Longitudinal Beam Diagnosis with RF Chopper System

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My talk is about the measurement of longitudinal beam size by existing two apparatus: an RF chopper System in the linac and a beam loss monitor in RCS. Therefore, my topics is different from the development of new monitor.

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   • RF amplitude and phase scan
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Outline of Japan Proton Accelerator Research Complex

Accelerator Complex
- 181 MeV Linac
- 3 GeV Rapid Cycling Synchrotron (RCS)
- 30 GeV Main Ring (MR)

Experimental facilities
- Materials and Life Science Experimental Facility (MLF)
- Hadron Experimental Facility
- Neutrino Experimental Facility
Overview of the J-PARC Linac

Major parameters

<table>
<thead>
<tr>
<th>Particles</th>
<th>$H^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output energy</td>
<td>181 MeV</td>
</tr>
<tr>
<td>Peak current</td>
<td>30 mA</td>
</tr>
<tr>
<td>Pulse width</td>
<td>0.5 ms</td>
</tr>
<tr>
<td>Chopper duty factor</td>
<td>56%</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>25 Hz</td>
</tr>
<tr>
<td>Output power</td>
<td>36 kW</td>
</tr>
</tbody>
</table>

- Present beam power is 16 kW (current: 15 mA, pulse width: 0.5 ms).
- The RF chopper system is placed at MEBT1 between RFQ and DTL.

Front End (IS, LEBT, RFQ, MEBT1)
Function of RF Chopper System

The J-PARC linac has three kinds of pulse structure.

- **Macro-pulse Structure**
  - Equivalent to the one acceleration cycle in RCS (25 Hz).

- **Medium-pulse Structure**
  - Eliminated by the RF chopper system
  - Equivalent to the RCS RF frequency (0.938 MHz).
  - Medium-pulse is for the mitigation of a beam loss in RCS.
  - Insufficient beam rejection power causes beam loss in RCS.

- **RCS RF buckets (0.938 MHz)**
  - Equivalent to the linac RF frequency (324 MHz).
RF Chopper System

- The system is placed in MEBT1.
- An RF chopper cavity and a scraper.
- The cavity is **not a slow-wave kicker** but an **RF deflector**.
- Beam is horizontally deflected, and then the beam is absorbed in the Scraper.
- The beam extinction: $10^{-7}$ ($\Delta\phi < +/-20$ deg)  
  Requirement: $10^{-4}$  
  $\Rightarrow$ Achieved our requirement with 3 order higher level.

- Beam: $H^-$
- Energy: 3 MeV
- Length: 2.7 m
- 8 x Quads, 2 x Bunchers
- RF Chopper System  
  (RF chopper cavity + Scraper)

- TE-11 like mode
- Frequency: 324 MHz
- Rise time: 11ns
- Electric field: 1.6 MV/m
- Deflection angle : 6 mrad/gap
- Amplifier: 35 kW max.  
  (2.0 MV/m)
**Principle of the RF Chopper System**

Beam is horizontally deflected by two RF gaps.

Deflection angle depends on:
- RF amplitude
- (Inversely) Beam width on phase axis

If beam becomes wider, higher RF amplitude is required to eliminate them.

At RF gaps:
- RF Wave
- Increase RF amp.
- Wider beam width

At Scraper:
- RCS
- cause the beam loss
Measurement Method
Effective Region

- A certain RF amplitude (threshold) is required for beam to hit the scraper.
- We call the as the phase in which RF amplitude is higher than the threshold as ``effective region''.

At RF gaps

At Scraper

threshold
effective region

hit to the scraper
Remnant in the beamline
Scraper
RCS
RF Amplitude and Phase Scan

- Scan the correlation of the synchronous phase ($\Delta \phi_s$) with Beam loss.
- Effective region shifts as the $\Delta \phi_s$ varies.

- Calculate the correlation of $\Delta \phi_s$ and beam loss.
  - Asymmetric distribution assumed.
  - Negative side beam loss show the positive side beam profile and vice versa.
    - Beam profile can be obtained from the slope shape.

- Phase scan by other RF amplitude
  - Equivalent to measure beam profile with different edge position.
    - Possible to obtain the threshold and edge.
Experimental Results

Monitor: RCS beam loss monitor signal at arc section
Knob: RF amplitude and synchronous phase of the RF chopper cavity
**RF Phase Scan Result**

**Time evolution of the BLM signal**

- RF amplitude: 2.0, 1.4 and 1.2 MV/m.
- Significant Beam loss at the beginning of acceleration.
- Signal saturation at 1.2 MV/m.
- Undershoot after 12 ms at 1.2 MV/m.

**Integrate from 3 ms to 12 ms.**

**RF Phase Scan Result**

- RF amplitude: 2.0 and 1.6 MV/m.
- $\Delta \phi_s = 0$ to +20: Gradually increase.
  - beam halo distributes in negative phase.
- Outside of 20 deg in 2.0 MV/m, $\Delta \phi_s < -15$ in 1.6 MV/m: rapid increase.
  - Edge of effective region reach to beam tail.
  - Phase margin is about +/- 20 deg.
Beam Size

Evaluate the longitudinal beam size from the phase and amp. scan result.

- Beam tail (fraction > $10^{-6}$) is near to the edge of effective region at
  - 2.0 MV/m, -20 deg
  - 1.6 MV/m, -15 deg
- Threshold is same for 2.0 and 1.6 MV/m, intersection point is equivalent to threshold.
- beam width ($\delta\phi$) satisfies the equation,
  \[ 2.0 \cos(-20 + \delta\phi) = 1.6 \cos(-15 + \delta\phi) \]
- The $\delta\phi$ is obtained to be 50 deg.
Summary

- We investigate beam profile in phase direction by using RF chopper system.
- The beam loss in RCS is sensitive to mischopped beam.
- We measure the beam loss in RCS with varying RF amplitude and driving phase.
- We performed RF phase scan to obtain the beam size:
  - Beam halo distributes in negative phase side
  - Beam width is obtained to be 50 deg.