepsilon_c (\text{keV}) = 0.665 E^2 (\text{GeV}^2) B (\text{T}),$$

where E is the beam energy and B is the magnetic field.

The photon energy is determined by the field of the bending magnet, which is a fixed parameter for a storage ring. The photon energy generated, is therefore fixed

Radiation Hardening:

In a low energy storage ring, the bending magnet radiation does not provide enough intensity at hard x-rays. Replacing a bending magnet by a superconducting magnet with the same deflection angle will provide more of hard x-ray. This superconducting magnet of a stronger field will be shorter in length.

Example:

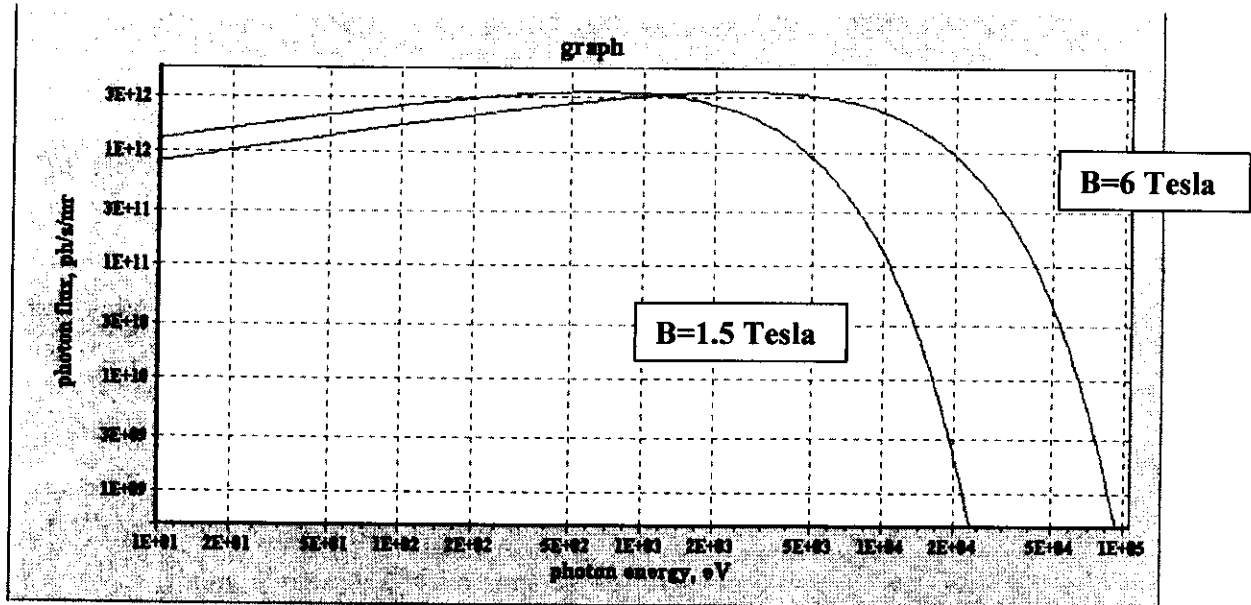
The bending magnet radiation of 1.5 GeV beam from a 1.5 Tesla bending magnet has the critical photon energy of

$$\varepsilon_c = 0.665 E^2 (\text{GeV}^2) B (\text{T}) = 2.24 \text{ keV}.$$

With a 6 Tesla superconducting magnet, the critical photon energy becomes 8.98 keV.

To obtain the same deflection angle, the length of the magnet can be obtained from

$$l(m) = \frac{\phi E(\text{GeV})}{0.3B(\text{T})}, \text{ where } \phi \text{ is the deflection angle in rad.}$$



The graph shows the photon spectrum from a 1.5 Tesla bending magnet and a 6 Tesla superconducting magnet. Employing a superconducting magnet can extend the photon spectrum to higher energy.

Wave Length shifter

For the same purpose of radiation hardening, a wave length shifter is installed in a magnet free section of the ring. A wave length shifter consists of three dipole magnets with a high field central magnet two lower field magnets, opposite direction on either side. The magnetic field of the side poles is designed to compensate the deflection by the central pole resulting in the total deflection angle of zero. The central pole serves as a radiation source and determines the photon energy. Its field strength can be adjusted freely and can be very strong with a superconducting magnet to generate higher photon energy.

