Phase Transfer Measurements at the Jefferson Lab Recirculated Linacs

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## CEBAF Beam Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>6 GeV</td>
</tr>
<tr>
<td>Beam current</td>
<td>A 100 $\mu$ A, B 10-200 nA, C 100 $\mu$ A</td>
</tr>
<tr>
<td>Normalized rms emittance</td>
<td>1 mm mrad</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>500 MHz/Hall</td>
</tr>
<tr>
<td>Charge per bunch</td>
<td>&lt; 0.2 pC</td>
</tr>
<tr>
<td>Extracted energy spread</td>
<td>$&lt; 10^{-4}$</td>
</tr>
<tr>
<td>Beam sizes (transverse)</td>
<td>&lt; 100 microns</td>
</tr>
<tr>
<td>Beam size (longitudinal)</td>
<td>100 microns (330 fsec)</td>
</tr>
<tr>
<td>Beam angle spread</td>
<td>$&lt; 0.1/\gamma$</td>
</tr>
</tbody>
</table>
Calculated Longitudinal Phase Space
Phase Space from CEBAF Bunching

$\Delta E$

-3 cm  3 cm  $z$

$\Delta E$

5 keV

-5 keV

$>100$ bunching factor!
Phase Transfer Technique

Simultaneously, digitize phase modulation and arrival time determined by a phase detector.
Some Early Results
Phase Space Correction Scheme

\[ \phi_{in} \rightarrow \phi_{out} \]

\[ \{ \rightarrow \} \]

\[ \{ \rightarrow \} \]

\[ \{ \rightarrow \} \]
Short Bunches in CEBAF

Short Bunch Configuration

Simulation calculations of longitudinal dynamics of JLAB FEL
Transfer Function Measurements


<table>
<thead>
<tr>
<th>Experiment</th>
<th></th>
<th>Simulation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td># 2</td>
<td>0.1172</td>
<td># 2</td>
<td>0.1070</td>
</tr>
<tr>
<td># 3</td>
<td>-0.0801</td>
<td># 3</td>
<td>-0.0834</td>
</tr>
<tr>
<td># 4</td>
<td>0.0911</td>
<td># 4</td>
<td>0.0256</td>
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<tr>
<td></td>
<td>0.0008</td>
<td></td>
<td>0.0007</td>
</tr>
<tr>
<td></td>
<td>0.0016</td>
<td></td>
<td>0.0003</td>
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<tr>
<td></td>
<td>0.0006</td>
<td></td>
<td>0.0004</td>
</tr>
</tbody>
</table>
Longitudinal Nonlinearities Corrected by Sextupoles

Basic Idea is to use sextupoles to get $T_{566}$ in the bending arc to compensate any curvature induced terms.
IR FEL Upgrade

1497 MHz Cavities
Injector to Wiggler Phase Transport

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**Bunch Length Operations**

**DAQ Ctrl**
- **Trigger**
  - **STOP**
  - **ABORT**
  - **RUN**
- **Input Level**
  - **OK**
  - **Other**
- **Signal Level**
  - **Minimum**
  - **Maximum**
- **Time Delay**
  - **Pre-Trigger Delay**
  - **Delay**

**Happy-ness:** Bunch Length is \(-117.852\)

- **Spread** = 25.689532
- **Ave** = 21.744031
- **Noise** = 143.5
  - **Speed** = 25.7
  - **Blw**
  - **Noise** = 25.690

**RampCtrls**
- **Frequency**
  - 49.500

**Phase Amp (Deg)**
- 12.00

**Offset (Deg)**
- 0.00

**Detector**
- **Phase Shifter**
  - \(144,434\)
- **Cavity**
  - 3.07391

**Fgen Ctrl**
- **Function Gen ON**
- **Function Gen OFF**

![Graph](Image)

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**Courtesy Dave Douglas, S. Benson**

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**Thomas Jefferson National Accelerator Facility**

Operated by the Southeastern Universities Research Association for the U.S. Department of Energy
Bunch Length at Wiggler

Courtesy Dave Douglas, S. Benson

~150 fsec rms

ERL2005 Phase Transfer Function Measurements
Operated by the Southeastern Universities Research Association for the U. S. Department of Energy

20 March 2005
Injector to Reinjection Phase Transport

Bunch Length Operations

DAQ Ctrl

Trigger: ABORT

Run: OK

DAQ Ctrl: Done

Time: 16

Gain: 6.294e-04

Pre-Trigger Delay: -1.800e-04

Happiness: Bunch Length is -116.772

Spread = 20.998729 Ave = -13.972835

Noise = 137.8 Spd = 21.0 Bw Noise = 20.889

Ramp Ctrl

Frequency

49.500

Phase Amp (Deg)

12.00

Offset (Deg)

0.00

Detector

Phase Shifter

Cavity 4 0 674 1

Fgen Ctrl

Function Gen ON

Function Gen OFF

Frequency (Hertz) Width (sec) Thumbwheel (MHz)

LASER 80 000 250 000 4 878

Courtesy Dave Douglas, S. Benson
Controlling nonlinearities with sextuples and octupoles is validated by high order transport measurement

Figure 1: initial optimized setup
Figure 2: lower trim quads to -185 g from initial -215 g
Figure 3: raise trim quads to -245 g
Figure 4: quads back at -215, but sextupoles 2000 g below design, at 10726 g-cm
Figure 5: back to start: trim quads -215 g sextupoles at 12726 g-cm
Conclusions

- In this talk I’ve introduced the idea of the phase transfer function measurement, and demonstrated some of its commissioning uses.
- Practical implementations have been made in all on the Jefferson Lab Recirculated Linacs.
- These techniques were instrumental in allowing reproducible production of short bunches in these accelerators.
- They allow *beam based measurements* of non-linear beam optical effects.