RADIATION SOURCES AT SIBERIA-2 STORAGE RING

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Optical functions \( \varepsilon_x = 98 \text{ nm rad} \)

Superperiod L \( \approx 3 \text{ m} \)
Prospects for Siberia-2 insertion devices

- **Wiggler** $B=0.36$ T
  - $dE = 25 – 1500$ eV

- **Wiggler** $B=0.36$ T
  - $dE = 4 – 1200$ eV

- **SC Wiggler** $B=3.5$ T
  - $dE = 5 – 26$ keV

- **SC Wiggler** $B=3.5$ T
  - $dE = 5 – 40$ keV

- **SC Wiggler** $B=3.5$ T
  - $dE = 5 – 26$ keV

- **Undulator** $B=0.75$ T
  - $dE = 2 – 7$ keV

- **Edge Radiation**
  - $dE = 0.1 – 350$ eV

- **SC Wiggler** $B=7.5$ T
  - $dE = 20 – 200$ keV
• ER is produced by relativistic electrons in fringe fields of the bending magnet edges. It was experimentally discovered in the late 1970s at Super Proton Synchrotron (SPS, CERN, Geneva) and at the electron synchrotron “Sirius” (INP, Tomsk, Russia).

• The photons, emitted at two adjacent bending magnets, appear in the same narrow cone and are subsequently synchronized by the electron itself. This leads to the interference of ER.
Aperture
H x V = 44 x 16 mm$^2$
H x V = 28 x 10 mrad$^2$

B=1.7 T, R=4.9 m,
$\alpha = 14^\circ$,
$\varepsilon_c = 7.2$ keV

B/4=0.42 T, R=1.96 m,
$\alpha = 26^\circ$,
$\varepsilon_c = 1.75$ keV

R=1.96 m,
=1.75 keV
ER numerical simulation

- Computer code SMELRAD - SiMulation of ELectromagnetic RADiation (Smolyakov N.V.)

- Emittance effects are included through convolution.

Electron beam parameters:
- $E=2.5 \text{ GeV}$, $I_{\text{beam}}=100 \text{ mA}$
- $\sigma_x=1.5 \text{ mm}$, $\sigma_y=77 \mu\text{m}$
- $\sigma'_x=0.09 \text{ mrad}$, $\sigma'_y=0.01 \text{ mrad}$
ER intensity

Angular distribution of ER intensity in the horizontal plane

Angular distribution of ER intensity in the vertical plane

Photon energy 0.1 eV

Zero emittance

Nonzero emittance

SR in 1.7 T:
1.4 \times 10^{10}

SR in 1.7 T:
1.8 \times 10^{10} \text{ at max}
The advantages of ER

- ER is inevitably generated by BM in any storage ring
- Small heat loading: ER – 10 Wt, SR – 110 Wt at E=2.5 GeV, $I_{\text{beam}}=100$ mA, into 10 x 10 mrad$^2$ solid angle

**ER flux vs. SR flux into 10x10 mrad$^2$ solid angle**

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- Small heat loading: ER – 10 Wt, SR – 110 Wt at E=2.5 GeV, $I_{\text{beam}}=100$ mA, into 10 x 10 mrad$^2$ solid angle
Mini-undulator as a diffraction limited source of X-Ray Radiation

- Spectral brilliance of light source

\[
B = \frac{d\hat{n}/(d\omega/\omega)}{4\pi^2 \sum_x \sum_y \sum'_x \sum'_y} \quad \Sigma_{x,y} = \sqrt{\sigma_{x,y}^2 + \sigma_R^2} \quad \Sigma'_{x,y} = \sqrt{\sigma'_{x,y}^2 + \sigma'_R^2}
\]

\(\sigma_{x,y}, \sigma_R\) – electron and photon beam size, \(\sigma'_{x,y}, \sigma'_R\) – electron and photon beam divergence

- Photon beam emittance

\[
\varepsilon_{\text{ph}} = \lambda/4\pi
\]

\(\lambda\) – wavelength of radiation

- Diffraction limited emittance of phonon beam defines the minimum value of electron beam emittance at which brilliance is maximum

- Electron beam emittance is defined by magnet structure of storage ring
Emittance minimization

<table>
<thead>
<tr>
<th>Work mode</th>
<th>“standard”</th>
<th>“brilliant”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>2.5 GeV</td>
<td>1.3 GeV</td>
</tr>
<tr>
<td>Emittance</td>
<td>98 nm·rad</td>
<td>4.9 nm·rad</td>
</tr>
<tr>
<td>Beam size, mkm: $\sigma_x / \sigma_y$</td>
<td>1500/78</td>
<td>363/17</td>
</tr>
<tr>
<td>Circumference</td>
<td>124.128 m</td>
<td></td>
</tr>
<tr>
<td>Coupling, $\varepsilon_y / \varepsilon_x$</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Momentum compaction</td>
<td>0.0103</td>
<td>4.2×10⁻³</td>
</tr>
<tr>
<td>Betatron tunes: $Q_x/Q_y$</td>
<td>7.775/6.695</td>
<td>9.707/5.622</td>
</tr>
<tr>
<td>R.m.s. energy spread</td>
<td>$9.5\times10^{-4}$</td>
<td>$5\times10^{-4}$</td>
</tr>
<tr>
<td>Damping times: $\tau_x$, $\tau_y$, $\tau_s$</td>
<td>3.2; 3; 1.5 ms</td>
<td>22; 22; 11 ms</td>
</tr>
<tr>
<td>Beam current</td>
<td>100-300 mA</td>
<td></td>
</tr>
</tbody>
</table>

