INTRA-BUNCH FEEDBACK SYSTEM FOR THE J-PARC MAIN RING

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Abstract

A new broadband feedback system (the bandwidth of around 100MHz) has been developed for suppression of intra-bunch oscillations and reduction of particle losses at the J-PARC Main Ring (MR). A new BPM has been designed and fabricated (completed in March 2014), based on the exponential coupler stripline type (the diameter of 134 mm and the length of 300 mm). In this BPM system, the frequency characteristics of differentiated bunch signals are corrected using the equalizer. The design and performance of the new BPM as well as preparation of a newly installed exciter and power amplifier is presented. We also report beam test results of suppression of intra-bunch oscillations at 3 GeV with the bunch length of 150-200 ns.

INTRODUCTION

The J-PARC is composed of three proton accelerators: the 400MeV linear accelerator (LINAC), the 3 GeV Rapid Cycling Synchrotron (RCS), and the Main Ring (MR) Synchrotron. The main parameters are listed in Table 1. At the J-PARC MR, transverse instabilities have been observed at the injection and during the acceleration. The present narrowband bunch-by-bunch feedback system (BxB FB) is effectively suppressing these transverse dipole oscillations, allowing to attaining the 230 kW beam power [1]. But the BxB feedback system can damp only the whole bunches. Even with the BxB feedback system on, internal bunch oscillations have been still observed, which is causing additional particle losses [2]. To suppress intra-bunch oscillations, a more wideband and advanced feedback system (named the intra-bunch feedback system) has been developed.

INTRA-BUNCH FEEDBACK SYSTEM

Figure 1 shows the schematic of the intra-bunch feedback system. It is composed mainly of three components: a BPM, a signal processing circuit and kickers. The signal processing circuit detects betatron oscillation of bunches using signals from the BPM and calculates feedback signals. These feedback signals are sent to the kickers through the power amplifiers. The new system and its set-up are similar to those of the current BxB feedback system [3]. The main improvement is that each component now has a wider frequency sensitivity than the one for the BxB feedback system. The intra-bunch feedback system has been installed at the D3 building, while the current BxB feedback system is still operational at the D1 building. The new components were installed in the MR address #159.

Table 1: Main Parameters of J-PARC Main Ring

Circumference	1568m
Injection Energy	3GeV
Extraction Energy	30GeV
Repetition Period	2.48s
RF Frequency	1.67-1.72 MHz
Number of Bunches	8
Synchrotron Tune	0.002-0.0001
Betatron Tune (Hor./Ver.)	22.41/20.75
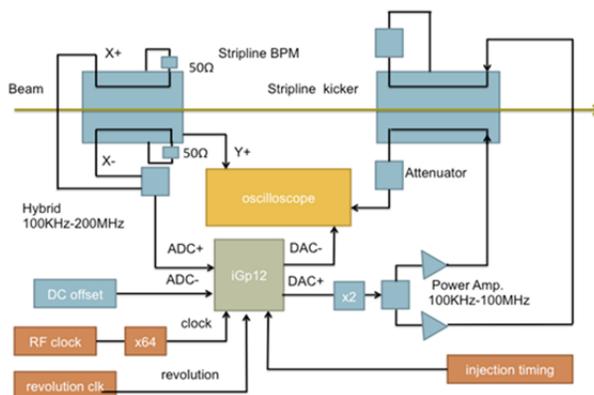
Figure 1: Schematic of the intra-bunch feedback system.

BPM

The new stripline BPM (based on Linnecar's design [4]) has been designed and fabricated (see Fig. 2). It is equipped with the exponentially tapered electrodes which allow wider frequency responses (the green line in Fig. 3) than the conventional rectangular ones (the blue line in Fig. 3). The diameter of the beam pipe is 147mm, and the length of the electrodes is 300mm. The electrodes are placed 67mm from the center of the beam pipe. The height of the electrodes from the chamber surface needs to be gradually reduced toward their tips for the impedance matching. The BPM characteristics were measured by the stretched wire method. Longitudinal transfer impedance is shown by the red line in Fig. 3. It can be seen that the BPM has good frequency response up to 1GHz. Position sensitivity is also measured. The position sensitivity is fluctuating around 0.027 by 0.002.
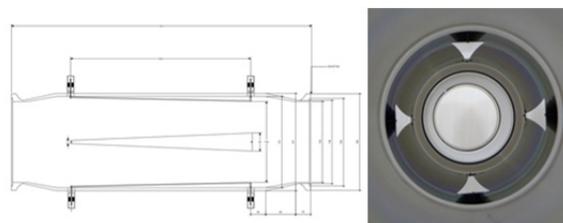
Figure 2: Side (left) and front (right) views of BPM.

