Accelerator Physics Around \( \frac{3}{4} \) of the World

A Summary of Experiences & Planned Work at FONT

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Hello, 안녕하세요, Hello Again...

- Introductory talk – to introduce myself and my work.
- PhD in 2012 from University of Virginia
- Dissertation work at Jefferson Lab in Newport News, Virginia, USA
- Research Fellow at the Rare Isotope Science Project (RISP), part of the Institute for Basic Science (IBS) in Daejeon, South Korea.
- Postdoctoral Research Assistant here in the FONT group.
- Talk will be more conceptual than quantitative.
So, where to begin...
A bit about JLab

- 6 GeV (12 now) recirculating electron linac
  - Continuous Electron Beam Accelerator Facility (CEBAF)
- Essentially a linac folded over upon itself up to 5 times
How CEBAF Works

~7/8 mile around
Each linac ~1/4 mile
What did I do at JLab?

- My first few jobs were in the SRF Institute
  - Bead pulls
  - HOM measurements in the cavity test cave
  - Vertical cavity tests
What did I do at JLab?

• Then I moved to the Center for Advanced Study of Accelerators (CASA) Group (http://casa.jlab.org/)
• Had to do a “warm-up” project
What did I do at JLab?

- Once I understood the CEBAF optics, the real work began.
- Developed procedure to characterize and tune beam

**Circular Machine**
- Many passes
  - Equilibrium orbit
- Global, self-consistent lattice
- Periodic condition
- Lattice defines Twiss Parameters
- Beam accommodates Twiss Parameters

**Open-Ended Machine**
- Single pass through system
  - No equilibrium orbit
- No periodicity constraints like circular
- Lattice defines path of beam
- Lattice transforms Twiss Parameters
- How can they be measured?
JLab’s Method 1: Quad Scan

- Adjust quadrupole by known amount
- Find smallest size at harp
- Relationship of beam radius at lens vs. waist gives emittance angle

Wire Current

Harp Position

Xrms

$1/f$
JLab’s Method 1: Quad Scan
The problems

- Noisy electronics (wire scanner)
- Sparse coverage
- Small emittance
- Time consuming - takes ~30 minutes to complete for ONE location
- Invasive – more time away from nuclear physics program
JLab’s Method 2: Courant-Snyder Tuning

- Used to maintain beam envelope matching

- Takes $x$ and $x'$ from measured trajectories, and uses $\alpha$ and $\beta$ from the design model to calculate the matched phase ellipse corresponding to the measured trajectory
JLab’s Method 2: Problems
Addressing The Weaknesses

• CEBAF needed a method that is minimally invasive to the nuclear physics program
• Must be able to either take into account cumulative phase advance errors, or provide a way in which it can be ignored without detriment
• Must be able to characterize the beamline both locally and globally
• Developed rayTrace to achieve this
rayTrace: What is it?

• Measures the differential orbit of the real beam at every location simultaneously
• Corrector kicks are set to follow the boundary of the model’s phase ellipse
• Allows for calculation of the Twiss parameters of the real beam
rayTrace – How it Works

Corrector Pair

BPM 1
Launchpoint

BPM 2

BPM 3
Data cleanup with SVD
Data cleanup with SVD
Devised a Resolution Test as validation of rayTrace
  - Want basic test – simple optics change analogous to optics error

Goals:
  1. Localize a known optics change
  2. Resolve the magnitude of optics change

The Test:
  - Create known optics change by varying strength of quadrupole
  - Take Baseline Data first, then change quad setting 20% Positive from Baseline, then 20% Negative from Baseline
  - Take second Baseline data set
Resolution Test

- Localized optics change to region between two BPMs
- Resolved better than 95% of the change entered
- Estimated BPM system errors within expected range

Analysis – Beta Comparison

\[
\sum_{1}^{m} (u_2 - M_{ij} u_1 - M_{kl} u'_1)^2 = \sum_{1}^{m} \Delta_{m}^2
\]

\[
\sigma = \sqrt{\frac{\sum_{1}^{m} \Delta_{m}^2}{N-1}}
\]

\[
M_{11} = \cos(\sqrt{kl}) - \sqrt{kl} \sin(\sqrt{kl})
\]

\[
M_{33} = \cosh(\sqrt{kl}) + \sqrt{kl} \sinh(\sqrt{kl})
\]

Analysis – Resolving the Change

<table>
<thead>
<tr>
<th>MQB1R01</th>
<th>Baseline 1</th>
<th>19.44%</th>
<th>-19.73%</th>
<th>0.75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated Quad Value (Gauss)</td>
<td>2937.63</td>
<td>3508.57</td>
<td>2357.89</td>
<td>2915.46</td>
</tr>
<tr>
<td>Percent Change From Baseline 1</td>
<td>0</td>
<td>19.44</td>
<td>-19.73</td>
<td>0.75</td>
</tr>
<tr>
<td>Archived Quad Value (Gauss)</td>
<td>2994.62</td>
<td>3593.45</td>
<td>2395.63</td>
<td>2994.63</td>
</tr>
<tr>
<td>Sigma (microns)</td>
<td>30.69</td>
<td>50.83</td>
<td>37.81</td>
<td>53.17</td>
</tr>
</tbody>
</table>
REAL BEAM LINE OPTICS FROM A SYNTHETIC BEAM*

R.M. Bodenstein#, M.G. Tiefenback, Y.R. Roblin
Jefferson Lab, Newport News, VA 23606, U.S.A.

