Selected Beam Studies at PITZ in 2016 (2nd ½)

- Motivation
- Correction of electron beam asymmetry
- Slice energy spread and longitudinal phase space measurements
- Studies on spiky structure of electron beam trains
- Some issues of the flattop pulse shaping

M. Krasilnikov
DESY-TEMF-Meeting, 23.01.2017
Beam at High1.Scr1 (EMSY at z=5.74m)

I main = -361 A, I bucking = 0 A

I main = +361 A, I bucking = 0 A

Main solenoid current is 361 A, normal and opposite polarity, bucking current is 0

E-beam X-Y asymmetry: Larmor angle experiment

Measurements (29.09.2015M-A):

- P\textsubscript{gun}=5MW (6.1MeV/c max)
- Launch phase: MMMG
- Cathode laser:
  - Gaussian 11.5 ps FWHM (expected)
  - BSA=1.2mm (VC2)
- Charge 0.5 nC

<table>
<thead>
<tr>
<th>Cathode</th>
<th>Z=0.18m</th>
<th>EMSY (z=5.74m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I main = +361A</td>
<td>![Beam image]</td>
<td>![Beam image]</td>
</tr>
<tr>
<td>I main = +361A</td>
<td>![Beam image]</td>
<td>![Beam image]</td>
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<tr>
<td>I main = -361A</td>
<td>![Beam image]</td>
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<tr>
<td>I main = -361A</td>
<td>![Beam image]</td>
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45° kick at z=0.18m \(\rightarrow\) skew quadrupole?
Simulations with rotation quads model (Q. Zhao)

Use rotation quads model in ASTRA simulation by scanning the rotation angle and z position.

- Find the parameters for beam images at High1.Scr1 to fit the experiment images, the direction of the beam wings for both solenoid polarity.
- 2D-3D space charge used in ASTRA simulation, z_trans=0.12m.

I main = -361A

I main = +361A

~13 degree

~78 degree

Summary of the simulations:

✓ Position: around z=0.18m
  - Rotation angle: Skew quads: 45 degree (negative polarity) / 135 degree (positive polarity).
  - Polarity: same, not effected by solenoid field polarity.

✓ Position: around z=0.34m
  - Rotation angle: Normal quads.
  - Polarity: when change the solenoid polarity, the quads polarity also changed.

Images table from simulation analysis

<table>
<thead>
<tr>
<th>Solenoid polarity [A]</th>
<th>rotation quad position at z = 0.18 m, beam image at High1 Scr1</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-361)</td>
<td>Experiment 5MW</td>
</tr>
<tr>
<td>(-0.6)</td>
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<tr>
<td>(+0.6)</td>
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<tr>
<td>(-0.6)</td>
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<tr>
<td>(+0.6)</td>
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Quads rotational angle [degree]

<table>
<thead>
<tr>
<th>0</th>
<th>5</th>
<th>10</th>
</tr>
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<tbody>
<tr>
<td>-0.6</td>
<td>0.6</td>
<td>-0.6</td>
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</tbody>
</table>

Q_length(1)=0.01, Q_K(1)= \(+0.6\), Q_pos(1)= x.xx, Q_zrot(1)= y.yy

Experimental setup:
Pgun=5MW, 6.178 MeV/c, gradient is 54.2 MeV/c, 500 pC, no booster
05.09A-06.09N.2015.
First design of the GUN Quad (I. Isaev)

- Aluminum frame
- 0.56 mm copper cable
- 180 windings per coil
- 2 thermal switchers (80 degC max)
- Non-magnetic screws
- Fixed by radiation-hard cable tie
- Usage with 3A power supply
Gun Quad tests (I. Isaev)

> Heating test at 3A

![Graph showing temperature over time with heating and cooling curves, with simulations line.

- $I = 3\,A$
- Surface temperature: 84.7 degC
- Maximum temperature: 86.7 degC

> Field measurements

![Graph of single coil measurements and quad field profile at 9.9 mm distance.

