Design of the THz CTR/CDR Station at PITZ

Outline

- Introduction
- Modifying of the screen station
- THz Diagnostics System
- THz Transport Calculations
- Summary & Outlook

Prach Boonpornprasert
PITZ Collaboration Meeting
DESY, Zeuthen site
13.06.2017
PITZ-like accelerator as the IR/THz source for pump probe experiments at the European XFEL

- Accelerator based IR/THz source meets all requirements for pump-probe experiments at Eu-XFEL (such as matching time structure, wide tunability range, good stability, etc.)
- Construction of a radiation shielded annex (like present PITZ facility) is possible close to user experiments at the European XFEL
- Prototype of the accelerator already exists – it is PITZ facility at DESY in Zeuthen
- Can be excellent investment of efforts of accelerator consortium after finishing construction and commissioning phases of the European XFEL

⇒ PITZ can serve as prototype for such a development
Case studies of THz radiation generation produced by the PITZ electron beam

**PITZ Highlights:**
- Pulse train structure
- High charge feasibility (4 nC)
- Advanced PC laser shaping
- E-beam diagnostics
- Available tunnel annex
- ...

**Current PITZ “boundary conditions”:**
- 22-25 MeV/c max
- No bunch compressor
- ...

**Progress on design and installation of the CTR/CDR station will be presented in this talk.**

Coherent Transition Radiation (CTR) and Coherent Diffraction Radiation (CDR) for $\lambda_{\text{rad}} \geq 100 \mu\text{m}$ ($f \leq 3 \text{ THz}$)

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CTR and CDR

Coherent Transition Radiation (CTR)

- TR energy ($U_{TR}$) emitted in the frequency range $d\omega$ into the solid angle $d\Omega$ can be calculated by Ginzburg-Frank Formula.

- CTR energy from an electron bunch can be expressed as
  \[
  \left(\frac{d^2U_{CTR}}{d\omega d\Omega}\right)_{bunch} \propto N^2 |F_{long}(\omega)|^2 \left(\frac{d^2U_{TR}}{d\omega d\Omega}\right)_{1-electron}
  \]
  where $N$ is number of electrons in the bunch and
  \[
  F_{long}(\omega) = \int_{-\infty}^{+\infty} \rho_{long}(t)e^{-i\omega t} dt
  \]
is longitudinal form factor of the electron bunch.

Coherent Diffraction Radiation (CDR)

- DR energy ($U_{DR}$) from a circular aperture radius $r$ can be calculated by
  \[
  \left(\frac{d^2U_{DR}}{d\omega d\Omega}\right)_{1-electron} = D(\omega, r) \left(\frac{d^2U_{TR}}{d\omega d\Omega}\right)_{1-electron}
  \]
  where $D(\omega, r)$ is the correction for DR.

- CDR energy from an electron bunch can be expressed as
  \[
  \left(\frac{d^2U_{CDR}}{d\omega d\Omega}\right)_{bunch} \propto N^2 |F_{long}(\omega)|^2 \left(\frac{d^2U_{DR}}{d\omega d\Omega}\right)_{1-electron}
  \]
Experimental optimization of electron beams

**Velocity bunching**

- Plot showing current (A) vs. time (ps) for different charges (250pC, 100pC, 20pC).
- Plot showing $N^2|\langle \Delta n \rangle|^2$ (a.u.) vs. frequency (THz) for different charges.

**Comb beams using the pre-modulated photocathode laser**

- Plot showing current (A) vs. time (ps) for different charges (100pC, 250pC, 500pC).
- Plot showing $N^2|\langle \Delta n \rangle|^2$ (a.u.) vs. frequency (THz) for different charges.

**Calculated radiation pulse energy**

- Graph showing pulse energy (μJ) vs. bunch charge (pC) for CTR and CDR.

**Other option for producing comb beams**

- Dielectric-lined Waveguide

Courtesy: F. Lemery, P. Piot, et. al
Modifying of the screen station

This screen station (PST.Scr2) has been modified to be a CTR/CDR station.

Top viewport is used as a THz window.

Acceptance angle for "backward" CTR/CDR is 0.4 rad.

Additional components
- THz window
- CTR/CDR radiators ➔ new screen holder
- THz diagnostics system

Layout of PST.Scr2 (initial)
Modifying of the screen station (2)

On the new holder...

1. YAG screen (36 mm x 55 mm)
2. Empty space (Φ = 36 mm)
3. CTR radiator (Al plate, 27mm x 55 mm)
4. 2 CDR radiators
   - gap, 2 mm
   - circular hole on Al plate, Φ = 2 mm

THz diagnostics system

Machining of the screen holder

To THz diagnostics system

THz window (z-cut crystal quartz)

To CCD camera

To THz diagnostics system

Machining of the screen holder

Machining of the screen holder

Courtesy: G. Koss

THz window (z-cut crystal quartz)

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Prach Boonpornprasert | Design of THz CTR/CDR Station at PITZ | 13.06.2017 | Page 7 / 15
THz diagnostics system

- THz radiation diagnostics system is placed in the tunnel, normal room environment.
- The system is used to measure radiation power, spatial profile, polarization and spectrum.
- Measure “macro-pulse” radiation properties (10 Hz repetition rate).

