Magnetized Electron Beam Development

JLEIC Collaboration Meeting

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Recall Old Results – Summer 2016

First insulator conditioned to 325 kV

Learning how to use new photocathode

1 mA non-magnetized

Need mask and ion precipitator
Outline

• Magnetized Electron Source
  I. $K_2CsSb$ Photocathode
  II. Gun HV Chamber
  III. Gun Solenoid
  IV. Steel Photocathode Holders (Pucks)
  V. Beamline

• Generation of Magnetized Beam

• Measuring Magnetization
  I. Slit and Viewscreens
  II. $TE_{011}$ Cavity: new method

• Outlook
We are now running magnetized beam to Faraday Cup – to dump in two weeks.
Photocathode Preparation Chamber

- Bias puck to monitor photocurrent during activation and measure QE in-situ
- Control gap between puck and Cs-K effusion source for precise film growth
- Use a mask for reducing active area to minimize beam halo
K₂CsSb Quantum Efficiency ~ 6%

- K₂CsSb grown with a mask – limit photocathode active area (3 mm φ) to reduce beam halo
- Active area can be offset from electrostatic center
- 5 mm active area also available
- Entire photocathode can be activated too

Work of M. Mamun and Y. Wang
Gun HV Chamber

- Upgraded HV Chamber with new doped alumina insulator and newly designed HV shed (triple point junction shield) to lower gradient from 12 MV/m to 10 MV/m at 350 kV
- Gun HV operating at 300 kV with gun solenoid at 400 A
Gun Solenoid

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<tbody>
<tr>
<td>Size</td>
<td>11.811&quot; ID, 27.559&quot; OD, 6.242&quot; Z</td>
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<tr>
<td>Conductor</td>
<td>L=500 m, A=0.53 cm² 16 layers by 20 turns</td>
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<tr>
<td>Coil Weight</td>
<td>254 kg (560 lbs)</td>
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<tr>
<td>Resistance</td>
<td>0.198 Ω</td>
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<tr>
<td>Field at Photocathode</td>
<td>1.4 kG</td>
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<tr>
<td>Voltage</td>
<td>79 V</td>
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<tr>
<td>Current</td>
<td>400 A</td>
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- Mapped and installed at GTS
- Using new spare CEBAF Dogleg magnet power supply (500A, 80V)
- Learned that gun solenoid can influence field emission
- First trials with gun at HV and solenoid on resulted in field emission and vacuum activity
- HV conditioned gun with solenoid up to 400 A
New steel holders (pucks) to enhance field to 2.0 kG at photocathode. Two types:

I. Molybdenum and carbon steel hybrid puck
II. Carbon steel puck
Beamline

- Shield Tube
- Slit
- YAG Screen
Magnetized Beam at GTS

- Generated magnetized beam on March 8
- Measured magnetization at 300 kV and solenoid field from 0 – 1.4 kG
- Delivered 20 µA to Faraday Cup – higher currents once beamline to dump is ready
Measuring Magnetized Beam – I

Use slit and viewscreens to measure mechanical angular momentum:

\[ \langle L \rangle = 2p_z \frac{\sigma_1 \sigma_2 \sin \varphi}{D} = eB_z a_0^2 \]

\( B_z \): solenoid field at photocathode
\( a_0 \): laser rms size
$\sigma_1 = 3.7 \text{ mm}$

$\sigma_2 = 4.9 \text{ mm}$

$\phi = 15^\circ$

$\langle L \rangle = 38 \text{ neV s}$

$eB_z a_0^2 = 38 \text{ neV s}$
Having a non-invasive technique to measure beam magnetization is very critical for JLEIC e-cooler. An RF cavity could be right device. Cavities distributed around e-cooler will monitor magnetization and others installed inside cooling solenoid will ensure magnetization is completely removed during cooling process. Once beam exists solenoid, cavities measure whether magnetization is fully restored.

RF field will be excited by rotating bunched beam producing an easily detectable signal – beam will deposit longitudinal energy into cavity, but not angular momentum.

Coupling to both electric and magnetic fields – expect main contribution to signal from electric field.
\( \text{TE}_{011} \) Mode in Pill-box Cavity

\[
E_r = 0 \\
E_\varphi = \frac{i \omega \mu}{k_c} AJ_0'(k_c r) e^{-ik_z z} \\
E_z = 0 \\
H_r = \frac{i \omega \varepsilon}{k_c} AJ_0'(k_c r) e^{-ik_z z} \\
H_\varphi = 0 \\
H_z = AJ_0(k_c r) e^{-ik_z z}
\]
Magnetic Moment of Magnetized Beam

➢ Magnetic moment along beam axis:

\[ M = \frac{e}{2mc} L \]

\[ L = \frac{1}{2} B_z r^2 \]

\[ L = \gamma mr^2 \dot{\phi} \]

➢ For Gaussian beam with sigma of \( a_0 = 1 \text{ mm} \) and \( B_z = 2 \text{ kG} \):

- Average canonical angular momentum is \( \langle L \rangle = eB_z a_0^2 = 200 \text{ (neV s)} \) at photocathode

- After exiting solenoid \( \langle L \rangle = 2\gamma m_e a_0^2 \dot{\phi} = 200 \text{ (neV s)} = 3 \times 10^8 \hbar \)

- Beam angular frequency, \( \dot{\phi} = 1.1 \times 10^{10} \text{ rad/s} \)
TE_{011} Cavity Magnetized Beam Test

- Plan to build and install a cavity at GTS to measure beam magnetization in collaboration with Electrodynamic, NM (Brock Roberts) and SRF Institute (Jiquan Guo et al.) – good project for a student.

- Will be part of year 3 LDRD proposal – requires $20k for shop and materials.

- Axially-symmetric electric field mode cannot create angular momentum for a passing electron beam – one must take into account presence of associated RF magnetic field – due to conservation of canonical angular momentum before and after cavity.
Outlook: April – September

- Measure magnetization vs gun solenoid field and laser size
- Benchmark simulation against measurements
- Measure photocathode lifetime vs magnetization at 5 mA and 300 kV
- Measure magnetization with steel/hybrid puck
- Study beam halo and beam loss vs magnetization
- Install RF laser
- Install TE\(_{011}\) cavity and commission with magnetized beam

- Sajini Wijethunga, student from ODU started her Ph.D. thesis on magnetized beam (advisor: Jean Delayen, funded by 75% JLab + 25% ODU)

- Plan to submit LDRD proposal for 3\(^{rd}\) year funding – TE\(_{011}\) cavity included