BUNCH BY BUNCH FEEDBACK SYSTEM USING iGp AT KEK-PF

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Abstract

A transverse bunch-by-bunch feedback system using iGp feedback signal processors has been tested at the KEK-PF. The system consists of a bunch position detection system using 1.5 GHz components of the beam (3 x f_{RF}), iGp feedback signal processors, and a transverse feedback kicker with a high power amplifier. It shows sufficient performance to suppress instabilities completely up to a beam current of 450 mA. Results of the mode analysis of the instabilities using the grow-damp function of the iGp are also shown.

INTRODUCTION

Photon Factory electron storage ring (PF-ring) has been operated in a single- or multi-bunch mode of 2.5 GeV. In the multi-bunch operation, several coupled-bunch mode instabilities are observed in both transverse and longitudinal planes as a stored beam current increases. As for the transverse instabilities, we have suppressed them by using a bunch-by-bunch feedback system developed based on that of SPring-8 [1]. Although this feedback system had worked without major problems since the installation of 2005, we are now planning to replace it to that using "integrated General purpose signal processors (iGp)", which have been developed by the collaboration of KEK, SLAC, and INFN-LNF [2]. The iGp is equipped with not only a greater flexibility for the change of tunes, but also many GUI panels that enable us to remotely change various parameters on digital processing such as coefficients of an FIR filter. It has already been used in the longitudinal bunch-by-bunch feedback system of PF-ring, and succeed in suppressing longitudinal dipole oscillations sufficiently [3]. In order to confirm its effectiveness for transverse instabilities, we have constructed the transverse feedback system using the iGp, and tested its basic performance. The details and some experimental results of the tentative feedback system are presented herein.

The main parameters of PF-ring are listed in Table 1.

Table 1: Main Parameters of PF-ring

Beam energy	2.5	GeV
Circumference	187	m
RF frequency f_{RF}	500.1	MHz
Harmonic number	312	
Revolution frequency f_{rev}	1.603	MHz
Betatron tune ν_x / ν_y	9.6 / 5.28	
Damping time τ_x / τ_y	7.8 / 7.8	ms
Stored current (single/multi)	50 / 450	mA

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FEEDBACK SYSTEM

The transverse bunch-by-bunch feedback system is mainly composed of three sections, an analogue front-end detection, a digital signal processing, and a beam correction. The block diagram of the whole system is shown in Fig. 1.

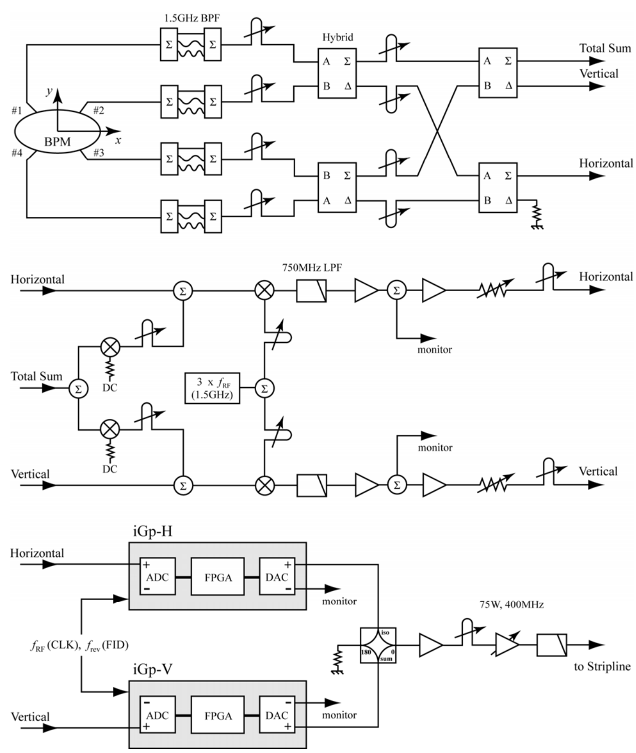

Figure 1: Block diagram of the transverse feedback system using the iGp.

Front-end Detection Section

The beam signals picked up by a 4-button BPM are processed individually via a 1.5 GHz bund-pass filter (BPF) which consists of a power combiner/splitter and three delay cables. The output signals are summed by hybrid circuits (M/A-COM, H-183-4) and converted into three signals, Horizontal, Vertical, and Total Sum. After offset components in Horizontal and Vertical are cancelled by using Total sum, the transverse position of each bunch is detected by a synchronous detection at the 3rd harmonic of the RF frequency (3 x f_{RF}). The timing of the signal processing is precisely adjusted with line stretchers while a single bunch is stored.