FURTHER ANALYSIS OF REAL BEAM LINE OPTICS FROM A SYNTHETIC BEAM*

R.M. Bodenstein#, Y.R. Roblin, M.G. Tiefenback
Jefferson Lab, Newport News, VA, USA

A Procedure for Beamline Characterization and Tuning in Open-Ended Beamlines

A Dissertation
Quick Info about the Rare Isotope Science Project

- Part of the Institute for Basic Science
  - Established by Korean government in 2011
- RISP officially established in 2011
  - In 2012, accelerator facility named RAON (라온), which is a traditional Korean word that translates to delightful, joyful, or happy.
- RISP goal: produce variety of stable and rare isotope beams for use in a variety of basic scientific research and applications
- Unique aspect:
  - Isotope production using both In-Flight Fragmentation (IFF) and Isotope Separation On-Line (ISOL)
D) Layout Diagram and a Few Parameters

<table>
<thead>
<tr>
<th>Particle</th>
<th>Driver Linac</th>
<th>Post Acc.</th>
<th>Cyclotron</th>
</tr>
</thead>
<tbody>
<tr>
<td>H⁺</td>
<td>600</td>
<td>400</td>
<td>70</td>
</tr>
<tr>
<td>O⁸⁺</td>
<td>320</td>
<td>400</td>
<td>-</td>
</tr>
<tr>
<td>Xe⁵⁺⁺</td>
<td>251</td>
<td>400</td>
<td>1000</td>
</tr>
<tr>
<td>U⁷⁹⁺</td>
<td>200</td>
<td>400</td>
<td>1000</td>
</tr>
</tbody>
</table>

**Driver Linac**
- SCL1 (10 keV/u, 12 μA)
- SCL2 (200 keV/u, 8.3 μA for U⁷⁹⁺)
- (600 MeV/u, 660 μA for p)

**Post Accelerator**
- SCL3

**ISOL system**
- ISOL Target
- RF Cooler
- Cyclotron (p, 70 MeV, 1 mA)

**Low Energy Experiments**
- Nuclear Astrophysics
- Material Science
- β-NMR

**High Energy Experiments**
- Nuclear Structure/Symmetry Energy

**μSR, Medical**

**IF system**

**Notes:**
- CB: Charge Breeder
- HRMS: High Resolution Mass Separator

**Parameters:**
- Particle: H⁺, O⁸⁺, Xe⁵⁺⁺, U⁷⁹⁺
- Beam energy (MeV/u): 600, 320, 251, 200, 18.5, 70
- Beam current (μA): 660, 78, 11, 8.3, -
- Power on target (kW): 400, 400, 400, 400, -
Ignoring the rest, here is the LEBT...

- Original achromatic match point
- Match into RFQ
TRACK simulation of LEBT

Distributions at the RFQ
**LEBT Test Facility**

For the test facility, must shorten final matching section. Parameters for test facility shown in table.

<table>
<thead>
<tr>
<th>Input Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle and Charge</td>
<td>Bismuth-209 29+</td>
</tr>
<tr>
<td>ECR Extraction Voltage</td>
<td>30 kV</td>
</tr>
<tr>
<td>HVP Voltage</td>
<td>42 kV</td>
</tr>
<tr>
<td>$\epsilon_{\text{RMS,Normalized,Total}}$</td>
<td>0.12 $\pi$-mm-mrad</td>
</tr>
<tr>
<td>$\alpha_{xy}$</td>
<td>0</td>
</tr>
<tr>
<td>$\beta_{xy}$</td>
<td>10.38 cm/rad</td>
</tr>
<tr>
<td>Beam Radius at ECR Exit</td>
<td>0.5 cm</td>
</tr>
</tbody>
</table>
Mismatch Factor X: 0.002197
Mismatch Factor Y: 0.00581
X-Envelopes, Bismuth 209 +29, No Space Charge

Limitations due to PS strength and distance b/w ECR & PS.

Centroid displacement exacerbated by horizontal bending magnets.

No data in Solenoids for TRACK

Required distance b/w last EQUAD and RFQ match point requires beam be focused sharply upstream in both planes.

Mismatch Factor X: 0.002197

Space required for diagnostics
Y-Envelopes, Bismuth 209 +29, No Space Charge

**Mismatch Factor Y: 0.00581**

- Limitations due to PS strength and distance b/w ECR & PS.
- Centroid displacement minimal in vertical.
- Required distance b/w last EQUAD and RFQ match point requires beam be focused sharply upstream in both planes.
- No data in Solenoids for TRACK.

Space required for diagnostics.
LEBT Test Facility

The Baseline Model
• The good:
  ➢ Adequately small beam size
  ➢ Matching section length reduced by nearly 2 meters
  ➢ Excellent matching into the RFQ
• The bad:
  ➢ Centroid offset, likely due to initial offset applied by TRACK code.
    ▪ Not present in TRANSPORT

Baseline with Space Charge
• The good:
  ➢ Beam size remains adequately small
  ➢ Matching is still excellent
• The bad:
  ➢ Difficulty adjusting mesh, which should be increased
    ▪ Engineers using MWS need to do this.

Baseline with Alignment Errors
• The good:
  ➢ Even with large alignment errors, beam in matching section shows resistance against errors
• The bad:
  ➢ None yet, but further investigation will surely show some.
Alright, so I’m here. Now what?

• I’m very excited to be here at JAI and Oxford
  • Opportunity to collaborate with ILC and CLIC
  • FONT provides place to both exercise and expand my experience

• Very happy to learn about feedback systems and linear colliders
  • Colliders are a different animal
  • Focus on a small but important aspect
    • How this applies to the greater aspects

• Looking forward to learning new programs and techniques for simulation
  • Taking up with Javier Resta-Lopez left off.
    • ILC & CLIC ground motion simulations for FB system
    • Overall beam delivery system simulations

• Given my background, I feel I will have much to contribute and even more to learn
Thanks!

감사합니다!