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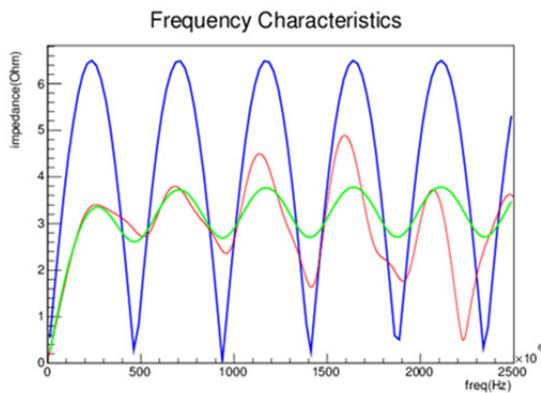
Figure 3: Longitudinal transfer impedance of BPM.

Stripline Kickers and Power Amplifiers

The new stripline kickers were also fabricated (see Fig. 4). The electrodes are 750mm long and they are put on the circle of the diameter 140mm. They are coated with the Diamond Like Carbon (DLC) to suppress the multipactoring effect, which may be serious when the kickers are used for slow extraction. The power amplifiers have 3kW capability. Their bandwidth is 100kHz-100MHz, which limits the bandwidth of the whole system now. The kick angle at 3 GeV when used with the two 3kW amplifiers is estimated to be 3.5μrad at DC.
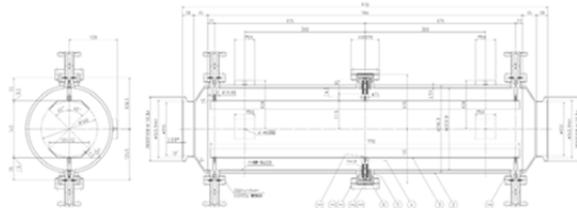
Figure 4: Kicker design.

Signal Processing by iGp12

We adopt the iGp12 signal processing module developed by Dimtel Inc. [5]. It samples BPM signals (through the hybrid coupler) at the rate of 64th harmonic of the RF frequency (~100MHz). It divides each RF bucket into 64 bins (slices). It extracts betatron oscillation signals by using the n-tap FIR (n≤16, n=8 is used) filter on each slice, and feedbacks kick signals to each slice. As seen in Fig. 3, the frequency characteristic of the BPM is approximately linear in the low frequency region (up to 200MHz). Thus, the beam position can be reconstructed by integrating the differentiated signals from the BPM.

BEAM TESTS AT 3 GEV OPERATION

Beam Conditions

The first beam test was done in May 2014 with a single bunch of 2.7×10^{12} ppp at the energy of 3GeV. This beam intensity is 1/5 of the current maximum intensity of MR. The main beam parameters are as follows: the bunch lenght is 150-200ns, the chromaticities are ξ_x=+0.5 and ξ_y=+1.2, and the synchrotron tune is ν_s=1.7×10^{-3}. First, we applied the intra-bunch feedback system to the

horizontal oscillations at the injection, while the vertical BxB FB system is always turned on (when it is tuned off, a large amount of particle losses prevents the testing).

Reduction of Horizontal Oscillations

Figure 5 shows the time evolutions of the horizontal oscillation signals of the 35th bunch slice (located almost at the center of the bunch) in the following three conditions: (top) both the intra-bunch and the BxB FB systems are off, (middle) only the BxB FB system is on, and (bottom) only the intra-bunch FB system is on. The large horizontal oscillations are excited around 15200th turn due to the mismatching field of the injection kicker magnets [6]. The horizontal oscillation decays even without the feedback systems, indicating that it is not instability. It can be clearly seen that the intra-bunch FB system damps the horizontal oscillations much quicker (decay constant is about 80 turn) than the BxB FB system.
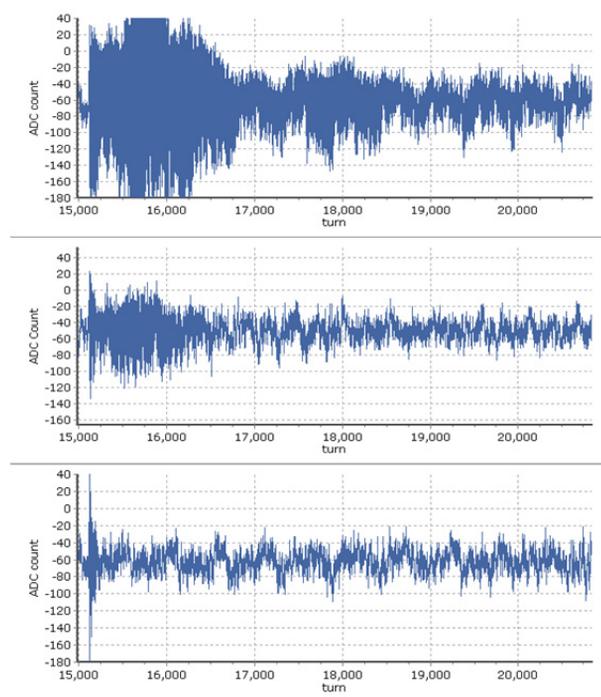
Figure 5: Time evolutions of the horizontal oscillations of the 35th bunch slice. (Top) Both the intra-bunch and BxB FB systems are off. (Middle) Only the BxB FB system is on. (Bottom) Only the intra-bunch FB system is on.

