MONITORING OF THE BETATRON TUNE AND AMPLITUDE AT MULTI-BATCH INJECTION OF J-PARC MR

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Abstract

The beam power of J-PARC Main Ring Synchrotron (MR) increased gradually from 2008, and came to be able regularly to supply the beam of 145kW February, 2011. Many of current beam losses are localized to collimators located at the injection section. One of the problems of the beam injection is that the orbit of the beam transportation line is unstable. It causes sometimes large transverse injection error. Because the transverse injection error is essentially correlated to the amplitude of the betatron oscillation, it is possible to observe by measuring the turn-by-turn position of every injected beam bunches using BPMs at the injection section. In this report, it is described the method how to measure injection error from beam position. It is also discussed about the effect of reflection of injection kicker magnets.

MR BEAM INJECTION

Beam Injection Line

Figure 1 shows the MR injection beam line. The beam accelerated in the RCS (Rapid Cycling Synchrotoron) is transported to MR through the 3-50BT line. It is bent with 2 injection-septa and shifted to the ring orbit with 3 injection-kickers. There are also 3 injection-bump-magnets to have the circulating beam wider dynamic aperture.
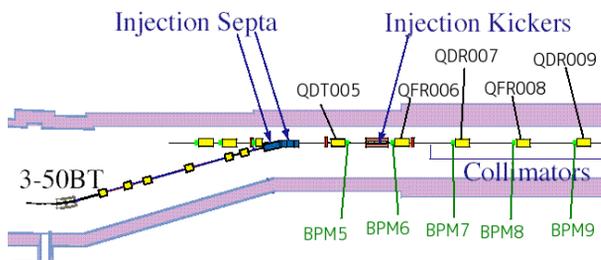

Figure 1: Injection Beam Line of J-PARC MR

Beam Injection Timing

In current condition, the harmonics of MR is 9. One of them is reserved for the rising time of the fast-extraction-kickers so 8 beam bunches are able to accelerated in the MR. Since RCS has 2 bunches(2 harmonics) in 25Hz (40ms interval) cycle, there are 4 batches of injection(we

call them K1,K2,K3,K4) for each batch 2 bunches (we call them the Front and Rear bunch) are injected into the MR.

DATA ACQUISITION

Setup

We use BPM6 and BPM8 (see Figure 1), which are located before focusing-quadrupole-magnets to measure the horizontal turn-by-turn beam position. Also for vertical, we use BPM7 and BPM9 located before defocusing-quadrupole-magnets. For the data processing circuit, most of the system are shared with COD measuring system [1] and it is added some dedicated digitizer which has 50k record length, 100MS/s sampling rate and 12bit resolution. To cutoff the magnet origin lower frequency noise, it is adapted offline digital high pass filtering to the waveform. The obtained position resolution is estimated about 0.2~0.6mm.

Bunch Identification

Since number of bunches circulating in the MR is changing (2~8) as the injection batch (k1~K4) passed, identifying the injected bunch among the circulating bunches was a kind of complicated issue. We chose the trigger which are synchronized with the RCS-extraction-kicker. As a result, the timing-jitters of the injection bunch become negligible, then we can easily identify it. (see Figure 2)
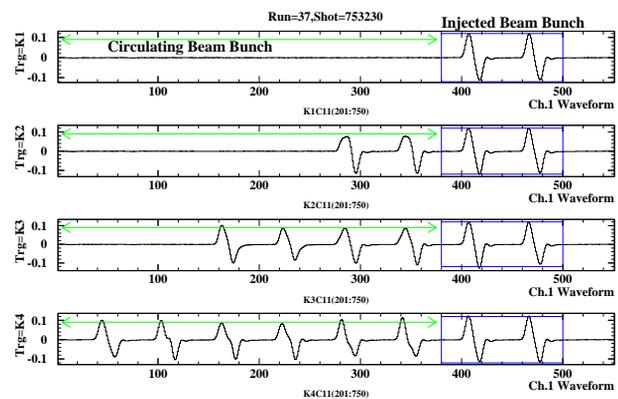

Figure 2: Raw waveform data of BPM ch.1 (from upper to lower, triggered at K1, K2, K3, K4). Couple of bunches surrounded in the blue box are injected beam. The other bunches in the green arrow region are circulating beam.

