SINGLE-LOOP TWO-DIMENSIONAL TRANSVERSE FEEDBACK FOR PHOTON FACTORY

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Abstract

A single-loop two-dimensional feedback system is installed and tested in the Photon Factory ring and shows the enough damping in horizontal and in vertical. This scheme reduces the number of components, which results in reduction of cost and trouble, and reduces the amount of tuning work of the system. The scheme and the result of test is described in this paper.

INTRODUCTION

Feedback system [1] is the effective device to suppress beam instabilities and to damp unwanted beam oscillation excited by the perturbations like beam injection and is indispensable for high quality and high intensity storage rings. Recently single-loop two-dimensional feedback [2] is proposed and this has several advantages such as 1) Reduction of components, this lead to reduction of the cost and troubles, 2) Reduction of the amount of works to tune the system

However, the required number of taps of the filter is almost twice of the one-dimensional feedback and the powerful digital device is required. Since the recent progress of FPGA enables us to make a powerful feedback processor [3] and the scheme to obtain such FIR filter [4] is also developed, we applied this single-loop two-dimensional feedback to the Photon Factory ring.

SETUP OF FEEDBACK

The parameters of the Photon Factory (PF) ring are shown in Table 1. We use x and y for the horizontal and vertical position and the suffix x and y to show the values are for horizontal and vertical directions, respectively.