Wiggler Magnet Radiation

Wiggler magnet is an insertion device, which consists of a series of dipole magnets with alternating field direction. The total deflecting angle is zero. Many poles of the magnet increase the photon flux. If the magnet is constructed to provide strong fields, it will serve as a wavelength shifter at the same time.

The magnetic field strength depends on:

- the period length
- the design and magnet materials used
- the gap height which is variable over a limited range

Define the strength parameter K,

$$K = 0.934B(\text{Tesla})\lambda_p(\text{cm}).$$

For a wiggler magnet, $K \gg 1$.

Undulator Radiation

In a series of dipole magnets with weak magnetic field ($K \leq 1$), the particles oscillate periodically like sinusoidal oscillation and generate quasi-monochromatic radiation.

The photon energy (forward radiation),

$$\epsilon_i(\text{eV}) = 9.4963 \frac{iE^2}{\lambda_p(1 + \frac{1}{2}K^2)},$$

where E : beam energy

K: strength parameter

λ_p : period length

i : harmonic number

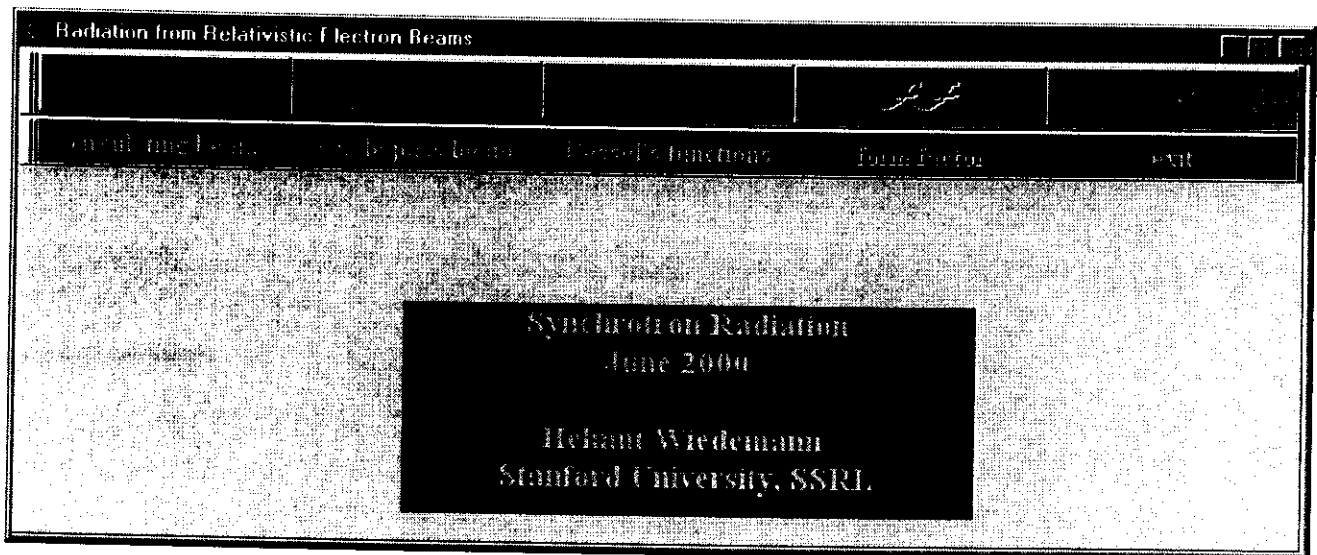
The photon energy is tunable as the undulator strength is adjusted (by changing the gap height).

Synchrotron Radiation and Insertion device Radiation Characterization using the Synchrotron Radiation program

The Synchrotron Radiation Program will be used to characterize the synchrotron radiation. You should use the program to calculate the radiation properties of the storage ring that you have designed, add some insertion devices and study the radiation properties obtained. The program can also be used to study the radiation properties for any storage ring of your interest (parameters for most of existing storage rings are available in the program). The following note will show you how to get start with the program.



- The Synchrotron Radiation program main window:



- For a study of synchrotron radiation from a storage ring, select the calculation for a circular beam.

- The Circulating Beam Parameters window will be opened. There are several storage rings listed in the table on the left. The parameters of the selected ring will be shown on the right.

