Screen investigations for low energetic electron beams at PITZ

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Contents

- Review of PITZ setup
- Screens and beam profile monitors at PITZ
- Test results
- Summary
Optimization of L-band Photo Cathode RF gun @ PITZ

- Photo cathode (Cs₂Te), QE~0.5-5%
- 1.6 cell RF un NC (copper)
- Main solenoid, Bz_peak~0.2T
- Bucking solenoid
- Coaxial RF coupler
- Cathode laser
- Electron bunch
- Mirror in vacuum

**Parameter** | **Value**
---|---
Max. RF repetition rate | 10 Hz
Max. RF power | 6 MW peak power
Max. RF pulse length | 800 μs
No. of pulses / train | 1 – 800
Bunch spacing | 0.2 – 1 μs
Max. bunch charge | a few nC
Current PITZ Setup (PITZ1.8)

high energy section (p_z ~24.8 MeV/c)  low energy section (p_z ~6.7 MeV/c)

- RF gun
- Booster
- Low Energy Diagnostics Section
- Trans. phase space reconstruction @ Tomography module
- Trans. projected emittance & phase space @ Emittance Measurement SYstem (EMSY)

Symbols:
- BPM
- ICT
- Optical screens
- Quadrupoles
- RF gun
- Matching Section
- Wire Scanner

Notes:
- Wire Scanner
- Spectrometer
- EMSY2
- EMSY1
- EMSY3
- DISP1
- DISP2
- DISP3
**Measurements of Transverse Projected Emittance & Phase Space**

**Single slit scan technique**
- **EMSY** stations consist of horizontal / vertical actuators with
  - YAG / OTR screens
  - 10 / 50 μm slits
- Beam size is measured @ EMSY position
  - Beam RMS sizes: 0.2 – 2.5 mm
- Beam divergence is estimated from beamlet sizes @ observation screen
  - Minimum beamlet RMS sizes: ~50 μm

**Phase space reconstruction**
- **tomography module** consists of
  - 3 FODO cells
  - 4 screen station
  - Phase advance of 45°
- Beam size is measured with a YAG / OTR screen
  - Minimum beam RMS sizes: 120 μm
Ce-doped Yttrium Aluminum Garnet (YAG) Powder Coating Screen

<table>
<thead>
<tr>
<th>Chemical formula</th>
<th>Y₃Al₂.₅Ga₂.₅O₁₂:Ce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of YAG powder layer</td>
<td>5 - 20 µm</td>
</tr>
<tr>
<td>Density of YAG power</td>
<td>5.1 g/cm³</td>
</tr>
<tr>
<td>Thickness of silicon substrate</td>
<td>100, 275, 380 µm</td>
</tr>
<tr>
<td>Density of silicon substrate</td>
<td>2.33 g/cm³</td>
</tr>
<tr>
<td>Incident angle</td>
<td>90°</td>
</tr>
<tr>
<td>Wavelength of peak emission</td>
<td>510 nm</td>
</tr>
</tbody>
</table>

YAG screen viewed by 12 bits camera

Resolution of beam image
- Beamlet image from 10 µm slit (03.06.2009)
  - Beam momentum ~14.7 MeV/c
  - Measured @ 1.76 m from slit position
- Detail structure of image ~50 µm
- Vertical RMS size <70 µm

YAG screen viewed by 12 bits camera

Resolution of beam image

![Graph showing beam image resolution with X_rms = 0.324 and Y_rms = 0.068]
Optical Transition Radiation (OTR) Screen

Material: Si-wafer with Al coating
Thickness of silicon wafer: 100 or 275 μm
Incident angle: 45°
Consider wavelength range: 400 – 750 nm

Beam energy increase from ~15 to ~25 MeV
- Δ(energy) ~10 MeV
- Δ(intensity) ~40%
Wire Scanner (WS)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire material</td>
<td>tungsten</td>
</tr>
<tr>
<td>Wire size</td>
<td>20 μm</td>
</tr>
<tr>
<td>Average step size used in measurements</td>
<td>100 μm</td>
</tr>
</tbody>
</table>

**Measured beamlet Y-profile from 50 μm slit**

Measured with two straight wires (10 mm distance)

Reference: Grabosch, FEL2007
Chemical Vapour Deposition (CVD) Diamond Screen

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>thickness</td>
<td>100 µm</td>
</tr>
<tr>
<td>diameter</td>
<td>30 mm</td>
</tr>
<tr>
<td>Incident angle</td>
<td>45°</td>
</tr>
<tr>
<td>High thermal conductivity</td>
<td>5 times higher than Cu</td>
</tr>
<tr>
<td>Emission wavelengths</td>
<td>415 – 478 nm</td>
</tr>
</tbody>
</table>

Reference: M. Degenhard, “CVD Diamond Screens for Beamline Diagnosis at PETRA III”, not yet publish
Comparison of YAG screen and wire scanner (WS)

WS (z = 9.47 m)

H1.S4 (z = 8.34 m)

H1.S5 (z = 8.92 m)
Workshop on Scintillating Screen Applications in Beam Diagnostics, GSI, Darmstadt, February 14th-15th, 2011

YAG screen and wire scanner (WS): beam size & profile

rms beam size: $\sigma_{xy} = \sqrt{\sigma_x \sigma_y}$

- Fixed parameters:
  - Momentum $\sim 24.5$ MeV/c
  - 1 bunch per train
  - Focusing (fixed main solenoid current)
  - Camera gain: 2 dB for H1.S4, 7 dB for H1.S5