Signal Processing Section

A key component of the iGp is a FPGA board including 8-bit 1GSPS ADCs, one FPGA chip (Xilinx, Vertex-II), and 12-bit 1GSPS DACs. The FPGA functions as a 16-tap FIR filter designed so as to have a maximum gain at a betatron frequency and achieve a phase shift of 90 ◦ between the pickup and the feedback kicker. Figure 2(a) and 2(b) show frequency responses of the horizontal and vertical FIR filters used in the experiment, respectively. These responses can be easily changed through the GUI.

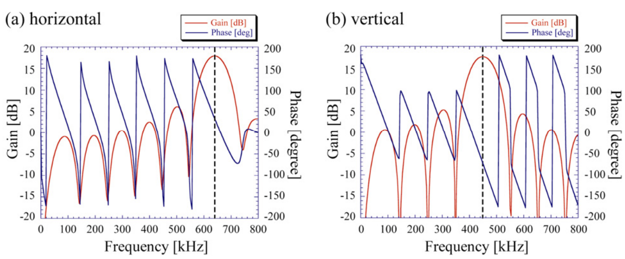

Figure 2: Frequency responses of the horizontal and vertical FIR filters.

The detected signal from the front-end section is digitised by ADCs operated at the RF frequency of 500 MHz, and then applied the FIR filter and a 1-turn delay function inside the FPGA. The processed signal is converted to analogue by DACs operated at 500 MHz, and summed to that of another transverse degree by an external hybrid.

Figures 3(a) and 3(b) are the input and output signals of the iGp measured at the single-bunch operation, respectively. The extraction of the betatron-frequency component and the DC-offset cancelling are implemented simultaneously with the 500 MHz clock signal.

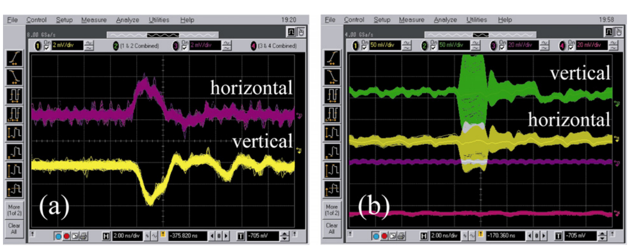

Figure 3: Input and output signals of the iGp for a single bunch.

Corrector Section

The correction signal from the iGp is amplified with a 75 W broadband amplifier (Amplifier Research, 75A400), and fed to a stripline kicker whose length is 45 cm. One of the ends of the stripline electrode is connected to a high-power attenuator. The attenuated signal from the stripline is used to monitor the correction signal associated with the beam-excited signal.

EXPERIMENTAL RESULTS

Overview

In order to prevent the onset of the transverse ion-trapping instabilities, test experiments of the iGp feedback system are performed with 280 out of 312 buckets filled. The bunch spacing is 2 ns. We apply the longitudinal bunch-by-bunch feedback and the RF phase modulation so as to suppress the longitudinal dipole and quadrupole oscillations. According to past experience, the transverse instabilities are excited more strongly as the magnet gap of in-vacuum undulators (ID gap) becomes narrow [4]. Therefore, in the first stage, we fix the ID gap to the maximum value of 45 mm.

Under such conditions, we injected the beam with the iGp feedback system working. As a result, the feedback system showed sufficient performance to suppress the transverse instabilities, and we succeeded in storing a 450 mA current which is the typical value for user operation. Without the transverse feedback, the stored beam was not lost, but the severe horizontal oscillations were observed. We could also confirm that the transverse instabilities were damped immediately if we closed the feedback loop again.

Figures 4(a) and 4(b) show the transverse beam profile measured by a CCD camera for the open- and closed-loop conditions, respectively. We can see that the horizontal beam size is reduced by closing the feedback loop. To quantify the effect, we performed Gaussian fits to horizontal projections of the profiles, and compared them as shown in Fig. 4(c). In this case, the horizontal beam size decreases by approximately 20 %.

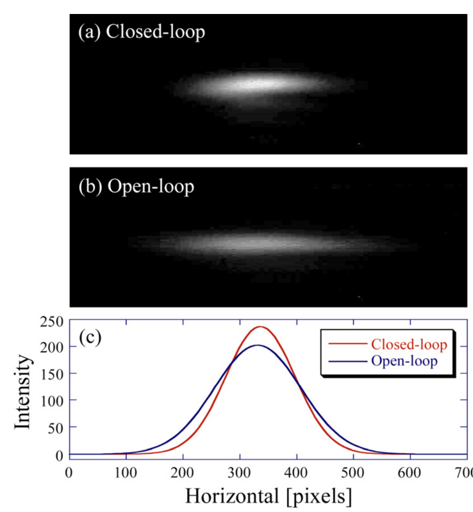

Figure 4: Transverse beam profiles measured by a CCD camera.

