THE BUNCH BY BUNCH FEEDBACK SYSTEM IN J-PARC MAIN RING

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Abstract

We report the current status of the transverse bunch by bunch feedback system for the J-PARC Main Ring. The J-PARC Main Ring is the synchrotron accelerating protons from 3 GeV to 30 GeV. It is normally operating at the intensity of 145 kW. The bunch by bunch feedback system have been developed and used for the normal operation of J-PARC Main Ring. The system aims to reduce the coherent transverse oscillation due to the instabilities and injection errors. It consists of a beam position monitor, a stripline kicker and a signal processing electronics. We've observed the injection error leading to the internal bunch oscillation and succeeded in damping such kind of oscillations and reducing the beam loss significantly.

INTRODUCTION

J-PARC has three main accelerators, which are LINAC, RCS (Rapid Cycle Synchrotron) and Main Ring (MR). MR is the final section of these accelerators. The proton beam is accelerated from 3 GeV to 30 GeV and extracted for the particle and nuclear experiments. The most important feature of J-PARC is the high intensity proton beam. The number of protons per single bunch (N_{ppb}) in MR is about 10^{13}. Considering the number of bunches (8) and repetition period (3 second), the intensity of the proton beam is about 145 kW.

In such a high intensity beam, the impedance of the injection or extraction kickers and beam pipes (resistive wall) causes beam instabilities. In fact, we already observed the transverse instability with zero chromaticity (ξ=0) even at $N_{ppb}=10^{12}$. If the instability happens, more than half protons in the beam are lost so that we could not increase the intensity. As the easiest solution, we damp the transverse oscillation with negative chromaticity (ξ=-5.8). However, the care with negative chromaticity is not enough as we increase the intensity up to $N_{ppb}=10^{13}$. In fact, there are two issues which should be taken care to achieve $N_{ppb}=10^{13}$. The first one is the injection error. Due to the residual field in the injection kickers, transverse coherent oscillation occurs at the injection. At $N_{ppb}=10^{13}$, the injection beam loss exceeds the collimator limit (400 W) even if we damp the oscillation with the negative chromaticity. The other is the beam loss at the beginning of the acceleration. Although the reason of this beam loss is not yet investigated, it is clear that this beam loss happens only with large negative chromaticity and no coherent oscillation is observed at this time. Therefore, we need different damping method of the transverse oscillation other than the negative chromaticity at the beginning of the acceleration.

The bunch by bunch feedback system in MR provides additional damping of the transverse oscillations. After the several test experiments, the system is used to the normal accelerator operation and contributes to the achievement of the current beam intensity.

BUNCH BY BUNCH FEEDBACK SYSTEM

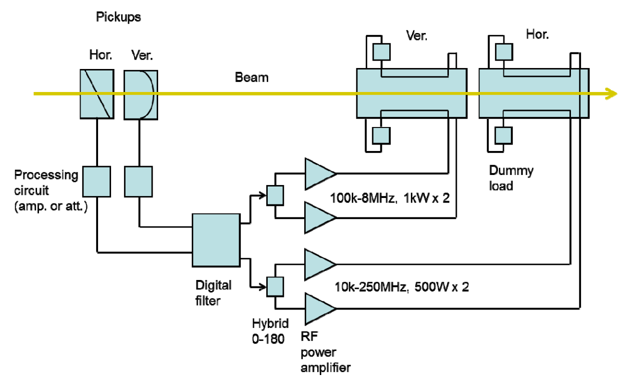

Figure 1: The schematic view of the MR transverse bunch by bunch feedback system.

