BUNCH BY BUNCH INTRA-BUNCH FEEDBACK SYSTEM FOR CURING TRANSVERSE BEAM INSTABILITIES AT THE J-PARC MR

O. Konstantinova*, Y.H. Chin, Y. Kurimoto, T. Obina, M. Okada, K. Takata, M. Tobiyama, T. Toyama, KEK, Japan, Y. Shobuda, JAEA, Japan

Abstract

At the J-PARC Main Ring (MR), transverse instabilities have been observed during the injection and at the onset of acceleration with large particle losses. The present bunch by bunch feedback system, operating in a narrowband mode, has been effectively suppressing these instabilities, allowing the beam power to reach 230kW with only 400W of particle losses. The observed beam signals show that bunches are still executing complicated intra-bunch oscillations even if the narrowband feedback system is on, though they are not imposing significant particle losses at present. The new and more advanced broadband feedback system has been developed for control of the intra-bunch oscillations and further reduction of particle losses. The elaborate analysis code has been also developed on the MATLAB platform to analyse effects of the broadband feedback system on intra-bunch oscillations. This paper describes the development of these advanced instruments and presents the analysis of the latest beam test results using the MATLAB code.

INTRODUCTION

J-PARC consists of three proton accelerators: a 400 MeV linear accelerator (currently operating at 180 MeV), a 3 GeV Rapid-Cycling Synchrotron (RCS) and a 50 GeV (currently 30 GeV) Main Ring (MR). The main parameters of the MR are summarized in Table 1.

Table 1: Main Parameters of the MR Ring

Circumference	1568 m
Injection Energy	3 GeV
Extraction Energy	30 GeV
Repetition Period	3 sec
RF Frequency	1.67-1.72 MHz
Number of bunches	8
Synchrotron tune	0.002-0.0001
Betatron tune	22.4, 20.77

The MR impedance is dominated by the transverse resistive-wall impedance of the stain-less steel chamber and the horizontal kicker impedance [1]. The kicker impedance has sharp peaks at about 1MHz and 10MHz. The transverse resistive-wall impedance is exceptionally high, since the first betatron unstable line appears at around 40kHz on the vertical plane where the skin-depth is comparable to the wall thickness and the transverse impedance is proportional to the inverse of the frequency, not the square root of the frequency. The bunch by bunch feedback (FB) system, operating in a narrowband mode, has been developed to suppress the beam instabilities and the resulting particle losses [2-3].

Figure 1 sketches the transverse bunch by bunch feedback system. The beam position signals from the Stripline Position Monitors (SPM) are sampled at an RF frequency times 64 rate (108.8MHz at 3GeV). The signal processing and digital filtering circuits consist of two LLRF4 boards with four 14-bit ADCs and two 14-bit DACs. They extract the betatron oscillation signals using 8-tap FIR filters. The kick signals are sent to the stripline damper kickers through the power amplifiers to provide a single kick per bunch per passage for the both directions.

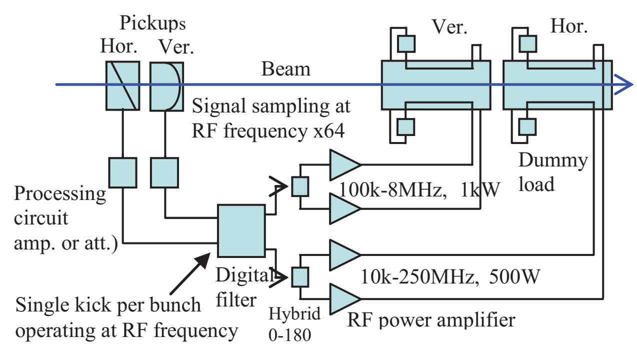

Figure 1: Schematic view of the present transverse bunch-by-bunch feedback system in a narrowband mode.

The particle losses at the injection and at the onset of acceleration are about 500W and 4,800W, respectively, far larger than the collimator tolerance of 400W, when the feedback system is off. They are reduced to 100W and 25W, respectively, when the FB is on. The FB is now a must in daily operation of MR. Although the simple dipole nodes are effectively damped by the present feedback system, the measured beam signals show that bunches are still executing complicated intra-bunch oscillations that are believed to be causing some additional particle losses. Figure 2 shows a snapshot of typical intra-bunch oscillation sampled at the rate of RF frequency times 64. To suppress these intra-bunch oscillations and minimize the particle losses, we have developed the new and more advanced broadband feedback system based on the iGp12 digital signal processing module [4] that is widely used in electron rings. This module is operated at the rate of RF frequency times 64 and replaces the present narrowband digital module shown in Fig. 1, which is operating at just the RF frequency. It divides each RF bucket into 64 segments (bins) and acts on each bin as if it is a small bunch (bunch-let) in a narrowband mode.

