The 12th Symposium on Accelerator Science and Technology, Wako, Japan 1999

Bunch by bunch feedback systems for KEKB rings

Makoto Tobiyama, Eiji Kikutani and John W. Flanagan,
Accelerator Laboratory, High Energy Accelerator Research Organization (KEK),
1-1 Oho, Tsukuba 305-0801, Japan

Abstract

Bunch-by-bunch feedback systems for curing coupled-bunch instabilities in the KEKB rings have been constructed. Even at a very early stage of the commissioning of the rings, strong transverse instabilities occurred in both rings which limited maximum storable currents. Stabilization of the beams with transverse feedback systems has been successful so far, enabling us to accumulate greater beam currents and to reduce part of the background in the interaction region. A preliminary report of transient-domain analysis of the instabilities using bunch oscillation memories is also given.

1 Introduction

The KEKB collider, which consists of an 8 GeV electron ring (HER) and a 3.5 GeV positron ring (LER), is designed to accumulate very high beam currents with many bunches. In the design goal, about 5000 bunches/ring will be stored at total beam currents of 1.1 A (HER) and 2.6 A (LER). The commissioning of the rings started at the end of 1998. We have successfully stored over 500 mA in each ring and begun physics running at a luminosity greater than $2 \times 10^{32}\mathrm{cm}^{-1}\mathrm{s}^{-1}$. During the commissioning, we have encountered strong coupled-bunch instabilities in the transverse plane for both rings which limited the total storable currents, shortened the beam lifetimes, and reduced the beam qualities. With the progress of the operation of the transverse bunch-by-bunch feedback systems, we have successfully suppressed the instabilities. Each feedback system consists of (1) position detection systems compatible with the minimum bunch spacing of 2 ns, (2) high-speed digital signal processing systems which work with the system clock of 509 MHz, and (3) wide-band kickers fed by wide-band, high-power amplifiers. Employing a large-scale memory board which is capable of accumulating bunch-by-bunch data up to 20 Mb, we have made transient-domain analysis of the instabilities by measuring the bunch oscillation transient with the feedback on and off. The final design of the feedback systems is described in reference[1]; we describe here the present status of our feedback systems, primarily the transverse systems, and give a preliminary report on the transient-domain beam analysis.

2 Outline of KEKB bunch feedback systems

At present, we are operating the transverse feedback systems not with the final configuration but with a simplified one. All of the feedback equipment is installed in the Fuji crossing area as shown in Fig. 1. We use two sections of monitor electrodes on each ring, each section having 20 pickup electrodes. Stripline-type kickers for transverse deflection are installed upstream of the first monitor chambers. Though we have prepared two kinds of transverse kickers, a 40 cm wide-band kicker for 300 kHz to 255 MHz and a 1.2 m lower band kicker for 5 kHz to 300 kHz, we have used only the wide-band kickers for transverse feedback up to this point. By this simplification, we are free from the complexity concerning the equalization of overlapping amplifiers, though the performance of the system below 50 kHz is not ideal. In operation this autumn we will try to use both the lower-frequency and wide-band kickers. The maximum power of the feedback amplifier is 250 W per stripline. We have installed two DAΦNE type longitudinal kickers[2] in the LER, each with four input ports and four output ports. In the HER, there are no longitudinal kickers.

The block diagram of the front-end circuit and the signal processing circuit are shown in Fig. 2. We have used the local DC rejection circuit not in S/H-feedback mode but in fixed-voltage mode. An example of phase advance and the betatron functions at the monitors and the kickers are shown in Table 1. Note that the functions strongly depend on the choice of the betatron tunes because the lattice in the Fuji section is used to absorb residual errors in the tunes. We adjust the phase difference between the monitor and the kickers by vectorially combining the two signals from the upstream and downstream positions.

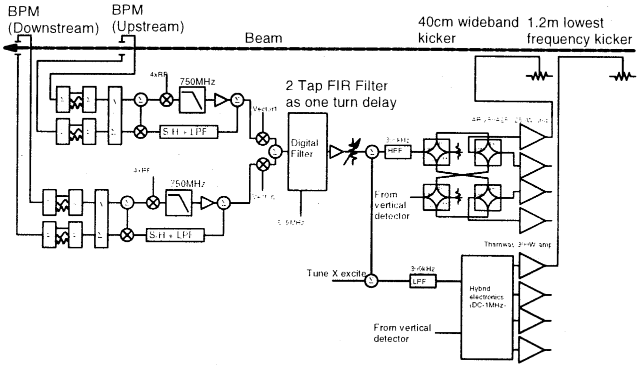

Figure 2: Final design of the block diagram of the signal processing circuit of the transverse feedback systems.

The signal processing system is now working as a simple digital delay, not as a two-tap filter[3]. When the optics become well understood, we may attempt to operate it in two-tap filter mode.