New brilliance lattice with horizontal emittance 18 nm·rad (on full energy) has been developed. The new lattice allows to obtain emittances $\varepsilon_x = 4.9$ nm·rad and $\varepsilon_y = 49$ pm·rad at 1.3 GeV. Thus, vertical emittance of electron beam is equal photon emittance for 2 keV photons.

Optical Function of “brilliance” structure
Undulator

Pure Permanent Magnet Structure

Wavelength of radiation $\lambda$ for planar undulator

$$\lambda_n = \frac{\lambda_u}{2\gamma^2 n} \left(1 + \frac{K_u^2}{2} + (\gamma \theta_x)^2 + (\gamma \theta_z)^2\right)$$

where $n=1,2,3...$ - harmonic number, $\theta_x, \theta_z$ – horizontal and vertical observation angle with respect to the axis.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap</td>
<td>2.2 mm</td>
</tr>
<tr>
<td>Permanent magnet material</td>
<td>NdFeB</td>
</tr>
<tr>
<td>Residual field, $B_r$</td>
<td>1.2 T</td>
</tr>
<tr>
<td>Undulator period, $\lambda_u$</td>
<td>7 mm</td>
</tr>
<tr>
<td>Pole width, $w$</td>
<td>50 mm</td>
</tr>
<tr>
<td>Parameter field decrease in horizontal direction, $\xi$</td>
<td>1.5</td>
</tr>
<tr>
<td>Field amplitude, $B_0$</td>
<td>0.75 T</td>
</tr>
<tr>
<td>Undulator parameter, $K_u$</td>
<td>0.492</td>
</tr>
<tr>
<td>Undulator length, $L_{ID}$</td>
<td>2.1 m</td>
</tr>
<tr>
<td>Wavelength radiation, $\lambda$</td>
<td>6.06 Å 2.045 keV</td>
</tr>
</tbody>
</table>

$$K_u = \frac{eB_0}{m_eck_u}$$

Undulator parameter
Angular flux density of first harmonic

Angular distribution of intensity in the horizontal plane

Angular distribution of intensity in the vertical plane

- $E = 1.3$ GeV, $I_{\text{beam}} = 100$ mA
- Computer code SMELRAD
Spectral photon flux distribution from IDs and bending magnet

- $E = 2.5 \text{ GeV}$, $I_{\text{beam}} = 100 \text{ mA}$, $\varepsilon_{x,y} = 0$
- Intensity of undulator radiation at change of gap from 2 to 10 mm

Graph showing
- SC Wiggler, 3 T
- Wiggler, 0.36 T
- Bending magnet, 1.7 T
- SC Wiggler, 7.5 T

Ph/s/mrad$^2$/0.1%BW vs. $E_{\text{ph}}$, keV
Thanks for attention
Main parameters of HiSOR storage ring

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<th>Parameter</th>
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<tr>
<td>Energy</td>
<td>700 MeV</td>
</tr>
<tr>
<td>Circumference</td>
<td>21.946 m</td>
</tr>
<tr>
<td>Bending radius</td>
<td>0.87 m</td>
</tr>
<tr>
<td>Stored current (Max)</td>
<td>100 mA</td>
</tr>
<tr>
<td>Bending field</td>
<td>2.7 T</td>
</tr>
<tr>
<td>Critical wavelength</td>
<td>1.42 nm</td>
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<tr>
<td>Length of straight section</td>
<td>8.24 m</td>
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Diagram:
- **Energy**: 700 MeV
- **Circumference**: 21.946 m
- **Bending radius**: 0.87 m
- **Stored current (Max)**: 100 mA
- **Bending field**: 2.7 T
- **Critical wavelength**: 1.42 nm
- **Length of straight section**: 8.24 m

**Experimental Data**

- **Mirror**
- **Lens**
- **BPF**
- **Polarizer**
- **NDF**
- **CCD camera**

**Main Components**
- **Linear Undulator**
- **Helical Undulator**
- **BM BM**
- **D**
- **Q Q**

**Other Components**
- **Mirror**
- **Lens**
- **BPF**
- **Polarizer**
- **NDF**
- **CCD camera**
Experimental Data

400 nm ER

950 nm ER
Conclusion

• Computer simulations of edge radiation and mini-undulator radiation spectra show that:

• Edge radiation flux far exceeds the SR flux for the photon energies less than 350 eV.

• In addition, ER beamline does not need any special insertion device.

• Insertion device with diffraction limited intensity in vertical direction is feasible at Siberia-2 storage ring