As shown in Figure 1, the transverse bunch by bunch feedback system consists of three components: beam position monitors, feedback kickers and signal processing electronics. The diagonal cut electrodes are used as the beam position monitors [1]. For the feedback kickers, we use stripline exciters with the length and the transverse shunt impedance of 1.4 m and 29 kΩ, respectively. For the signal processing parts, we use LLRF4 boards [2] [3]. It consists of four 14-bit ADC with maximum sampling speed of 125 MSPS, a Spartan3 FPGA, two 14 bit DAC up to 260 MSPS and a USB interface to communicate with external system. The firmware including EPICS interface and the system integration was made by Dimtel Inc. [4]. The 64^{th} harmonic of the RF frequency (1.7 × 64 = 108.8 MHz) are used as the signal processing clock. The firmware calculates the transverse bunch by bunch position by making difference of the peaks of the two BPM waveforms (LR or UD) and extracts the betatron oscillation using the 8 tap FIR filter. The signal calculated in such ways is sent to the feedback kickers through the power amplifiers (500 W, 10 kHz-255 MHz). It is noted that whole protons in single bunch are kicked in same direction with same amount since only one feedback value is calculated for a bunch

DAMPING OF THE INJECTION ERROR

As we mentioned, there is the transverse coherent oscillation due to the residual field in the injection kickers. The bunch by bunch feedback system reduces such oscillation significantly and results in smaller beam loss at the injection. Without the feedback system, the injection beam loss exceeds the collimator limit (400 W)

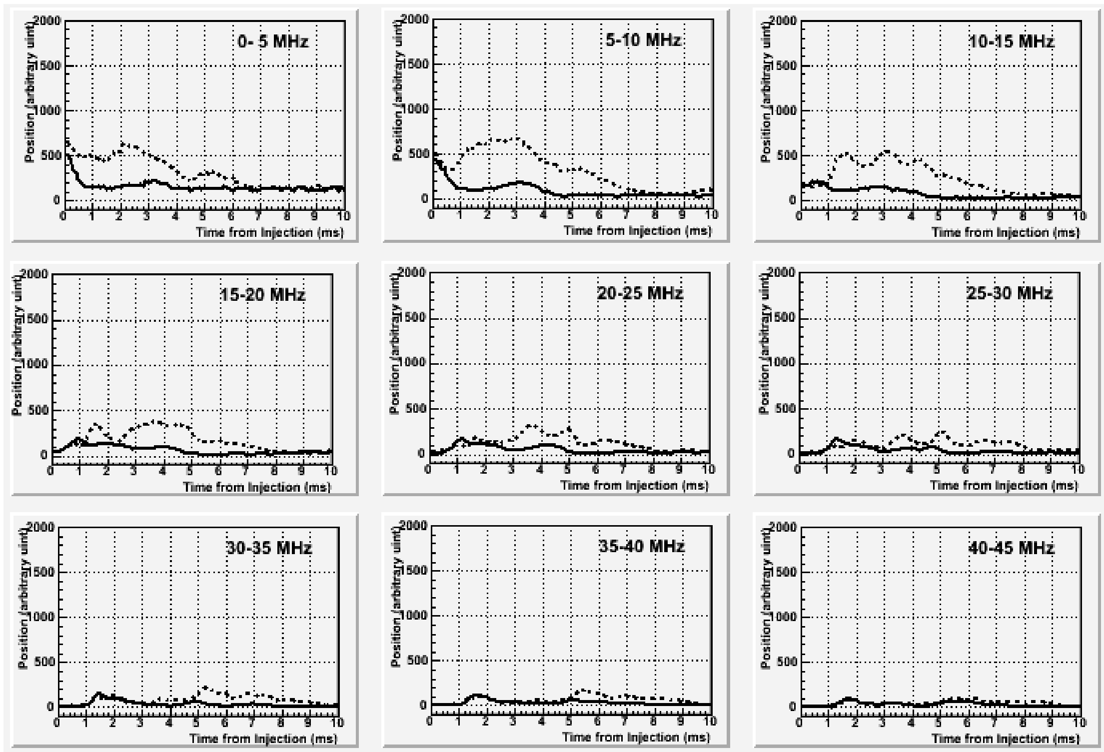

Figure 2: Time dependence of the horizontal oscillation amplitude within 10 ms from the injection for each frequency component obtained by the stripline monitor (ξ=-5.8, 130 kW). The dot lines show the case without the feedback and the solid line show the case with the feedback.

while the loss is less than 200 W with the feedback system at the intensity of 145 kW.

