High Intensity Beam Physics at the University of Maryland Electron Ring

46th ICFA Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams
Sept 27-Oct 1, 2010

Institute for Research in Electronics and Applied Physics
Brian Beaudoin

Acknowledge: S. Bernal, T. Koeth, R. Kishek, I. Haber, D. Sutter, P. O’Shea and M. Reiser
• Introduction and Motivation: The University of Maryland Electron Ring (UMER)

• Studies of transverse dynamics

• Studies of longitudinal dynamics and the need for confinement

• Conclusion and future plans
Motivation:
Investigating space-charge physics at long path-lengths, both transverse… & longitudinal….

System Parameters

Beam Length 5 ns (30 cm) - 132 ns (8 m)
Circulation Time 197 ns
Beam Energy 10 keV

<table>
<thead>
<tr>
<th>Aperture #</th>
<th>$r_0$ (mm)</th>
<th>$I$ (mA)</th>
<th>$\tilde{\varepsilon}_n$ (μm)</th>
<th>$r$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 “pencil”</td>
<td>0.25</td>
<td>0.6</td>
<td>0.4</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>0.875</td>
<td>6</td>
<td>1.2</td>
<td>3.2</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>23</td>
<td>2.0</td>
<td>4.9</td>
</tr>
<tr>
<td>4</td>
<td>2.85</td>
<td>78</td>
<td>4.3</td>
<td>8.7</td>
</tr>
<tr>
<td>5</td>
<td>3.2</td>
<td>104</td>
<td>4.9</td>
<td>9.9</td>
</tr>
</tbody>
</table>
Optics Layout

DC Magnetic Quadrupoles
Wide Pulsed Quadrupoles
DC Bending Dipole
Solenoid
Pulsed Dipole
Bergoz Coil
Induction Gap
Diagnostic Chamber

Single turn injection at 60 Hz
FULL LATTICE PERIODS: 0.32 m

Ring Diagnostics:

14 Fast, Capacitive BPMs
1 Wall Current Monitors
RF-Knockout
Slow and Fast Fl. Screens
OTR Screens

WCM
BPM
Y-Section
1.0 m
3.66 m

I-Cell
Outline

• Introduction and Motivation: The University of Maryland Electron Ring (UMER)

• Studies of transverse dynamics

• Studies of longitudinal dynamics and the need for confinement

• Conclusion and future plans
Tune Measurement / Calculation

Quad Current Space → Tune Space

6.0 mA @ 10 keV: Transmitted
Fractional Currents at 20th turn:
2025 ($I_F, I_D$) points

nth turn relative to the Injected turn

$$\text{Ratio}_n = \frac{I_n}{I_0}$$

Lattice/Beam Model + Measured Tunes

FFT, 6.0 mA @ 10 keV,
F,D Quad Curr. = 1.812A

$\chi = 0.6$
5th Turn - Transmitted Current

\( \chi = 0.3 \)

\( \chi = 0.6 \)

\( \chi = 0.9 \)

0.6 mA*

21 mA

6.0 mA

*0.6 mA: with or w/o long. focusing
10\textsuperscript{th} Turn - Transmitted Current

\[ \chi = 0.3 \]

\[ \chi = 0.6 \]

\[ \chi = 0.9 \]

\begin{itemize}
  \item 0.6 mA*: with or w/o long. focusing
  \item 21 mA
  \item 6.0 mA
\end{itemize}
20\textsuperscript{th} Turn - Transmitted Current

\[ \chi = 0.3 \]

\[ \chi = 0.6 \]

\[ \chi = 0.9 \]

0.6 mA*  \quad 21 \text{ mA}  \quad 6.0 \text{ mA}

*0.6 mA: with or w/o long. focusing
LATTICE FUNCTIONS

Betatron Function (6.0 mA) Measurement at QR33

\[ y = 6.5561 + 0.043x \quad R = 0.87194 \]
\[ y = 6.7749 - 0.057x \quad R = 0.98217 \]

Horizontal Dispersion Function for 0.6, 6.0 mA beams

\[ \beta_{0x,y} \approx \pm 4\pi \frac{\Delta \nu_{x,y}}{\Delta k} \]
\[ \beta = \frac{\beta_{0x,y}}{\text{Tune Depression}} \]

- Exp. Av. Disp. 0.6 mA = 4.9 cm
- Exp. Av. Disp. 6.0 mA = 3.1 cm
Outline

• Introduction and Motivation: The University of Maryland Electron Ring (UMER)

• Studies of transverse dynamics

• Studies of longitudinal dynamics and the need for confinement

• Conclusion and future plans
Baseline restoration of RC10 wall current monitor signal

Injected Turn 0.52 mA

Tune shift of 0.85

Eroding Head

WCM

Ferrite

Ferrite

Beam Pipe
Longitudinal Synchronization for Confinement

Selectable focusing frequencies ( \( f_{\text{rev}} = 5.066 \text{ MHz} \) )

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>1.013</th>
<th>0.844</th>
<th>0.723</th>
<th>0.633</th>
<th>0.562</th>
<th>0.506</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-harmonic #</td>
<td>1/5</td>
<td>1/6</td>
<td>1/7</td>
<td>1/8</td>
<td>1/9</td>
<td>1/10</td>
</tr>
</tbody>
</table>

Line-density

Energy

Head

Tail

\[ E_z = 0 \]

\[ \bar{E}_z \neq 0 \]

\[ \bar{E}_z \neq 0 \]

\[ E_z \propto -\frac{\partial \lambda}{\partial z} \]

Synchronization between bunch and fields

\[ 1/987 \text{ ns} = 1.013 \text{ MHz} \]

Beam Current and Focusing Fields

Time (\( \mu \text{s} \))
Unbunched and Bunched Beam

**NO Confinement**

- **59.6 V – 1/10**
- **Leaky Confinement**

**Launching of Multiple Waves**

- **129.4 V – 1/5**

**“Good” Confinement**

- **59.6 V – 1/5**
Longitudinal Mismatch Induced Waves

"Good" case
59.6 V – 1/5
Estimation of Beam Size from Sound Speed Calculations of Induced Waves

<table>
<thead>
<tr>
<th></th>
<th>Mean Current (mA)</th>
<th>S (m)</th>
<th>$v_o$ (m/s)</th>
<th>Initial Emittance (mm-mr)</th>
<th>Beam radius (mm)</th>
<th>$C_s$ - Theory (m/s)</th>
<th>$C_s$ - Measured (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>0.425</td>
<td>1854.7</td>
<td>5.836E7</td>
<td>7.86</td>
<td>1.56</td>
<td>2.42E5</td>
<td>1.84E5</td>
</tr>
<tr>
<td>$S_2$</td>
<td>0.425</td>
<td>1693.4</td>
<td>5.836E7</td>
<td>7.86</td>
<td>1.56</td>
<td>2.42E5</td>
<td>2.01E5</td>
</tr>
</tbody>
</table>

"Good" case
59.6 V – 1/5
Charge Preserved with Focusing

Injected Charge of 52 pC

"Slower-loss" Charge of 31 pC
Concluding Remarks and Future Plans

• Observed linear resonances over wide range of parameters.

• Demonstrated longitudinal confinement of the low-current beam beyond a 1000 turns, exceeding design by a factor of 10.

• We are currently researching the optimization of confinement.

• Plans:
  – Work around injection section for better matching.
  – Exploring resonance scans with longitudinal confinement.
  – Alternate longitudinal focusing solutions could minimize the number of wave induced distortions of the bunch shape.
  – Next stage for longitudinal focusing is to move on to the 6 mA beam, increasing space-charge and thus the tune shift.