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TUNE AND INJECTION ERROR

Looking at the turn-by-turn transverse positions measured by a specified BPM, it is observed dipole oscillation (betatron oscillation) represented by Eq.(1)

$$x_n = A \cdot \sin(2\pi\nu \cdot n + B) + C \qquad (1)$$
$$A = \sqrt{x_0^2 + (\alpha_x x_0 + \beta_x x_0')^2}$$

where, x_n is transverse beam position of turn n, amplitude A is corresponding to the transverse-injection-error (inj-err) which depend on initial position and momentum (x_0, x_0') and α_x, β_x are twiss parameters of the BPM location, ν is the betatron tune, B is initial phase and C is the offset position which is originated from COD and BPM's alignment error. Amplitude A can be minimized when we chose the proper (x_0, x_0') by adjusting the bending angle of injection-septa and injection-kickers.

To get the tune and inj-err in real-time, the time-domain position array are transformed by FFT. This method is faster and more robust than the least square fitting to time-domain array and result is same(see Figure 3). Figure 4,5 shows example of the operation interface(OPI).
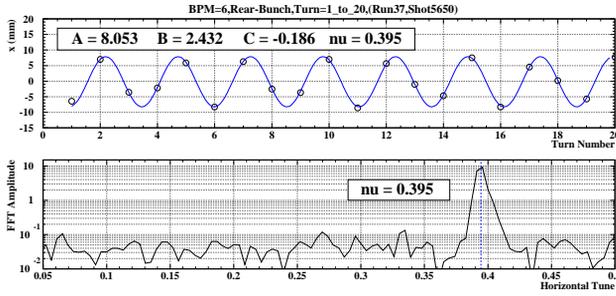

Figure 3: (Upper): Time-domain turn-by-turn horizontal(x) position at BPM6. It is fitted by Eq.(1). (Lower): Frequency-domain of beam position. The peak frequency 0.395 corresponds to decimal part of horizontal betatron tune of the current MR operation point(22.40).
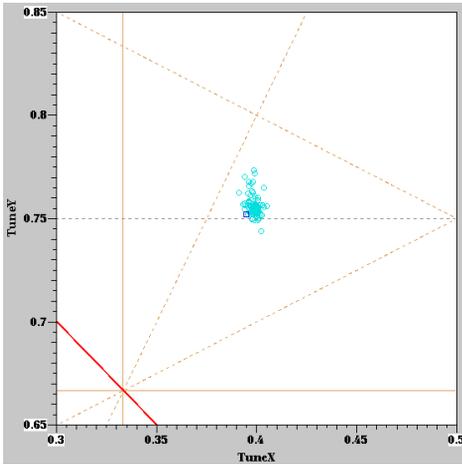

Figure 4: Snapshot of the OPI automatic plotting the tune in the diagram around the operating point (22.40, 20.75).

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Trg_Tmg	Banch_Type	BPM#006		BPM#008		BPM#007		BPM#009	
		TuneX	AmpX	TuneX	AmpX	TuneY	AmpY	TuneY	AmpY
K1	(1) K1_Front	0.390	0.64	0.391	0.60	0.764	0.22	0.764	0.20
	(2) K1_Rear	0.396	0.48	0.396	0.45	0.764	0.23	0.764	0.26
K2	(1) K1_Front	0.398	0.18	0.396	0.17	0.752	0.05	0.757	0.05
	(2) K1_Rear	0.397	1.21	0.396	1.21	0.742	0.05	0.848	0.03
	(3) K2_Front	0.403	0.37	0.403	0.36	0.756	0.23	0.754	0.20
	(4) K2_Rear	0.396	0.72	0.396	0.73	0.757	0.22	0.757	0.21
K3	(1) K1_Front	0.400	0.72	0.399	0.76	0.730	0.05	0.805	0.04
	(2) K1_Rear	0.397	0.32	0.399	0.28	0.764	0.04	0.794	0.05
	(3) K2_Front	0.400	0.21	0.396	0.21	0.828	0.06	0.763	0.05
	(4) K2_Rear	0.401	1.29	0.401	1.22	0.838	0.04	0.686	0.03
	(5) K3_Front	0.396	0.51	0.397	0.48	0.752	0.19	0.755	0.19
	(6) K3_Rear	0.394	0.81	0.395	0.80	0.752	0.21	0.753	0.23
K4	(1) K1_Front	0.405	3.16	0.406	3.14	0.803	0.06	0.799	0.04
	(2) K1_Rear	0.405	1.82	0.404	1.78	0.772	0.03	0.753	0.03
	(3) K2_Front	0.403	0.52	0.406	0.42	0.850	0.04	0.858	0.04
	(4) K2_Rear	0.404	0.23	0.407	0.20	0.740	0.06	0.784	0.04
	(5) K3_Front	0.407	0.31	0.406	0.30	0.861	0.04	0.784	0.03
	(6) K3_Rear	0.405	0.91	0.404	0.95	0.751	0.04	0.756	0.05
	(7) K4_Front	0.406	1.00	0.405	0.99	0.742	0.28	0.743	0.28
	(8) K4_Rear	0.402	0.59	0.401	0.61	0.743	0.31	0.742	0.33

