Beam Physics Challenges in RAON

HB2014 workshop

Dong-O Jeon, Hyo Jae Jang, Ji-Ho Jang, Hyung Jin Kim, ASD members (RISP/IBS)
Ji-Kwnag Hwang, Eun-San Kim (KNU)
RAON Layout and Beam Parameters

Contents
- Introduction
- Driver Linac
  - injector
  - SCL (CSS)
- Summary

High Energy Exp. 2
High Energy Exp. 1
Low Energy Exp.
## RAON Layout and Beam Parameters

<table>
<thead>
<tr>
<th>Particle</th>
<th>Driver Linac</th>
<th>Post Acc.</th>
<th>Cyclotron</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H⁺</td>
<td>O⁺⁸</td>
<td>Xe⁺⁵⁴</td>
</tr>
<tr>
<td>Beam energy (MeV/u)</td>
<td>600</td>
<td>320</td>
<td>251</td>
</tr>
<tr>
<td>Beam current (μA)</td>
<td>660</td>
<td>78</td>
<td>11</td>
</tr>
<tr>
<td>Power on target (kW)</td>
<td>&gt; 400</td>
<td>400</td>
<td>400</td>
</tr>
</tbody>
</table>

- injector
- SCL (CSS)

### Summary

- Low Energy Exp.
- Cryogenic System
- Charge Stripper
- ISOL
- TEM
- Cyclotron

### Contents
- Introduction
- Driver Linac - injector - SCL (CSS)
- Summary
RAON Site
Budget and Schedule

- The RAON Project Cost
  Accelerator and Experimental Systems: $420M (46.02B KRW)
  Conventional Facility: $568M (62.43B KRW)
  Site Cost: $327M (36.00B KRW)

- Conventional facility budget was finalized 2014.05.
- Construction to be completed by 2021.12.
RAON Injector

- Injector consists of ECR IS, LEBT, RFQ and MEBT
- Two charge states (33, 34) of Uranium beams
- Fabrication of prototype components finished and their tests are in progress.
28 GHz ECR Ion Source

- Superconducting sextupole and solenoid prototypes were tested and achieved > 30% margin.
- Superconducting magnet assembly (sextupole + 4 solenoids) was completed.
- Cryostat fabrication was completed and test will be performed.
- Preparing for beam test in late 2014.

$B_{\text{inj}} = 3.5 \, \text{T}$, $B_{\text{ext}} = 2.2 \, \text{T}$, $B_r = 2 \, B_{\text{ecr}}$, $B_{\text{min}} = 0.7 \, \text{T}$

Six 4K cryocoolers, One single stage cryocooler

Cryostat fabrication
LEBT

- Electrostatic quadrupoles: two charge states for uranium beams (33,34)
- MHB and VE: reducing rms beam emittance of RFQ output beams.

[ Track simulation results ]

[ Solenoids ]
[ ESQ triplet ]
[ Bending Magnet ]
## RFQ Beam Dynamics Design

### [ RFQ parameters ]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particles</td>
<td>Proton $\sim ^{238}\text{U}^{33+,34+}$</td>
</tr>
<tr>
<td>Frequency</td>
<td>81.25 MHz</td>
</tr>
<tr>
<td>Input/Output Energy</td>
<td>10 keV/u, 500 keV/u</td>
</tr>
<tr>
<td>Peak Surface Field</td>
<td>1.7 Kilpartic</td>
</tr>
<tr>
<td>Type</td>
<td>Four Vane</td>
</tr>
<tr>
<td>Operation Mode</td>
<td>CW</td>
</tr>
<tr>
<td>Transmission</td>
<td>98%</td>
</tr>
<tr>
<td>Length</td>
<td>4.94 m</td>
</tr>
</tbody>
</table>

### [ PARMTEQ simulation ]
Technical design was completed (August 2013) and reviewed November 2013.

Mode separation 1.84 MHz
RFQ Prototype

• RFQ Prototype
  - vane machining and 3D measurement
  - The 1\textsuperscript{st} brazing failed (2014.04)
  - Brazing procedure modified (2014.05)
  - Confirmed brazing procedure (2014.06)
  - RFQ prototype completed successfully through domestic vendor (2014.10)

• RFQ Prototype test
  - 15kW SSA, coupler, RCCS are ready
MEBT

- MEBT: 8 quadrupole magnets, 3 rebuncher cavities
- MHB and VE: reducing rms beam emittance of RFQ output beams.
RAON Superconducting Linac

- RAON SCL is designed to accelerate high intensity beams.
- Focusing by NC quad doublets rather than SC solenoids.
- Optimized geometric beta of SC cavities (0.047, 0.12, 0.30, 0.51).
- Employs larger aperture to reduce beam loss (40 / 50 mm aperture).
- Prototyping of SC cavities and cryomodules is under way and preparing for test.
Superconducting cavity

