J-PARC Upgrade

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Outline
-Overview of J-PARC
-Superconducting proton linac at J-PARC
-Cryomodule development
Overview of J-PARC (1)

J-PARC = Japan Proton Accelerator Research Complex

Joint Project between KEK and JAEA
Overview of J-PARC (2)

J-PARC Photo

November, 2006
# Overview of J-PARC (3)

## History of beam commissioning

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Construction started.</td>
</tr>
<tr>
<td>2006</td>
<td>Linac beam commissioning started.</td>
</tr>
<tr>
<td>2007</td>
<td>Linac beam energy of 181 MeV was achieved. &lt;br&gt; RCS beam commissioning started. &lt;br&gt; RCS beam energy of 3 GeV was achieved.</td>
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<tr>
<td>2008</td>
<td>MR beam commissioning started. &lt;br&gt; First proton beams reached to the neutron target. &lt;br&gt; MR beam energy of 30 GeV was achieved. &lt;br&gt; <strong>User operation of MLF started.</strong></td>
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<tr>
<td>2009</td>
<td>First proton beams reached to the Hadron target. &lt;br&gt; First proton beams reached to the Neutrino target.</td>
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Superconducting Proton Linac (1)

- **Major Parameters of Linac**
  - Accelerated particles: $^1\text{H}^-$ (negative hydrogen)
  - Energy: 181 MeV, The last two SDTLs are debunchers (400 MeV for ACS, 600 MeV for SCL)
  - Peak current: 30 mA (50 mA for 1MW at 3GeV)
  - Repetition: 25 Hz (additional 25 Hz for ADS application)
  - Pulse width: 0.5 msec

Block Diagram of the Linac
Superconducting Proton Linac (2)

Preliminary design of SC proton linac

Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Energy</td>
<td>400-600 MeV</td>
</tr>
<tr>
<td>Frequency</td>
<td>972 MHz</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.71-0.79</td>
</tr>
<tr>
<td>No. of Cell</td>
<td>9 cell/cavity</td>
</tr>
<tr>
<td>No. of Cavity</td>
<td>2 cavity/cryomodule</td>
</tr>
<tr>
<td>No. of Cryomodule</td>
<td>11 cryomodules</td>
</tr>
<tr>
<td>Length</td>
<td>57.7 m</td>
</tr>
<tr>
<td>Surface Peak Field</td>
<td>30 MV/m</td>
</tr>
<tr>
<td>Accelerating Field</td>
<td>9.7-11.1 MV/m</td>
</tr>
<tr>
<td>Synchronous Phase</td>
<td>-30 deg</td>
</tr>
<tr>
<td>No. of Klystron</td>
<td>11 klystrons</td>
</tr>
<tr>
<td>Total RF Power</td>
<td>10 MW</td>
</tr>
<tr>
<td>Loaded Q</td>
<td>$\sim$500,000</td>
</tr>
</tbody>
</table>

Amplitude and phase stability ($\pm 1\%$ & 1deg) in pulsed operation
Superconducting Proton Linac (3)

Phase stability on two cavity excitation by one klystron

- Required stability
  - Amplitude < ±1 %
  - Phase < ±1 deg.

Pulsed operation

↓

Dynamic Lorentz force detuning

↓

Dynamic phase change

- Single cavity excitation: dynamic phase change can be compensated by LLRF control.
- Two cavity excitation: only vector sum can be compensated. Phase between two cavities have to be stabilized within ±1 deg.

Calculated result for dynamic Lorentz force detuning in pulsed operation
Cryomodule design

- Two 9-cell elliptical cavities at 2K (972 MHz)
- Stiff structure for cavity and tuner to reduce Lorentz force detuning
- 80K thermal shield by LN$_2$ and 5K thermal intercept by LHe
Cryomodule development (1)

Prototype Cryomodule Photo

- Joint Box
- Radiation shield
- Cryomodule
- Valve Box
- Waveguide
Cavity

Cavity Wall thickness 4 mm
Vertical test Esp=32, 34 MV/m
Horizontal test Esp=37, 35 MV/m
(10Hz, 3 ms, @2.1K)

Vertical test results (measured by K. Saito, KEK)
Horizontal test results (E. Kako et. al, PAC2005)
Cryomodule development (3)

Two-cavity excitation

- Klystron output: stabilized by digital feedback system → developed for NC cavity, not optimized for SC cavity
- Pulse length: 1 ms

- Eacc: 9.7 & 10.4 MV/m due to different $Q_L$
  - L: 240,000 & R: 300,000
- Lorentz force detune angle could not be measured.
  Calculation: $\sim$5 deg.

Eacc: 9.7 & 10.4 MV/m

Klystron output power & phase stabilized by digital FB system

Cavity Eacc and phase
Cryomodule development (4)

Cavity Phase for several pulses during ~1min
(Eacc~10MV/m, Pulse length:1ms, Repetition:25Hz)

@2.1K

@4.2K

- Phase stability < ±1 deg
- Changing slowly
  → Control of LHe vessel pressure &
  automatic tuning system

- Phase stability < ~5 deg
- Scattering significantly
  (Microphonics ?)
  (Bubbling of He ?)

Phase stability of ±1deg is realized in 2K operation
Micro-structure of the phase within a pulse

- Experimental data for cavity phase indicate systematic structure.
- Dynamic analysis indicates two dominant vibration modes, 3.9 and 6.3 KHz, which looks consistent with the experimental data.

Calculated result for dynamic Lorentz force detuning

Cavity phase at 2.1 K

Mechanical vibration mode of the cavity
Feedback control of vector sum for two cavities

- FB control of vector sum signal has been performed successfully.
- Flat top length is not enough and overshoot is found, because the digital FB system has not optimized for SC cavities.
- Stabilities of amplitude and phase are satisfactory.
- Phases are changing slowly, which will be stabilized with pressure control of LHe vessel and automatic tuning system.

- Multi-cavity excitation is demonstrated successfully with stiff structure of cavity to reduce Lorentz force detuning and 2K operation.
Beam commissioning of J-PARC is progressed almost on schedule and SC proton linac is planned on the second construction phase.

In the cryomodule development, design field of SC cavities have been obtained, however, duty factor is limited due to poor cryogenic performance.

Effect of the Lorentz force detuning is not severe for phase stability because of stiff structure of the cavity.

Sufficient phase stability has been obtained at 2K.

Slow phase shift will be stabilized with pressure control of LHe vessel and automatic tuning system.

Vector sum control has been successfully demonstrated at 2K.