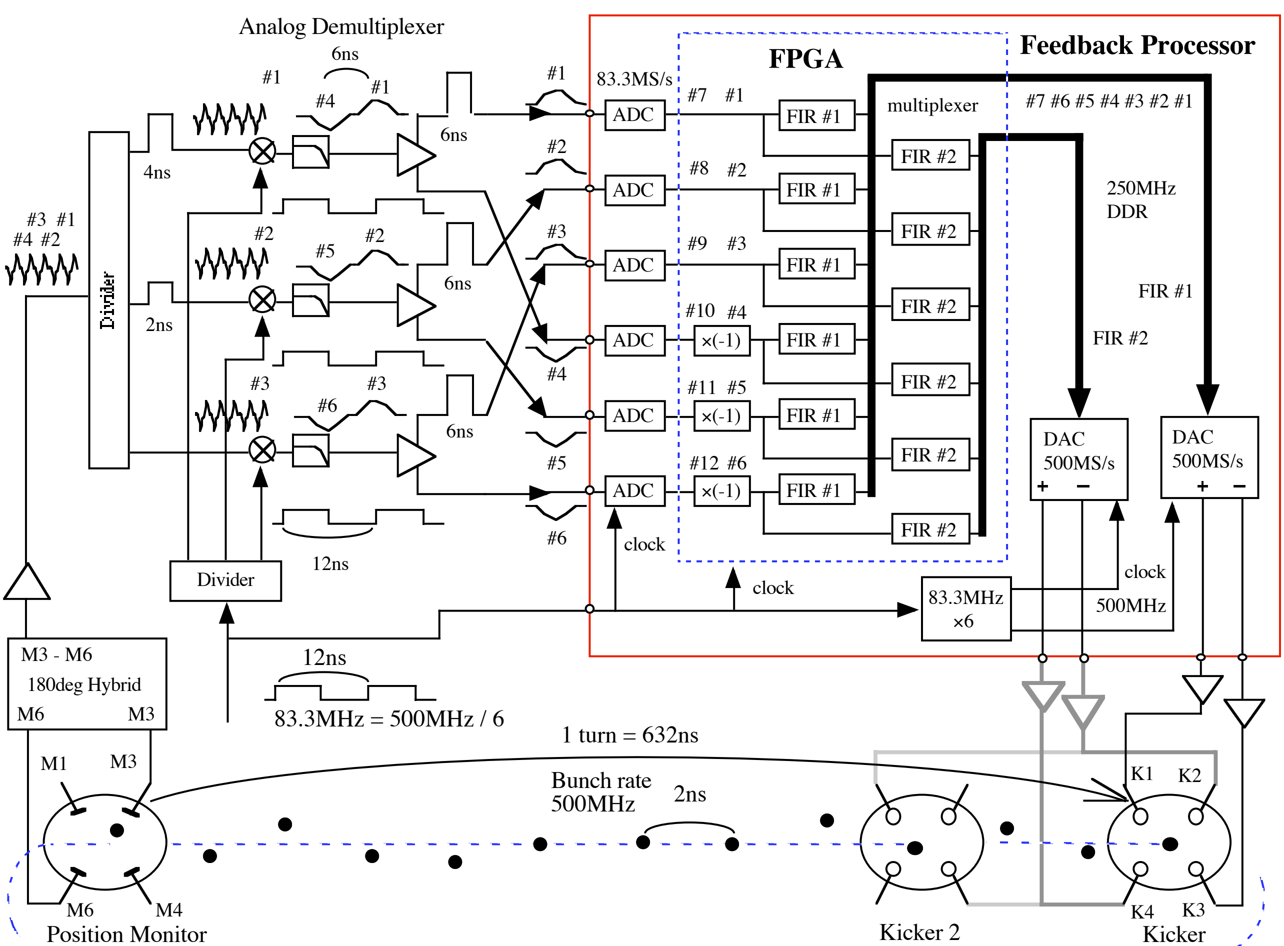

Figure 1. Block diagram of the single-loop two-dimensional feedback system for the Photon Factory ring. Currently two kicker electrodes connected FIR #1, K1 and K3, are used for feedback. Lines for the electrode K2 and K4, and lines for Kicker 2 show optional schemes that are enabled by using another stream of FIR filter (FIR #2).

Table 1: Parameters of the Photon Factory ring

Parameters	Symbol	Value
Fractional tunes	$\Delta\nu_x$ / $\Delta\nu_y$	0.60 / 0.28
Beta Functions	β_x / β_y	5.8 m / 5.8 m
Ratio of sensitivity of BPM U_x, U_y	$\left\|\left(\frac{\Delta V}{\Delta x}\right)\Big/\left(\frac{\Delta V}{\Delta y}\right)\right\| = \frac{U_x}{U_y}$	3
Ratio of kicker efficiency η_x, η_y	$\left\|\left(\frac{x'}{V}\right)\Big/\left(\frac{y'}{V}\right)\right\| = \frac{\eta_x}{\eta_y}$	1
betatron radiation damping time	τ_β	7.8 ms
harmonics	h	312 = 6×4×13
RF frequency	f_{RF}	500.1 MHz
Stored current	I	450 mA

The diagram of the single-loop two-dimensional transverse feedback is shown in Figure 1. The diagonal pair of button type electrodes at skewed position is used for the detection of two-dimensional transverse oscillation.

This signal is send to the feedback processor, in which the signal is digitized and processed by an FIR filter that distinguish the x and y by its oscillation frequency (tunes) and add gains and phase shifts that required to damp the beam oscillation.

We have to point out that this scheme cannot be applied to fully coupled beam with the same fractional tunes both in horizontal and in vertical. In such case, the fully coupled two-dimensional oscillation produces two orthogonal modes and the system cannot detect the mode normal to axis of the BPM pair and fails to suppress the instability of this mode.

FEEDBACK PROCESSOR

The feedback processor [3] is composed of one FPGA for digital signal processing, six 12-bit 125MSPS ADCs operated at 83.3MSPS and five 1GSPS 14-bit DACs operated at 500MSPS(6×83.3MSPS) as shown in Figure 1. Each ADC samples every six bunches and the six ADC covers all bunches of which rate is 500MHz. The FPGA can handle two FIR filters as shown in Figure 1 and each FIR filter output has two DACs. Then we have two sets of gain and phase defined by two FIR filters. This makes the system flexible to use more kicker electrodes or one more kicker at different cells, as shown by shaded lines in Figure 1. The feedback processor also has operation mode with four-ADC to sample every four bunches.

FIR FILTER

We will describe the FIR filter for the single-loop two-dimensional feedback. FIR filter has a form of

$$F_n = \sum_{k=1}^{M} a_k S_{n-k} \tag{1}$$

where a_k are the coefficients and S_n and F_n are the input and the output of the filter, respectively, and M is the number of taps. The frequency response of the filer is

$$H(\phi) = \left|H(\phi)\right| e^{i\theta(\phi)} = \sum_{k=1}^{M} a_k e^{-i\phi k} \tag{2}$$

where ϕ is the phase advance per step or, in this case, the phase advance per turn.