Circulating Beam Parameters

select source configuration or add new one:

Source	Energy (GeV)	Current (mA)
SSRF	3.5	300
Delta	1	250
LSU	1.5	400
SRRC-1.5	1.5	200
SRRC	1.3	400
PEP	18	55

Delta

Energy (GeV)	1	Current (mA)	1956.94
Energy (GeV)	250	Current (mA)	
Energy (GeV)	1	Current (mA)	
Energy (GeV)	0.05	Current (mA)	5.00
Energy (GeV)	0	Current (mA)	
Energy (GeV)	10	Current (mA)	0

- To add a new storage ring on the list, click Yes at *add new one (storage ring)*. A new blank entry will appear at the top of the list together with a new beam configuration sheet.

select source configuration or add new one:

Source	Energy (GeV)	Current (mA)
SSRF	3.5	300
Delta	1	250
LSU	1.5	400
SRRC-1.5	1.5	200
SRRC	1.3	400

Delta

Energy (GeV)		Current (mA)	
Energy (GeV)		Current (mA)	
Energy (GeV)		Current (mA)	
Energy (GeV)		Current (mA)	
Energy (GeV)		Current (mA)	
Energy (GeV)		Current (mA)	

- Create a new ring configuration using the information from your storage ring design.
- Select Accept and Close option.

Bending Magnet Radiation

select radiation source: NewBendMagnet

Name	Type	magnet	field	psi_x	psi_y
NewBendMagnet					
SSRF-bend	EM	Syn	1.105	0	0
WL Shifter	EM	Syn	4	0	0
Bend Magnet	EM	Syn	1.25	0	0

filter data with: select filter text

beam parameters

parameter set MyStorageRing

beam energy 3 GeV

beam current 100 mA

radiation source

source:

field strength T

bend.radius 9.056 m

- Click **apply** to update the parameters and click **recalculate** for radiation properties. The results will be posted in the window.

recalculate

select radiation source: NewBendMagnet

Name	Type	magnet	field	psi_x	psi_y
NewBendMagnet	EM		1.22		
SSRF-bend	EM	Syn	1.105	0	0
WL Shifter	EM	Syn	4	0	0
Bend Magnet	EM	Syn	1.25	0	0

filter data with: select filter text

beam parameters

parameter set MyStorageRing

beam energy 3 GeV

beam current 100 mA

radiation source

source: NewBendMagnet

field strength 1.22 T

bend.radius 8.202 m

rigidity 10.007 T m

global radiation parameters

total power 87.47 kW;

angular power 13.92 W/mr

power density: @ source point 157.900 W/mm²

@ z = 1.0 m: 27.120 W/mm² : normal incidence

27.120 W/mm² : @ incidence angle of 90.0 deg

spectral radiation and polarization

wavelength 12.399 C

e_photon 12.399 keV

e_ph/e_crit 1.698

band width 0.0831 %

opening angle_y, σ_y 0.0831 mr

vertical observ. angle, σ_z 0.0831 1/ γ

total photon flux, 2.845E12 ph/s/mr

flux in units of ph/s/mr² :

σ -mode	x-mode	total
1.37E+13	0.00E+00	1.37E+13

- Select **spectrum** to illustrate the spectral photon flux in a graph format.
- The spectrum window is then activated. Select the spectrum of the interest and its parameter to be plotted.

Synchrotron Radiation Spectrum

beam parameters

parameter set	MyStorageRing	source	SSRF-bend	
beam energy	3 GeV	max. field....	1.105 Tesla	band width..... 0.1 %
beam current	100 mA			

