Test of Fast-Digital Beamline Feedback Control at the Photon Factory

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Abstract

A fast-digital feedback system stabilizing the photon beam position for a beamline was tested. A DSP (digital signal processor) board linked with 16-bit ADC and 14-bit DAC boards was used as a digital controller of the feedback system. The DSP system sampled the signals from a photon beam position monitor at a high rate of 10 kHz and set the magnet currents for a 3-magnet orbit bump steering system at the same rate. The system frequency response was easily compensated in gain and phase by programming. As a result, the feedback system well suppressed the beam motion up to 100 Hz.

I. INTRODUCTION

In the Photon Factory (PF), a local feedback system dedicated to a beamline should be so designed that it can cover a wide frequency range, because the frequency components of the photon beam motion at the beamline spread up to 100 Hz. The beam motion is caused by various disturbances such as ring building distortion due to thermal stress[1], temperature variations of the cooling water for the PF storage ring, stray magnetic field variations of the TRISTAN acceleration-deceleration cycle and floor vibrations[2].

The local feedback systems controlled by the analog circuits have been developed in many facilities[3-5] and also in the Photon Factory[6]. Although the analog controllers had a fast feedback speed, they generally had difficulty in high-level computation and easy modification of their transfer functions. Recently DSPs have made great progress in processing speed and come to be used as controllers of various fast feedback systems in place of analog circuits. In fact, a global orbit feedback system was designed by use of a DSP board[7]. Therefore we constructed a local feedback system digitally controlled by a DSP system and tested it at a beamline. In this paper, we present the feedback system and the test result.

II. SYSTEM DESCRIPTION

The feedback system is composed of a new fast-digital controller, existing photon beam position monitor, vertical steering magnets and power supplies. Figure 1 shows the block diagram of the feedback system. The controller is a DSP system (LORY ACCEL from mtt), which consists mainly of a 32-bit floating-point DSP (TMS320C30) board, a 4-channel ADC board with 16-bit resolution and an 8-channel DAC board with 14-bit resolution. The DSP board is linked with ADC and DAC boards through a DSP local bus in the system case and connected to the bus of a PC9801 micro-computer (from NEC). The photon beam position monitor[8]

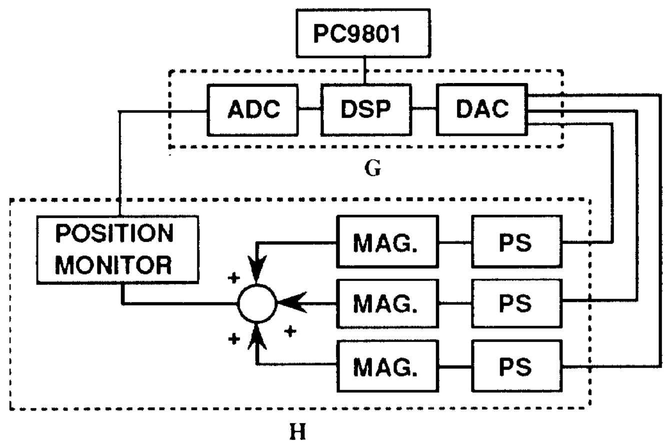

Figure 1. Block diagram of the feedback system.

is located at branch C of beamline 4 (BL-4C) and the three vertical steering magnets[9] near bending magnet 4 (BM4). The steering magnets make a closed orbit bump to cancel the beam position displacement detected by the monitor.

A control program is coded in C-language and compiled/linked with the PC9801 microcomputer, and then it is downloaded to the DSP. The feedback is switched on/off by the keyboard of the microcomputer and can be programmed. While the DSP system running, the microcomputer numerically and graphically monitors various parameters such as the photon beam position and the setting currents of the magnet power supplies. The sampling rate of the ADC data can be increased up to 10-20 kHz with normal action of the DSP system. The setting of the DAC data follows the sampling of the ADC data with a time lag of the sampling time. The upper limit of the sampling rate is basically decided by the I/O control time and also depends on the computation time. The sampling rate was set at 10 kHz during the test.

III. TRANSFER FUNCTION

The transfer function of the feedback system is divided into two components G(z) and H(z), which correspond to the controller and the rest including the magnets, power supplies and monitor. Although H(z) is mainly dominated by eddy currents of the PF aluminium vacuum chamber, G(z) is decided by the control program. Therefore the open-loop and closed-loop transfer functions of the feedback system defined by G(z)H(z) and 1/(1+G(z)H(z)) can be modified easily by programming.