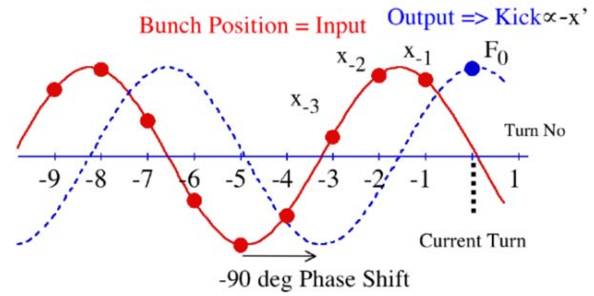

Figure 2: The required response of the FIR filter. The one-dimensional case is shown. The phase shift between the input and the output should be -90 degree.

We focus on the oscillation of a bunch. The horizontal and vertical betatron oscillations of the bunch are

$$z_k = A_z \cos(\phi_z k + \psi_z) = \mathrm{Re}\left[A_z e^{i(\phi_z k + \psi_z)}\right] + C_z, \quad z = x, y \tag{3}$$

where we use z to show x and y, the suffix k to show that the data is at k-th turn, $\phi_z = 2\pi\Delta\nu_z$ is the betatron phase advance per turn, A_z and ψ_z are the amplitude and phase of the betatron oscillations, respectively, and C_z is a constant. The position signal of the bunch detected by BPM can be expressed as

$$S_k = \sum_{z=x,y} U_z z_k = \sum_{z=x,y} \mathrm{Re}\left[U_z A_z e^{i(\phi_z k + \psi_z)}\right] + C \tag{4}$$

where U_z are the coefficient of sensitivity of BPM and

$$C = \sum_{z=x,y} U_z C_z \, . \tag{5}$$

The history of S_k of M previous turns are stored in a memory of a feedback processor and by adapting the FIR filter in Eq. (1) to the history of Eq. (4), we have

$$F_n = \sum_{z=x,y} \mathrm{Re}\left[H(\phi_z) U_z A_z e^{i(\phi_z n + \psi_z)}\right] + H(0) C \tag{6}$$

, while the required feedback signal should be

$$F_n = \sum_{z=x,y} \mathrm{Re}\left[G_z e^{i\theta_z} A_z e^{i(\phi_z n + \psi_z)}\right] \tag{7}$$

where G_z and θ_z are the gain and the phase shifts required to damp the betatron oscillations, and the DC component, C, should be suppressed. The damping rate is proportional to the product of G_z, the value of the beta function and the kicker efficiency.

By comparing Eq. (6) and Eq. (7) and using Eq. (2), we have constraints for the FIR filter coefficients a_k :

$$H(\phi_z) = \sum_{k=1}^{M} a_k e^{-i\phi_z k} = \frac{G_z}{U_z} e^{i\theta_z} \qquad z = x, y \tag{8)}$$

$$H(0) = \sum_{k=1}^{M} a_k = 0 \, . \tag{9}$$

The number of constraints for a_k is five and at least 5-tap FIR filter is required for single-loop two-dimensional feedback. To obtain wider acceptance to the shift of the tunes, we add more equations to flatten the response at target tunes:

$$\left.\frac{\partial H(\phi)}{\partial \phi}\right|_{\phi=\phi_z} = \sum_{k=1}^{M} a_k k e^{-i\phi_z k} = 0 \qquad z = x, y \quad . \ (10)$$

Then, with these four more constraints, we have to use more than 9-tap FIR filter to fulfill the requirements.