calculate and plot photon flux

critical photon energy: e_{crit} 6.613 keV

photon flux spectrum

spectrum..... eV < e_i < eV

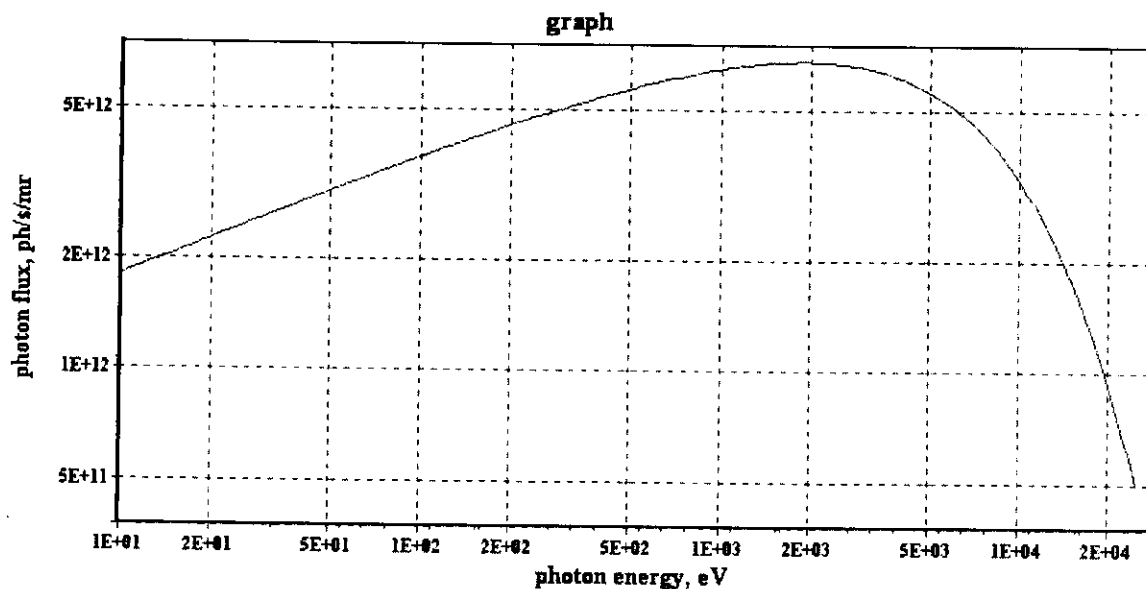
percent step size... $\Delta e_{ph} / e_{ph}$ %

vertical obs. angle, ψ 1/ γ

☐
☒
☐
☐

☐
☐
☐
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☐

- For example, a graph of photon flux:



- The calculations for Synchrotron Radiation from Wiggler magnet and Undulator Radiation work in a similar way.



Wiggler Magnet Radiation

select radiation source

Name	type	conv	period	field	U	N	p	L	p
SSRF W80	PM	hybrid	Wig	1.35	3.3	52	80		
NSRL WweLen	EM	REC	Wig	5	0	1	1000		
ALS-Wiggler	PM	hybrid	Wig	1	3.3	74	160		
Pep-Undulator	PM	REC	Und	1.75	0.9	52	77		

filter data with: All

beam at source point:

storage ring	MyStorageRing	x	y
energy	3 GeV	σ 128.06	37.34 μ m
current	100 mA	σ' 64.03	2.20 μ rad

general radiation parameters

obs. angle_x	mm	e_crit	8.013 keV
		λ_{crit}	1.547 C

total radiation power: 2.126 kW

power density: @source point 70.770 kW/mm²

and z = m downstream 1.299 kW/mm²

permanent magnet ?

magnet type hybrid

gap mm

valid if: $0.07 < g/l_p < 0.7$

field T

number of poles

period length mm

wiggler length 2.080 m

K-value 10.010

path displacement 43.4 μ m

deflection 1705.0 μ rad

select photon parameters

wavelength C

e_photon 12.400 keV

e_ph/e_crit 1.547

vert.cone, σ_θ 87.4 μ rad

band width %

flux density 7.60E+14 ph/s/mm²

angular flux 1.66E+14 ph/s/mm

brightness 2.53E+10 ph/s/mm²/mm²

Undulator Radiation

select radiation source

Name	type	conv	period	field	U	N	p	L	p
Pep-Undulator	PM	Und	REC	1.75	0.9	52	77		
U23	PM	Und	hybrid	1	3.33	80	23		
U60	PM	Und	hybrid	1	3.33	166	60		
54-pole wiggler	PM	Und	hybrid	2	3.33	54	66		

filter data with: 'Und' apply

beam parameter

storage ring MyStorageRing

energy 3 GeV;

current 100 mA;

beam at source point

x	y
σ 128.06	37.34 μ m
σ' 64.03	2.20 μ rad

permanent magnet ?

magnet type REC

gap 17 mm

valid if: $0.07 < g/l_p < 0.7$

field 1.775 T

number of poles 52

period length 77 mm

K-parameter 5.576

undulator length 2.002 m

osc.amplitude 11.6 μ m

deflection 949.8 μ rad

forward radiation

harmonic "i": 1

e_i 67.1 eV

λ_i 184.8 C

total radiation power 685.70 W

power density: @source point 20.970 kW/mm²

and z = 1.8 m downstream 3.888 kW/mm²

- Features in the calculations for Undulator Radiation include **line spectrum** in which the calculation of the photon spectrum for higher harmonic can be done, as well as the undulator line spectrum plot.