We have prepared the longitudinal detection systems, two-tap filters, QPSK demodulators and the longitudinal kickers with amplifiers which a supply maximum power of 560 W in the LER. Fortunately, we have encountered no longitudinal instability in the LER. We have therefore only performed

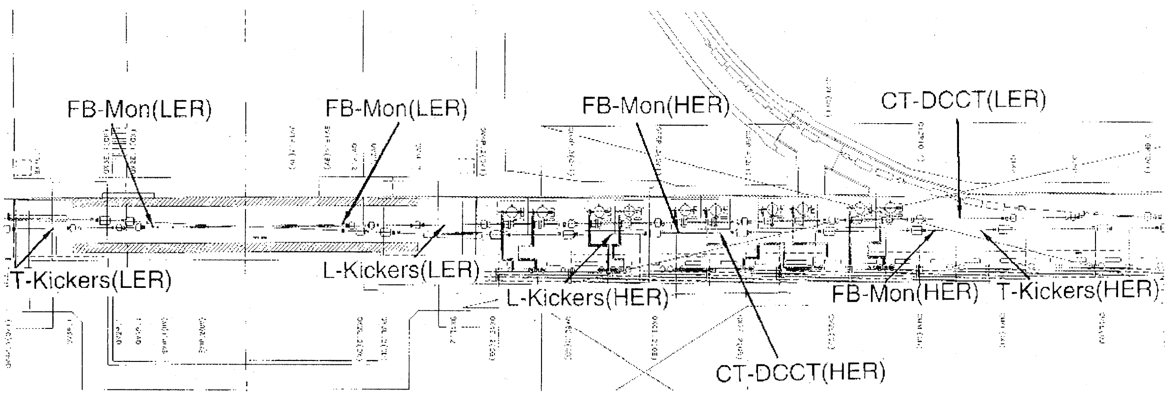

Figure 1: Location of the feedback equipment at Fuji crossing area. Positrons comes from left side and electrons comes from the right side. Feedback amplifiers are installed under the crossing bridge.

Ring	LER / HER	
Energy	3.5 / 8.0	GeV
Circumference	3016.26	m
Bunch current	0.5 /0.2	mA
Betatron tune	45.525/44.098 (LER) 44.536/42.104 (HER)	
RF voltage	4.5/8.5	MV
RF Frequency	508.887	MHz
Harmonic number	5120	
Damping time (L)	22 / 23	ms
Betatron functions	β_x / β_y	
BPM1	22m / 22m	LER
	10m / 24m	HER
BPM2	22m / 22m	LER
	42m / 13m	HER
Kickers	28m / 19m	LER
	27m / 7m	HER
Phase advance	$\Delta\nu_x$/ $\Delta\nu_y$	
BPM1 - BPM2	0.190 /0.190	LER
	0.256 / 0.160	HER
Kicker - BPM1	0.065 / 0.139	LER
	0.068 / 0.090	HER

Table 1: Feedback related parameters of KEKB.

some limited testing of the system.

3 Experience with the transverse feedback systems

The first step in the commissioning of the feedback system was to adjust the all the timings, such as the timing delay between the opposing electrodes, the phase of the detection frequency (2 GHz), and the clock of the two-tap filter, very precisely. The timing between the feedback signal and the bunch was at first roughly adjusted via digital delay then finely tuned with coaxial phase shifters. The size of the digital delay was about 9.29 μs for the LER and 9.03 μs for the HER. These procedures were mainly carried out with a single-bunch beam.

In the next step, we tuned the vectorial sum of the two-signal position monitors. With some instabilities occurring under multi-bunch operation, the vectorial sum was tuned to minimize the instabilities. If the tuning the unsuccessful, the feedback might have functioned in a reactive mode causing betatron tune shift. In practice, most of the power was used to damp the instability even with the rough tuning, and no obvious tune shift was observed.

We can roughly estimate the damping time of the feedback systems from several parameters, though it strongly depends on both the optical parameters and the degree of tuning of the system. The typical damping time was about 0.5 ms for both LER and HER. Up to this point, we have been able to completely suppress all transverse instabilities with a gain greater than 40 dB for all planes in both rings. Though most of the physics experiments were performed at a 20 ns bunch spacing mode, we have confirmed the operation of the feedback system with 4 ns bunch spacing with no significant problem. Figure 3 shows an example of the filling pattern during a physics run measured with our bunch current monitor, at a bunch spacing of 8 ns.

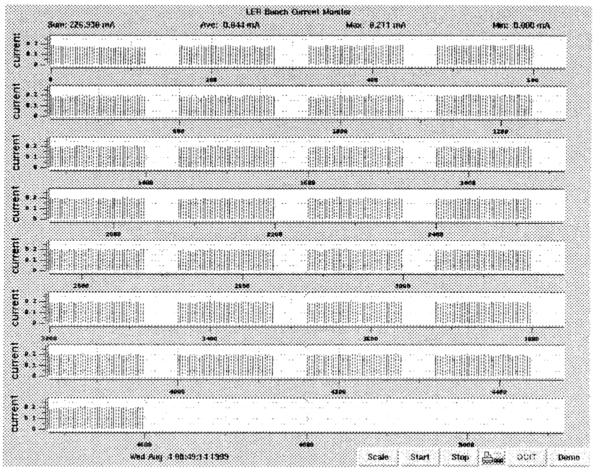

Figure 3: Example of filling pattern during a physics run. The bunch spacing was 8 ns.