- $Q_{\text{grad}} = 0.0207\,T/m$ at 1A
Experiment with single gun quad

**Experimental setup:** BSA = 1.2mm / Gun power = 5MW / GunPhase = MMMG / Charge = 500pC / I_Bucking = 0A / Booster OFF.

### Normal oriented Gun Quad

- **Gun.Q1=0A**
  - Imain=+335A, Gun.Q1=0A
  - Imain=-335A, Gun.Q1=0A

### E-beam X-Y at High1.Scr1

### Skew oriented Gun Quad

- **Imain=+336A, Gun.Q1=0A**
- **Imain=-336A, Gun.Q1=0A**
- **Imain=+336A, Gun.Q1=-0.5A**
- **Imain=-336A, Gun.Q1=-0.5A**

### Gun.Q1 is applied

- **Imain=+335A, Gun.Q1=+0.5A**
- **Imain=-335A, Gun.Q1=-0.5A**
- **Imain=-335A, Gun.Q1=+0.5A**
- **Imain=+335A, Gun.Q1=-0.5A**
Emittance measurements with single gun quad

Gun.Quad = 0A

Skew oriented Gun Quad

Normal oriented Gun Quad

EMSY picture

X phase space

Y phase space

Gun.Quad = 0A

EMSY picture

X phase space

Y phase space
Second design: Gun.Q1 and Gun.Q2 (I. Isaev)

Parameters:
- Combination of a normal and a skew quads
- Aluminum frame
- 0.56 mm copper cable
- 140 windings per coil
- 2 thermal switchers (80 degC max)
- Non-magnetic screws
- Fixed by radiation-hard cable tie
- \( Q_{\text{grad}} = 0.0117 \, \text{T/m @ 1A} \)
**Experiment with two quads**

**Experimental setup:** BSA = 1.2mm / Gun power = 5MW / GunPhase = MMMG / Charge = 500pC / I_Bucking = 0A / Booster OFF.

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<tbody>
<tr>
<td>Low.Scr2</td>
<td>GQ1, A</td>
<td>0.7</td>
<td>-0.3</td>
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<tr>
<td></td>
<td>GQ2, A</td>
<td>-0.2</td>
<td>-0.6</td>
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<tr>
<td>Low.Scr3</td>
<td>GQ1, A</td>
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<tr>
<td></td>
<td>GQ2, A</td>
<td>0.0</td>
<td>-0.7</td>
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<td>Hihg1.Scr1</td>
<td>GQ1, A</td>
<td></td>
<td></td>
<td>+0.55</td>
<td>-0.55</td>
<td>0.2</td>
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<td>-0.6</td>
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<td>GQ2, A</td>
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<tr>
<td>High1.Scr3</td>
<td>GQ1, A</td>
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<td></td>
<td>0.2</td>
<td>-0.6</td>
<td>0.5</td>
<td>-0.9</td>
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<tr>
<td></td>
<td>GQ2, A</td>
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<td></td>
<td></td>
<td>-0.5</td>
<td>-0.2</td>
<td>-0.7</td>
<td>0.1</td>
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</table>
Influence on measured emittance

- \( X_{emit} = 1.60 \text{mm mrad} \)
- \( Y_{emit} = 1.23 \text{mm mrad} \)
- \( XY_{emit} = 1.41 \text{mm mrad} \)

**Gun.Q1 = 0A, Gun.Q2 = 0A**

**X phase space**

- Mean \( x = -6.515 \)
- Mean \( y = 10.200 \)
- RMS \( x = 0.395 \)
- RMS \( y = 0.274 \)

**Y phase space**

- Mean \( x = 6.507 \)
- Mean \( y = 16.172 \)
- RMS \( x = 0.276 \)
- RMS \( y = 0.347 \)

**GQ1 = -0.6A, GQ2 = -0.6A**

**X phase space**

- \( X_{emit} = 1.34 \text{mm mrad} \)
- \( Y_{emit} = 1.47 \text{mm mrad} \)
- \( XY_{emit} = 1.41 \text{mm mrad} \)