Undulator Line Spectrum

beam parameters

parameter set	MyStorageRing	source: Pop-Undulator	number of periods	26	
beam energy	3 GeV	K	5.576	undulator length	2.002 m
beam current	100 mA	band width	%	period length	77.000 nm

line spectrum

fundamental wavelength: λ_0 184.8 C or fundamental energy: e_0 67.06 eV

scan harmonics, i from to:

184.8 C > λ_i > 20.54 C
 67.06 eV < e_i < 603.5 eV

i	$\lambda(C)$	$e_{ph}(eV)$	BW_eff(%)	*
1	184.825	67.050	3.873	5.921E21
2	92.412	134.100	1.936	1.461E22
3	61.608	201.174	1.359	1.861E22
4	46.205	269.291	0.892	1.334E22
5	36.965	335.291	0.711	1.513E22
6	30.804	409.407	0.621	1.635E22
7	26.536	483.523	0.542	1.735E22
8				
9				

*) radiation units as chosen

choose radiation quantity

☒ angular flux, ph/s/sr
☐ flux, ph/s
☐ flux density, ph/s/mm²
☐ brightness, ph/s/mm²/mr²

☐ save data to file
☒ show graph
☐ add to graph
☐ replace graph

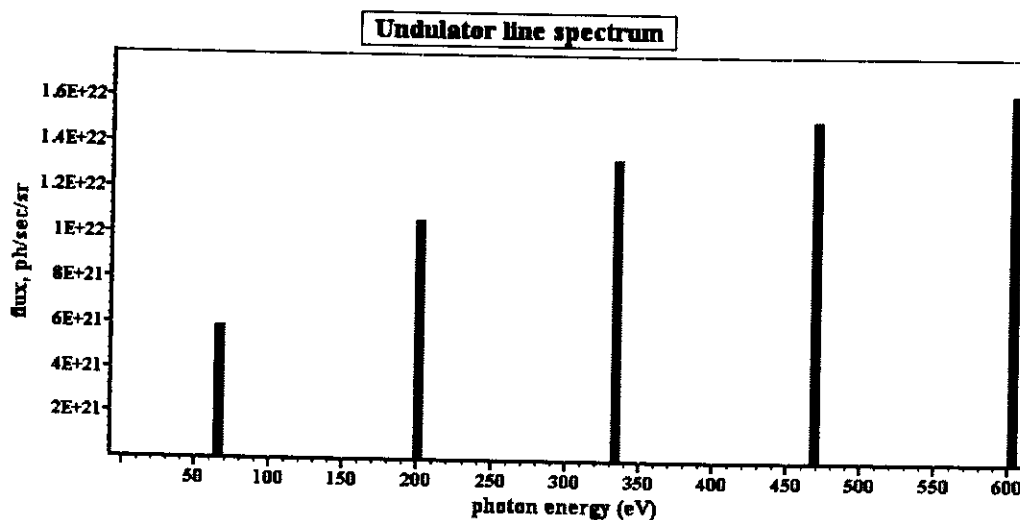
vary gap or K and plot:

☒ plot vs photon energy
☐ plot vs K parameter
☐ plot vs gap

min. gap mm
 maxi. gap mm

K_min
 K_max

- Undulator line spectrum up to the 9th harmonic:



- The calculations with variations of undulator gaps or K parameters are also available.

vary gap or K and plot:

☒ plot vs photon energy
☐ plot vs K parameter
☐ plot vs gap

min. gap **10** mm
 maxi. gap **100** mm

☒ vary undulator gap

- For example, varying the Pep-undulator gap from 10 mm to 100 mm, the photon flux up to the 9th harmonic will be as shown in the graph.

