Proton Linac for the Frankfurt Neutron Source

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**Frankfurt Neutron Source at Stern-Gerlach-Zentrum**

**FRANZ**

- Development of new accelerator concepts for intense proton and ion beams.
- Development of high power targets.
- Measurement of neutron capture cross sections, nuclear astrophysics.

**Technology and knowledge transfer from Karlsruhe.**

**Expertise of IAP in linac design**

- 4-rod RFQ
- IH-DTL

**Measurement of neutron beam**

- Neutron source at Stern-Gerlach-Zentrum

**Neutron beam**

- 7Li target

**High intensity proton beam**

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- © U. Ratzinger

4π BaF$_2$ Detector
Compressor Mode

- Pulsed operation, rep. rate 250 kHz, $\tau = 1\text{ ns}$
- $\langle I_b \rangle \sim 2\text{ mA}$

Activation Mode

- Cw operation $I_b \sim 3-30\text{ mA}$
- Neutrons: $10^{10}-10^{11}\text{ n/cm}^2\text{s}$

Operation Modes of the Frankfurt Neutron Source FRANZ.
**Volume type ion source**

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Cross-sectional view of the ion source.

<table>
<thead>
<tr>
<th>Operation Mode</th>
<th>dc</th>
<th>Extraction Voltage</th>
<th>62 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Species / Fraction</td>
<td>Protons / 90 %</td>
<td>Beam Output Energy</td>
<td>120 keV</td>
</tr>
<tr>
<td>Extraction Current</td>
<td>200 mA</td>
<td>Emittance (rms norm.)</td>
<td>0.07 ( \pi ) mm mrad</td>
</tr>
</tbody>
</table>
Low Energy Beam Transport (LEBT) Section

- High voltage terminal operational.
- Water and electricity supplies installed.
- Solenoids and diagnostics chambers are being tested.

Solenoid Lenses:
Aperture 100 mm, $B_z = 0.78$ T, length 251 mm
ExB Chopper System

Chopping of High Intensity Beams:
- *Avoiding long drifts* due to high space charge.
- *Minimizing duty factor* for electrostatic beam deflection in order to reduce risk of voltage breakdowns.
- *Beam dumping outside transport line* preferable in order to avoid high power deposition and uncontrolled production of secondary particles.

**Chopping Parameters**
- Beam Current: 200 mA
- Beam Energy: 120 keV
- Beam Power: 24 kW
- Input: DC Beam
- Output: Pulsed Beam
- Pulse Time: 100 ns
- Rep. Time: 4 µs

Optical Diagnostics of Beam Deflection Measurements

18 keV He-Beam

Slit
ExB Chopper System

- Solenoid 2
- ExB Chopper
- Septum Magnet
- Solenoid 3
ExB Chopper System

Solenoid 2  
ExB Chopper  
Septum Magnet  
Solenoid 3  
Deflector & HV Pulse Generator
ExB Chopper System

Static magnetic deflection

$B_y = -60 \text{ mT}$

$B_y = -300 \text{ mT}$

DC Beam

Solenoid 2

ExB Chopper

Solenoid 3

Septum Magnet

Dumped Beam

Deflector & HV Pulse Generator

$V_{\text{defl}} = 0 \text{ kV}$
ExB Chopper System

Static magnetic deflection compensated by pulsed electric deflection during 100ns pulse.

- $B_y = -300 \text{ mT}$
- $B_y = -60 \text{ mT}$
- $V_{\text{defl}} = 11 \text{ kV}$
Radio Frequency Quadrupol - RFQ
Focusing, Bunching and Acceleration

Proton Source  LEBT  RFQ

RFQ test module  RFQ technical design

© A. Schempp / NTG company
Coupled RFQ-IH-Structures

**Proton Beam**

- $l_{RFQ} = 1.7 \text{ m}$
- $l_{IH} = 0.6 \text{ m}$
- $d = 0.51 \text{ m}$
- $f_0 = 175 \text{ MHz}$

**Beam Parameters**

- $W_b = 120 \text{ keV}$
- $W_b = 700 \text{ keV}$
- $W_b = 2 \text{ MeV}$

**Max. Proton Current**

- 200 mA

**Exp. Power Consumption**

- RFQ: 150 kW
- IH-DTL: 45 kW

**RFQ Acceptance (norm. rms)**

- 0.56 $\pi \text{ mm mrad}$

**Coupling of RFQ and IH-DTL:** Only one power amplifier $\rightarrow$ lower investment costs.

- **RFQ:** Bunching and first acceleration stage.
- **IH-DTL:** Main acceleration stage.
IH-DTL and CH-Rebuncher

IH-Drift Tube Linac: Acceleration from 0.7 MeV to final energy of 2 MeV.

• 8 accelerating gaps

Magnetic quadrupole triplets

• 4 gaps for accelerating/decelerating

CH-Rebuncher: Energy variation ± 0.2 MeV.

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Design was based on Mobley-type bunch compressor and extended for high intensity beams.

- Homogenous Dipoles
- Gradient Dipoles
- 5 MHz Kicker
- Rebuncher

9 Bunches

Single 1ns Pulse at Li-Target
High Power Target

Compressor Mode:
Average power ~ 4 kW

Target prototype development at Karlsruhe for beam power up to 6 kW.

\[ _1^1H + _3^7Li \rightarrow _4^7Be + _0^1n - 1,646 \text{ MeV} \]

Threshold: 1.881 MeV

Neutron yield and maximum neutron energy in forward direction (0°).
4π BaF₂ Detector Array

- Gamma calorimeter
- Fast timing (<1 ns) for acceptable TOF resolution
- Low neutron sensitivity

- 80 cm flight path
- \( E_n = 1 \ldots 200 \) keV

Other Reactions

Prompt Flash

\((n,\gamma)\) on sample

\( E_n = 200 \) keV

\( E_n = 128 \) keV

Time of Flight Method

4π BaF₂ detector after transfer from Karlsruhe to Frankfurt.
Neutron Characteristics

- **Short 1 ns Pulse** (Compr. Mode).

- **Intensities** of up to $10^7$ n/cm²s (Compr. Mode) resp. $10^{10}$ n/cm²s (Activat. Mode).

- **Neutron Energy**: $E_{\text{min}} = 1$ keV; $E_{\text{max}} = 400$ keV; Neutron spectrum of Red Giant stars is reproduced in the laboratory (Activat. Mode).


Increase of up to a factor of 1000 compared to previous setup at FZK. Allows measurement of small samples.
Summary

Source constructed  LEBT vacuum tests  Chopper design

RFQ test module  Compressor design  Detector reassembled
FRANZ will provide a rich experimental program:

- Accelerator physics (high intensity beam transport, shaping, acceleration).
- High power target development.
- Detector development.
- Measurement of neutron capture cross sections.
- Nuclear astrophysics.

FRANZ is a university project:

- Education of students in the fields of nuclear and accelerator physics.
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FZK / GSI / IAEA
Thank you for your attention