Ultrafast High Voltage Kicker System Hardware for Ion Clearing Gaps

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DOE SBIR Award DE-SC0019684
DOE NP SBIR/STTR Phase II PI Exchange Meeting, August 17, 2023
RadiaBeam

- Founded in 2004
- ~50 employees and growing
- 30,000 ft\(^2\) headquarters in Santa Monica, CA

- Accelerator R&D, design, engineering, manufacturing and testing all under one roof in a dynamic, small-business setting
Tour: Machine Shop

- Multiple CNC milling and turning centers, > $3 million investment
- Dedicated “clean shop” for RF and UHV machining
- Full-suite of inspection equipment, including CMM
- 10 highly-skilled machinists
- ISO 9001 compliant quality system
Project Goals

The ionization scattering of the electron beam with residual gas molecules causes ion trapping in the electron rings, both in the collider and electron cooling system. The trapped ions may cause emittance growth, tune shift, halo formation, and coherent coupled bunch instabilities. Therefore, the beam temporal structure needs gaps to clear the ions to prevent them from accumulating turn after turn. Typically, the gap in the bunch train has a length of a few percent of the ring circumference.

- A fast deflector (kicker) is needed for EIC ERL cooler to form a ~100ns gap at ~1MHz (37.5MHz, ultimately 98.5MHz micro-bunches)
- Aperture 14 mm
- Maximum insertion length is 75cm
- Stripline kicker is a practical solution for such need
- Radiabeam is building a kicker and two-channel pulsed power source intended to be installed and tested at Jefferson Lab
# Kicker Specification

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflecting angle</td>
<td>20 mrad (deflecting voltage 140 kV)</td>
</tr>
<tr>
<td>Flange-to-flange length</td>
<td>50 – 60 cm</td>
</tr>
<tr>
<td>Electron Beam Energy</td>
<td>7 MeV</td>
</tr>
<tr>
<td>Bunch Repetition Rate</td>
<td>37.5 MHz</td>
</tr>
<tr>
<td>Bunch rms transverse size</td>
<td>σ=1 mm</td>
</tr>
<tr>
<td>Deflecting Pulse Width</td>
<td>92 ns flat-top required to deflect 4 out of 31 bunches in train</td>
</tr>
<tr>
<td>Kicker operation per rate</td>
<td>1.4 MHz (715ns between the pulses)</td>
</tr>
<tr>
<td>Rise + Fall Time</td>
<td>&lt;20 ns (10ns desired)</td>
</tr>
<tr>
<td>Aperture (gap)</td>
<td>14 mm</td>
</tr>
<tr>
<td>Required pulsed power</td>
<td>27.6 kW peak power per channel (55.2 kW total); 3.8 kW average power per channel (7.6 kW total)</td>
</tr>
</tbody>
</table>
RF design

Power required for 20 mrad deflection

40cm interaction length
Beam dynamics study

Exit offset spectrum over injection parameters

Kicked bunch (400mm)  Unkicked bunch (400mm)

Kicked bunch (600mm)  Unkicked bunch (600mm)

