Case Study for 100 µm SASE FEL Based on PITZ Accelerator for Pump-Probe Experiment at the European XFEL

Start-to-End Simulations

Outline

- Introduction
- Beam Optimization
- Beam Transport
- Simulation of FEL Radiation
- Summary & Outlook

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AKBP 9.3
Introduction: IR/THz source Project at PITZ

Aims of development IR/THz sources at PITZ

- Prototype facility for an IR/THz source for pump and probe experiments planned at the European XFEL.
- Electron beam diagnostics from the radiation properties.
- Development of the experimental setup and testing of radiation diagnostics devices.

Studies for 2 types of radiation:
- High gain FEL
- Coherent Transition Radiation (CTR)

Proceedings concerning this project:
Introduction: Overview of FEL parameter space

The calculations have been performed with code FAST (Calculated by M.Yurkov & E. Schneidmiller).

Generate SASE FEL radiation wavelength of 100 µm using:

- Helical undulator with period length of 40 mm
- Electron beam with 15 MeV/c momentum, 4 nC bunch charge, ~2 mm rms bunch length

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- Transverse normalized emittance ($\varepsilon_n$) has almost no impact on saturation power.
- Higher $\varepsilon_n \Rightarrow$ shorter saturation length.
**Main Goals** - Develop, test and optimization of high brightness electron beams sources
- Commissioning and optimizing RF guns for the European XFEL

Simplified Layout of Current PITZ Beamline and Extension for THz FEL

- RF photoelectron gun solenoids (~7 MeV/c)
- Cut Disk Structure (CDS) booster (~25 MeV/c)
- UV photocathode laser
  - Cylindrical pulse shape (Gaussian, flat-top).
  - 3D-ellipsoidal pulse shape
- Electron beam diagnostics stations

Bunch charge of Few pC ... 4 nC
1. Beam Optimization
   - Tool: ASTRA
   - Z = 0 to 5.277 m

<table>
<thead>
<tr>
<th>Input Parameters for ASTRA</th>
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<tbody>
<tr>
<td>laser pulse shape</td>
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<tr>
<td>laser temporal time</td>
</tr>
<tr>
<td>rms laser spot size</td>
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<tr>
<td>Bunch charge</td>
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</table>

   - Final beam momentum ~15 MeV/c
   - Optimize gun phase*, booster phase*, main solenoid current for compromising between **High peak current** ↔ **Low energy spread**

2. Beam Transport
   - Tools: ASTRA, MADX, SC Software (developed by HZB)
   - Z = 5.277 to 22.500 m (16.023 m length)
   - Transport strategy:
     - Transverse rms size is limited to 6 mm.
     - Symmetric transverse emittances and beam sizes at the undulator entrance.

3. FEL Simulation
   - Tool: GENESIS 1.3
     - Time-dependent mode, space-charge calculation included, no seeded power
     - Helical undulator, 40 mm period length
     - Resonance wavelength of 100 µm
Optimization of Gun Phase, Booster Phase and Main Solenoid Current

The optimized parameters are:

- Gun phase = -20°
- Booster phase = -10°
- Main solenoid current = 356 A
Beam Transport to the Undulator Entrance

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
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<tbody>
<tr>
<td>$\sigma_x$ [mm]</td>
<td>0.475</td>
</tr>
<tr>
<td>$\sigma_y$ [mm]</td>
<td>0.481</td>
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<tr>
<td>$\sigma_z$ [mm]</td>
<td>2.022</td>
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<tr>
<td>$\epsilon_{n,x}$ [mm.mrad]</td>
<td>7.917</td>
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<tr>
<td>$\epsilon_{n,y}$ [mm.mrad]</td>
<td>7.599</td>
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<tr>
<td>Peak current [A]</td>
<td>199.3</td>
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<tr>
<td>$P_{z,\text{rms}}$ [keV/c]</td>
<td>134.736</td>
</tr>
</tbody>
</table>

Slice emittance

Slice rms momentum

Slice current
Results of FEL Simulation for Radiation Wavelength of 100 µm

Peak Power along the Undulator axis

Saturation length ($Z_u$) is 3.60 m.
Peak power at saturation is 186 MW.

Temporal Profile of Radiation Pulse at the Saturation ($Z_u = 3.60$ m)

Spectral Profile of Radiation Pulse at the Saturation ($Z_u = 3.60$ m)
Summary

► S2E simulation of the SASE FEL for 100 µm with actual PITZ beamline was performed.
► The results show that a radiation peak power of ~180 MW and a narrow bandwidth below 5% are achievable.

Outlook

► Improve beam transport strategy.
► Perform start-to-end simulation with 3D-ellipsoidal cathode laser, Planar undulator.

Other Talks from PITZ:

AKBP3.9  Igor Isaev  ➔ RF Field simulations
AKBP7.5  Gaurav Pathak  ➔ Gas density measurement
AKBP9.5  Georgios Kourkafas  ➔ Electron beam matching
AKBP14.1 James Good  ➔ 3D ellipsoidal laser system

Thanks for your attentions!
Backup Slides
Experimental Demonstration of 4nC Bunch Charge Generation at PITZ