- Varied parameters:
  - Bunch charge $\sim 0.1, 0.2, 0.4, 0.6, 0.8, 1$ nC

X-profiles for Q$\sim$500 pC
Comparison of YAG and OTR Screens

* use 12 bit camera and adjusted camera gain and no. of pulses to have intensity a bit below saturation
YAG and OTR screens: comparison of RMS beam size

RMS beam size: \( \sigma_{xy} = \sqrt{\sigma_x \sigma_y} \)

- \( \sigma_{xy} \): geometrical mean RMS size
- \( \sigma_x \): horizontal RMS size
- \( \sigma_y \): vertical RMS size

\[ \delta\sigma(\%) = \left( \frac{\sigma_{YAG} - \sigma_{OTR}}{\sigma_{OTR}} \right) \times 100\% \]

- \( <\delta\sigma_x> \sim 16.8\% , <\delta\sigma_y> \sim 14.9\% , <\delta\sigma_{xy}> \sim 15.8\% \)

<table>
<thead>
<tr>
<th>Screen station</th>
<th>YAG screen ( \sigma_x ) (mm)</th>
<th>YAG screen ( \sigma_y ) (mm)</th>
<th>OTR screen ( \sigma_x ) (mm)</th>
<th>OTR screen ( \sigma_y ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PST.Scr1</td>
<td>0.342</td>
<td>0.280</td>
<td>0.304</td>
<td>0.244</td>
</tr>
<tr>
<td>PST.Scr2</td>
<td>0.246</td>
<td>0.229</td>
<td>0.210</td>
<td>0.201</td>
</tr>
<tr>
<td>PST.Scr3</td>
<td>0.245</td>
<td>0.266</td>
<td>0.204</td>
<td>0.226</td>
</tr>
<tr>
<td>PST.Scr4</td>
<td>0.290</td>
<td>0.257</td>
<td>0.246</td>
<td>0.228</td>
</tr>
</tbody>
</table>

- **Included** correction of different optical path length for YAG and OTR
  - Not yet corrected for depth-of-field from 45° mounting configuration
- **Fixed parameters**
  - Momentum ~24.8 MeV/c
  - No. of bunch per train: 1
  - Camera gain
  - Focusing (solenoid & quadrupole)
Intensity is linearly proportional to bunch charge
- Measured @ H1.S4
- Fixed parameters:
  - Momentum ~24.8 MeV/c
  - Camera gain: 2 dB
- Varied parameters:
  - No. of bunches per train
  - Focusing (adjusted solenoid current to have the same beam area)

Intensity is linearly proportional to camera gain
- Measured @ H1.S5
- Fixed parameters:
  - Momentum ~24.8 MeV/c
  - Bunch charge: YAG (200 pC), OTR (1 nC)
- Varied parameters:
  - Camera gain
  - No. of bunches per train
  - Focusing

Intensity per bunch = intensity per bunch per charge

factor of ~25
RMS beam size: \[ \sigma_{xy} = \sqrt{\sigma_x \sigma_y} \]

RMS beam size and intensity vs. momentum @ H1.S5
- Included correction of beam size due to different optical path length
- Varied parameters:
  - No. of bunches per train
  - Bunch charge per train: YAG (200 pC), OTR (1 nC)
  - Camera gain
  - Focusing (solenoid current)
YAG and OTR screens: intensity distribution & projection profiles

YAG screen shows more detail structure of the beam image & profile (OTR: smoothing image and profiles)

- **Fixed parameters:**
  - Momentum ~24.5 MeV/c
  - Bunch charge: 1 nC
  - Focusing
  - Camera gain: 1 dB

- **Varied parameters:**
  - No. of bunches per train
    - YAG: 1 bunch
    - OTR: 24 bunches
Comparison of YAG and CVD diamond Screens

Optical system is not yet optimized: measured beam size value was not yet reliable
YAG and CVD diamond screens: sensitivity

**Integrating intensity vs. bunch charge @ H2.S4**

- **Fixed parameters:**
  - Momentum \( \sim 24.8 \text{ MeV/c} \)
  - Camera gain: 20 dB

- **Varied parameters:**
  - No. of bunches per train
  - Focusing

\[
\delta \sigma = \left( \frac{\sigma_{\text{YAG}} - \sigma_{\text{CVD-diamond}}}{\sigma_{\text{CVD-diamond}}} \right) \approx 36\%
\]
YAG and CVD diamond screens: dependence on momentum

RMS beam size vs. beam momentum @ H2.S4
- Fixed parameters:
  - Momentum: ~24.8 MeV/c
  - Bunch charge: 1 nC
  - Camera gain: 20 dB
- Varied parameters:
  - No. of bunches per train: YAG (1 bunch), CVD diamond (5 bunches)
  - Focusing (solenoid)

Intensity = integrating intensity per bunch per beam area

CVD diamond screen has more smoothing image and profiles
Summary & Outlooks

- Properties of YAG powder coating, OTR and CVD screens @ PITZ were summarized
- Test results of different screen type were presented
  - Sensitivity: YAG > CVD diamond > OTR
  - OTR provided smaller RMS beam size than YAG

<table>
<thead>
<tr>
<th>Screen</th>
<th>Sensitivity</th>
<th>RMS beam size</th>
</tr>
</thead>
<tbody>
<tr>
<td>YAG</td>
<td>100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>OTR</td>
<td>4 %</td>
<td>84 %</td>
</tr>
<tr>
<td>CVD diamond</td>
<td>20 %</td>
<td>to be investigated</td>
</tr>
</tbody>
</table>

- Experimental tests to compare RMS beam sizes and beam profiles from wire scanner and from YAG screen at two locations were performed with different bunch charges
  - Results showed good agreement for both beam size and projection profiles
Acknowlegdements

- G. Asova for data taken at the tomography module
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Thank you for your attention!