Beam Diagnostics at the First Beam Commissioning of the J-PARC MR

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KEK / J-PARC

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• **Summary**
Overview of J-PARC

J-PARC = Japan Proton Accelerator Research Complex

RCS (3 GeV; 25 Hz, 1MW)

MR (50 GeV; 0.73 MW)

Neutrino to Kamiokande (T2K)

500 m

Materials and Life Science Experimental Facility

Linac (330m)

Nuclear Transmutation

Hadron Beam Facility

J-PARC = Japan Proton Accelerator Research Complex
Location of instrumentations

List of ring monitor (Blue: future plan)

<table>
<thead>
<tr>
<th>Monitors</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPM</td>
<td>186</td>
</tr>
<tr>
<td>Single-pass BPM</td>
<td>2</td>
</tr>
<tr>
<td>Dump/abort BPM</td>
<td>2 + 2</td>
</tr>
<tr>
<td>WCM (&gt;100MHz)</td>
<td>3</td>
</tr>
<tr>
<td>FCT (~20MHz)</td>
<td>6 + 1 (v-BT)</td>
</tr>
<tr>
<td>DCCT (DC-30kHz)</td>
<td>2</td>
</tr>
<tr>
<td>MWPM</td>
<td>1 (inj.), 2 (SX, Abort BT)</td>
</tr>
<tr>
<td>Flying Wire (H/V)</td>
<td>1 / 1</td>
</tr>
<tr>
<td>IPM (H/V)</td>
<td>1, 1 / 1</td>
</tr>
<tr>
<td>BLM</td>
<td>Proportional type 238 Air ion chamber 18</td>
</tr>
</tbody>
</table>

List of 3-50 BT monitor

<table>
<thead>
<tr>
<th>Monitors</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-pass BPM</td>
<td>14</td>
</tr>
<tr>
<td>FCT (~20MHz)</td>
<td>5</td>
</tr>
<tr>
<td>MWPM (SEEM)</td>
<td>3 + 6</td>
</tr>
<tr>
<td>BLM</td>
<td>Proportional type 50 Air ion chamber 3</td>
</tr>
</tbody>
</table>

Ref. T. Koseki, HB2006
Requirements for beam monitors

J-PARC MR Beam power > 100×(KEK-PS beam power)

However,

Beam loss criteria: 0.5 W/m same as KEK-PS!!
This criteria corresponds to 1.8% (3GeV)~0.1%(50GeV) beam loss

- Beam loss monitoring covering < 0.1% to 100%
- Beam halo monitoring
- Beam current monitoring with wide band and wide dynamic range

Beam monitoring system with wide dynamic range over 10^3 level.
Challenging and essential issue!!
## Day-one beam parameters

- 3 GeV DC mode
- 30 GeV acceleration mode
- 1/100 particle per bunch
- single bunch injection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design</th>
<th>Day-one</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle per pulse</td>
<td>$3.3 \times 10^{14}$ (8 bunches)</td>
<td>$1\sim 4 \times 10^{11}$ (single bunch)</td>
</tr>
<tr>
<td>Peak current</td>
<td>41.3-220</td>
<td>0.5 - 6</td>
</tr>
<tr>
<td>Circulating current</td>
<td>~13</td>
<td>0.003-0.012</td>
</tr>
<tr>
<td>velocity ($\beta$)</td>
<td>0.9712-0.9998</td>
<td>0.9712-0.9998</td>
</tr>
<tr>
<td>Bunch half width</td>
<td>180-33.7</td>
<td>35-20</td>
</tr>
<tr>
<td>Emittance</td>
<td>54</td>
<td>~15</td>
</tr>
<tr>
<td>Revolution frequency</td>
<td>186-191</td>
<td>186-191</td>
</tr>
<tr>
<td>period</td>
<td>5.38-5.24</td>
<td>5.38-5.24</td>
</tr>
<tr>
<td>RF frequency</td>
<td>1.67-1.72</td>
<td>1.67-1.72</td>
</tr>
<tr>
<td>period</td>
<td>599-581</td>
<td>599-581</td>
</tr>
</tbody>
</table>

- $\pi \text{mmrad}$ (unnormalized, 3 GeV)

- MHz
- ns
- μs
- kHz
- A
- ppp

- $1/c$
**BPM**

Electrostatic type BPMs are installed near almost all QM

**Ring BPM:**
- Mainly used in the ring
- Good linear response covering full aperture
- Bore: Φ130mm (standard), Φ134, 165, 200, 257, 140x302mm (special)

**Single pass BPM:**
- Mainly used at 3-50BT
- Bore: Φ230, 200mm

**Diagonal cut type**

Calibration: wire method

**Errors (in rms unit):**
- Sensitivity: ±0.3%
- Offset: ±0.12 mm
- Rotation: ±3.6 mrad

**Quad parallel type**

Corrected on the computer
Single-pass BPM (3-50BT)

• To expand lower cut-off frequency, a transformer has installed at an output connector ⇒ 230kHz

• 8 bit, 100MHz, 2GS/s ADC
• Q-mode measurement (future plan)
Ring BPM

- Lower cut-off frequency is 17MHz ⇒ differential wave form
- 14 bit, 10MHz, 80 MS/s ADC
- Off-line position calc. (COD mode): Raw signal (4096 point) ⇒ average over 4 data (1024 point) ⇒ FFT ⇒ peak search (3.4MHz = 2 × f_{rf}) ⇒ Position

Installation error (in rms unit)
- Offset: Δx = 0.41±0.96mm, Δy = -0.35±0.50mm
- Rotation: 0.96±3.3 mrad
  ⇒ corrected on the computer

position resolution:
< ± 0.5 mm / three BPM correlation
( 3.5x10^{11} protons/bunch, single bunch )
Beam current monitors

