Status of the Intra-bunch Feedback at J-PARC Main Ring

Takeshi Toyama
KEK / J-PARC

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Collaborators

Keigo Nakamura
Kyoto University

Makoto Tobiyama, Masashi Okada,
Yong Ho Chin, Takashi Obina, Tadashi Koseki
KEK

Yoshihiro Shobuda
JAEA
Japan Proton Accelerator Research Complex

Tokai, Ibaraki

LINAC 40mA (50mA)
3 GeV RCS 500 kW ← operation
30 GeV MR 350kW (750kW) ← one shot
ν detector
MLF

295 km Kamioka → operation ← one shot
350 kW (750 kW) ← goal

Kamioka
Outline

• Introduction
  – Upgrade history of the J-PARC MR transverse feedback

• Feedback during acceleration
  – Timing slip
  – Timing matching
  – Initial result

• Summary and prospect
J-PARC MR parameters

- Circumference: 1567.5 m
- Injection Energy: 3 GeV
- Extraction Energy: 30 GeV
- Revolution at injection: 5.384us (185.7kHz) RF 1.67MHz
  at extraction: 5.231us (191.2kHz) RF 1.72MHz
- Harmonic number: 9
- Repetition time for fast extraction: 2.5 s

At high beam power
- Collective motion causes beam losses, other than non-linear resonances (due to space charge).
Two obstacles

(1) Injection error & succeeding collective motion

\( N_B \sim 1.67 \times 10^{13} \) ppp
2 bunches
\( \xi_x \sim -7.5 \)
\( \xi_y \sim -7.0 \)

circulating beam is kicked by kicker pulse-tail & reflection

Injection from the RCS:

K1

K2

Front bunch
Rear bunch

Intensity
Bunch area, average of 10 turno
(2) Instability during acceleration

Instabilities have been observed at the beam power 230kW, with chromaticity $\xi_y=-0.3$. We avoid this instability by tuning chromaticity $\xi_y=-3.2$.

Observed bunch motion

Vertical betatron oscillation amplitude

Keigo Nakamura, et al., IPAC2014, Dresden, Germany
B x B feedback

Bunch-by-bunch (BxB) feedback
slice ~ 590 ns

Kick

Beam bunch
Intra-bunch feedback slice ~ 10 nsec

Intra-bunch feedback

Kick

Beam bunch

FIR filter in iGp12
Schematic view

For the horizontal (x) plane

Beam

X+

50Ω

Stripline BPM

Stripline kicker

Hybrid

100KHz-200MHz

X-

50Ω

ADC+

ADC-

iGp12

DAC-

DAC+

x2

Power Amp.

100KHz-100MHz

RF clock

x64

clock

revolution clk

DC offset

Attenuator

Same as the vertical (y) plane
For the horizontal (x) plane

Beam

Hybrid
100KHz-200MHz

Stripline BPM
50Ω

Stripline kicker
50Ω

oscilloscope

iGp12

ADC+

ADC-

DAC+

DAC-

x2

Power Amp.
100KHz-100MHz

Attenuator

RF clock

x64

rev. for timing clk

trig. for timing table

DC offset

clock

revolution

Same as the vertical (y) plane
iGp12 for y

Trigger for timing table

iGp12 for x
3 GeV injection flat bottom

Oscillation of one bunch slice

Without FB

Bunch signal every 5 turns

Without FB

BxB FB on

+ intra-bunch FB on

+ intra-B on
Timing slip

Parameters are changing during acceleration upto 30 GeV

Beam transit time $\Delta \phi_B(t)$

Acc. RF cavity

$\phi_{syn}(t)$ synchronous phase

RF AMP

RF CNTL

BPM

Tr. kicker

RF AMP

iGp12

Observing the beam and the RF kick simultaneously

length: $l$

$f_{RF}(t)$

Oscillator

Parameters are changing during acceleration upto 30 GeV
Example of revolution frequency

\[ f_{\text{rev}} = 185.7\text{kHz} \rightarrow 191.2\text{kHz} \]
Example of synchronous phase

Subject to change depending on the beam tuning

We need rapid parameter optimization
Sampled by iGp12 \[\leftarrow \text{Compare} \rightarrow \text{signals on the stripline kicker}\]

\[\Delta \phi_B(t) \text{ beam transit time}\]

