Study of CSR Impact on the Electron Beam in the JLab ERL

Christopher Hall

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Collaborators:


1 Colorado State University
2 Thomas Jefferson National Accelerator Facility
3 Los Alamos National Laboratory
Outline

- Introduction
- Motivation
- The JLab FEL Driver
- Summary of the Experiment*
- Results/Comparison to Simulation
- Conclusion

Coherent Synchrotron Radiation Overview

Incoherent Emission

Coherent Emission

\[ \lambda_{rad} > l_b \quad P \propto N_e^2 \]

CSR leads to slice energy spread increase

Projected emittance growth after a dipole will increase
A small modulation in density leads to a modulation in energy via impedances.

Traversing a region with time/energy correlation can increase the density modulation, under the right conditions.
MEIC

Medium Energy Ion-Electron Collider at Jefferson Lab

Courtesy of D. Douglas
MEIC

Medium Energy Ion-Electron Collider at Jefferson Lab

Simulations suggest CSR induced microbunching will need to be accounted for

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MEIC

- 0.5 nC with 3 cm long bunch (rms) tracked for 100 turns with CSR

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Courtesy of D. Douglas

Medium Energy Ion-Electron Collider at Jefferson Lab

Simulations suggest CSR induced microbunching will need to be accounted for.

Courtesy of D. Douglas
Motivation

- ERL are very different from other accelerators:
  - Not at equilibrium like a ring.
  - Recirculation loops very different compared to standard linac.
- Bates bend structures allow for novel experiment. Using quads to adjust total $R_{56}$.
- Can study CSR over wide range of compression dynamics.
- Verify against 1-D CSR model*.

*E. Saldin, et. al, NIM A 398, 373 (1997)
The Jefferson Lab ERL FEL

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Repetition Rate [MHz]</td>
<td>75</td>
</tr>
<tr>
<td>Bunch Charge [pC]</td>
<td>135</td>
</tr>
<tr>
<td>Beam Energy [MeV]</td>
<td>up to 160</td>
</tr>
<tr>
<td>Max Beam Current [mA]</td>
<td>10</td>
</tr>
<tr>
<td>Beam Power [MW]</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Observe 200 W/mA of CSR power
Controlling Momentum Compaction in the Arc

Transverse kicks given to the beam:

Quadrupole Kick \[ \delta x' = -Ax \]

Sextupole Kick \[ \delta x' = -Bx^2 \]

In the dipole:

\[ R_{52} = -\rho(1 - \cos\theta) \quad \text{and} \quad \theta = 180^\circ \]

Path Length Difference: \[ \delta z = -2\rho\delta x' \]
Varying the Compression Point

Quadrupoles in the 1st arc can be adjusted to change $R_{56}$ while maintaining achromatic transport.

- $R_{56} \rightarrow$ variable
- $R_{56}$ between -0.5 to +1.0 m possible
- Quadrupoles in the 1st arc can be adjusted to change $R_{56}$ while maintaining achromatic transport.

$R_{56} = -52$ cm

$R_{56}$ for Critical Compression: +20 cm
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# Experiment Machine Parameters

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<thead>
<tr>
<th>Symbol</th>
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</tr>
</thead>
<tbody>
<tr>
<td>$E_0$</td>
<td>Injection energy [MeV]</td>
<td>9</td>
</tr>
<tr>
<td>$E_f$</td>
<td>Final energy [MeV]</td>
<td>135</td>
</tr>
<tr>
<td>-</td>
<td>Charge per bunch [pC]</td>
<td>135</td>
</tr>
<tr>
<td>$\sigma_0$</td>
<td>Bunch length after injector [ps]</td>
<td>3</td>
</tr>
<tr>
<td>$\sigma_f$</td>
<td>Bunch length at max compression [fs]</td>
<td>150</td>
</tr>
<tr>
<td>$h$</td>
<td>Energy-position correlation (chirp) [$m^{-1}$]</td>
<td>±5</td>
</tr>
<tr>
<td>-</td>
<td>RF phase [degrees]</td>
<td>±10</td>
</tr>
<tr>
<td>-</td>
<td>RF frequency [GHz]</td>
<td>1.497</td>
</tr>
<tr>
<td>$R_{56}^{bc}$</td>
<td>Optical cavity chicane $R_{56}$ [cm]</td>
<td>-52</td>
</tr>
<tr>
<td>$R_{56}^{bb}$</td>
<td>THz suppression chicane $R_{56}$ [cm]</td>
<td>-4.6</td>
</tr>
<tr>
<td>$R_{56}^{thz}$</td>
<td>Bates arcs $R_{56}$ [cm]</td>
<td>variable</td>
</tr>
</tbody>
</table>
Measuring Energy Loss
Measuring Energy Loss

