Superconducting Linac for the RISP
(Rare Isotope Science Project)

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Collaboration with KNU, POSTECH, SNU, NFRI, Vitzrotech, SFA, TRIUMF, IHEP
Rare Isotope Science Project (RISP)

- Conceptual Design Study (2009.3 - 2011.2)
- Rare Isotope Science Project (RISP) launched (2011.12)

- Construction period: 2012-2021
- 46B KW (~443M USD) from central government for heavy ion accelerator itself
- 62B KW (~597M USD) from central government for buildings and tunnel construction
- 39BKW (~375M USD) from central government for land purchase
RISP – Bird Eye View

Supply/Test/Office Bldg
Exp. Halls
IF Target
Driver SC Linac
Injector
Preserved Forest Area
Main Control Center
Exp. Halls
Post Accelerator

1,049,505m²
### RISP – Bird Eye View

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Driver Linac (SCL1-SCL2)</th>
<th>Post Acc. (SCL3-SCL2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle</td>
<td>Proton</td>
<td>Uranium</td>
</tr>
<tr>
<td>A/q</td>
<td>1</td>
<td>7(+33.5)→3(+79)</td>
</tr>
<tr>
<td>Beam energy</td>
<td>600 MeV</td>
<td>200 MeV/u</td>
</tr>
<tr>
<td>Beam current</td>
<td>660 μA</td>
<td>8.3 pμA</td>
</tr>
<tr>
<td>Power on target</td>
<td>&gt; 400 kW</td>
<td>400 kW</td>
</tr>
</tbody>
</table>

- Power on target > 400 kW
- Beam current 660 μA
- Beam energy 600 MeV
- A/q 1
- Preserved Forest Area
- IF Target
- Driver SC Linac
- Injector
- Main Control Center
- Exp. Halls
- Post Accelerator
RISP consists of Injector, SC Linac and IF systems.

SC Linac comprises low energy linac (SCL1), charge stripper section (CSS) and high energy linac (SCL2).

**SCL Characteristics**

- Linac baseline frequency is 81.25MHz
- Niobium Cavities operating at 2K and 4.5K
- Focusing by normal conducting quad doublets
- Optimized geometric beta of SC cavities (0.047, 0.12, 0.30, 0.51)
- Employs larger aperture to reduce beam loss (4cm and 5 cm aperture)
## Layout of Driver Linac

<table>
<thead>
<tr>
<th>ECR</th>
<th>LEBT</th>
<th>RFQ</th>
<th>MEBT</th>
<th>SCL11</th>
<th>SCL12</th>
<th>STRIP</th>
<th>SCL21</th>
<th>SCL22</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>QWR</td>
<td>HWR</td>
<td></td>
<td>SSR1</td>
<td>SSR2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(81.25MHz)</td>
<td>(162.5MHz)</td>
<td></td>
<td>(325MHz)</td>
<td>(325MHz)</td>
</tr>
</tbody>
</table>

1. **22 cryomodules** → **Output 2.7 MeV/u**

- **22 β=0.047 QWRs, 44 quadrupoles**

2. **13 cryomodules** → **Output 6.0 MeV/u**

- **98 β=0.12 HWRs, 64 quadrupoles**

3. **23 cryomodules** → **Output 56.5 MeV/u**

- **69 β=0.30 SSR1, 46 quadrupoles**

4. **23 cryomodules** → **Output 200 MeV/u**

- **138 β=0.51 SSR2, 46 quadrupoles**

**Stripper:** charge state 33, 34 → 77, 78, 79, 80, 81 for Uranium

**Total 331 cavities, 100 cryomodules, 196 quadrupoles, 122m (LEL,CSS), 181m (HEL)**
**Beam Physics**

**Lattice Design**

- Transverse emittance increase is less than 20%.
- Longitudinal emittance is improved.

**Machine Imperfection Effects**

- Beam centroid exhibits max orbit deviation of 8 mm.
- It is expected that beam loss will reduce with orbit correction.