Mode Analysis of Instabilities

The iGp can hold two FIR filter coefficient sets in an internal memory of the FPGA, and switch them with arbitrary timing. This function enables us to perform the transient-domain analysis of instabilities for the horizontal and vertical plane, individually [5]. In Figs. 5(a) and 5(b), results of the transient-domain analysis for the horizontal plane are illustrated. The time interval from the start of data acquisition to the resumption of the horizontal feedback was set to be 12.5 ms. The stored beam current at this time was 370 mA.

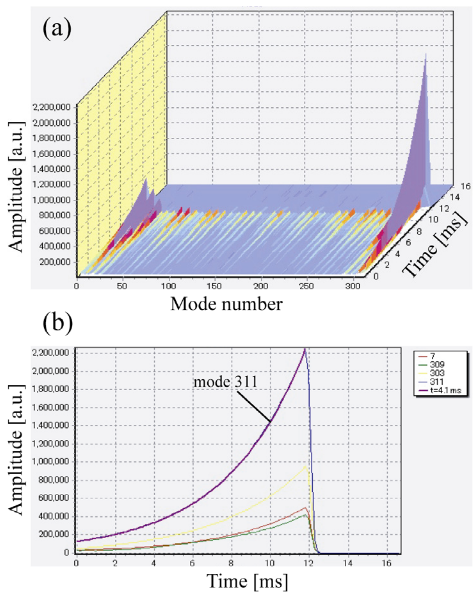

Figure 5: Time evolution of the modes of the horizontal instabilities.

Mode 311 (-1), which is the highest order mode, is most strongly excited among all modes in the horizontal plane. It is also shown that this mode is recaptured easily when we resume the horizontal feedback after the 12.5 ms interval, and suppressed immediately. Fitting exponential functions to the growing part of mode 311, we can estimate the growth time of 4.1 ms. This value changes depending on various parameters such as the stored beam current and the vacuum pressure. In the case of a 450 mA current, although the most strongly excited mode is 311, its growth time shortens to 3.7 ms. On the other hand, the damping time of mode 311 is sufficiently short in both currents, approximately 0.1 ms (160 turns).

We performed the same measurement for the vertical plane. Noticeable instabilities were, however, not observed in this plane even if the vertical feedback was turned off completely.

ID-gap Dependence

When we narrowed the ID gap with a 370 mA current, the growth time of instabilities decreased obviously, while the excited modes did not change. The growth time of horizontal mode 311 was measured for several values of the ID gap and the result is shown in Fig. 6. It shows us that the instability grows rapidly in smaller gap less than 10 mm. According to the intuition, the observed instabilities seem to have been excited by the resistive-wall instability. The resistive-wall instability should, however, occur in the vertical plane as observed at SPring-8 and ESRF [6,7]. In this case, we could not observe any instabilities in the vertical plane even with the minimum gap of 4 mm. In addition, we cannot also explain that the highest order mode is most strongly excited, because the transverse impedance of the resistive-wall instability should be inversely proportional to the square root of the frequency [8]. Further investigations are required to identify the cause of these phenomena.

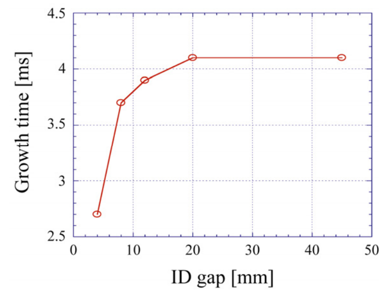

Figure 6: Dependence of the growth time of horizontal mode 311 on the ID gap.

SUMMARY AND FUTURE PLAN

We have constructed and tested a transverse bunch-by-bunch feedback system using the iGp at PF-ring. The feedback system has shown sufficient performance to suppress the transverse instabilities up to a beam current of 450 mA. We have also performed the transient-domain analysis of instabilities, and determined that the highest order mode 311 of the horizontal plane grows most rapidly among all instability modes. The growth time of this mode has changed depending on a stored beam current and a magnet gap of in-vacuum undulators. It has shown a drastic decrease especially in smaller magnet gap less than 10 mm.

We are now constructing the transverse feedback system using the iGp for ordinary use, which has two feedback loops, aiming at the installation within this year. After the installation, we continue the study to identify the cause of the transverse instabilities at PF-ring.

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