Matched input beam in PXIE RFQ

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Project X meeting
May 6, 2014
Ultimate question was: what beam quality at the entrance of SC cavities is achievable?

Particular questions:
- What beam quality can LEBT provide?
- What is matched beam for “real” RFQ?
- What are the tolerances for the input matched beam?
- How output beam from RFQ depends on matching quality?
After number of PIC simulations two important conclusions can be made:

- In general LEBT can provide matched beam.
- Depending on particular beam optics transverse emittance may grow by factor of $\approx 2$ along LEBT.
RFQ. RF fields from complete model.

Tuning is necessary because the modules are different due to the modulation.

<table>
<thead>
<tr>
<th>Module</th>
<th>MWS, flat tips</th>
<th>MWS, modulated tips, run 1</th>
<th>MWS, modulated tips, run 2*</th>
<th>COMSOL, modulated tips</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>162.424 MHz</td>
<td>162.398 MHz</td>
<td>162.408 MHz</td>
<td>162.403 MHz</td>
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<tr>
<td>2</td>
<td>-</td>
<td>162.261 MHz</td>
<td>162.294 MHz</td>
<td>162.289 MHz</td>
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<td>3</td>
<td>162.393 MHz</td>
<td>162.205 MHz</td>
<td>162.241 MHz</td>
<td>162.235 MHz</td>
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<tr>
<td>4</td>
<td>162.319 MHz</td>
<td>162.203 MHz</td>
<td>162.209 MHz</td>
<td>162.202 MHz</td>
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<tr>
<td>Full model</td>
<td>162.41 MHz</td>
<td></td>
<td>162.311 MHz</td>
<td>162.260 MHz</td>
</tr>
</tbody>
</table>

This “tuned” field was used in PIC simulations.

Axial asymmetry is not taken into account yet.
This plane is used in simulations for input beam. Output beam is defined 5 cm downstream from output end vane tips. The scraper is ignored.
Generation of input beam. TRACK output beam parameters.

Input beam:
- Two transverse emittances were considered: $\varepsilon_{\text{rms\_norm}} = 0.11 \pi \text{ mm mrad}$ (Staples) and $\varepsilon_{\text{rms\_norm}} = 0.23 \pi \text{ mm mrad}$ (maximum that I got from LEBT).
- For each emittance two particle distributions in transverse plane were considered: uniform (“waterbag”) and normal (Gaussian).
- Input Twiss parameters $\alpha$ and $\beta$ were swept assuming axial symmetry of input beam.

TRACK graphic output for well matched input beams (starting point for parameter sweep):

Phase ellipses enclose 95% particles.
Example of output beam reaction

\[ \varepsilon = 0.11 \pi \text{ mm mrad}, \alpha = 1, \beta = 6 \text{ cm/rad} \quad \text{blue line} \]

\[ \varepsilon = 0.11 \pi \text{ mm mrad}, \alpha = 2.5, \beta = 13.6 \text{ cm/rad} \quad \text{red line} \]

\[ \varepsilon = 0.11 \pi \text{ mm mrad}, \alpha = 4.75, \beta = 26.11 \text{ cm/rad} \quad \text{green line} \]
Output beam parameters vs input Twiss parameters

Only output transverse emittance depends on input Twiss parameters
Output transverse emittance vs input Twiss parameters

Gaussian distribution.
For input $\alpha$ and $\beta$ from inner contour emittance growth in the RFQ does not exceed 20%

Uniform distribution
For input $\alpha$ and $\beta$ from inner contour emittance growth in the RFQ does not exceed 35%

Particle losses inside RFQ start to occur approximately on the border of green area.
Conclusion

• The output transverse emittance and particle losses inside RFQ are only obvious criterion for input beam matching.
• For nominal input emittance of 0.011 \( \pi \text{ cm} \cdot \text{mrad} \) the tolerances for input Twiss parameters are pretty relaxed.
• Input particle distribution is not particularly important for transverse emittance growth and matching.
• TRACK doesn’t show low energy tail. CST PIC shows such tail even for perfectly matched beam with nominal emittance (only 1-2% of total particles in one bunch, but probably some dark current accumulation may occur for long beam pulses).