- BPMs

Diagram showing a process flow with labeled parts:
- 1st Bates bend
- Optical cavity chicane
- IR wiggler
- T11z suppression chicane
- 2nd Bates bend
Measuring Energy Loss
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Measuring Energy Loss

BPMs

1st Bates bend  optical cavity chicane  IR wiggler  2nd Bates bend

1st Arc BPM avg (mm)

Quad MQT2F08 (G Int. Field)
Measuring Energy Loss

BPM readings from each side of 180° bend average to remove any betatron offset
BPM readings from each side of 180° bend average to remove any betatron offset.

Averaged reading taken in 1\textsuperscript{st} and 2\textsuperscript{nd} arc. Common jitter is removed by subtracting out the measurement from arc 1.
Measuring Energy Loss

BPM readings from each side of 180° bend average to remove any betatron offset.

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Averaged reading taken in 1ˢᵗ and 2ⁿᵈ arc. Common jitter is removed by subtracting out the measurement from arc 1.
Falling RF Measurement
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Falling RF Measurement
Rising RF Measurement

Did not sweep far enough to see full compression in the 1st arc

Impact of sextupoles shown in this measurement
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Did not sweep far enough to see full compression in the 1st arc.

Impact of sextupoles shown in this measurement.
Linearization

Sextupoles Off

Sextupoles On - Linearized Bunch

Compressible region

optical cavity chicane

IR wiggler

THz suppression chicane
When bunch is compressed, energy redistribution from CSR/LSC is observed. This redistribution is dependent on the degree of compression.
Energy Distribution Simulation
Energy Distribution Simulation

Data from SDDS file fullScan_slm5f02.pyhist, table 200

Frequency

\( y (\text{m}) \)

\( p (\text{m}_e\text{c}) \)
Energy Distribution Simulations

Chicane End

After CSRdrift*

Can fit a parabola to the longitudinal phase space:

\[
\delta(z; h) = -\left(\frac{1}{h} + \frac{R_{56}}{2T_{566}}\right) + \pm \frac{1}{2T_{566}} \sqrt{\left(\frac{1}{h} + R_{56}\right)^2 + 4T_{566}z}
\]

Average energy of the head of the bunch will shift as compression is changed.

CSR wake strongest at head of the bunch. Causes fragmentation of the energy spectrum dependent on compression.
Impact of Sextupoles

Sextupoles Off

Sextupoles On

Charge Distribution

Energy Distribution

Current (A)

\( \delta t \)

\( \delta t \)

Number of Occurrences

\( p \ (m_e c) \)

\( p \ (m_e c) \)
Energy Spectrum Simulations with LSC

Fragmentation in the energy spectrum is enhanced by longitudinal space charge
Conclusions

- Better understanding of CSR will be critical for the success of many upcoming accelerators.
- Measurements show good qualitative agreement to 1-D CSR model.
- CSR in drifts after a bunch compressor can have a large impact on the energy distribution.
- Important to control longitudinal curvature to keep energy distribution uniform.
  - Leads to greater energy loss overall due to better compression.
Further Work

- Perform a better analysis of simulations for microbunching.
- Include longitudinal space charge in simulation.
  - Underway currently
  - Leads to large enhancement of fragmentation in energy spectrum
- Further experiments?
  - Better test sextupole impact
  - Measure emittance
THANK YOU!