* On leave from National Research Tomsk State University, Tomsk, Russia. The work is done partially under the project 2.3684.2011 of Tomsk State University and FTP, contract № 14.B37.21.0911.

ISBN 978-3-95450-122-9

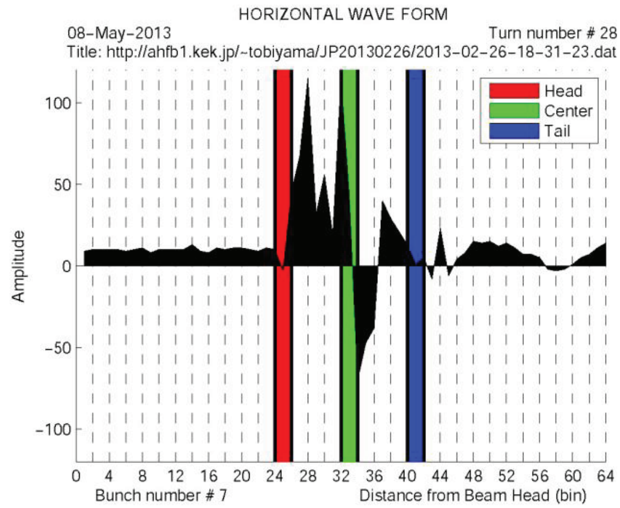

Figure 2: Snapshot of typical intra-bunch oscillation sampled at the rate of RF frequency times 64.

1ST BEAM TEST WITH IGP12 MODULE

The first beam test of the IGp12 module was conducted in February 2013 with a low intensity single bunch of 2.6 x10^{11} ppp (equivalent to 125W beam power) at the injection energy of 3GeV. The measurement setup is illustrated in Fig. 3. After rough adjustment of timing between the beam signal from the SPM and the output from the iGp12 (just the simple delay after the 1 turn filter), we started investigating the bunch behaviour when different parts of the bunch are excited artificially by the iGp12 module; the whole bunch, the first half, the center and the tail of a bunch, respectively. The aim of this study is see how the excitation of a fractional part of the bunch can affect the behaviour of other parts of the bunch. The best excitation was achieved at 80 kHz, close the betatron oscillation frequency of 76 kHz.

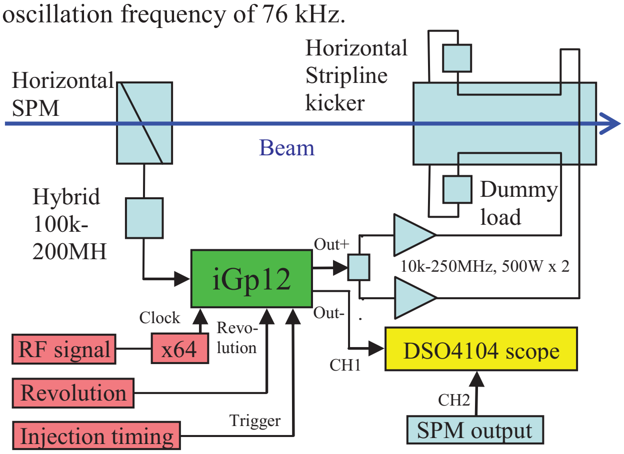

Figure 3: Measurement setup of the intra-bunch feedback system with the iGp12 module.

Whole Bunch Kicked

First, the whole bunch was kicked together by the iGp12 module. This is equivalent to a dipole kick by the present narrowband feedback system and provides the reference behaviour of the bunch oscillations for the latter studies. The time evolutions of the oscillations of the head, the center and the tail of the bunch are plotted in Fig. 4 over 22,000 turns (~100ms). Here, the head (tail) of the bunch is defined as the middle point between the center and the head (tail) edge of the bunch, respectively. They are marked by the red, the green, and the blue lines in Fig. 2, respectively. It can be seen that the oscillation amplitudes are of similar magnitude at the three different points: they are mostly determined by the strength of kicks by the iGp12 module in this forced oscillation mode. Figure 5 shows the projection of the bunch oscillations over time to the longitudinal bunch coordinate for this case. The oscillation profile looks symmetrical about the center of the bunch.