For the PF ring, we use the 20-tap FIR filter obtained with TDLSF method [1,3]. Additional freedom of taps, 20-9=11, is used to reduce the gain not at the tunes to reduce noise and to avoid the overflow of the digital data. The frequency response of the FIR filter is shown in Figure 3. As the damping rate is $1/\tau_{x,y} = \eta_{x,y}\beta_{x,y}G_{x,y}$ and the ratio of $\eta_{x,y}$ and $\beta_{x,y}$ are shown in Table 1. To obtain he same damping time in both directions, we set $G_x = G_y$, or $|H(\phi_y)| = 3|H(\phi_x)|$ by Eq. (8), to compensate the ratio of the sensitivity of the BPM, $U_x/U_y = 3$. About the phase, we set θ_y to be -90 deg. while θ_x to be 90 deg. This is because the position of the electrodes M3 and M6 of BPM and the position of electrodes K1 and K3 of the kicker are at flipped position in horizontal axis each other as shown in Figure 1. We chose this configuration to reduce the gain not at tunes and to obtain wider tune acceptance.

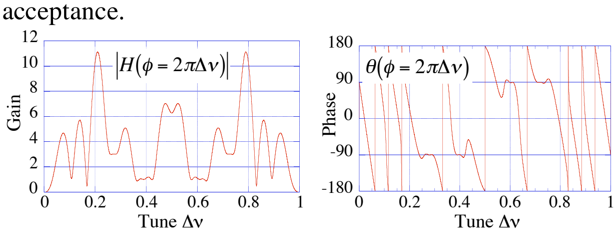

Figure 3: Frequency response of the 20-tap FIR filter for single-loop two-dimensional feedback for the PF ring. Horizontal tune $\Delta\nu_x = 0.6$ and vertical tune $\Delta\nu_y = 0.28$.

EXPERIMENT

The damping time measurement was performed. The betatron oscillation is excited by external force and its damping after the turning off of the force was measured. The bunch current is 1mA/bunch and 50bunches are stored. The result is shown in Figure 4. Without the feedback, the beam is unstable and we compared with the data at low gain and the data at high gain. The data shows that the single-loop two-dimensional feedback damps horizontal and vertical betatron oscillation with two order higher strength than radiation damping. The studies on instabilities are summarized in a paper [4].

SUMMARY

We performed the single-loop two-dimensional feedback scheme at the Photon Factory ring and obtain enough damping time in horizontal and vertical direction. This scheme is in operation also in TLS [5].

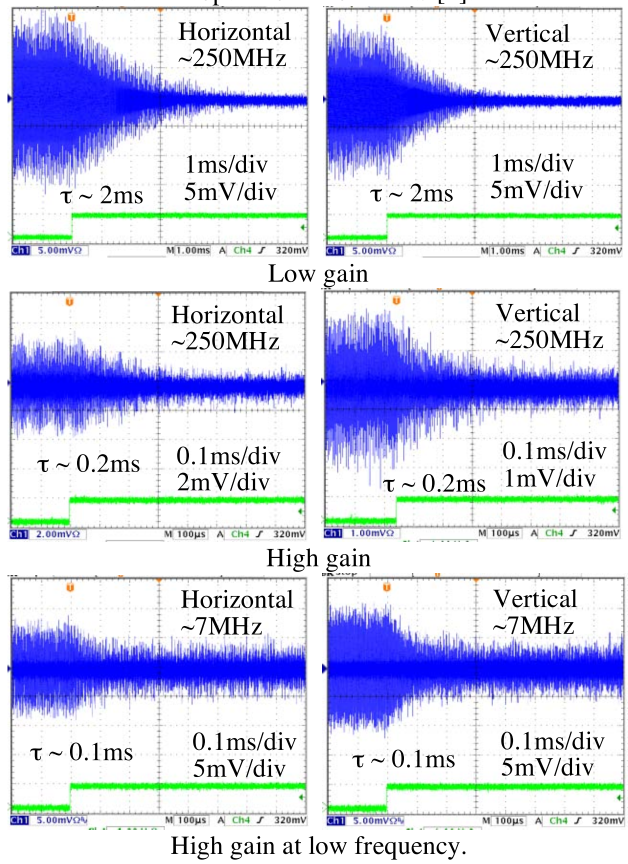

Figure 4: The damping of oscillation excited by external forces under the feedback ON with lower gain and higher gain. The forces are turned off when gate signals in the lower traces shift high. The directions and frequencies of the forces and damping time τ are shown in the figures.

REFERENCES

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