**Y phase space**
Experiment on beam tilt in LEDA

Parameters:
• 5.04 MW in the gun
• 5.9 MeV/c
• MMMG phase
• Dipole current = -1.55A
• $I_{main} = 380A$ (407A was used for momentum measurements)

GQ1 – normal quad
GQ2 – skew quad
Beam asymmetry: Summary and Outlook

- Two gun quad designs are modeled, produced and tested
- It is possible (partially) compensate the beam X-Y asymmetry for all solenoid settings (current and polarity)
- Compensation of the beam asymmetry requires 2 quads (N- and Skew) setup, which is currently in the operation
- E-beam tilt in LEDA can be compensated
- Gun quads make emittance and transverse phase space more symmetric, but not smaller*

- A beam shape evaluation and optimization algorithm has to be improved
- Further experiments on emittance with optimized beam steering (trajectory) and on beam tilt in LEDA for systematic dependencies $GQ1/2=F(I_{\text{main}}, P_{\text{gun}}, \text{GunPhase}, \ldots)$ have to be prepared
- The position and geometry of the gun quads must be optimized for better beam asymmetry compensation
δE-program at PITZ (from the last meeting)

Idea: establish δE measurements (best resolution and flexibility) and measure δE for various conditions (temporal profiles, SC effect, etc.)

Motivation from DESY-HH:
- Initial δE for micro-bunching instability studies (M. Dohlus)

Motivation from PITZ:
- Measurements vs. simulations
- Improve measured σE (projected) understanding
- Detailed emission modeling (e.g. zero-crossing phase)

**ASTRA simulations with “Pz-heater” at cathode (z=0)**

![Graph showing ASTRA simulations with "Pz-heater" at cathode (z=0).]
Photocathode laser: transverse distribution at VC2 (17.11.2016 20:58)

BSA = 0.75 mm

XYrms = 0.186 mm

Xrms = 0.179 mm

Yrms = 0.194 mm

XYrms = 0.186 mm

Used in ASTRA simulations
XYrms = 0.186 mm
Trms = 4.88 ps
(11.5 ps FWHM)
δE Measurements with long Gaussian on 17.11.2016A-N: Pz-gun

- LEDA scan (17.11.2016 21:29)
  - Measured at LEDA
    - $E_{max} = (6.4937 \pm 0.0017)$MeV/c at $-130^\circ$
    - $p_{RMS} = (2.30 \pm 0.12)$keV/c at $-134^\circ$

- LEDA projection at MMMG phase, -138 deg (17.11.2016 21:30)
  - Phase: $-138^\circ$
    - Statistics (Img): 59
    - Statistics (Bkg): 50
    - $p_{\text{mean}} = (6.4916 \pm 0.0019)$MeV/c
    - $p_{\text{RMS}} = (6.4 \pm 1.9)$keV/c

- LEDA scan (17.11.2016 23:11)
  - Measured at LEDA
    - $E_{max} = (6.4887 \pm 0.0015)$MeV/c at $-137^\circ$
    - $p_{RMS} = (2.69 \pm 0.15)$keV/c at $-134^\circ$

- LEDA projection at MMMG phase, -138 deg (17.11.2016 23:30), + fine tuned solenoid
  - Phase: $-138^\circ$
    - Statistics (Img): 50
    - Statistics (Bkg): 50
    - $p_{\text{mean}} = (6.4818 \pm 0.0014)$MeV/c
    - $p_{\text{RMS}} = (6 \pm 2)$keV/c
Longitudinal Phase Space measurements: TDS SP scan in HEDA2

Square of measured slice energy spread (keV²)

\[ y = 3294x^2 - 53.39x + 49.41 \]
\[ R^2 = 0.9996 \]