Stripline kicker = directional coupler
- can observe
- beam signal
- RF power from the feedback system

\[\Sigma \text{–signal of stripline kicker}\]

Sampled signal @iGp12

\[\text{marker @slice#570}\]

\[\text{marker @slice#5}\]
Unit in oscilloscope (kicker) = \textbf{time (sec)}

Referencing the marker #5, 570 scaling and shift

Unit in iGp12
RF CLK x 64
Unit in oscilloscope (kicker) = \textbf{time (sec)}

Referencing the marker #5, 570 scaling and shift

Unit in iGp12 RF CLK x 64
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Unit in iGp12
RF CLK x 64
Unit in oscilloscope (kicker) = time (sec)

Referencing the marker #5, 570 scaling and shift

Unit in iGp12 RF CLK x 64
Unit in oscilloscope (kicker) = \textbf{time (sec)}

Referencing the marker #5, 570 scaling and shift

Unit in iGp12
RF CLK x 64
Unit in oscilloscope (kicker) = \textbf{time (sec)}

Referencing the marker #5, 570 scaling and shift

Finally superpose the beam signal by shifting horizontally the \textbf{amount of shift = the delay time that we want}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{diagram.png}
\caption{Acceleration}
\end{figure}
Timing CNTL by preset table

2.48 sec cycle

Kinetic Energy [GeV]

STATE 1  2  3  4  5  ....

Time from P1 (sec)
Timing CNTL by preset table

External trigger initiates each "STATE"
STATE specifies the delay, filter gain, phase, # of tap

a function of "iGp12"
Timing CNTL by preset table

2.48 sec cycle

| STATE | 1 | 2 | 3 | 4 | 5 | .... |

Graph showing kinetic energy versus time from P1 (sec):
- Top graph: Kinetic energy in GeV.
- Bottom graph: Frequency (f rev) versus time from P1 (sec).

Graphs illustrate changes in energy and frequency over time.
Timing CNTL by preset table

2.48 sec cycle

Kinetic Energy [GeV]

f_{rev}

Time from P1 (sec)
Timing CNTL by preset table

STATE 1 2 3 4 5 ......

Graph showing kinetic energy and frequency over time.
Timing CNTL by preset table

2.48 sec cycle

Kinetic Energy [GeV]

STATE 1  2  3  4  5  ......
Timing CNTL by preset table

2.48 sec cycle

Kinetic Energy [GeV]

f rev

Time from P1 (sec)
Timing CNTL by preset table

2.48 sec cycle

Kinetic Energy [GeV]

STATE 1  2  3  4  5  . . . . . .

Time from P1 (sec)

$f_{rev}$
Timing CNTL by preset table

2.48 sec cycle

Kinetic Energy [GeV]

STATE 1  2  3  4  5  ......
Timing CNTL by preset table

2.48 sec cycle

Kinetic Energy [GeV]

STATE 1  2  3  4  5  ......
Timing CNTL by preset table

2.48 sec cycle

Kinetic Energy [GeV]

STATE 1  2  3  4  5  

\[ \text{Time from P1 (sec)} \]

\[ \text{f rev} \]
iGp12 parameter settings

Injection flat bottom

FIR filter parameters

This trial

Acceleration

This trial
2015. 7. 1
2 bunches, ~80kW, ~4.2×10^{13} \text{ p}

BEFORE

shot513300

\xi_x \sim -5.9
\xi_y \sim -5.2

Acceleration

\Delta x
\Delta y

P1+100ms  P2
2015. 7. 1
2 bunches, ~80kW, ~4.2x10^{13} p

BEFORE

shot513300

\( \xi_x \sim -5.9 \)
\( \xi_y \sim -5.2 \)

AFTER

shot513301

Stabilized only by switching on STATE 2
Summary

✓ Transverse intra-bunch feedback during acceleration period was successful upto P2 + ~80 ms.
  • Horizontal instability at the beginning of acceleration was suppressed.
  • Stable parameters (delay, gain, frequency) are obtained

Prospect

➢ Further parameter optimization for further accel. period
➢ Stability check both with experiments and simulations
➢ Contribute high beam intensity upgrade