The feedback system was tested for five different cases (Cases A to E) where the system has different transfer

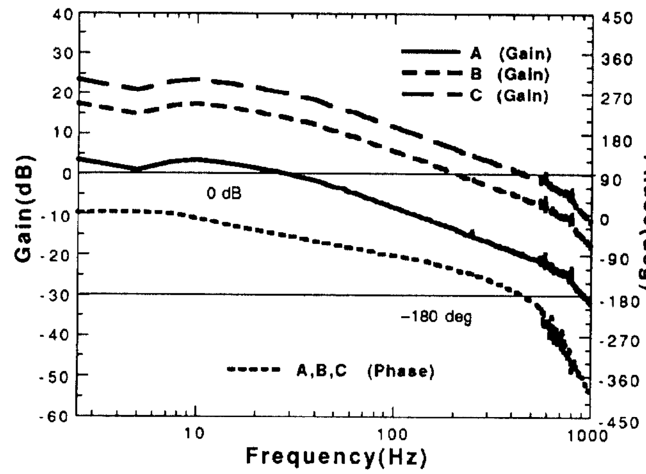

Figure 2. Open-loop frequency response curves for Cases A, B and C. In Case B and C, only the gain is compensated.

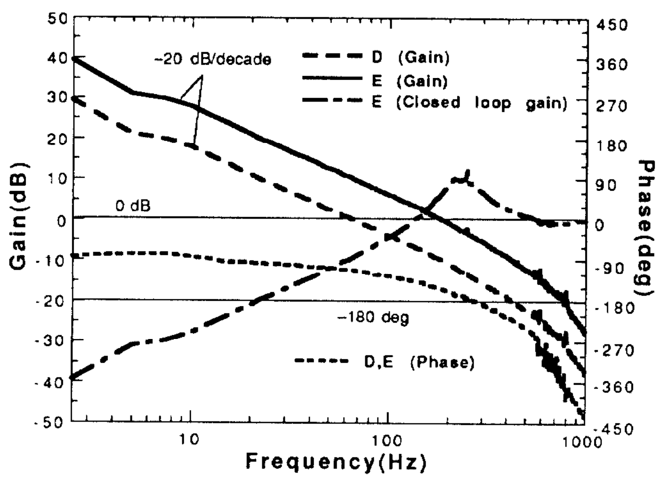

Figure 3. Open-loop frequency response curves for Cases D and E, and a closed-loop gain curve for Case E. In these cases, both the gain and phase are compensated.

functions. Figure 2 shows open-loop transfer functions for Cases A to C in terms of their frequency response curves. In Case A, the controller is programmed to simply set the currents of the power supplies which correspond to the DC bump strength cancelling the beam position displacement. In Cases B and C, a simple gain compensation is given in the control program. As a result, the system gets a higher open-loop gain by a factor of 5 (14 dB) and 10 (20 dB) than in Case A, though it still has the same phase response as in Case A. For these three cases, G(z) is expressed with the frequency f and sampling time T_s (= 100 μs) for f « $1/T_s$ as follows:

$$G(z) = K z^{-\frac{3}{2}} \quad (z = e^{2\pi j f T_s}). \tag{1}$$

Here j is an imaginary number ($j^2 = -1$). K = 1, K = 5 and K = 10 are taken for Cases A to C respectively. From this equation, the contribution of the controller to the whole transfer function is estimated to be negligibly small (only 5.4-degree phase rotation at 100 Hz). In Case C, the open-loop gain response has no sufficient gain margin when the phase response curve crosses −180-degree line. Therefore, the system was expected to be unstable with the loop closed.

Figure 3 shows open-loop frequency response curves for Cases D and E. In these cases, both gain and phase compensations are added to the control program. G(z) is given by the following expression including two additional compensation terms:

$$G(z) = K z^{-\frac{3}{2}} G_c(z) \ , \tag{2}$$

where

$$G_c(z) = \left\{ 1 + \frac{1+z^{-1}}{2\,(T_i/T_s)\,(1-z^{-1})} \right\} \times \frac{1 + (T_d/T_s)\,(1-z^{-1})}{1 + 0.1\,(T_d/T_s)\,(1-z^{-1})} \ . \tag{3}$$

K = 0.0316 and K = 0.1 are taken for Cases D and E. The first term with the integral time T_i (= 100 μs) in Eq. (3) has a gain curve with an approximate rate of −20 dB per frequency decade for f « $1/T_i$ and improves the loop gain especially in the low frequency region. The second term with the differential time T_d (= 5.3 ms) suppresses the phase rotation due to H(z) and the first term to guarantee sufficient gain and phase margins for the system stability. The computation time for these compensation terms is about 10 μs and much shorter than the sampling time.

IV. TEST RESULT

First the feedback loop was closed for the five different cases described in the previous section. Figure 4 shows the beam stability recorded by a chart recorder (bandwidth ~ 5 Hz) for Cases A, B, D and E. In Case A, the beam stabilization by the feedback system was clearly found to be incomplete. In Case B, the system gave better beam stability than in Case A, but the performance was not yet enough. The system in Case C became unstable as expected in the previous section. On the other hand, the system in both Cases D and E nicely suppressed the beam motion within a few μm. The good performance is produced by the high loop gain especially in the low frequency region.