Figure 5: Snapshot of the OPI to show the table of tune and inj-err for all injected bunches and circulating bunches updating in real-time.

DETERMINING TWISS PARAMETERS

Using the transfer matrix between BPM(s_1) and BPM(s_2) the transverse position (x) and momentum ($x' = dx/ds$) are described by Eq.(2)

$$\left[\begin{array}{c} x(s_2) \\ x'(s_2) \end{array}\right] = \left[\begin{array}{cc} m_{11} & m_{12} \\ m_{21} & m_{22} \end{array}\right] \left[\begin{array}{c} x(s_1) \\ x'(s_1) \end{array}\right] \qquad (2)$$

Then momentum x' can be determined as following,

$$x'(s_1) = -\frac{m_{11}}{m_{12}}x(s_1) + \frac{1}{m_{12}}x(s_2) \qquad (3)$$

$$x'(s_2) = \frac{m_{12}m_{21} - m_{11}m_{22}}{m_{12}}x(s_1) + \frac{m_{22}}{m_{12}}x(s_2) \qquad (4)$$

Twiss parameters (α_x, β_x) can be calculated using measured (x, x') as following [2],

$$\alpha_x = \frac{-<x \cdot x'>}{\sqrt{<x \cdot x><x' \cdot x'> - <x \cdot x'>^2}} \qquad (5)$$

$$\beta_x = \frac{<x \cdot x>}{\sqrt{<x \cdot x><x' \cdot x'> - <x \cdot x'>^2}} \qquad (6)$$

wehre $<x \cdot x>$ is averaging by turn n defined as bellow,

$$<x \cdot x> = \sum_{n=n_0}^{n_0+100} x_n \cdot x_n \qquad (7)$$

Usually $n_0 \sim 100$ is chosen because betatron oscillation is not stable in the early turns. Using the above twiss parameters, phase space in physical coordinate is transformed to normalized coordinate as following,

$$\left[\begin{array}{c} X \\ X' \end{array}\right] = \left[\begin{array}{cc} 1/\sqrt{\beta_x} & 0 \\ \alpha_x/\sqrt{\beta_x} & \sqrt{\beta_x} \end{array}\right] \left[\begin{array}{c} x \\ x' \end{array}\right] \qquad (8)$$

Using Eq.(8) to Eq.(2), the transfer matrix is represented by the rotation matrix as Eq.(9).

$$\begin{bmatrix} X(s_2) \\ X'(s_2) \end{bmatrix} = \begin{bmatrix} \cos\psi_{21} & \sin\psi_{21} \\ -\sin\psi_{21} & \cos\psi_{21} \end{bmatrix} \begin{bmatrix} X(s_1) \\ X'(s_1) \end{bmatrix} \quad (9)$$

where, ψ_{21} is phase advance between s_1 and s_2.

Figure 6 shows the phase space of horizontal position in the physical coordinate(left) and the normalized coordinate(right). In this data inj-err is intentionally enlarged by changing the septum current. Figure 7 is example of the OPI to show the phase space of all injected bunches and circulating bunches.
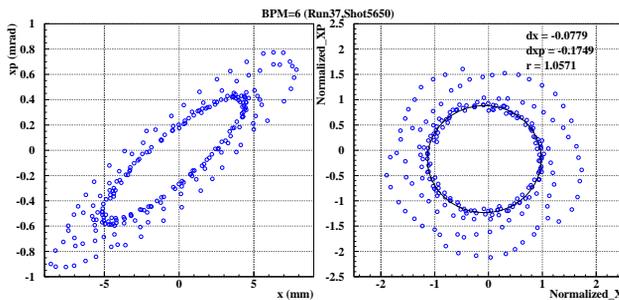

