RF field asymmetry simulations for the PITZ RF Photo Gun.

The PITZ RF Photo Gun
Motivation
Field simulations
Particle tracking simulations
Results
Conclusions

Igor Isaev
DPG-Frühjahrstagung
Wuppertal, 9 March 2015
The PITZ RF Photo Gun

The RF photo gun purpose is high brightness beam production for FEL application.

The RF photo gun operates with a standing wave regime in the $\pi$-mode with resonant frequency of 1.3 GHz

The gun consists of:
- normal-conducting cavity (1.6 copper cells)
- exchangeable molybdenum cathode with CuBe contact spring
- pair of solenoids

**Main parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerating gradient at the cathode, MV/m</td>
<td>60</td>
</tr>
<tr>
<td>Beam energy after gun, MeV</td>
<td>~6.5</td>
</tr>
<tr>
<td>Full RF power, MW</td>
<td>8</td>
</tr>
<tr>
<td>Number of bunches in the train</td>
<td>1..700</td>
</tr>
<tr>
<td>RF pulse, $\mu$s</td>
<td>≤800</td>
</tr>
<tr>
<td>Repetition rate, Hz</td>
<td>10</td>
</tr>
</tbody>
</table>

*Design concept for the PITZ (XFEL) injector (RF gun) – rotational symmetry of the beamline.*
Motivation

- The electron beam asymmetry was observed during emittance measurements at PITZ.
- The asymmetry is found for the beam transverse profile.
- The electron beam emittance shows additional undesirable tails which say about beam asymmetry.

Electron beam at the observation screen

**x phase space of the electron beam**

$I_{\text{main}} = 395.9, [A]$; $Q = 0.980 \pm 0.008, [nC]$

Slit axis = $X$; 6 pulses; $S_{\text{in MoI}} / S_{\text{All}} = 0.955$

**y phase space of the electron beam**

$I_{\text{main}} = 396.0, [A]$; $Q = 0.998 \pm 0.011, [nC]$

Slit axis = $Y$; 8 pulses; $S_{\text{in MoI}} / S_{\text{All}} = 1.090$
Coupler kick studies

RF field simulations (CST MWS):

- The full model of the gun:
  - the gun cavity
  - the coupler
  - simplified cathode
- Frequency domain solver (F-solver)
- Tetrahedral mesh (~10^6 elements) with 2nd order curved elements
- Half structure symmetry

The kick origin is:
- asymmetric transition for WR650 to coaxial waveguide
- Too short coaxial antenna
Model for particle tracking

Particle tracking in CST particle studio

- The simplified model of the gun:
  - 2 cylinders for particle tracking
  - 2 simplified cathode models

- Solver:
  - Tracking (Trk)
  - Particle in cell (PIC)

- Hexahedral mesh (~1.2 \( \cdot 10^6 \) elements)

- Imported RF fields for the limited volume

Imported electrical RF field distribution
Particle tracking in CST particle studio. Trk solver.

Numerical effect must be 0

x kick angle:
- w/o solenoid: $k_x = 0.01$ mrad
- w/ solenoid: $k_y = 0.38$ mrad

y kick angle:
- w/o solenoid: $k_x = 0.66$ mrad
- w/ solenoid: $k_y = 0.27$ mrad
Particle tracking in CST particle studio. PIC solver.

- Particle-in-cell solver
- Hexahedral mesh (~4.7\cdot10^6 elements)
- Imported fields for the limited volume

- Particle source parameters:
  - 0.6 mm radius
  - 22 ps flattop pulse length
  - 1 nC bunch charge

  x kick angle: $k_x = 0.31$ mrad
  y kick angle: $k_y = 0.37$ mrad

<table>
<thead>
<tr>
<th>Frame</th>
<th>Time, ps</th>
<th>Z mean position, mm</th>
<th>X mean position, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0020</td>
<td>100.1</td>
<td>18 (1st cell)</td>
<td>0</td>
</tr>
<tr>
<td>0140</td>
<td>700.2</td>
<td>196 (RF coupler region)</td>
<td>-0.006</td>
</tr>
<tr>
<td>0546</td>
<td>2730.1</td>
<td>803 (LOW.Scr1)</td>
<td>-0.251</td>
</tr>
<tr>
<td>1152</td>
<td>5760.1</td>
<td>1708 (LOW.Scr3)</td>
<td>-0.589</td>
</tr>
</tbody>
</table>

Detailed studies of the kick impact onto the phase space (emittance) are ongoing.
Conclusions

- CST MWS simulations of the realistic PITZ (XFEL, FLASH) RF gun setup have revealed an **RF field asymmetry** within the coaxial coupler area. This **transverse kick** onto the accelerating particles is considered as possible reason of the electron beam asymmetry experimentally observed at PITZ.

- Particle tracking studies using CST PS yield an estimation of the **transverse kick** on to the beam centroid for the nominal PITZ (XFEL) gun conditions (6.5MeV electron beam, solenoid on):

<table>
<thead>
<tr>
<th>Coupler transverse kick</th>
<th>Particle tracking (no SC)</th>
<th>PIC (+SC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w/o solenoid</td>
<td>w/ solenoid</td>
</tr>
<tr>
<td>$k_x$ (mrad)</td>
<td>0.01</td>
<td>0.38</td>
</tr>
<tr>
<td>$k_y$ (mrad)</td>
<td>0.66</td>
<td>0.27</td>
</tr>
</tbody>
</table>

- The RF kick together with solenoid field can introduce a **X-Y coupling** into the phase space of electron beam. More detailed studies of this effect, its impact onto transverse phase space have to be performed. The transient effect (transverse to temporal coupling) has to be studies as well.

- In order to avoid (reduce) the RF field asymmetry a **re-design** of the coupler area is required.
Outlook. Another models of coupler.

Only symmetrical design of an RF coupler can provide symmetrical fields at the gun cavity input.
Thank you for your attention.

Other Talks from PITZ:

- AKBP7.5  Gaurav Pathak  ➔ Gas density measurement
- AKBP 9.3  Prach Boonpornprasert  ➔ Start-to-End Simulations for a 100 $\mu$m SASE FEL at PITZ
- AKBP9.5  Georgios Kourkafas  ➔ Electron beam matching
- AKBP14.1  James Good  ➔ 3D ellipsoidal laser system