Status Report

100 keV DC Gun Test Stand

August 11, 2006
What Happened Since the Last LEG Project Meeting

- Improved solenoid scan with non-linear fitting routine
- Single slit emittance measurements
- Pinhole array emittance measurements
Solenoid Scan Measurement Method (I)

- As demonstrated in the last LEG Meeting, in thin lens approximation the fit applied to the measured data is quadratic in $k$:

$$
\sigma^2 = \varepsilon \beta = C^2 \varepsilon \beta_s - 2SC \varepsilon \alpha_s + S^2 \varepsilon \gamma_s
$$

$$
\begin{align*}
\vdots \\
= k^2 \left( L^2 l^2 \varepsilon \beta_s \right) + k \left( 2L^2 l \varepsilon \alpha_s - 2Ll \varepsilon \beta_s \right) + \left( \varepsilon \beta_s - 2L \varepsilon \alpha_s + L^2 \varepsilon \gamma_s \right)
\end{align*}
$$

- However, due to the strong focusing applied with the solenoid, the thin lens approximation is not appropriate:

$$
\begin{align*}
l_{\text{eff}} ? f_{\text{sol}} = 1/(k \cdot l_{\text{eff}})
\end{align*}
$$
Solenoid Scan Measurement Method (II)

- Treat solenoid (focussing strength $k$, rotation angle $\phi$) and subsequent drift (length $L$) as a thick lens (better yet: thick slices as originally calibrated)

\[
\mathcal{M} = \begin{pmatrix}
\cos \phi - L \sqrt{k} \sin \phi & \frac{1}{\sqrt{k}} \sin \phi + L \cos \phi \\
-\sqrt{k} \sin \phi & \cos \phi
\end{pmatrix}
\]

where $k = \left( \frac{\hat{B}}{2 p/e} \right)^2$ and $\phi = \int \frac{B \, ds}{2 p/e}$ are functions of $I_{\text{sol}}$

- Use Levenberg-Marquardt Method to solve the non-linear problem

\[
\sigma = \sqrt{\varepsilon \left( \beta_0 \mathcal{M}_{1,1}^2 - 2 \alpha_0 \mathcal{M}_{1,1} \mathcal{M}_{1,2} + \frac{1 + \alpha_0^2}{\beta_0} \mathcal{M}_{1,2}^2 \right)}
\]

measure $I_{\text{sol}}$ output from fit
Solenoid Scan Measurement Method (III)

- Example taken at 40 kV, $U_g = -173$ V, $Q_{tot} = 39$ pC, $\hat{I} = 637$ $\mu$A, 5 shot average
- Levenberg-Marquardt routine implemented in IDL (recycled old code originally written by Andreas Streun in 1999)

![Graph showing beam radius vs. solenoid current with beta and alpha values]
Solenoid Scan Measurement Method (IV)

- Comparing methods shows how emittances are estimated too low by using the thin lens approximation.

<table>
<thead>
<tr>
<th>Method</th>
<th>$\varepsilon_x$ [mm mrad]</th>
<th>$\varepsilon_y$ [mm mrad]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin lens</td>
<td>1.73 ± 0.07</td>
<td>2.26 ± 0.11</td>
</tr>
<tr>
<td>Thick lens (hard-edge)</td>
<td>1.89 ± 0.08</td>
<td>2.47 ± 0.01</td>
</tr>
<tr>
<td>Thick lens (slices as calibrated)</td>
<td>2.35 ± 0.01</td>
<td>3.07 ± 0.02</td>
</tr>
</tbody>
</table>

+36%
Single Slit Emittance Measurement

- Measure RMS beam size at location of single slit (YAG)
- Measure RMS width of emerging beamlet downstream \( (d \ll \sigma_x) \)
- Calculate emittance directly according to:

\[
\varepsilon_x = \sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle}, \quad \text{where} \quad \langle x'^2 \rangle = \frac{\sigma_x^2}{L^2}
\]

\( \varepsilon_x = (2.54 \pm 0.29) \) mm mrad

- In agreement with solenoid scan results
- Pro: Calculate emittance from a single image
- Con: No Courant-Snyder parameters or phase space distribution information
Pinhole Array Emittance Measurement (I)

- Beamlets emerge from pinhole
- Measure beamlet intensity distribution downstream (P43)

40kV, Q=56pC

\[ \Delta L = 39 \text{mm}, I_{\text{sol}} = +0.698 \text{A} \rightarrow B_z = 40.8 \text{mT} \]
Pinhole Array Emittance Measurement (II)

- Measure position of beamlet centroids $\rightarrow$ divergence centroids
  
  $\bar{x}_i' = \langle x_i - \bar{x}_i \rangle / L$

- Measure RMS beamlet width $\rightarrow$ divergence spread for each slice ($d \ll \sigma_x$)
  
  $\sigma_i' = \sqrt{\langle (x_i - \bar{x}_i)^2 \rangle / L^2 - (\bar{x}_i')^2}$
Pinhole Array Emittance Measurement (III)

- 1-sigma ellipse slices $\rightarrow$ second order moments $\rightarrow$ Courant-Snyder parameters

\[ \epsilon_x = (2.85 \pm 0.57) \text{ mm mrad} \]
\[ \beta_x = (0.592 \pm 0.065) \text{ m} \]
\[ \alpha_x = (-1.16 \pm 0.20) \]
Pinhole Array Emittance Measurement (IV)

- Reconstruct not just twiss parameters, but full phase space distribution!

Every pixel of the CCD image can be back-transformed to its source point in phase space!

Relative intensities of beamlets correspond to relative intensities of bunch slices.
Pinhole Array Emittance Measurement (V)

- Pinhole array emittance measurements in agreement with single slit and solenoid scan measurements
- Pro: One image allows reconstruction of full transverse phase space; when used in pepper-pot configuration measure emittance evolution along beam path!
- Con: SNR is crucial: low SNR increases error margins and introduces systematic errors (background subtraction!)
Conclusion & Outlook

• Different emittance measurement methods are in agreement

• Transverse phase space can be reconstructed

• Beam intensity remains a problem (better SNR $\rightarrow$ lower errors on results)

• Install 3D manipulator
  • Correct for misalignment
  • Change accelerating gap $\rightarrow$ modify focussing properties of diode structure

• Test stand can now be used to compare beam quality of different sources
  • Spindt-type FEAs (SRI)
  • LMN FEAs (focussing layer!)
  • Single tip, laser-induced field emission