Figure 6: First 230 turns of K1-injected Rear bunch measured by BPM6. (Left): phase space of physical coordinate (x, x'), (Right): normalized coordinate (X, X').
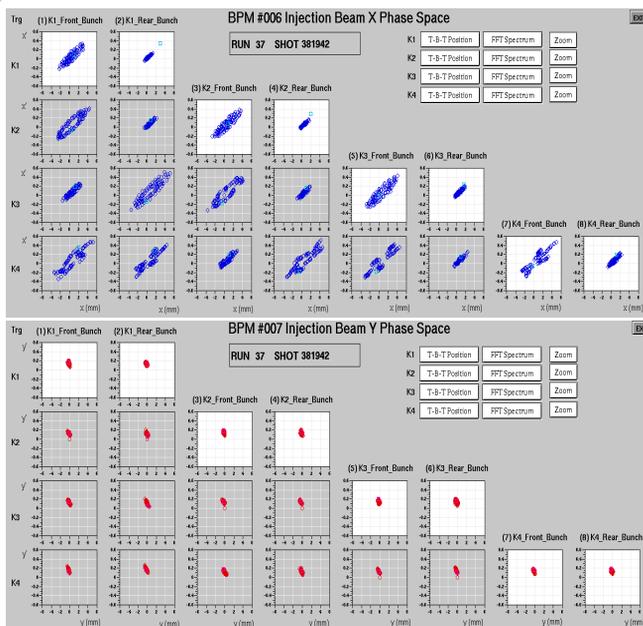

Figure 7: Snapshot of the OPI to show the phase space in physical coordinate for all injected bunches and circulating bunches. Graphs in the gray background are circulating bunches. Upper blue plots are (x, x'). Lower red plots are (y, y'). It is updating in real-time.

EFFECT OF KICKER REFLECTION

One can notice that in the Figure 7 the amplitude of horizontal(x) betatron oscillation of later circulating bunches are sometimes larger than that of early injected bunch. This was a sort of mystery. Eventually we found this phenomenon occurs that the reflection pulse of inj-kicker affects to other circulating bunches and amplitude of betatron oscillation is enlarged.

To confirm it we just injected single bunch (for example at K2 timing) then one of the kicker is inhibited to fire at K3. At that time BPM is triggered at just $300\mu s$ before K3 to see the behavior of the circulating bunch. The result is that enlargement of betatron oscillation is suppressed. (see Figure 8).
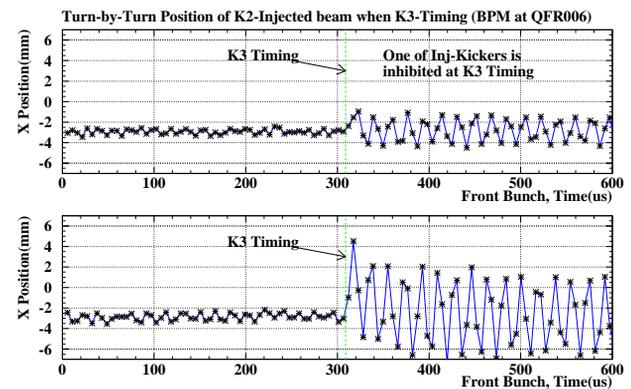

Figure 8: Time-domain horizontal(x) position of the K2-injected Front bunch triggered at K3 timing. (Upper): One of inj-kickers is inhibited at K3 timing. (Lower): All inj-kickers are fired at K3 timing.

SUMMARY

We have developed the system to monitor the betatron tune and amplitude at the injection time of the MR. We presented some OPIs utilized for beam commissioning. We found the problem that reflection of the injection kicker affects to the orbit of the circulating beam bunch. Some improvement was seen after the transverse bunch-by-bunch feedback system [3] was introduced. For the fundamental solution, it is planned radical improvement of the injection kicker system in the future.

REFERENCES

[1] S. Hatakeyama et. al., "THE DATA ACQUISITION SYSTEM OF BEAM POSITION MONITORS IN J-PARC MAIN RING", Proceedings of IPAC10, Kyoto, Japan, May 2010.

[2] K. Ohmi et. al., "OPTICS MEASUREMENT AT THE INTERACTION POINT USING NEARBY POSITION MONITORS IN KEKB", Proceedings of IPAC10, Kyoto, Japan, May 2010.

[3] M. Tobiyama et. al., "BUNCH BY BUNCH FEEDBACK SYSTEMS FOR J-PARC MR", Proceedings of IPAC10, Kyoto, Japan, May 2010.

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