A Plan for Neutron Source Based on 100-MeV Proton Linac at KOMAC

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KOMAC
Korea Atomic Energy Research Institute
Outline

◆ Introduction to KOMAC facility
◆ Present status: Neutron generation based 100-MeV Linac
◆ Plan: R&D for improvement of neutron source at KOMAC
  ✓ Neutron generation target
  ✓ High energy accelerator
◆ Summary
KOMAC - KOr ea Multi-purpose Accelerator Complex

- Located on Miraero (road to the future), Gyeongju (a historic city)

- Developed via Proton Engineering Frontier Project (2002.7~2012.12, 10.5 Year)
- Budget investigated: ~300M $US (Gov: 180M, Gyeongju: 110M, Industry: 10M)

KTX Station
Daejeon ↔: 1:05 hours
Seoul ↔: 2:05 hours

Free-way #1 (Seoul-Pusan)

Reserved
(260,000m²)
650m x 400m
KOMAC Close-up view (in July 2017)

- **1.** 100MeV Proton Linac
- **2.** Power Station
- **3.** Utility Building
- **4.** Cooling Tower
- **5.** Sewage Plant
- **6.** Ion Beam Facilities
- **7.** Dormitory
- **8.** Information
- **9.** Main Hall (Under Const.)

**Details:**
- Area: 180,000 m²
- Building: 27,322 m²
- Power: 154 kV, 20 MVA
100-MeV Linac and Beam Lines

Features of KOMAC 100-MeV linac

- 50-keV Injector (Ion source + LEBT)
- 3-MeV RFQ (4-vane type)
- 20 & 100-MeV DTL
- RF Frequency : 350 MHz
- Beam Extractions at 20 or 100 MeV
- 5 Beamlines for 20 MeV & 100 MeV

Extraction Energy (MeV)

<table>
<thead>
<tr>
<th>Extraction Energy (MeV)</th>
<th>20</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Beam Current (mA)</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Max. Beam Duty (%)</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>Avg. Beam Current (mA)</td>
<td>4.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Pulse Length (ms)</td>
<td>2.0</td>
<td>1.33</td>
</tr>
<tr>
<td>Max. Repetition Rate (Hz)</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>Max. Avg. Beam Power (kW)</td>
<td>96</td>
<td>160</td>
</tr>
</tbody>
</table>
### Operation Statistics

- **Operated in weekly-based schedule through a yearly plan**

<table>
<thead>
<tr>
<th>Year</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation hours</td>
<td>2,290</td>
<td>2,863</td>
<td>2,948</td>
<td>2,961</td>
<td><strong>11,062</strong></td>
</tr>
<tr>
<td>Availability</td>
<td>82.0%</td>
<td>86.3%</td>
<td>90.5%</td>
<td><strong>94.9%</strong></td>
<td>89.2%</td>
</tr>
</tbody>
</table>
Beam Service Statistics

◆ Proton Accelerator Utilization

R&D Fields: Bio/medical(26.4%), Materials(26.4%), SpaceRad./Basic Sci.(22.6%) etc.

KOPUA: Korea Proton Beam User Association (Self-organized user network)
✓ PAC(Program Advisory Committee): Review proposals & Allocate beamtime
KOMAC prepares programs to improve proton linac and to supply secondary particle.

- Neutron: Neutron imaging, Nuclear data, Detector, Semiconductor, etc.
- RI: Medical imaging\(^{(67Cu, 82Sr, 22Na, etc.)}\), \(\beta\)-NMR\(^{(8Li, 11Be, 31Mg, etc.)}\), etc.
Plan for the Secondary Particle Facility

Neutron target

100 MeV

20 MeV

3 MeV

RFQ

DTL I

DTL II

MEBT

AC

TR105

TR101

TR25

TR21

TR24

TR23

TR22

100 MeV Beamlines

20 MeV Beamlines

Proton linac

Short pulse injector

Long pulse injector

Li-8 target

Pulsed neutron beam line

Pulsed neutron Experiment facility

Secondary Particle User Facility

Laser for Polarization

Mass separator

Polarizer

Low Field Spectrometer

High Field Spectrometer

Beta-NMR facility
Neutron Generation Based on 100 MeV Beam

- Neutron yield: 0.2 n/p (Cu target), 0.37 n/p (W target)
- Neutron generation by Cu target irradiated by 100 MeV and 1 kW proton beam
  - $I_{\text{avg.}} = 10 \mu\text{A} (= 6.25 \times 10^{13} \text{ protons/s})$
  - Neutron yield = $1.3 \times 10^{13} \text{ neutrons/s (time averaged)}$
  - Neutron flux at 1 m away from target:
    - $1.03 \times 10^8 \text{ n/cm}^2 \text{ s (time average)}, \ 1.03 \times 10^{11} \text{ n/cm}^2 \text{ s (peak, 0.1% duty)}$