Next the frequency spectra of the monitor signal were measured for Case E before and after the feedback loop was closed. In Case E, the system has the best transfer function, because it almost keeps the highest loop gain from 0 to 100 Hz without losing the system stability. Figure 5 shows the various frequency components with the loop open and closed. From this figure, the system was found to significantly suppress the frequency components peaking from 0 to 100 Hz. The 14.5 Hz component was reduced by ~24 dB and the 50 Hz component by ~12 dB. This was in good agreement with the closed-loop gain curve of the system for Case E shown in Figure 3.

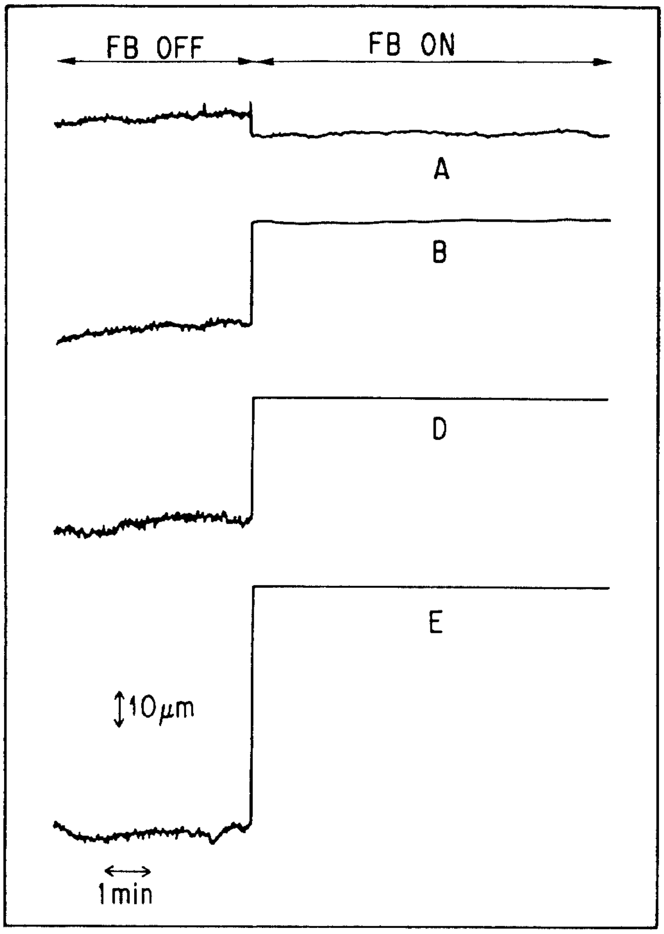

Figure 4. Typical chart recording without and with feedback for Cases A, B, D and E. In Case C, the system became unstable with feedback.

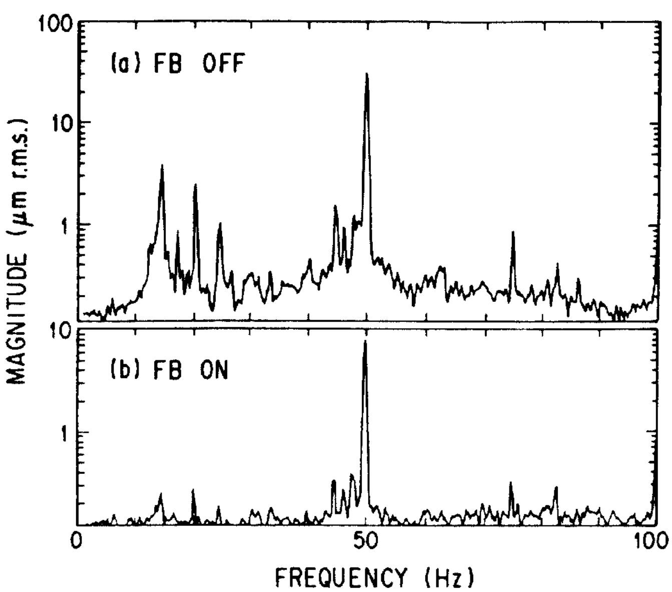

Figure 5. Frequency spectra of the position monitor signal without and with feedback for Case E.

V. CONCLUSIONS AND FURTHER DEVELOPMENT

The local feedback system controlled by the DSP system successfully stabilized the beam motion up to 100 Hz. The gain and phase compensations improving the beam stability could easily be added and modified. These facts mean that the feedback system has both good feedback performance and flexibility. However, further development must be done to use such a system for actual operation at some beamlines. The values of the compensation parameters T_i and T_d in Eq. (3) were properly chosen but not fully optimized. Further optimization will improve the feedback performance. The monitoring of interlock signals related to the system is also required for automatic feedback on/off. In addition, the DSP system should be applied to a 4-magnet orbit bump steering system with two position monitors to stabilize both the position and direction of the beam at a light source point.

VI. ACKNOWLEDGEMENTS

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