---

**Item** | **Quantity** | **Error** | **Distribution**
--- | --- | --- | ---
Cavity | Misalignment | 1mm | Uniform
Tilt | 5 mrad | Uniform
Voltage, phase | 1%, 1° | Gaussian
Quadrupole | Misalignment | 0.15mm | Uniform
Tilt | 5 mrad | Uniform
Magnetic field | 1% | Gaussian
What is considered in RISP design

- Linac operation cost
  - The long-term operating costs of the accelerating linac are significant
    - Superconducting linac operating costs are dominated by the cryoplant and operating temperature.
    - RISP is focused on a superconducting linac design.
    - Components design is focused on optimization for reducing the cryogenic equipment and their operating costs.

- Linac hardware cost
  - Superconducting cavity, cryomodule and cryoplant are complicated and costly.
Design of SC Cavity

Optimization of Cavity Parameters

- Mechanical analysis
- Multipacting analysis

Mechanical analysis

- Frequency shift
- Multipacting analysis

Frequency shift

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonant Frequency</td>
<td>81.25MHz</td>
</tr>
<tr>
<td>Cavity length (upper)</td>
<td>-67.1kHz/mm</td>
</tr>
<tr>
<td>Cavity length (lower)</td>
<td>+1.3kHz/mm</td>
</tr>
<tr>
<td>Welding (0.58mm shrink)</td>
<td>+38.2kHz</td>
</tr>
<tr>
<td>EP/BCP (125um)</td>
<td>+267kHz</td>
</tr>
<tr>
<td>External pressure (Vacuum, L-He)</td>
<td>-4.6Hz/mbar</td>
</tr>
<tr>
<td>Cool down (293K → 2K)</td>
<td>+203kHz</td>
</tr>
<tr>
<td>Lorentz Detuning</td>
<td>-1.7Hz/(MV/m)^2</td>
</tr>
</tbody>
</table>
## Superconducting cavity

**EM design optimization: Parameters sweeping**

<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>$\beta_g$</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>21</td>
<td>42</td>
<td>98</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>0.9</td>
<td>1.3</td>
<td>1.9</td>
<td>3.6</td>
</tr>
<tr>
<td>$E_{peak}/E_{acc}$</td>
<td></td>
<td>5.6</td>
<td>5.0</td>
<td>4.4</td>
<td>3.9</td>
</tr>
<tr>
<td>$B_{peak}/E_{acc}$</td>
<td></td>
<td>9.3</td>
<td>8.2</td>
<td>6.3</td>
<td>7.2</td>
</tr>
<tr>
<td>$Q_{calc}/10^9$</td>
<td>-</td>
<td>1.7</td>
<td>4.1</td>
<td>9.2</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>
SC Cavity Prototyping

- MATERIAL INSPECTION
- DEEP DRAWING
- MACHINING
- 3D SCAN (CMM)
- BCP
- EBW

CAVITY Manufacturing Process

Vitzrotech and SFA
SSR Cavity Prototyping

- CAVITY PARTS – Material: Nb
  - SPOKE
  - END COVER
  - OUTER CYLINDER
  - BEAM TUBE 1
  - BEAM TUBE 2
  - VACUUM TUBE
Cavity Prototyping - EBW Test

Beam port cup

Outer conductor

Beam port cup

Outer conductor
Prototyping SC Cavity

QWR Final EBW

<table>
<thead>
<tr>
<th>Date</th>
<th>Cutting length</th>
<th>Resonant Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.20</td>
<td>3mm</td>
<td>88.8MHz-64kHz/mm</td>
</tr>
<tr>
<td>5.21</td>
<td>3.2mm-4mm (initial)</td>
<td>88.8MHz</td>
</tr>
<tr>
<td>5.23</td>
<td>Upper and center</td>
<td>85.3MHz-95MHz</td>
</tr>
<tr>
<td>5.27</td>
<td>Lower and center</td>
<td>85.3MHz-110MHz</td>
</tr>
</tbody>
</table>

HWR Clamp-up Test

SSR1 Clamp-up Test

SSR2 Clamp-up Test

Final welding will be done in June by Vitzrotech and SFA. Vertical tests will be performed in 2014.

