Pulse-to-pulse transverse beam emittance controlling for the MLF and MR in the 3-GeV RCS of J-PARC

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Outline:

1. Introduction
2. RCS Injection and transverse Painting scheme
3. Methods for changing painting area pulse-to-pulse
4. Experimental and simulation results
5. Summary
Not only the beam power itself but RCS has to control also the extracted beam emittance/profile pulse-to-pulse between MLF and MR.

**For MLF: Wider beam profile**
To reduce damage on the neutron production target.

**For MR: Narrower beam profile**
In order to reduce beam loss at the 3-50BT collimator as well as in the MR because of much narrower beam line aperture.

- Multi-turn $^1$H$^-$ stripping injection.
- Injection Energy: (181) 400 MeV
- Extraction Energy: 3 GeV
- Repetition: 25 Hz
- Beam power (design): 1MW

Extracted beam is simultaneously delivered to the MLF and MR.
Design apertures of 3-NBT, 3-50BT and MR

3-NBT (Beam transport of RCS to MLF target) aperture: $324\pi$ mm mrad (Same as RCS primary collimator).

3-50BT (Beam transport of RCS to the MR) aperture: $120\pi$ mm mrad.
3-50BT collimator: $54\pi$ mm mrad.
(limit: 2 kW)

MR aperture: $81\pi$ mm mrad.
MR collimator: $70\pi$ mm mrad.
(limit: ~2 kW)
RCS injection and transverse painting scheme

SB1~4: Injection chicane magnets
PBH1~4: Hori. painting magnets
PBV1~2: Verti. painting magnets
**PSTR1,2: Pulse steering magnets**
Transverse injection painting method

Horizontal plane:
Injected beam is fixed at foil. Closed orbit is varied during injection for painting injected beam center to outside in the circulating phase space.

Vertical plane:
Injected beam angle is varied during injection.

Center to outside
→ Correlated painting
Outside to center:
→ Anti-correlated painting
Transverse injection painting method

Close view of injection and circulating beam orbits during painting process

To injection beam dump

PBV1
PBV2
ISEP1
ISEP2
PSTR1
PSTR2
L-3BT

1st foil
(Injection point)

2nd foil

3rd foil

H^-

H^+

H^+

H^+

H^+

Beginning of painting

End of painting

Circulating beam

PBH1–2
QFL
Chicane magnets SB1–4
QDL
PBH3–4

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Painting area vs. transverse beam profile and extracted beam emittance

Uniformed transverse distribution is obtained by painting

$216\pi \rightarrow 100\pi$ injection painting
$\rightarrow 25\%$ reduction of rms emittance
Methods for changing painting area pulse-to-pulse

Horizontal direction:

Method 1 : By using Pulse Steering magnets (PSTR1,2).
          + Horizontal painting magnets.

Method 2 : By using only Horizontal painting magnets.

Vertical direction:

By using vertical painting magnets.
Method 1: To change painting area pulse-to-pulse by PSTR magnets

- PSTR1,2 are placed in the injection beam transport line.
- For MLF, x and x’ of the inj. beam at the foil in the hori. direction are adjusted and fixed by two Injection septa, ISEP1,2 (DC).
- For changing painting area MLF to MR, angle (x’) of the injected beam at foil is controlled by PSTR1,2 keeping its position (x) unchanged.
- SB height for MR is also increased by ~10% than MLF.
- In the vertical direction, size of the injected beam angle (y’) is controlled pulse-to-pulse for MLF and MR.
Design specification of the PSTR magnets

Purposes:

1. To change horizontal painting area pulse-to-pulse between MLF and MR.
2. No painting (center) injection in to compensate inadequate power capacity of the ISEP2 (at 400 MeV inj.).

We considered two independent as well as bipolar power supplies for each magnets.

For 1) AC PS with max $\pm 0.45 \text{ kA}$ (0.026 Tm ; 8 mrad)
For 2) DC PS with max $\pm 3.0 \text{ kA}$ (0.174 Tm ; 54 mrad)
Experimental study with PSTR magnets

Injection energy: 181 MeV
For MLF: 150π; For MR: 100π

PSTR1: 33A (-1.9x10^{-3} Tm; 0.59mrad)
PSTR2: -15A (0.86x10^{-3} Tm; 0.27mrad)

For MLF beam triggers
Expected
Injected beam position in between ISEP 1 & 2

For MR beam triggers

PSTR1 WF online
Beam emittance control by changing injection painting area in a pulse-to-pulse mode in the 3-GeV rapid cycling synchrotron of Japan Proton Accelerator Research Complex


Experimental demonstration of the pulse-to-pulse beam emittance control between MLF and MR

The corresponding simulations were performed by using ORBIT 3-D code. The simulation results agreed well with experimental data.

Transverse beam profiles are well controlled as expected!
Methods for changing painting area pulse-to-pulse

**Horizontal direction:**

Method 1 : By using Pulse Steering magnets (PSTR1,2).
   + Horizontal painting magnets.

Method 2 : By using only Horizontal painting magnets.

**Vertical direction:**

By using vertical painting magnets.
Method 2: Use only painting magnets for changing painting area pulse-to-pulse

Both $x$ and $x'$ of the injected beam at foil is fixed for both MLF and MR.

PBH is used to control closed orbit variation for MLF and MR.
Method 2 cont’d: PBH pattern for painting

It was first tried after injection energy was upgraded to 400 MeV. Upgraded PBHs PS now have enough margin and also better controllable.
Method 2: Experimental results

MWPM @ 3NBT

Injection: 400 MeV
Extraction: 3 GeV
Beam power: 553 kW-eq.

Reduction of horizontal rms emittance ~34%
Reduction of vertical rms emittance ~20%

Courtesy: S. Meigo
MR beam loss dependence on the RCS transverse painting

<table>
<thead>
<tr>
<th>RCS painting</th>
<th>MR Power</th>
<th>MR Total loss</th>
</tr>
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<tbody>
<tr>
<td>$100\pi$ mm mrad</td>
<td>230 kW</td>
<td>$\sim 250$ W</td>
</tr>
<tr>
<td>$50\pi$ mm mrad</td>
<td>230 kW</td>
<td>$\sim 170$ W</td>
</tr>
</tbody>
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$\sim 30\%$ loss reduction

Courtesy: Y. Sato
Summary

- A pulse-to-pulse direct control of the injection painting emittance is considered and is also shown to be very effective for controlling extracted beam emittance in simultaneous operation.

- A reduction of 20~34% in rms emittance for the MR as compared to MLF is obtained for an equivalent beam power of 550 kW.

- Two independent methods, especially for changing painting area in the horizontal direction are considered and are also successfully applied in the real machine.

- The system is already in service with good reliability even for the present RCS operation with 300 kW beam power.