[ Design Parameters ]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>QWR</th>
<th>HWR</th>
<th>SSR1</th>
<th>SSR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_g$</td>
<td>-</td>
<td>0.047</td>
<td>0.12</td>
<td>0.30</td>
<td>0.51</td>
</tr>
<tr>
<td>$F$</td>
<td>MHz</td>
<td>81.25</td>
<td>162.5</td>
<td>325</td>
<td>325</td>
</tr>
<tr>
<td>Aperture</td>
<td>mm</td>
<td>40</td>
<td>40</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>$QR_s$</td>
<td>Ohm</td>
<td>22</td>
<td>42</td>
<td>94</td>
<td>112</td>
</tr>
<tr>
<td>$R/Q$</td>
<td>Ohm</td>
<td>468</td>
<td>310</td>
<td>246</td>
<td>296</td>
</tr>
<tr>
<td>$V_{acc}$</td>
<td>MV</td>
<td>1.1</td>
<td>1.5</td>
<td>2.4</td>
<td>4.1</td>
</tr>
<tr>
<td>$E_{peak}$</td>
<td>MV/m</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>$B_{peak}$</td>
<td>mT</td>
<td>57</td>
<td>55</td>
<td>58</td>
<td>64</td>
</tr>
<tr>
<td>$Q_{calc}/10^9$</td>
<td>-</td>
<td>2.1</td>
<td>4.2</td>
<td>9.0</td>
<td>10.5</td>
</tr>
<tr>
<td>Temp.</td>
<td>K</td>
<td>4.5</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

[ Energy gain ]

[ QWR]

[ HWR]

[ SSR1 ]

[ SSR2]
Beam Dynamics in Linac (1/2)

- Lattice: Doublet with normal conducting quadrupole magnets
- $^{238}\text{U}^{33+,34+}$ in SCL1, $^{238}\text{U}^{77+\sim 81+}$ in SCL2 after CSS

<table>
<thead>
<tr>
<th></th>
<th>SCL11</th>
<th>SCL12</th>
<th>SCL21</th>
<th>SCL22</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM#</td>
<td>22</td>
<td>13</td>
<td>19</td>
<td>23</td>
</tr>
<tr>
<td>Cav. # / CM</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Cav. Type</td>
<td>QWR</td>
<td>HWR</td>
<td>HWR</td>
<td>SSR1</td>
</tr>
</tbody>
</table>

[ QWR ] [ HWR ]

Charge Selection Section

[ SCL1 ]

[ SSR1 ] [ SCL2 ]

[ SSR2 ]

[ Final Energy ]

$\text{O}$

$\text{U}$

$\text{Xe}$

$\text{proton}$
Beam Dynamics in Linac (2/2)

[ Beam Envelope (rms) ]

[ Normalized rms emittance in SCL1 ]

[ Normalized rms emittance in SCL2 ]
Charge Selection Section

- 90-degree bending section: using mirror symmetry
- 2\textsuperscript{nd} order achromat: 6 sextupole magnet to minimize $T_{126}$, $T_{266}$, $T_{436}$
- Emittance growth: $\Delta \epsilon_x = 1.8\%$, $\Delta \epsilon_y = 1.5\%$, (first order achromat: $\Delta \epsilon_x = 23.6\%$)

[ TRACK simulation results ]
[ Particle distribution at center of CSS ]
Machine Imperfection Effects

- Beam loss requirement (1W/m) is met even without orbit correction.
- It is expected that beam loss will reduce with orbit correction.

### Charge Stripper Section

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity</td>
<td>Misalignment</td>
<td>1mm</td>
</tr>
<tr>
<td>Tilt</td>
<td>5 mrad</td>
<td></td>
</tr>
<tr>
<td>Voltage, phase</td>
<td>1%, 1°</td>
<td></td>
</tr>
<tr>
<td>Quadrupole</td>
<td>Misalignment</td>
<td>0.15mm</td>
</tr>
<tr>
<td>Tilt</td>
<td>5 mrad</td>
<td></td>
</tr>
<tr>
<td>Magnetic field</td>
<td>1%</td>
<td></td>
</tr>
</tbody>
</table>

[ Error Limit ]  
[ Beam Loss Result ]
SC Cavity Prototyping

- Prototype superconducting cavities are fabricated through domestic vendors.
Cryomodule Prototyping

• Fabrication of QWR and HWR cryomodule prototypes is completed.
• LN₂ test is performed from Oct/22/2014.
• LHe test will be performed afterward.
Summary (1/2)

• Integration of independent ISOL & IF systems is one of the distinct feature of the RAON.
• Technical Design Report was completed in 2013.09 meeting the project milestone.
• Optimization in beam dynamics is in progress.
• Prototyping of major accelerator parts has been in progress since 2013 through domestic vendors.
  – ECR ion source cryostat was fabricated (2014.09)
  – RFQ prototype fabricated successfully (2014.10)
  – SC cavity prototypes were delivered for test (since 2014.05)
  – Cryomodule prototypes to be delivered from 2014.12
• Some prototypes are in testing stage.
  – ECR ion source, RFQ, MEBT buncher
  – Superconducting cavities (QWR, HWR)
Summary (1/2)

• Experimental systems are being developed in parallel.
  − KOBRA is the first experimental system at RAON, which is a recoil spectrometer for nuclear structure and nuclear astrophysics studies.
  − MR-TOF system will be developed as a high precision mass measurement system by 2018.

• The conventional facility budget for the RAON was finalized in 2014.05.

• Conventional facility preliminary design contract is to be signed by Nov/28/2014.
Thank you for your attention!
감사합니다