Pz~22MeV/c
Slice energy spread: systematic errors estimation

Slice energy spread measurement

- Real slice energy spread
- TDS contribution
- Beta function contribution

\[ \delta_{E\text{ measured}} \approx \sqrt{\left(\delta_{E\text{ real}}\right)^2 + \left(\delta_{E\beta}\right)^2 + \left(\delta_{E\text{TDS}}\right)^2} \]

8.2 keV for TDS zero (Short Gaussian)

\[ y = 4187.1x^2 + 4E-12x + 66.833 \]
\[ R^2 = 0.9964 \]

6.8 keV for TDS zero (Long Gaussian)

\[ y = 3112.6x^2 + 46.229 \]
\[ R^2 = 0.9994 \]

Measurement example

20161113N ↔ 20161117N
100 pC, 0.75 mm
ASTRA simulations with long Gaussian (11.5 ps FWHM) photocathode laser pulse

Measurements SP(TDS)=0.25

~7keV/c
Some recent observations (21-22.01.2017M)

- E-beam momentum modulations observed in:
  - LEDA (Pz~6.4MeV/c)
  - HEDA1 (Pz~22.1MeV/c)

### Temporal profile FWHM
Long Gaussian ~11-11.5ps
Slice energy spread at PITZ: Conclusions and outlook

➢ LPS ($\delta E$) measurements with Gaussian photocathode laser pulses (short 2ps and long 11.5ps) yield the measured rms slice energy spread of 6-7keV/c (whereas ASTRA→<1keV/c for long Gaussian pulses)

➢ Still resolution on the slice energy spread seems to be a limiting factor:
  ▪ Beam transverse size in the HEDA2 dipole (beta function)
  ▪ TDS induced energy spread (estimated $\frac{d(\delta E)}{dS_P(TDS)} \sim 3 \frac{eV}{MV}$)

➢ Measured longitudinal phase space (LPS) shows modulation even with long Gaussian cathode laser pulses:
  ▪ “MB-instability” at the photocathode (observed already in LEDA)?
  ▪ Space charge effect while transport?
  ▪ Measurement artifact (but observed at 3x locations)?
  ▪ Up to now was not observed in e-beam temporal profile

➢ TDS in the low energy section would be useful

➢ Any ideas (to explain measurements and to refine them) are welcomed
Studies on profile of electron bunch trains – „Q-train“ (Y. Chen)
Motivation (/Observation at FLASH)

> Emission issue of fresh cathode 73.3 (and some others) at FLASH\(^1\)-\(^2\)

Fresh cathode in the gun 4-Feb-2015; QE=10%

- A **flat** energy distribution of the laser pulse train produces a 'spike' at the head of the electron bunch train emitted from a fresh cathode
- Spike strength depends on laser energy density and accelerating field on cathode
- The **decay time** decreases slowly with time over weeks

1) Siegfried Schreiber, Sven Lederer, FEL Seminar DESY, 2016
2) S. Schreiber, S. Lederer, FEL15’, Daejeon, Korea, 2015
“Q-train“ studies: Start-up measurements at PITZ

- RF stabilities along charge pulse train (amplitude and phase)
  - following emission model, full field at cathode influences QE
  - simultaneous recording gun field amplitude and phase@uTCA

- Cathode laser energy distribution along charge pulse train
  - check laser energy profile using photodiode after BSA and photomultiplier at laser trolley

- Charge measurements using LOW. ICT1 @ADC and FCs @Scope

- Plays to correlate relevant parameters
  - BSA size
  - Cathode laser energy
  - Accelerating field gradient

![Diagram of PITZ MBI Laser Beamline (partial)](image)
Effective QE” = \frac{\text{Charge, nC}}{\text{Photodiode (or PMT) voltage, V}}

- Fixed BSA SP ≈ 2.2395 mm, 6.5MW @ MMMG phase, cathode #682.1 (fresh)
  - As laser intensity (or photon density) increases,
    - QE decaying time increases
    - QE decreasing trends more pronounced

LT=2%

LT=3%

LT=4%

LT=5%

LT=6%

LT=7%

Resolution ~7%

Time for QE dropping to “within 2%”

∆QE~2%