Electron Beam Based Laser Diagnostics

X.J. Wang, M. Babzien and Z. Wu
National Synchrotron Light Source,
Brookhaven National Laboratory
Upton, NY 11973, USA

Presented at SLAC Workshop on Laser Issues for Electron RF Photoinjectors
October 25, 20002
What We would like Our Laser To be

- No timing jitter
- No energy fluctuation
- Perfect point stability
- 7/24 available
- Remote controllable
- NO laser physicist.

Programmable in both transverse and longitudinal distribution

<table>
<thead>
<tr>
<th></th>
<th>rms</th>
<th>peak</th>
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</thead>
<tbody>
<tr>
<td>Timing jitter</td>
<td>0.25, ps</td>
<td>1.0, ps</td>
</tr>
<tr>
<td>energy</td>
<td>1,%</td>
<td>5,%</td>
</tr>
<tr>
<td>Point stability</td>
<td>0.25,</td>
<td>1,%</td>
</tr>
<tr>
<td>Transverse uniformity</td>
<td>2.5,%</td>
<td>10,%</td>
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Outline

- Introduction - Photocathode RF Gun injection system
- Beam based laser diagnostics
  1. Timing jitter requirements and measurements.
  2. Longitudinal and transverse laser distribution.
- Summary
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Introduction
Photocathode RF Gun Injection System

- Photocathode RF gun injection system:
  1. RF gun.
  2. Solenoid Magnet.
  3. RF gun associate beam diagnostics.
  4. Laser system and optics.
  5. Cathode technology
  6. Operating principle

Stability and Reliability
The HGHG Experiment

Seed Laser
$\lambda = 10.6 \mu m$
$P_{pk} = 0.7$ MW

HGHG FEL
$\lambda = 5.3 \mu m$
$P_{pk} = 35$ MW

Modulator Section
$B_w = 0.16T$
$\lambda_w = 8$ cm
$L = 0.76$ m

Dispersion Section
$L = 0.3$ m

Radiator Section
$B_w = 0.47T$
$\lambda_w = 3.3$ cm
$L = 2$ m

Electron Beam Input Parameters:
$E = 40$ MeV
$\Delta \gamma / \gamma = 0.043\%$
$I = 110A$
$\tau_e = 4$ ps
$\varepsilon_n = 4\pi$ mm-mrad

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VISA SASE Saturation

Fundamental Microbunching vs. SASE

2nd Harmonic Microbunching vs. SASE

Microbunching @ 845nm

\[ \varepsilon_n \leq 2.0 \text{ mm-mrad} \]

Microbunching @ 422nm

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Stability and Reliability Leads To Better Performance
Oblique incident is preferred for better laser diagnostics and less effect on the beam.

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1. QE $> 10^{-4}$
2. Life time $> \text{weeks}$
3. Spatial Uniformity: p-p $< 10\%$
Thermal Emittance

Electrons are emitted with a kinetic energy $E_k$

$$
\varepsilon_{th} = \frac{r}{2} \sqrt{\frac{E_k}{m_e c^2}} \quad \text{laser spot assumed uniform with radius } r
$$

\[E_k = h \nu - \Delta + \alpha \sqrt{\beta_{RF} E_{RF} \sin \theta_{RF}}\]

$$\Delta = \Phi , \text{or } E_G + E_A$$

Example of measurement for Cu-cathode

(Courtesy of W. Graves)

Linear fit gives $E_k=0.43$ eV

Nonlinear fit gives $\beta_{rf}=3.1+/-0.5$, $\Phi_{cu}=4.73+/-0.04$ eV, and $E_i=0.40$ eV

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ICFA/BD Sardinia July 2002
Ph. Piot, DESY
Thermal Emittance of Mg Cathode

\[ \Delta \varepsilon_{\text{res}} = \frac{\sigma_{\text{res}} \sigma_{\text{quad}}}{L}, \quad \text{where } \sigma_{\text{res}} \text{ is a const.} \]

Laser wave length match to work function is not good idea.
Longitudinal Emittance Compensation

\[ \mathcal{E} = \sqrt{\mathcal{E}_{\text{ther}} + \mathcal{E}_{\text{rf}} + \mathcal{E}_{\text{sc}}} \]

Longitudinal emittance compensation demands lower RF gun phase, which lead to tighter timing jitter requirements.

- *PAC 97*
The Advanced FEL Photoinjector Operates at 20 MV/m Gradient and 200 mA Average Current

- 1300 MHz
- $E_b = 15-20$ MeV
- $I_{\text{macro}} = 100-400$ mA
- $Q = 1-4$ nC
- $\varepsilon_{\text{rms}} = 1.6$ mm-mrad
- $\Delta \gamma / \gamma = 0.2\%$
- Injection $\phi = 30^\circ$
- Solenoid = 300A
- Bucking Sol. = 310A

(D. Nguyen’s talk at BNL PERL workshop, Jan 2001)
Typical operating parameters
** determined in the RF gun with a picosecond Nd:YAG laser **

(1) Laser injection phase in RF gun: 30°
   ⇒ for a maximum energy with low emittance

(2) Linac RF phase: 47°
   ⇒ for a minimum energy spread

(3) Solenoid magnetic field: 1.57kG
   ⇒ For an optimal emittance compensation at 0.6nC, 14MeV
Emittance measurements for gaussian and square laser pulse shapes

\[ \varepsilon_n = \sqrt{(a' \cdot Q)^2 + b'^2} \]

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<tr>
<th></th>
<th>( a' )</th>
<th>( b' = \sqrt{\varepsilon_{if}^2 + \varepsilon_{th}^2} )</th>
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<tbody>
<tr>
<td>Gaussian(9ps)</td>
<td>1.85 ± 0.13</td>
<td>0.83 ± 0.05</td>
</tr>
<tr>
<td>Square (9ps)</td>
<td>0.92 ± 0.05</td>
<td>0.81 ± 0.03</td>
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The reduction of the linear space-charge emittance for the square pulse shape: \( \sim 50\% \).
Emittance Optimization at the BNL ATF

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Emittance vs. launch phase

Sigma-Z at gun exit vs. launch phase for different Charge

Smaller Phase ⇒ tight timing jitter
Photo-injector Beam Diagnostics

- Energy
- Charge
- RF Gun Phase

![Graph showing relative RF gun phase and photoelectron beam energy.](image)

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Photo-injector Diagnostics

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Beam Profile and Point Stability
Non-cylindrical symmetry
non-uniform lasers

- Non-uniform beam ~ fine grained and randomly; Five special laser masks are used to produce different laser uniformities.

Emittance measurements

Laser and Photoinjector Characterization

\[ Q(\phi) = \int_{-\infty}^{\infty} d\tau A I(\tau) (\hbar \nu - \phi + \alpha \sqrt{\beta E(\phi - \tau)})^2 \]
The stability and reliability of the photocathode RF gun is dominated by the laser system. Our experience shows good and on-line diagnostics is critical for the stable and reliable operation. Electron beam can be used for all aspects of the laser diagnostics, i.e., transverse and longitudinal distribution, energy stability, point stability and timing jitter.

Thank You!