Beam loss with various interaction lengths

<table>
<thead>
<tr>
<th>Case</th>
<th>20mm Kick</th>
<th>$I_{lep}$ (mm)</th>
<th>$g$ (mm)</th>
<th>$V_t$ (V)</th>
<th>Offset, (mm)</th>
<th>Tilt, (mm)</th>
<th>Beam loss (%)</th>
<th>$P_e$ (W) LERF</th>
<th>$P_e$ (W) JLEIC</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>yes</td>
<td>200</td>
<td>14</td>
<td>2275</td>
<td>0</td>
<td>0</td>
<td>1.0 × 10^{-5}</td>
<td>4 × 10^{-4}</td>
<td>0.04</td>
</tr>
<tr>
<td>2</td>
<td>yes</td>
<td>300</td>
<td>14</td>
<td>1560</td>
<td>0</td>
<td>0</td>
<td>8.8 × 10^{-5}</td>
<td>0.04</td>
<td>3.4</td>
</tr>
<tr>
<td>3</td>
<td>yes</td>
<td>400</td>
<td>14</td>
<td>1175</td>
<td>0</td>
<td>0</td>
<td>8.8 × 10^{-5}</td>
<td>1.1</td>
<td>104.5</td>
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<tr>
<td>4</td>
<td>yes</td>
<td>600</td>
<td>14</td>
<td>790</td>
<td>0</td>
<td>0</td>
<td>0.0027</td>
<td>873</td>
<td>1.4</td>
</tr>
<tr>
<td>5</td>
<td>yes</td>
<td>600</td>
<td>14</td>
<td>1175</td>
<td>0</td>
<td>0</td>
<td>0.21</td>
<td>0.022</td>
<td>0.04</td>
</tr>
<tr>
<td>6</td>
<td>yes</td>
<td>600</td>
<td>14</td>
<td>1175</td>
<td>0</td>
<td>0</td>
<td>5.4 × 10^{-5}</td>
<td>0.022</td>
<td>0.04</td>
</tr>
<tr>
<td>7</td>
<td>yes</td>
<td>600</td>
<td>14</td>
<td>790</td>
<td>0</td>
<td>0</td>
<td>4.7 × 10^{-5}</td>
<td>0.022</td>
<td>0.04</td>
</tr>
<tr>
<td>8</td>
<td>yes</td>
<td>600</td>
<td>14</td>
<td>790</td>
<td>0</td>
<td>0</td>
<td>4.8 × 10^{-3}</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

40cm interaction length
- Standard 1-5/8” EIA compatible
- 60 cm flange-to-flange
- 40 cm interaction length
- XYZ Positioning stage
- Independent electrodes alignment
- Dielectric-free
Pulser testing setup

- 50cm-long 50 Ohm stripline, VSWR <1.1 from DC to 1 GHz
- Si MOSFET and GaN water-cooled high-power switches
- 500 V / 10 A DC supply
Pulser testing (Si MOSFET)

Achieved:
• 7ns rise and 6ns fall times at 100 ns flat-top with 87ps rms timing jitter
• Highly stable and controllable pulse length
• 1.4 MHz repetition rate
• 50% efficiency
Pulser testing (Gallium Nitride)

Achieved:
• 6.8ns rise and 4.5ns fall times @ 107 ns flat-top with 100ps rms timing jitter
• Highly stable and controllable pulse length
• 1.4 MHz repetition rate
• 82% efficiency
• Failed at 800 V
RadiaBeam pulser development (GaN) - v1

Achieved:
- 10 ns rise and 11 ns fall times @ 107 ns flat-top
- 1.4 MHz repetition rate (short bursts)
- 85% efficiency

Up to 600V so far (to be improved)
RadiaBeam pulser development (GaN) – v2

Simplified circuit diagram

Assembled Pulser PCB
RadiaBeam pulser development (GaN) – v2

### Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output voltage</td>
<td>1200 V</td>
</tr>
<tr>
<td>Pulse length</td>
<td>from 25 ns</td>
</tr>
<tr>
<td>Rise/fall time</td>
<td>3.9/11 ns</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>up to 1.4 MHz</td>
</tr>
<tr>
<td>Dimensions</td>
<td>3.15 x 2.84 x 1 in</td>
</tr>
</tbody>
</table>
RadiaBeam pulser development (GaN) – v2

- 100 us (150 pulses) burst
- 1200 V, 100 ns FWHM
- 1.4 MHz rep rate
- 10% of the required duty factor is achieved
RadiaBeam pulser development (GaN) – v3

- 4 transistors
- Improved cooling
- Testing is in progress
Summary:

- Kicker EM and mechanical design are complete
- Pulser development status: 1200 V, 4ns/11ns rise/fall, 1.4 MHz, 10% power
- Improve GaN-based pulser cooling to achieve full 3.8 kW output
- Assemble two-channel pulser with control system
- Kicker fabrication, assembly and tests
- Installation and beam-based tests at JLAB