To measure the coherent oscillation, we use a thin and short stripline monitor with the length of 18 cm [1]. Figure 2 shows the time dependence of the horizontal oscillation amplitude within 10 ms from the injection for each frequency component obtained by the stripline monitor. The dot lines show the case without the feedback and the solid lines show the case with the feedback. The effect of the feedback system is apparently observed especially in the low frequency region (0-20 MHz). The effect in high frequency region (~40 MHz) is less. This can be understood by considering that the system kicks the bunch in same direction with same amount but 40 MHz corresponds to the oscillation within the bunch since the bunch length at the injection is about 100 ns (10 MHz). Despite of the less effect at the high frequency region, total damping of the oscillation is significantly faster by using the feedback system.

INTERNAL BUNCH OSCILLATION

As we mentioned, there is high frequency component, which indicates the internal bunch oscillation. To measure the internal bunch position, we also use the stripline monitor. Figure 3 shows the transverse position depending on the longitudinal position in single bunch. The interval between each plot is 100 turns (1 turn is corresponding to about 5 microseconds) and the shapes of 10 continuous turns are superposed in each plot. The number of turns shown in the plots is counted from the injection. The data is taken in the normal operation (ξ=-5.8 at the injection, feedback on, 145 kW). The frequency becomes higher and the oscillation is localized at the rear part of the bunch as time goes on. At the current intensity, the contribution to the beam loss from such higher frequency oscillation is not a fatal. However, it could be a fatal at the higher intensity. Therefore, we consider the upgrade of the feedback system with larger band width to damp the internal bunch oscillation.

INSTABILITY AT ACCELLERATION

At the beginning of acceleration, we need to increase the chromatic correction otherwise the beam loss is not acceptable. The chromaticity pattern that we use is shown in Figure 4. The beam loss with large negative chromaticity is not yet investigated. It may be caused by the resonance due to the tune spread since the ripple of Q and B-field of MR magnets is still quite large (10^{-3}-10^{-4} at the 3 GeV). Although we can reduce such beam loss with chromatic correction, the larger instability due to transverse oscillation appears as we correct the chromaticity. Figure 5 shows the horizontal difference signal of the stripline monitor using the chromaticity pattern shown in Figure 4 without the feedback. The first four spikes correspond to the injection error (two bunches are injected to MR four times). After these spikes, the growth of the oscillation amplitude is observed. As shown in Figure 6, the beam loss coinciding with this oscillation is not acceptable for normal operation. However, if we turn on the feedback, we can damp such

