Bunch Compressor for Intense Proton Beams


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LINAC10, Tsukuba, Japan
2010/09/16
Outlines:

- Frankfurt Neutron Source FRANZ
- Bunch Compressor Concepts
- Single Bunch Beam Dynamics
- Magnet Design
- Final Focus – Effects of Space Charge Forces
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**FRANZ:** High current LINAC combined with 1ns-bunch-compressor

**Test stand:** Novel accelerator technology, high current beam diagnostics

**Applications:** ⇒ Astrophysical \((n, \gamma)\)-cross sections, TOF
⇒ Activation measurements, detector developments
⇒ Material sciences
High current applications:
=> Where are the limits of conventional accelerator technologies?
=> Are there alternative concepts?

• Beam forming at high rep. rates: $E \times B$ chopper (C. Wiesner, THP071)

• High current cw RFQ (A. Schempp, TUP039)

• Coupled RFQ-IH combination


• Alternative beam dynamics: KONUS (U. Ratzinger)

• Alternative beam focusing device: Space Charge Lens (K. Schulte, O. Meusel, MOP102)

• Non destructive diagnostics: beam tomography (O. Meusel)
**FRANZ: Bunch Compressor - Requirements**

**Volume Type Ion Source**

- 150 kV Terminal

**Diagnostics chambers**

**Steerer**

- Chopper
- $f_{cp} = 250$ kHz
- $\Delta t = 50-100$ ns

**Macro pulse forming**

**Micro pulse forming**

**RFQ**

**f_b = 175 MHz**

**Rebuncher**

**Kicker**

- $f = 5$ MHz

**Bunch Compressor**

**Li Target for Activation Mode**

**Multiaperture Rebuncher**

**Li Target for Compressor Mode**

**FRANZ: Bunch Compressor - Requirements**

**FRANZ (Frankfurt Neutron Source at the Stern-Gerlach Zentrum) / NNP (Non Neutral Plasma Group) / IAP (Institute for Applied Physics)**

**LINAC10, Tsukuba, Japan, September 16th, 2010**

**Pulse Structure at the Entrance**

- **175MHz-DTL**
  - rep.rate = 250kHz
  - $E \sim 2.0$ MeV
  - $I = 150$ mA

**~4 \mu s**

**~100 ns**

**Macro Bunch**

**Micro Bunch**

**Requirements at the Final Focus**

- $R < 10$ mm
- $\Delta W/W < \pm 5\%$
- $\Delta T = 50-100$ ns $\Rightarrow \Delta T \approx 1$ ns
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L ≈ 4 m => ΔW ≈ ±500keV

Large energy spread (RF-cavity)

Negligible energy spread (RF-deflector)
Mobley-Buncher: (μA-Proton Beams)

Kicker
→ separation of the micro bunches

Bending system (1 Dipole)
→ “weak” focusing
→ path length differences
→ longitudinal compression

Negligible energy spread (RF-deflector)
ARMADILLO – **Arc Magnetic Dipole Chicane with Large Aperture Longitudinally Focusing Cavities**

**Mobley-Buncher: (μA-Proton Beams)**

- **Kicker**
  → separation of the micro bunches

- **Bending system (1 Dipole)**
  → “weak” focusing
  → path length differences
  → longitudinal compression

**Improvements for 150mA Proton Beams:**

- **2 main dipoles (gradient)**
  → more parameters for beam dynamics

- **2 auxiliary dipoles (homogeneous)**
  → linear separation of the trajectories
  → momentum exchange in trans. plane

- **2 rebuncher cavities**
  → longitudinal beam dynamics

**LINAC**

\[ (9 \times 5.7\text{ns} \times 150\text{mA}) @ 250\text{kHz} \]

**Li-Target**

\[ (1\text{ns} \times 7.7\text{A}) @ 250\text{kHz} \]
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Single Bunch Beam Dynamics: 95% Envelope

IH + CH

dip1

dip2

quadrupole triplets

Multi-Aperture Rebuncher

Final Focus Rebuncher

LORASR
Beam dynamics solutions for all bunches can be found by manual optimization!
• Beam dynamics solutions for all bunches can be found by manual optimization!

• Smarter solution was proposed by D. Noll: using “Particle Swarm Optimization” (PSO)*

* [J. Kennedy, R. Eberhart, 1995, Proceedings of IEEE International Conference on Neural Networks. IV. pp. 19421948.]

• Cavity design: Multi-Aperture + Final Focus Rebuncher ⇒ D. Noll, MOP101
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• Beam dynamics solutions for all bunches can be found by manual optimization!

• Is it possible to design a magnet with the required parameters?
Magnet Design: Improvement for Beam Dynamics

- Particle in Cell (PIC) transport with realistic fields compared to 1\textsuperscript{st} order paraxial approach with given fringe field integral and edge angles.

- Ideal traj. $\equiv$ const. fields + hard edges.

- Convergence to the ideal trajectory.

- Slope and core of distributions fit very well.

- Aberration caused by field gradients near shimmed edges.

$\Rightarrow$ Single bunch beam dynamics with 1\textsuperscript{st} order paraxial approach is good enough for geometrical design.

$\Rightarrow$ Magnet design is possible!
Concepts for Main Dipole

- modular pole face
- global gradient => longitudinal focusing of the macro bunches
- individual reverse gradient => horizontal focusing of the micro bunches
- individual edge angles => vertical focusing of the micro bunches
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Multi Bunch Beam Dynamics: Effects of Space Charge

- Merging along **last 300 mm to the final focus**: realistic distributions from single bunch beam dynamics.
- Full Space Charge Forces (FSCF, red + purple).
- Space Charge Compensated transport (SCC, blue), e.g. provided by Space Charge Lens => K. Schulte, MOP102.
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Beam spot at the target
Multi Bunch Beam Dynamics: Effects of Space Charge

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### Current profile at the target

<table>
<thead>
<tr>
<th></th>
<th>2·σ FSCF</th>
<th>2·σ SCC</th>
<th>Δ(2·σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>7.86</td>
<td>6.92</td>
<td>-12%</td>
</tr>
<tr>
<td>y</td>
<td>8.90</td>
<td>7.02</td>
<td>-21%</td>
</tr>
<tr>
<td>z</td>
<td>16.52</td>
<td>12.38</td>
<td>-25%</td>
</tr>
</tbody>
</table>

\( (\Delta T)_{rms} = 2\cdot\sigma \)

Average \( \pm 2\cdot\sigma = 95.5\% \)

### Requirements

- \( R \) < 10 mm
- \( \Delta W/W \) < ±5%
- \( \Delta T = 50-100 \) ns => \( \Delta T \approx 1 \) ns

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\[ \Delta W = 104.6 \] keV

\[ \Delta W = 55.0 \] keV

\[ \Delta W = 47\% \]
• **ARMADILLO** bunch compressor is presented.

• **Geometrical concept** is principally able to reach a long. compression ratio of 45.

• **Single bunch and multi bunch beam dynamics** results, even with full space charge forces, are promising to **satisfy the requirements**.

• Preliminary and **improved magnet designs** are proposed.

• **Optimization of hardware and complementary code** has to be continued.

• **Front to end simulations** with realistic fields have to be done.

• **Detailed error studies** have to be done.
Thank you for your attention

on behalf of


IAP, Goethe University Frankfurt

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