**Neutron energy spectrum**

**Neutron angular distribution**
## Neutron Target System

**Target – Moderator – Reflector (TMR)**

<table>
<thead>
<tr>
<th>Components</th>
<th>Materials</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Tungsten</td>
<td>bonded with water cooled copper jacket</td>
</tr>
<tr>
<td>Moderator</td>
<td>TBD</td>
<td>Candidates: H&lt;sub&gt;2&lt;/sub&gt;O, D&lt;sub&gt;2&lt;/sub&gt;O, graphite, polyethylene</td>
</tr>
<tr>
<td>Reflector</td>
<td>TBD</td>
<td></td>
</tr>
</tbody>
</table>
Fast and Slow Neutron Spectrum

- Fast neutrons
- Slow neutrons
- Proton beam
- Reflector
- Neutron target
- Moderator

Graph showing neutron spectrum vs. neutron energy (eV):
- Fast
- Moderated
Effect of Proton Energy on Neutron Source

To increase neutron yield and neutron energy, higher energy proton beam is required.
Higher Proton Energy

✓ Superconducting linac (SCL) has been developed to upgrade proton energy up to 160 MeV.
✓ Half Wave Resonator (HWR) cavity
✓ 24 cavities will be installed at existing tunnel space (end of 100-MeV linac).
Baseline Design Concept

- 4 cavities / cryo-module
- External normal conducting quadrupole magnet for focusing
- Lattice: doublet
- Operation temperature: 2 K
- Cavity geometry: height ~ 0.5 * λ, diameter ~ βg * λ, cylindrical cryo-module
- Use well proven technologies (tuner, coupler, cryo-module, etc) except HWR cavity
Design constraint: $E_{\text{peak}} < 35 \text{ MV/m} \\
B_{\text{peak}} < 70 \text{ mT}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>350</td>
<td>MHz</td>
</tr>
<tr>
<td>Optimum $\beta$ ($\beta_{\text{opt.}}$)</td>
<td>0.65</td>
<td>-</td>
</tr>
<tr>
<td>Geometric $\beta$</td>
<td>0.58</td>
<td>-</td>
</tr>
<tr>
<td>Stored energy</td>
<td>20.26</td>
<td>J</td>
</tr>
<tr>
<td>$V_{\text{acc.}} @ \beta_{\text{opt.}}$</td>
<td>3.623</td>
<td>MV</td>
</tr>
<tr>
<td>$V_0$</td>
<td>4.074</td>
<td>MV</td>
</tr>
<tr>
<td>$E_{\text{acc.}} @ \beta_{\text{opt.}}$</td>
<td>7.295</td>
<td>MV/m</td>
</tr>
<tr>
<td>$E_0$</td>
<td>8.200</td>
<td>MV/m</td>
</tr>
<tr>
<td>$E_p$</td>
<td>34.370</td>
<td>MV/m</td>
</tr>
<tr>
<td>$B_p$</td>
<td>69.680</td>
<td>mT</td>
</tr>
<tr>
<td>$E_p/E_{\text{acc.}}$</td>
<td>4.71</td>
<td>-</td>
</tr>
<tr>
<td>$B_p/E_{\text{acc.}}$</td>
<td>9.55</td>
<td>mT/(MV/m)</td>
</tr>
<tr>
<td>$R/Q @ \beta_{\text{opt.}}$</td>
<td>294.9</td>
<td>ohm</td>
</tr>
<tr>
<td>$G$</td>
<td>128.4</td>
<td>ohm</td>
</tr>
<tr>
<td>$Q_0 @ R_s=20 \text{ n}\Omega$</td>
<td>6.42E+09</td>
<td>-</td>
</tr>
<tr>
<td>Cavity loss @ $R_s=20 \text{ n}\Omega$</td>
<td>6.94</td>
<td>W</td>
</tr>
<tr>
<td>Aperture</td>
<td>40</td>
<td>mm</td>
</tr>
<tr>
<td>$L_{\text{eff.}}$</td>
<td>0.496799</td>
<td>m</td>
</tr>
</tbody>
</table>
HWR Design - Beam Energy