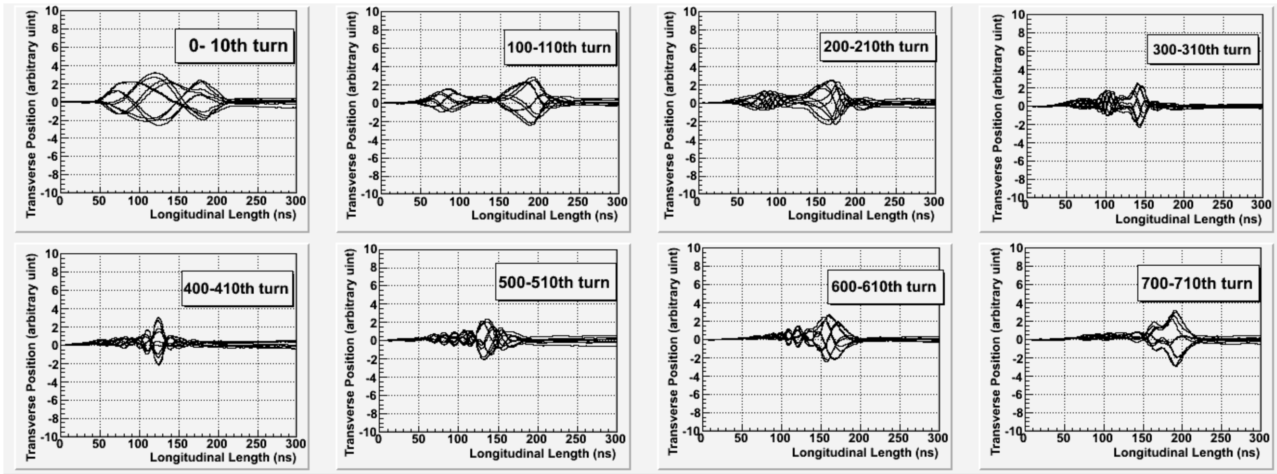

Figure 3: Transverse position depending on the longitudinal position in single bunch. The interval between each plot is 100 turns (1 turn is corresponding to about 5 microseconds) and the shapes of 10 continuous turns are superposed in each plot (ξ=-5.8, feedback on, 145 kW).

oscillation before it causes significant beam loss (Figure 7). The study of the frequency and growth rate of such instability occurring at the acceleration should be done in the near future.

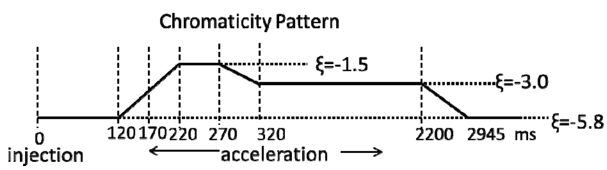

Figure 4: Chromaticity pattern.

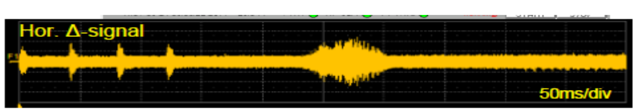

Figure 5: The horizontal differential signal of the stripline monitor without the feedback. The horizontal axis shows time from the injection and full scale is 500 ms.

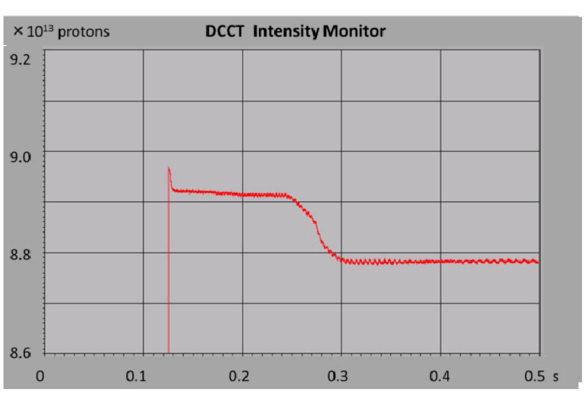

Figure 6: The beam intensity measured by the DCCT monitor without the feedback. The horizontal axis shows time from the injection.

SUMMARY

The transverse bunch by bunch feedback in the J-PARC MR is developed and used in the normal operation. The system plays significant roles in achieving current intensity by reducing both injection and acceleration beam loss due to the transverse coherent oscillation. For the injection loss, we plan to replace the injection kickers with new ones which have less residual field so that the oscillation amplitude at the injection will be smaller. Therefore, the instability at the acceleration could be the biggest obstacle to higher intensity. For the instability at the acceleration, further measurement of the frequency and growth rate must be done to fix the requirement for the upgrade of the feedback system.

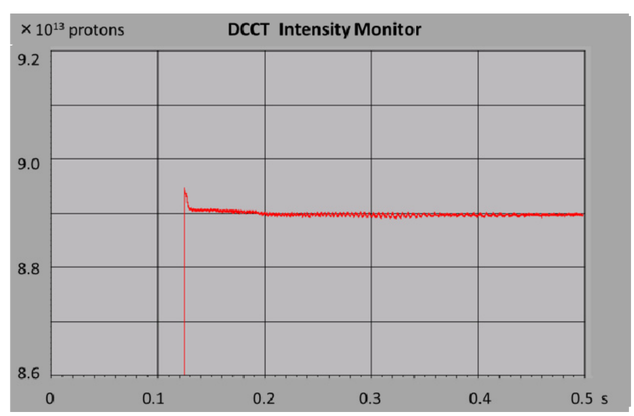

Figure 7: The beam intensity measured by the DCCT monitor with the feedback. The horizontal axis shows time from the injection.

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