High Current Electron Source for Cooling

Jefferson Lab Internal MEIC Accelerator Design Review

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January 17, 2014
Outline

- MEIC Electron Beam Cooling Requirements
- Thermionic Gun
- Photogun
- Magnetized Beam
- Emittance Compensation for Magnetized Beam with Space Charge
- Summary
## Bunched Electron Beam for Cooling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch Length</td>
<td>100 ps (3 cm)</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>25 MHz</td>
</tr>
<tr>
<td>Bunch Charge</td>
<td>2 nC</td>
</tr>
<tr>
<td>Peak Current</td>
<td>50 A</td>
</tr>
<tr>
<td>Average Current</td>
<td>20 mA</td>
</tr>
<tr>
<td>Emitting Area</td>
<td>6 mm φ</td>
</tr>
<tr>
<td>Transverse Normalized Emittance</td>
<td>10s microns</td>
</tr>
<tr>
<td>Solenoid Field at Cathode</td>
<td>2 kG</td>
</tr>
</tbody>
</table>
Performance & Dependencies

- Thermal Emittance: Intrinsic property of a cathode. Depends on work function, surface roughness, laser wavelength, temperature.
  - Normalized Emittance: \( \epsilon_n = \beta \gamma \epsilon_{geom} \)
  - Thermal Emittance (normalized to emitting radius or the rms for a gaussian beam): \( \epsilon_{th} = \frac{\epsilon_n}{R} \)

- Achievable Current: QE, laser wavelength, laser power, laser damage, heating, temperature.

- Bunch Charge: laser peak power, repetition rate, active cathode area

- Cathode Lifetime: ion back bombardment, dark current, contamination by residual gas, evaporation, beam loss, halo beam
Thermionic Gun

Example 1: TRIUMF e-Linac for photo-fission of actinide target materials to produce exotic isotopes:

- BaO: 6 mm diameter, 775°C
- Grid at 650 MHz
- Gun HV: 300 kV
- Average beam current: 10 mA
- Bunch charge: 16 pC
- Normalized emittance: 30 microns. Emittance is dominated by the electric field distortion caused by the grid.

Production target sets no requirement on beam emittance

- Thermionic: for storage ring injection
  - BaO: 3 mm diameter, 1100°C
  - 3 GHz and 1.6 MeV
  - Normalized emittance: 35 microns
  - Large energy spread (2%)

  To switch, reduce T=1100°C to T=700°C

- Photocathode: for FEL
  - Bunch charge: 0.2 nC
  - Laser: 9 ps, 10 Hz, 263 nm
  - Average beam current: 2 nA
  - Normalized emittance: 5.5 microns
  - QE: 1.1 x 10^{-4}

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gun HV</td>
<td>300 kV</td>
</tr>
<tr>
<td>Maximum peak current</td>
<td>1.8 A</td>
</tr>
<tr>
<td>Maximum average current</td>
<td>30–45 mA</td>
</tr>
<tr>
<td>Maximum bunch repetition rate</td>
<td>22.5 MHz</td>
</tr>
<tr>
<td>Bunch length</td>
<td>1.3 ns</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>1.5-2 nC</td>
</tr>
<tr>
<td>Normalized emittance</td>
<td>10 microns</td>
</tr>
</tbody>
</table>
• RF system consisting of 3 identical 180.3 MHz cavities powered by different generators
  – Bunching/chirping cavity RFC1 with a voltage of up to 100 kV
  – Two accelerating cavities RFC2 and RFC3 with a voltage of up to 800 kV
  – Phase of RFC3 adjusted to also de-chirp removing correlated energy spread
  – 1.5 ns bunch from the gun compressed to 100 ps at the exit from the injector
  – Final bunch energy is 1.5 MeV
**Example 1:** JLab 200 kV Inverted dc Gun with K$_2$CsSb photocathode:

- Average beam current: 10 mA
- Laser: 532 nm, dc
- Lifetime: very long (weeks)
- Thermal emittance: 0.7 microns/mm(rms)

### Example 2: JLab 350/500 kV Inverted Gun:

<table>
<thead>
<tr>
<th></th>
<th>200 kV Gun</th>
<th>350/500 kV Gun</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chamber</strong></td>
<td>14” φ</td>
<td>18” φ</td>
</tr>
<tr>
<td><strong>Cathode</strong></td>
<td>2.5” T-shaped</td>
<td>6” φ Ball</td>
</tr>
<tr>
<td><strong>Cathode Gap</strong></td>
<td>6.3 cm</td>
<td>6.3 cm</td>
</tr>
<tr>
<td><strong>Inverted Ceramic</strong></td>
<td>4” long</td>
<td>7” long</td>
</tr>
<tr>
<td><strong>HV Cable</strong></td>
<td>R28</td>
<td>R30</td>
</tr>
<tr>
<td><strong>HV Supply</strong></td>
<td>Spellman 225 kV, 30 mA</td>
<td>Glassman 600 kV, 5 mA</td>
</tr>
<tr>
<td><strong>Maximum Gradient</strong></td>
<td>4 MV/M</td>
<td>7 (10) MV/m</td>
</tr>
</tbody>
</table>
Achieved 350 kV with no FE (December 2013), next:
  o  Keep pushing to reach 500 kV
  o  Run beam with $K_2CsSb$ photocathode
Example 3: Cornell dc Gun with K$_2$CsSb photocathode:

- Gun HV: currently operating at 350 kV (designed 500-600 kV)
- Average beam current: 100 mA
- Bunch charge: 77 pC
- Bunch length: 10 ps, 1.3 GHz
- Normalized emittance: <0.5 microns
Magnetized Beam and Emittance Compensation

I. Magnetized Cathode:
   - To produce magnetized electron beam (to ensure zero angular momentum inside cooling-solenoid section)

II. Magnetized Injector:
   - To compensate space-charge emittance growth

Solenoid ($B_z \sim 2kG$)
(magnetized beam)

Solenoid ($B_z \sim 2kG$)
(space-charge emittance growth compensation)
Summary

I. Thermionic gun would be our first choice (less maintenance but may need complicated injector):

- TRIUMF/BINP Gun with Inverted Ceramic

II. To allow for laser pulse shaping, a photogun could be an option:

- JLab 350/500 kV Inverted Gun and JLab K$_2$CsSb