Figure 6 shows FFTs of the horizontal oscillations (over 55830 turns) shown in Fig. 5. The black, the red and the blue lines corresponds to cases: all FB systems off, only BxB FB system on, and the only intra-bunch FB system on, respectively. The figure is magnified around the betatron sideband. Even when the BxB FB system is on, some complicated structures are visible that are likely caused by the synchrotron oscillations. But, they disappear when the intra-bunch FB system is turned on. Figure 7 shows the evolution of the bunch signals at every 100 turns after the large perturbation at the 15120th turn. In each plot, signals are superimposed 10 times for every

5 turns. It can be seen in the bottom figure that the intra-bunch oscillations are almost completely damped along the entire bunch by the intra-bunch FB system after the first 100 turns.
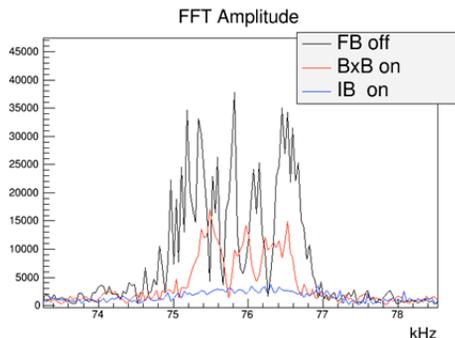
Figure 6: FFT of horizontal oscillation amplitude.

CONCLUSIONS AND FUTURE PLANS

The first beam test successfully demonstrates that the new intra-bunch FB system is quite effective to suppress intra-bunch oscillations within a bunch. However, the horizontal oscillations presented in this paper are merely incoherent oscillations caused by the kicker mismatching field. More serious instabilities and resulting particle losses are observed on the vertical plane at the injection and during the acceleration (when $\xi_y=-0.3$). They can be, however, suppressed by setting the vertical chromaticity to $\xi_y=-3.2$. The horizontal intra-bunch FB system is now used in routine operation. The beam loss at the injection is reduced from 350W to 170W [6]. In principle, the present intra-bunch FB system should work also on the vertical instabilities. A smaller (slightly negative) vertical chromaticity is preferable for operational purposes. We are now preparing the next beam test to prove the validity of the intra-bunch FB system on the vertical instabilities.

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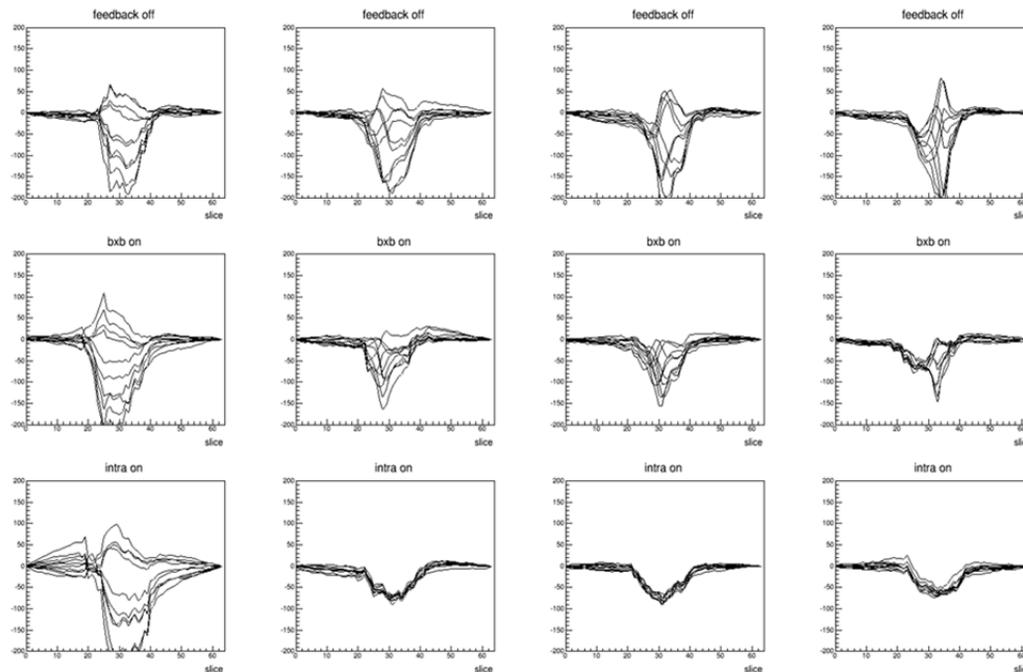
Figure 7: Time evolution of the bunch signals at every 100 turns after the large perturbation at the 15120th turn. In each plot, signals are superimposed 10 times for every 5 turns. (Top) Both the intra-bunch and the BxB FB systems are off. (Middle) Only the BxB FB system is on. (Bottom) Only the intra-bunch FB system is on. The 1st row corresponds to 15200th turn, the 2nd row to 15300th turn, the 3rd row to 15400th turn, and the 4th row to 15500th turn, respectively.