\[ t_{beam,pk} = 20 \text{ mA} \]
HWR Design - Electric and Magnetic Field

**Electric field distribution**

**Magnetic field distribution**
## HWR Design - Mechanical Aspect

### Lorentz force density

### Displacement due to Lorentz force

<table>
<thead>
<tr>
<th>Wall thickness</th>
<th>2.5</th>
<th>3.0</th>
<th>3.5</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>[mm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lorentz Detuning</th>
<th>-2.2</th>
<th>-1.7</th>
<th>-1.4</th>
<th>-1.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Hz/(MV/m)^2]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>He pressure sensitivity</th>
<th>5.1</th>
<th>5.0</th>
<th>3.3</th>
<th>3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hz/torr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tuning sensitivity</th>
<th>88.8</th>
<th>87.1</th>
<th>89.3</th>
<th>101.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>kHz/mm (±0.5 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
✓ End lever Saclay-I type (well-proven in TTF, SNS)
✓ Piezo tuner for fast tuning may be omitted
✓ Detailed mechanical analysis will be performed
\( \beta = 0.51 \) (150 MeV), \( l_{\text{beam, pk}} = 20 \) mA, \( Q_b = 7.74 \times 10^5 \)

- Max. detuning due to Lorentz force \( \sim 400 \) Hz
- Avoid fast tuner by large bandwidth of RF coupler and RF power margin

\[ \Delta f_{\text{opt}} = 131 \text{ Hz} \]
### High Power RF System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>350 MHz</td>
</tr>
<tr>
<td>1dB bandwidth</td>
<td>+/- 2 MHz</td>
</tr>
<tr>
<td>Rated power</td>
<td>120 kW</td>
</tr>
<tr>
<td>Max. pulse width</td>
<td>1.6 ms</td>
</tr>
<tr>
<td>Max. duty cycle</td>
<td>10 %</td>
</tr>
<tr>
<td>Harmonics</td>
<td>Less than -30 dB</td>
</tr>
<tr>
<td>Load VSWR</td>
<td>Handles 1.5 mismatch</td>
</tr>
<tr>
<td>RF input signal</td>
<td>10 dBm for full power</td>
</tr>
<tr>
<td>Connectors</td>
<td>3-1/8” flange</td>
</tr>
<tr>
<td>Cooling</td>
<td>Forced air</td>
</tr>
<tr>
<td>Protection</td>
<td>Over temperature</td>
</tr>
<tr>
<td></td>
<td>Over drive</td>
</tr>
<tr>
<td></td>
<td>Out-of-band input</td>
</tr>
<tr>
<td></td>
<td>Excessive VSWR</td>
</tr>
</tbody>
</table>
Cryo-module Design

- Based on SNS and CEBAF
- Cylindrical CM (cavity diameter ~ height)
- Focusing in warm region

Helium return end can

Two phase pipe

Helium supply end can

HWR cavity

He vessel

Magnetic shield (inner)

Multi layer insulation

50 K thermal shield

Multi layer insulation

Space frame

Magnetic shield (outer)

Vacuum vessel
Inside Cryo-module

- Two phase pipe
- Magnetic shield (inner)
- He vessel
- Nitronic rod
- Tuner
- Space frame
- RF coupler
- Vacuum vessel
- Support
Summary

◆ KOMAC Prepares secondary particle utilization
  ✓ Secondary particle utilization expands application fields of 100-MeV linac
  ✓ Pulsed neutron for neutron-related science and technology
  ✓ RI for medical imaging and Li-8 beam for beta-NMR (advanced surface analysis)

◆ R&D Status for Neutron Source
  ✓ Neutron generation, numerical study and measurement were conducted.
  ✓ Development of Target-Moderator-Reflector (TMR) system
  ✓ Development of superconducting linac for higher proton energy
Thank you