(Some) Gun Requirements for ERLs

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Outline

• Presenter Bias

• Job Description

• Obvious Trade-offs & Generalities

• Concluding Thoughts
Acknowledgements & Thanks

• Colleagues at NPS, Argonne, JLab

• Meeting organizers

• Sponsors (ONR, JTO)
Currently working on ERL-FELs for naval applications

**Generic parameter set**

- $f_{rf} \sim 700$ MHz
- $f_{beam} \sim 0.1 – 1 f_{rf}$
- $I_{beam} \sim 100$ mA
- $Q_{bunch} \sim 0.15 – 1.5$ nC

**Machine constraints**

- compact (~10m long)
- runs as FEL (large energy spread)
- no chicane compressors
- no harmonic cavities
- 5-MeV injection into ERL loop
General Assumptions

ERL can drive an FEL (amplifier / SASE variant) or a storage-ring replacement (SRR)

Linac frequency \( \sim 1 \) GHz (makes for easy math)

SRR users are after brightness & pulse duration, not flux

SASE-FEL users expect some shot-to-shot variation
Job Description for an ERL Gun

Deliver beam:

– Reliably
– Stably
– With the required parameters for the user
– With all parameters within the user operations envelope

The weighting changes slightly depending on whether we’re talking about an FEL or SRR
Trans. Emittance Requirements (FEL)

Assume $\lambda_w=3\text{cm}$, $K=2.5$ ($a_w=1.76$)
Trans. Emittance Requirements (SRR)

General goals: \( >10^2 \) peak brightness improvement over existing SR sources
< ps bunch durations

\[
B_{\Delta \omega/\omega} \propto \frac{\gamma^2 N^2 I}{\sqrt{\varepsilon_n, x \varepsilon_n, y}}
\]

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>APS</td>
<td>43 x 0.5</td>
<td>3 – 18</td>
<td>20 - 40</td>
<td>300</td>
<td>1</td>
<td>1*</td>
</tr>
<tr>
<td>LCLS-like Gun</td>
<td>1 x 1</td>
<td>1.0</td>
<td>0.33</td>
<td>3000†</td>
<td>46</td>
<td>4.6*</td>
</tr>
<tr>
<td>New Gun (I)</td>
<td>0.1 x 0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>1000†</td>
<td>154</td>
<td>46*</td>
</tr>
<tr>
<td>New Gun (II)</td>
<td>0.1 x 0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>1000†</td>
<td>154</td>
<td>4.6†</td>
</tr>
</tbody>
</table>

† With linac-based bunch compressor
‡ Assuming 10 mA average beam current
* Assuming 100 mA average beam current
Bunch Charge Floors

\[ I_{\text{beam}} = Q_b \cdot f_{\text{rf}} \cdot D \]  \implies  \[ B_{\Delta \omega / \omega} \propto \frac{1}{D} \]

average brightness inversely proportional to bunch spacing

constant current --> constant flux --> constant heat load on optics

(if \( \varepsilon_n \propto Q_b \))
<table>
<thead>
<tr>
<th>Current (mA)</th>
<th>Uptime 1 hour</th>
<th>Uptime 1 day</th>
<th>Uptime 1 week</th>
<th>Uptime 1 month</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mA</td>
<td>3.6 C</td>
<td>86.4 C</td>
<td>605 C</td>
<td>2,592 C</td>
</tr>
<tr>
<td>10 mA</td>
<td>36 C</td>
<td>864 C</td>
<td>6,050 C</td>
<td>25,920 C</td>
</tr>
<tr>
<td>100 mA</td>
<td>360 C</td>
<td>8,640 C</td>
<td>60,500 C</td>
<td>259,200 C</td>
</tr>
<tr>
<td>1 A</td>
<td>3,600 C</td>
<td>86,400 C</td>
<td>605,000 C</td>
<td>2,592,000 C</td>
</tr>
</tbody>
</table>

Cathode must be *really* robust for higher current machines

Need a fast, reliable, automated cathode changer
## Drive Laser & Cathode Choices

### Drive laser requirements

<table>
<thead>
<tr>
<th>Cathode Material</th>
<th>Quantum Efficiency</th>
<th>Operating Wavelength</th>
<th>Harmonic laser power needed for:</th>
<th>Fundamental laser power for 100 mA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 mA</td>
<td>100 mA</td>
</tr>
<tr>
<td>Metal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>$10^{-5}$</td>
<td>266 nm</td>
<td>4.6 kW</td>
<td>46 kW</td>
</tr>
<tr>
<td>Magnesium</td>
<td>$5 \cdot 10^{-5}$</td>
<td>266 nm</td>
<td>930 W</td>
<td>9.3 kW</td>
</tr>
<tr>
<td>CsTe</td>
<td>0.5%</td>
<td>266 nm</td>
<td>9.3 W</td>
<td>93 W</td>
</tr>
<tr>
<td>Alkali, NEA</td>
<td>5%</td>
<td>532 nm</td>
<td>0.46 W</td>
<td>4.6 W</td>
</tr>
</tbody>
</table>

For CW machines:
- Metal cathodes are impractical
- Cs$_2$Te cathodes need laser development and very robust cathodes
- The high-QE cathodes require superb vacuum
- NEA cathodes, some alkalis may have problems with high gradients

Other options are being explored
Beam Halo

Why worry?
- Extra shielding
- Extra RF
- Machine damage

Gun-Induced Halo
What causes it?
- drive laser spray?
- dust on optics?
- cathode QE changes?
- changing match?
- something else?

How do we measure it?
Can we correct dynamically?
Is collimating at the gun a good idea?

Related topic: Bunch contamination
Uptime Comments

• Synch Rad users typically like l-o-n-g uptimes

• Maintenance: interval- and duration-critical
  – quick turn-around for common tasks
  – Incorporate on-line backups when possible
  – Gun *cannot* demand majority of maintenance time

• Similar comments for drive laser systems
Beam-Loss / No-Beam Events

frequency

duration

[Images of emoticons and a photo of a mob]
APS Reliability – Faults by System
Reliability Concerns

• Power supplies and RF systems
  – Highest fault rates / counts
  – Most downtime

Guess what our guns will be relying on?

• What about the drive laser…?!
Recommended Gun Technology

High performance
Lots of fun to run flat-out

Reliable and solid
An appliance

High maintenance
High insurance costs
Need experts to use it effectively

Low & predictable maintenance
Low insurance costs
Most people can drive it effectively
Random Thoughts

• Each machine is different, but...
  – User community will want similar features
  – Many overarching common concerns

• Cathodes cannot be ignored!
  – Some cathodes generate ampere beams for years...

• An argument: Slightly detuned, stable beams are better than peak-performance beams with razor-thin margins of error / adjustment
Conclusions

• This is not a comprehensive talk

• Available sources required to validate needed technology
  – halo monitors
  – cathode replace / regen technology

• Many details to be filled in this week!