Though remote control of the two-tap FIR filter and some of the components, such as RF switches, voltage controlled attenuators for changing the total gain of the feedback system, and control/monitor of the amplifiers were possible through the EPICS system, it was in practice fairly difficult to tune the system without seeing the various signals in the local control room.

4 Transient-domain analysis of the instabilities

The transient behavior of the beam just after switching the feedback loop on or off reveals many important characteristics on the coupled-bunch motions of the instabilities as well as the function of the feedback systems. This powerful analysis of the instability is known as transient-domain analysis[4]. We have constructed a memory board with a capacity of 20 Mb which can record 4096 turns (41 ms) of all 5120 bunches, based on the same technology as that of the two-tap FIR filter system.

Figure 4 shows an example of the growth of horizontal instability in the LER from just after turning off the horizontal feedback up to 41 ms later. The total current was 120 mA with a filling pattern of 16 bunch trains equally spaced in the ring, each train containing 50 bunches with a bunch spacing of 4 ns. Figure 4(a) shows the time evolution of the betatron-oscillation components for each bunch. By taking the Fourier transform of bunch amplitude at each time, taking into account the betatron phase advances, we measure the modes of the instability over time as shown in Fig. 4(b). The growth time of the instability was about 5 ms in this case. We have measured transient-domain data while changing filling pattern and betatron tunes for both rings in both planes. Figure 5 shows the vertical feedback switch-on transient in the HER.

5 Summary

The transverse bunch-by-bunch feedback systems constructed for the KEKB rings have been contributing to both the commissioning of the rings and the operation of the colliding experiment. The large-scale memory systems for transient-domain analysis of the instabilities are also providing us with a very powerful tool for understanding and overcoming strong and strange instabilities.

In the next stage, we will continue to upgrade the transverse feedback systems. The first item is to add the lower-frequency kickers which will contribute to suppressing lower-mode instabilities such as resistive wall instability. Remote control and semi-automatic control of the system, especially vectorial combination and DC suppression, will follow.

Though we have not met severe longitudinal instabilities yet, surveying the performance of the longitudinal feedback system is a very important issue for us.

6 Acknowledgements

The authors are grateful to the commissioning group of KEKB for their great patience with our systems, especially in the early stages of the commissioning. They thank Prof. H. Fukuma and Dr. Y. Ohnishi for their contribution on the transient-domain analysis.

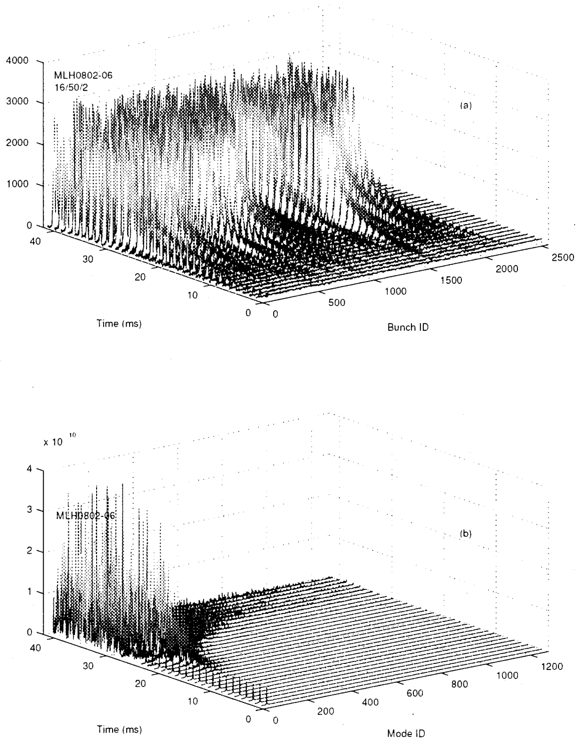

Figure 4: An example of growing transient of the horizontal instability in the LER; (a) time evolution of the betatron amplitude for each bunch (b) time evolution of the modes of the instability.

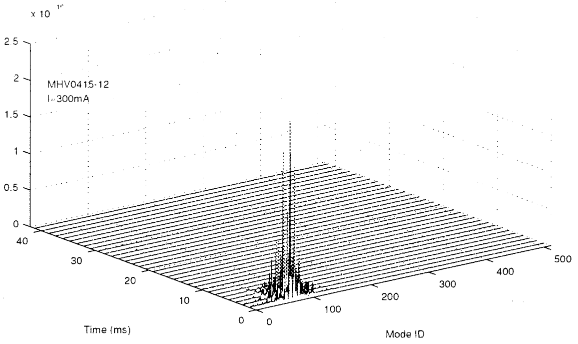

Figure 5: Example of damped transient of the vertical instability in the HER.

7 References

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