DCCT
- FINEMET (HITACHI metal Ldt.) core
- Frequency band: DC~20kHz
- Gain selection: 0.2A, 2A, 20A
- $\Delta I < 100\mu\text{A} \Rightarrow \Delta N_B \approx 6.5 \times 10^9 \text{ppp (rms)}$

WCM
- FINEMET (HITACHI metal Ldt.) core
- Lower cut-off frequency: 150, 380, 400 Hz
- Shunt impedance: 92mΩ
- Heat load on resister is 40-50 W
  $\Rightarrow$ Air blow system is needed
- RF feedforward

FCT
- FINEMET (HITACHI metal Ldt.) core
- Frequency band: 16Hz~180MHz
- RF feedback

Air blow system
Tune meter

- Horizontal and Vertical exciters
  50Ω striplines
  max. power: 2x1 kW
  white noise (1-2MHz)

- Beam oscillation is analyzed
  by “Real-time spectrum analyzer”

Exciter

by S. Yamada
Proportional type BLM(1)

Gain curve of the BLM measured by using secondary cosmic rays, mainly muon

BLMs have been installed at each QM

Anode wire 50 µm Pt
HV cathod I.D. 23 mm stainless steel
Ar 99% + CO₂ 1%: 1.1 atm
Effective area
800 mm

Raw signal
bias: 1.6kV, Z_{in} of amp: 50Ω, amp gain: ×10
Proportional type BLM (2)

- Sum of beam loss signals from inj. to ext.
- Loss signals are just shown in arbitrary unit, not yet in number of lost particles

Correlation between the sum of the local BLM integrated signals and a number of loss particle to be compared with the simulation

Beam loss criteria
0.5W/m for 0.75MW, $3.3 \times 10^{14}$ ppp
0.1% for 50 GeV $\Rightarrow 3.3 \times 10^{11}$ ppp
1.8% for 3 GeV $\Rightarrow 5.9 \times 10^{12}$ ppp

Meet the beam loss criteria
But nonlinear behaviour
Further investigation should be made !!

Preparing Ar ionization chambers
Multi-wire profile monitor:

- Tangsten wire
  - $\phi$ 30 $\mu$m
  - pitch 2.5, 3.5, 4 mm
  - (depends on design beam size)

- Carbon-graphite ribbon
  - $t$ 1.6 $\mu$m
  - width 3.0 mm, pitch 4.5 mm, 67 ch.

- Injection: 1 just after septum
- Abort: 1 (Ti foil)
- SX: 5 screens for day-one, 1 SEEM (C ribbon)

J-PARC 3 GeV proton beam (single bunch: 5e13 p):
- Upper two traces: W wire
- Lower two traces: carbon-graphite ribbon

SEEM (secondary electron emission monitor)

- Low beam loss
- High rad-resistant

Measured profiles
Flying wire profile monitor

- One horizontal type for day-one
- Vertical one is now under development
- Wire: Carbon fiber of $\phi 7\mu m$
- Wire speed: 10m/s
Residual gas ionization profile monitor: IPM

Ion collection with HV
- 35kV for day-one ⇒ will be upgraded to 50kV

Electron collection with magnetic field
- Required for 0.75MW beam profile measurement ⇒ future plan

Micro Channel Plate (MCP) for signal read out device
- 2 stage MCP assembly with 32 ch strip anode
- Active area: 31×81 mm²
- Width of each anode: 2.5 mm
- Gain: ~10⁶

Calibration devise for MCP gain balance
- Electron generator arrays ⇒ Photonis Ltd.

Horizontal plane: 1 IPM (η=0)
Vertical plane: 1 IPM

One more will be installed at an arc section (η=2m)

LPF: ~5µsec
Digitizer: 200MHz, 100kS/s, 1 Mwords
Summary

• Various instrumentations are installed and used on the day-one beam commissioning
  – 3 GeV one-pass to the injection beam dump, and storage
  – Acceleration up to 30 GeV,
    extracted to the abort beam dump, hadron beam dump and neutrino target
• The beam current was ~1% of designed value,
  however, the system shows good performances
• Some monitors will be ready until the October machine operation
  – Horizontal IPM arc section (η=2.0m)
  – W target SEEM ⇒ carbon-graphite target
  – Feedback damper system
• For higher intensities:
  – BPM's will be attached attenuators
  – low sensitive BLM's, Ar ionization chambers, will be installed
    at the high radiation areas like collimators and the slow extraction section
  – IPM's should realize electron collection
  – Beam based alignment of the BPM's
  – a quadrupole mode measurement
Backup
Countermeasures against noise problem

• High shielded cables tested radiational hardness at Co60 γ-ray facility of Takasaki lab./JAEA
• Grounding copper plates along the ring
• Noise cut trans on an AC line
• Common mode choke coil on a signal line

Connect a electric shield to a grounding copper plate

34 in 1 coaxial cable for MWPM and IPM
4 in 1 coaxial cable for BPM

High shielded cables with radiational hardness (<2.5MGy) for J-PARC Fujikura Ltd.
BLM - Ionization Chamber

Irradiation test will be held in summer with $^{60}\text{Co}$
Beam loss at collimators (local bump = 40mm)

Total loss from Inj. to Ext.

73863 point

1 to 20
74492 point

DCCT

3.49 x 10^{11} ppp

1.31 x 10^{11} ppp
IPM data processing

Digitizer: 200MHz, 100kS/s, 1 Mwords

Averaged over 100 pulses to reduce high frequency noise, statistical error due to small number of detected ions, signal level fluctuation due to broad gain distribution of the MCP.

MCP gain at the proportional mode:

\[ f(g) = f_0 e^{-g/\langle g \rangle} \]

\( \langle g \rangle \): average gain