Example of setup as a Michaelson interferometer for spectrum measurement

P means 90° off axis parabolic mirror
F means flat mirror

Courtesy: G. Koss
THz diagnostics system (Components)

**Gold coating mirrors**
- 1/2” parabolic mirror
- 2” flat mirror
- 4” parabolic mirror

**HRFZ-Si Beam splitter**

**HDPE Polarizer**

**THz pyroelectric detector**
Test of THz transport calculations

- Tool ➔ THzTransport code (B.Schmidt, DESY HH)

- Input for the tool
  - Transition radiation from a 45° oblique screen with the size of **27 mm x 55 mm**
  - Electron beam parameters: $\sigma_{xy} = 150 \, \mu m$, $P_z = 15 \, MeV/c$ and $Q_{\text{bunch}} = 500 \, pC$.
  - The grid parameters were **not** optimized.
  - Transport in **2D** space (no mirror rotation)

<table>
<thead>
<tr>
<th>Location</th>
<th>S [mm]</th>
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<tbody>
<tr>
<td>CTR screen ➔ P1</td>
<td>152.4</td>
</tr>
<tr>
<td>P1 ➔ P2</td>
<td>276.2</td>
</tr>
<tr>
<td>P2 ➔ P3</td>
<td>167.4</td>
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<tr>
<td>P3 ➔ beam splitter</td>
<td>80.0</td>
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**Layout for the transport calculations**
Test of THz transport calculations (2)

10 THz

1 THz
Test of THz transport calculations (3)

0.5 THz

0.1 THz
Test of THz transport calculations (4)

Ratio of intensity ($I$) at different locations to the intensity at P1 ($I_{at\ P1}$)

Transport from P2 to the beam splitter has to be re-designed
Summary & Outlook

- Design and installation of the THz station is ongoing.
- The THz transport was calculated. ➔ have to re-design

Experimental plan

- **Schedule:**
  - July 2017 ➔ Installation of the station
  - August 2017 ➔ First experiments

- 2 cases: velocity bunching, comb PC (optional: dielectric waveguide).

- **Challenges**
  - Laser pulse shaping
  - Low pulse energy ➔ may require ~600 e-bunches/RF pulse
  - Cannot do the optics alignment during the experiments

Next step

- Improvement of the THz transport
- Using of a THz camera
- Single-shot radiation measurement ➔ Electro-optical sampling (EOS).
Acknowledgment

- **DESY, Zeuthen**
  M. Krasilnikov, G. Koss, S. Philipp, J. Good, T. Rublack and the PITZ team

- **DESY, Hamburg**
  B. Schmidt, B. Marchetti, G. Vashchenko, M. Yurkov and E. Scheidmiller

- **HZDR, Dresden**
  M. Gensch

- **Chiang Mai University, Chiang Mai, Thailand**

Thank you for your attention
BACKUP SLIDES
### Parameters of PST.SCR...

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<thead>
<tr>
<th>Viewports Material Size</th>
<th>PST.SCR</th>
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<tr>
<td>VAB SFK 63 Q Fused silica CF 63</td>
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<table>
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<tr>
<th>Number available viewports</th>
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<tr>
<th>Drive system</th>
<th>Stepper motor</th>
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<th>Number of actuators needed for 3 screens*</th>
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<table>
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<tr>
<th>Rotation possible</th>
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<th>Viewport diameter (mm)</th>
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<table>
<thead>
<tr>
<th>Distance from centre of screen to viewport (mm)</th>
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<table>
<thead>
<tr>
<th>Acceptance angle (rad) **</th>
<th>0.3998</th>
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</table>
Setup as a Michaelson interferometer with a radiation collector
Setup for the spatial profile measurement

- Shielding plate with a hole 2D movable (y-z)
- Pyroelectric detector
- Radiation collector
- Polarizer
- E-beam
- PST.Scr2 viewport

Prach Boonpornprasert  |  Design of THz CTR/CDR Station at PITZ  |  13.06.2017  |  Page 19 / 15
Dimension of the radiation collector

- 10 mm
- 56.05 mm
- 50.8 mm
- 20°
Outlook: Possible “PITHz” Layout

Supplementary Systems and Infrastructure

General: Radiation protection and personal IL
Control system and DAQ

Water Cooling System
Electronics: e-beam diagnostics
Electronics: THz diagnostics

Laser(s)
UED
Modulator
CTR
Chicane BC
CTR
THz diag

Undulator

RF gun
DLW
CDs-1
DLWslab
CDs-2

10MW MBK
10MW MBK

Magnets power supplies
S-band Klystron
Vacuum components supplies

Hardware costs: VERY rough estimations

Table:

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<th>Section</th>
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<th>endZ</th>
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<td>2</td>
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<tr>
<td>Matching 6</td>
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<td>25</td>
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\[Σ \approx 15 \text{M€}\]