WEPRI035 (IPAC2014)
RF Coupler

  - Performance test in progress
- Frequency: 325 MHz
- Nominal Power: 14.5 kW

  - Frequency: 162.5 MHz
  - Nominal Power: 3.7 kW

T-box

Window assembly with inner conductor

Outer conductor

IBS Coupler

RF power :4kW

Window and Inner conductor with air cooling is available.

Air

Window

Inner conductor

2개 커플러 시험 커플러 사항에 따른 비교

2개 커플러 시험 동일 결과
Cryomodule

<table>
<thead>
<tr>
<th>Module</th>
<th>Thermal load (4.5K equivalent, W) Without margin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Static</td>
</tr>
<tr>
<td>QWR</td>
<td>227</td>
</tr>
<tr>
<td>HWR#1</td>
<td>389</td>
</tr>
<tr>
<td>HWR#2</td>
<td>682</td>
</tr>
<tr>
<td>SSR#1</td>
<td>475</td>
</tr>
<tr>
<td>SSR#2</td>
<td>790</td>
</tr>
<tr>
<td>Total</td>
<td>2,563</td>
</tr>
</tbody>
</table>

- **tolerance**
  - X: ±0.25mm
  - Y: ±0.25mm
  - Z: ±0.5mm
  - Pitch: ±0.1˚
  - Yaw: ±0.1˚
  - Roll: ±0.1˚

WEPRI035, WEPRI036 (IPAC14)
Design of Charge Stripper

Charge state evolution (top left), charge state distribution (top right), energy loss (bottom left) and $5Q^+$ populations for Uranium with C foil.
Design of Li Charge Stripper

Schematic drawing of Li stripper

Charge state evolution (top left), charge state distribution (top right), energy loss (bottom left) and 5Q+ populations for Uranium with Li

Cold trap of Li purifier

Design of EM pump
Cryogenic System

- Total HL = SCL1,2,3 + Distribution + IF + Beam Loss + ZDS
  = 11.0 + 1.0 + 0.5 + 0.2 + 0.1 = 12.8 (kW)
- Cryoplant Capacity: 19.2 kW (with 50% margin) \(\Rightarrow\) “18 kW Plant”
RF System

- **RF system**

  - Clock signal generator
  - LLRF
  - Freq. doubler
  - 81.25 MHz
  - 162.5 MHz
  - 325 MHz
  - Freq. multiplier
  - SSPA
  - PID Feedback loop
  - QWR
  - HWR
  - SSR

- **Control system**

  - Ethernet
  - RAON
  - LLRF EPICS IOC
  - LLRF OPI
  - RAON (?) mode
  - Local operation mode
  - Measured RF amplitude
  - Measured RF phase
  - Tuner position
  - RF on time
  - Target RF amplitude
  - Target RF phase
  - Motor control information

**Measured RF amplitude**
**Measured RF phase**
**Tuner position**
**RF on time**
**Target RF amplitude**
**Target RF phase**
**Motor control information**
LLRF+SSPA integration test

**Setup**

- Clock signal
- RF input
- Internal trig.
- FPGA
- RF output
- LLRF controller
- LLRF

- RF peak power-meter
- -3 dB coupling
- Ch. A
- Ch. B
- Dummy load
- -64.7 dB coupling

4 kW SSPA

**Long Term Test Result**

- With feedback control
- LLRF+SSPA
- 3 h CW operation

<table>
<thead>
<tr>
<th>SSPA output power (kW)</th>
<th>Power fluctuation (%)</th>
<th>Phase fluctuation (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>@ 3 kW</td>
<td>Max</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>0.06%</td>
<td>0.02°</td>
</tr>
</tbody>
</table>
It will be ready for operation in 2015.

- 2 vertical test stands
- 3 cryomodule test benches
- 1 buffered chemical processing
- 2 high pressure rinsing
- 1 high temperature furnace
- 1 ultrasonic clean
- Cryogenic system
Summary

- Superconducting linac has been designed to meet the requirement of science goals and various users.

- Superconducting cavities have been designed for four different types, and their prototyping is done and under cold test.

- Cryomodules have been designed, and their prototyping is under way.

- Budget of thermal load and requirement of cryogenic system are documented.

- RF power sources (SSPA) are prototyped and being tested.

- SRF test facility will be completed in mid 2015.
Thank you!
감사합니다!