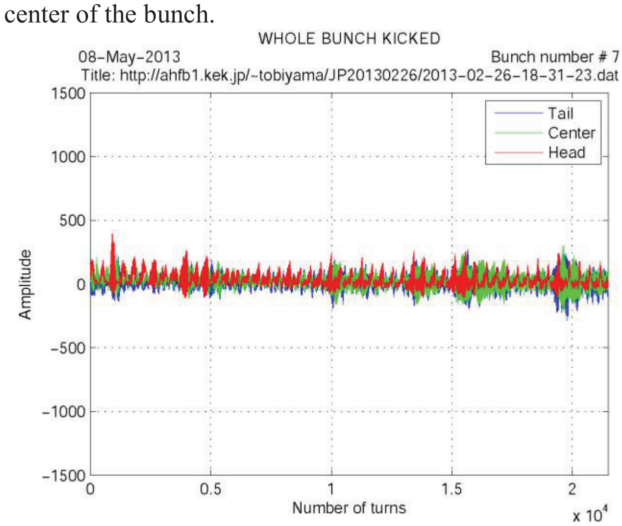

Figure 4: Time evolutions of the oscillations of the head, the center and the tail of the bunch over 22,000 turns, when the whole bunch is kicked by the iGp12 module.

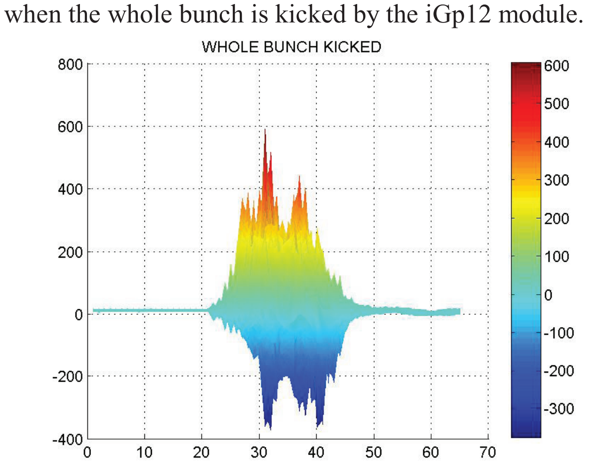

Figure 5: Projection of the bunch oscillations over time to the longitudinal bunch coordinate for the whole-bunch-kicked case.

Bunch Head Kicked

Second, only the first half of the bunch (the head part) was kicked. Figure 6 shows the time evolutions of the oscillations at the head, the center and the tail of the bunch over 22,000 turns (~100ms), respectively. The head of the bunch, which is still forced to oscillate by the iGp12, has a similar oscillation amplitude as the one in the whole-bunch-kicked case (compare with the red line in Fig. 4), while the oscillation amplitude is growing toward the tail edge of the bunch by a factor of several. The result indicates that the tail parts of the bunch are excited by the wakefields generated by the oscillation of the head part of the bunch, not by kicks from the iGp12, and the synchronization between the tail oscillation and the wakefields in the frequency and the phase is driving the tail oscillation to the larger amplitude. The different behaviours of the oscillation amplitudes at the center and the tail of the bunch between the previous whole-bunch-kicked case and the present bunch-head-kicked case demonstrate that the iGp12 module is in fact exciting only the head part of the bunch, not the whole bunch, as configured, and the behaviour of the oscillation amplitude provides a good indication of where localized kicks by iGp12 are being applied in a bunch.

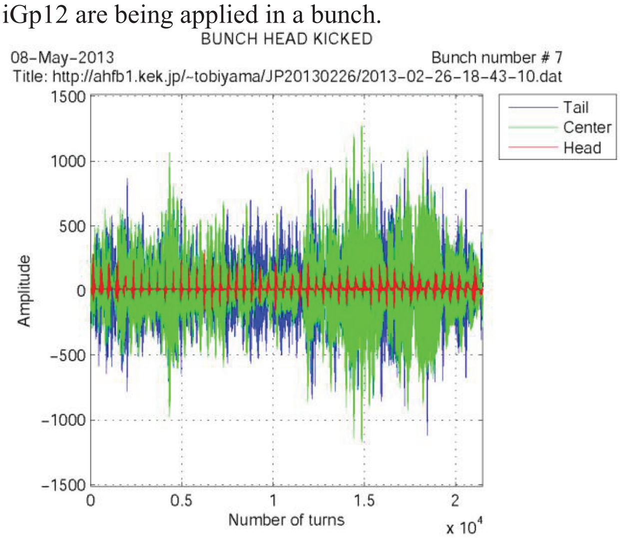

Figure 6: Time evolutions of the oscillations of the head, the center and the tail of the bunch over 22,000 turns, when only the head part of the bunch is kicked.

