The new FAIR post-stripper DTL

Alvarez 2.0
Outline

- Motivation
- Beam dynamics
- RF design
- FoS (First of Series) – 1st cavity section
- Schedule
- Summary
### UNIversal Linear Accelerator (UNILAC)

**Design Parameters after Upgrade**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ion A/q</td>
<td>( \leq 8.5 ), i.e. (^{238}\text{U}^{28+})</td>
</tr>
<tr>
<td>beam current (pulse) * A/q</td>
<td>1.76 (0.5% duty cycle) mA</td>
</tr>
<tr>
<td>input beam energy</td>
<td>2.2 keV/u</td>
</tr>
<tr>
<td>output beam energy</td>
<td>3.0 - 11.7 MeV/u</td>
</tr>
<tr>
<td>operating frequency</td>
<td>36.136 / 108.408 MHz</td>
</tr>
<tr>
<td>length</td>
<td>( \approx 115 ) m</td>
</tr>
<tr>
<td>beam pulse duration</td>
<td>( \leq 1000 ) µs</td>
</tr>
<tr>
<td>beam repetition rate</td>
<td>( \leq 10 ) Hz</td>
</tr>
</tbody>
</table>

**Diagram**

- MUCIS
- MEVVA
- CHORDIS
- IH-Cavity
  - 1.4 MeV/u
- ECR
- RFQ
  - 120 keV/u
- IH-DTL
  - 1.4 MeV/u
- Gaseous Stripping
- Alvarez-DTL
  - 3.6 / 4.8 / 5.9 / 8.6 / 11.4 MeV/u
- Single Gap Resonators
Alvarez DTL
What is the motivation for a new post stripper DTL?

1. FAIR goal
   - High current applications as required by FAIR (high intensity operation of heavy ions was not considered in the 1960’s)

2. Operational risk
   - Alvarez DTL is in regular operation since 1978 (expected lifetime: ~20 years).
   - An increase in failures is observable.
   - Maintenance effort is increasing.
### What are the operational risks?

<table>
<thead>
<tr>
<th>Risks</th>
<th>Tank and endplates</th>
<th>Drift tubes</th>
</tr>
</thead>
<tbody>
<tr>
<td>i)</td>
<td>Water leaks</td>
<td>Water leaks</td>
</tr>
<tr>
<td>ii)</td>
<td>Degredation of RF-properties</td>
<td>Degredation of RF-properties</td>
</tr>
<tr>
<td>iii)</td>
<td>Failure of cooling system</td>
<td>Failure of cooling system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>iv) Electrical shortcut of internal windings</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reasons</th>
<th>Tank and endplates</th>
<th>Drift tubes</th>
</tr>
</thead>
<tbody>
<tr>
<td>i)</td>
<td>Corrosion (mild steel)</td>
<td>Erosion</td>
</tr>
<tr>
<td>ii)</td>
<td>Aging of the Cu layer</td>
<td>Aging of the Cu layer</td>
</tr>
<tr>
<td>iii)</td>
<td>Corrosion/Erosion products clog up the cooling channels</td>
<td>Corrosion/Erosion products clog up the cooling channels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>iv) Aging isolation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Countermeasures</th>
<th>Tank and endplates</th>
<th>Drift tubes</th>
</tr>
</thead>
<tbody>
<tr>
<td>i), ii)</td>
<td>Substitution of tanks and endplates</td>
<td>Substitution of drift tubes</td>
</tr>
</tbody>
</table>
| ii)                           | Cu-stripping and re-Cu-plating | iii)  
|                               | Rinsing            | Rinising, closed stainless steel cooling circuit in 2013 |
| iii)                          | Rinsing            |                                                  |

Minimizing the operational risk means a one-to-one copy of the existing DTL
• no win of performance
• costs (and resources) for refurbishment are comparable to the costs of a new post-stripper DTL
What defines the FAIR goal?

- "upgraded" SIS18 space charge limit gap caused by design of UNILAC from 1960's, w.r.t. the post-stripper DTL:
  - not a dedicated HC DTL (intertank sections)
  - quadrupoles gradients are limited (phase advance)

 FAIR goal

(courtesy p: Spiller)
How to reach the FAIR goal?

Extensive upgrade program along the UNILAC

- Upgrades are backed by front-to-end-simulations
  - prediction: an upgraded UNILAC reaches the FAIR requirements
  - tool for further optimisation, future commissioning and operation

P. Gerhard et al.
FR1A04, 9:50 am
How to reach the FAIR goal with the new DTL beam dynamics layout?

- periodic focusing
  (new design of the inter-tank sections takes care about strict periodicity)

- avoid space charge driven emittance growth resonances
  (higher quadrupole gradients)
What are the results?

