Compact ring FEL as a source of high power infrared radiation

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Outline

1. Introduction
2. General concept of the ring FEL (brief review)
3. Possible layout of the infrared ring FEL
4. Lattice of isochronous bends
5. Simulation of the ring FEL operation
6. Conclusion
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The scheme of the single-pass high gain FEL amplifier

- **Seeding laser**
- **Shot noise**
- **Incoming beam**
- **Undulator**
- **Outcoming beam**

**Exponential growth**
- **Initial stage**
- **Saturation**

**Graphical representation:**
- Z-axis: z, a.u.
- Y-axis: $|I_{0g}|^2$, a.u.
- Initial stage and saturation are indicated on the graph.
General scheme and principles of operation of ring FEL

The beam microbunching is partly conserved in the isochronous bend
Experimental observation of the coherency of radiation from two undulators

The scheme to observe radiation coherency at the achromatic bend of electrons in the magnetic system of the optical klystron on VEPP-3: M1-M5 – horizontal bending correctors; L – quadrupole lens focusing in horizontal direction; U1 and U2 undulators; TL and ML – optical telescope lens and imaging lens respectively; RS – registering screen.

Interference pictures observed at a conventional (non-achromatic) bend (a), at an achromatic bend without the delay compensation (b) and with the delay compensation (c).

R_{5.1} and R_{5.2} = 0
Signal from the old bunch to the fresh one is transferred by radiation
Ring FEL requires ERL as a source of electron beams, as the average beam power can be very high.
Circuit representation and linewidth of ring FEL

\[ u_{out}(t) = \int_{0}^{\infty} K(\tau)[I_1(t-\tau) + I_s(t-\tau)] d\tau \]

\[ I_1 = \beta I_2 = \beta F(u_{in}) \]

\[ u_{out}(t) = \int_{0}^{\infty} K(\tau)[\beta F[u_{in}(t-\tau)] + I_s(t-\tau)] d\tau \]

\[ \frac{\delta \omega}{\omega} \sim \frac{e \omega}{I} \left( \frac{\Delta \omega}{\omega} \right)^2 |K(\omega)|^2 \sim \frac{2\pi}{N_{e,\lambda_0}} \left( \frac{\lambda_w}{L_G} \right)^2 |K| \sim 10^{-9} \]

Natural linewidth is very small!
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Possible layout of the infrared ring FEL
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Lattice of isochronous bends

Typical lattice of short isochronous bend

Second order aberrations are compensated by sextupoles
Energy spread and emittance can cause debunching

\[ \frac{d}{ds} c \tau = hx - \frac{\delta}{\gamma_0^2} - \frac{h x \delta}{\gamma_0^2} + \frac{3 \delta^2}{2 \gamma_0^2} + \frac{x'^2}{2} + \frac{y'^2}{2} \]

These terms are negligible compared to the others

Choosing the proper values of sextupoles one can adjust \((x|x_0^2)\) to make \(T_{511}\) zero

\[ \sigma_{cr}^2 \leq \frac{\varepsilon_x^2}{2} \left( \int_0^s \gamma_x(s') ds' \right)^2 + \frac{\varepsilon_y^2}{2} \left( \int_0^s \gamma_y(s') ds' \right)^2 \]

Twiss parameters

\[ T_{511}(s) = \frac{1}{\beta_0} \int_0^s \left( \frac{C_x'^2}{2} + h(x | x_0^2) \right) ds' \]
Linear lattice functions $\beta_x$, $\beta_y$, and $D_x$ of the isochronous bend of the infrared (6 microns) ring FEL

$\delta_e / \rho \simeq 0$.

Table name = TW

Debunching induced by second-order aberrations is small

$\left| \langle e^{i\omega_0 \tau} \rangle \right| = 0.96$
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### Basic parameters used in simulations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron energy, MeV</td>
<td>50</td>
</tr>
<tr>
<td>Peak current, A</td>
<td>50/100</td>
</tr>
<tr>
<td>Beam charge, nC</td>
<td>1</td>
</tr>
<tr>
<td>Relative r.m.s. energy spread, %</td>
<td>0.1</td>
</tr>
<tr>
<td>Normalized r.m.s. emittance, mm×mrad</td>
<td>5</td>
</tr>
<tr>
<td>Undulator period, cm</td>
<td>6</td>
</tr>
<tr>
<td>Undulator deflection parameter $K$</td>
<td>1.5</td>
</tr>
<tr>
<td>Bend angle, degrees</td>
<td>180</td>
</tr>
<tr>
<td>Bend length, m</td>
<td>3</td>
</tr>
</tbody>
</table>

Simulation of the ring FEL operation
Simulation scheme

GENESIS simulation with zero initial radiation field and particle distribution imported from previous run.

Nonlinear phase space mapping by external code. CSR wake and quantum fluctuations are applied here.

GENESIS simulation with fresh particle distribution and initial radiation field imported from previous run.
50 A peak current case

Dependence of the electron efficiency on the pass number in ring FEL

Electron efficiency, %

Dotted curve corresponds to ideal case without CSR effects
Dependence of the beam bunching factor and peak radiation power on the longitudinal coordinate in the last undulator section

Dotted curves – CSR effects are not included

Dotted curves – CSR effects are not included
Stationary beam bunching radiation power and spectral distributions at the exit from the last undulator section

Dotted curves – CSR effects are not included,
dashed curve – beam current profile
### Parameters of the output radiation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength, μm</td>
<td>~ 6.6</td>
</tr>
<tr>
<td>Peak power, MW</td>
<td>~ 10</td>
</tr>
<tr>
<td>Pulse duration, ps</td>
<td>~ 10</td>
</tr>
<tr>
<td>Electron efficiency, %</td>
<td>0.15</td>
</tr>
</tbody>
</table>
100 A peak current case

Dependence of the electron efficiency on the pass number in ring FEL

Dotted curve corresponds to ideal case without CSR effects
Stationary beam bunching radiation power and spectral distributions at the exit from the last undulator section

Dotted curves – CSR effects are not included, dashed curve – beam current profile
Beam current distribution and electron energy deviation induced by CSR

Dotted curves illustrate the beam bunching (green) and radiation power (red) distributions
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Conclusion

✔ We have shown theoretically the feasibility of the compact high power ring FEL for the infrared region.

✔ At that we have considered the problem of beam debunching in the bends and CSR effects.

✔ The next step should be the building of such FEL and demonstrating the feasibility of the ring FEL concept in practice.
Thank you for your attention!

The end.