Bunch Center Kicked

Third, we shifted the kick of the iGp12 to the center part of the bunch. The most of head and the tail parts of the bunch are not kicked. Figure 7 shows the time evolutions of the oscillations at the head, the center and the tail of the bunch over 22,000 turns (~100ms), respectively. Now the head and center parts of the bunch have the oscillation amplitudes similar to those in Fig. 4, while the tail part of the bunch, which is outside of the center kick region, has about twice larger oscillation amplitude than those at the head and the center of the bunch. This oscillation amplitude is not as great as the one in Fig. 6 for the bunch-head-kicked case, since the tail part is too close to the forced oscillation region, and thus the wakefields are not able to be developed as strong as the one at the tail in Fig. 6. It can be confirmed again that the oscillation amplitude in the forced oscillation region stays low and has similar magnitude in the three different cases; good indication of areas where the localized kicks by iGp12 are applied.

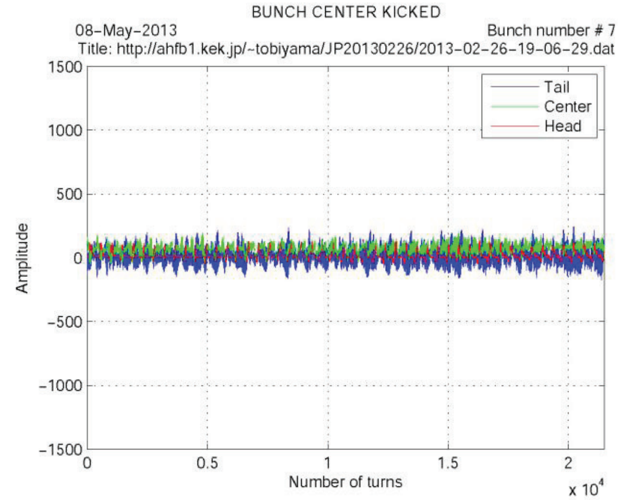

Figure 7: Time evolutions of the oscillations of the head, the center and the tail of the bunch over 22,000 turns, when only the center of the bunch is kicked.

Bunch Tail Kicked

At last, we shifted the kick of the iGp12 to the tail part of the bunch. Figure 8 shows the projection of the bunch oscillations over time to the longitudinal bunch coordinate in this case. The oscillation profile is now quite asymmetrical, tilted heavily to the tail side, suggesting that the kicks are strongly localised in the tail part.

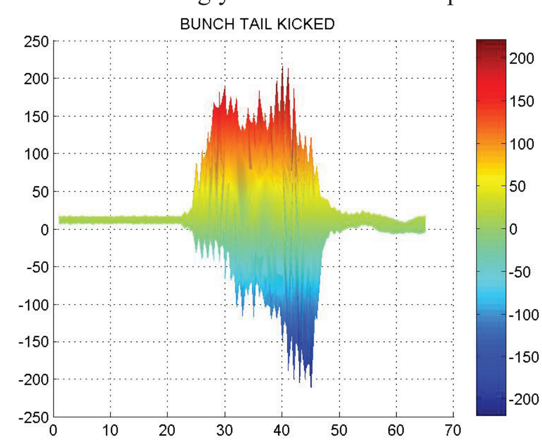

Figure 8: Projection of the bunch oscillations over time to the longitudinal bunch coordinate when only the tail of the bunch is kicked.

REFERENCES

[1] Y.H. Chin et al., "Impedance and Beam Instability Issues at J-PARC Rings", HB2008, Nashville, August 2008, WGA01, p.40 (2008).
[2] Y. Kurimoto et. al., "The Bunch by Bunch Feedback System in J-PARC Main Ring", DIPAC2011, Hamburg, May 2011, TUPD74, p482 (2011).
[3] Y.H. Chin et al., "Head-Tail Instabilities Observed at J-PARC MR and their Suppression Using a Feedback System", 9th Annu. Meeting of Part. Accel. Society of Japan, Osaka, August 2012, WELR09, p.97 (2012).
[4] Dimtel, Inc., San Jose, USA, http://www.dimtel.com/