<table>
<thead>
<tr>
<th></th>
<th>FAIR</th>
<th>Zero current</th>
<th>Low energy</th>
<th>Larger long. emit.</th>
<th>Smaller long. emit.</th>
<th>Transvers. flat beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current, mA</td>
<td>16.5</td>
<td>0</td>
<td>0</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
</tr>
<tr>
<td>Input $\varepsilon_x$ (rms), mm mrad</td>
<td>0.175</td>
<td>0.175</td>
<td>0.175</td>
<td>0.175</td>
<td>0.175</td>
<td>0.0875</td>
</tr>
<tr>
<td>Input $\varepsilon_y$ (rms), mm mrad</td>
<td>0.175</td>
<td>0.175</td>
<td>0.175</td>
<td>0.175</td>
<td>0.175</td>
<td>0.35</td>
</tr>
<tr>
<td>Input $\varepsilon_z$ (rms), mm mrad</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
<td><strong>0.14</strong></td>
<td><strong>0.035</strong></td>
<td>0.07</td>
</tr>
<tr>
<td>Output energy, MeV/u</td>
<td>11.4</td>
<td>11.4</td>
<td><strong>3.3</strong></td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>Transmission, %</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>$\Delta \varepsilon_x$ (tot, 95%), %</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>$\Delta \varepsilon_y$ (tot, 95%), %</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>$\Delta \varepsilon_z$ (tot, 95%), %</td>
<td>10</td>
<td>0.7</td>
<td>1.7</td>
<td>5</td>
<td>11</td>
<td>4</td>
</tr>
</tbody>
</table>
What is expected in front of SIS18?

- taking tolerances into account

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadrupole x,y displacement</td>
<td>± 0.15 mm</td>
</tr>
<tr>
<td>Quadrupole x,y rotation</td>
<td>± 1°</td>
</tr>
<tr>
<td>Quadrupole z rotation</td>
<td>± 0.1° - 0.4°</td>
</tr>
<tr>
<td>Gap voltage</td>
<td>± 1%</td>
</tr>
<tr>
<td>Gap phase</td>
<td>± 1°</td>
</tr>
<tr>
<td>Initial energy</td>
<td>± 0.5%</td>
</tr>
<tr>
<td>Input rms emittance (x,y,z)</td>
<td>± 15%</td>
</tr>
<tr>
<td>Input beam mismatches (x,y,z)</td>
<td>± 10%</td>
</tr>
<tr>
<td>Input Current</td>
<td>± 15%</td>
</tr>
</tbody>
</table>

SIS18-multi-turn injection performance chart
What is new concerning the rf-design?

At 1.0 Kilpatrick (maximum surface field), ~13% increase in shunt impedance

Modernisation of UNILAC RF-systems

1.8 MW THALES cavity amplifier prototype (2ms rf pulse length @10Hz)

G. Schreiber, B. Schlitt, GSI
What are the challenges?

- Dimension of the cavities  
  (tight spatial conditions, higher gradients)
- Storage/assembling/testing areas on-site
- Expertise is retired
- Cu-plating  
  Equipment is scrapped partly
- New drift tube design
- Regular beam time in parallel
- FAIR project in parallel
What is the First of Series (FoS)?

- Feb 2017: System-Decision: Alvarez type DTL
- Jul/Aug 2017: FoS funded with 1.5 M€ until 2021
- Nov 2017: Procurement of components starts
- 2018-2020: R&D: System design process development preparation test stand delivery of components
- 2021 Full performance tests -> rf characteristics -> pulsed quadrupoles -> cooling system

1st section of A1 cavity (11 + two ½ drifttubes)
What is the FoS-status?

Dummy cavity ($d_{out}=2.4$, $l=2.5m$)
- fabrication: balance between effort in fabrication and acceptable tolerances
- Cu-plating (120µm Cu-layer): surface quality ex factory, alternative process, handling, etc.

Pulsed quadrupole design (1st of ~200)
- Gradient: 51 T/m
- Effective length: 99.5 mm
- Integral field ($G^* L_{eff}$) = 5.07 T
- Current: 1109.6 A
- Conductor diameter: 5.5 mm
- Cooling channel diameter: 3.5 mm
- No. of windings: 5
- No. of cooling circuits: 1
- Yoke material: VACOFLUX50

Drift tube prototyping
- know-how acquisition (feasibility, spare part production, welding, etc.)

Cu-plating R&D
- new additive for electrolyte
- Test pipes (200µm)
### How the schedule looks like?

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2/2021</td>
<td>Successful FoS project, TDR &amp; funding available</td>
</tr>
<tr>
<td>Q2/2022</td>
<td>Delivery of components/cavities starts</td>
</tr>
<tr>
<td>Q2/2024</td>
<td>All components in-house</td>
</tr>
<tr>
<td>Q2/2024 + X</td>
<td>De-installation of existing post-stripper DTL</td>
</tr>
<tr>
<td>Q4/2024 + X</td>
<td>Cavity-wise installation and commissioning</td>
</tr>
<tr>
<td>Q4/2025 + X</td>
<td>DTL commissioning w/o and with beam</td>
</tr>
</tbody>
</table>

**Strict boundary condition:**

**minimize the downtime**

- don't touch the existing if there is any uncertainty about the new Alvarez
- sequential installation and commissioning
- UNILAC downtime has to match the FAIR schedule
Summary

- Two aspects require the substitution
  - Operational risk
    refurbishment of the existing DTL means an one-to-one-copy
    -> no gain in performance, no significant cost savings
  - FAIR intensity requirements for heavy ion beams
    -> existing DTL is not designed for HC applications
    -> intertank-sections and limited quadrupole gradients

- Robust beam dynamics (focusing periodicity)
  - re-design of intertank-sections
  - higher quadrupole gradients

- RF-efficiency is increased by new drift tubes geometry

- FoS-Project is funded until 2021
  -> testing of innovations in design and fabrication
  -> procurement and development is in progress

- Kick-off for series production is a successful FoS project

- No immediate „urgency“ until the existing UNILAC is in operation, a delay X can be allowed w.r.t. the overall FAIR schedule and the project’s progress
Thanks

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Gerald Schreiber,
...

Foto: Sep 2018 by T. Middelhauve/FAIR