BUNCH BY BUNCH FEEDBACK SYSTEMS FOR THE KEKB RINGS

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Abstract

Transverse bunch-by-bunch feedback systems for damping coupled-bunch instabilities in the KEKB rings have been working since the early stage of the commissioning of the rings. Stabilization of the beams with the system have been successful, permitting tests of higher beam currents and various filling patterns. The performance of these systems has been demonstrated under the normal physics run pattern of 8 ns bunch spacing over long-time operation, and also under special filling patterns with minimum bunch spacing of 2 ns.

1 INTRODUCTION

The KEKB collider, which consists of an 8 GeV electron ring (HER) and a 3.5 GeV positron ring (LER), are designed to accumulate very high beam current with many bunches. About 5000 bunches per ring will be stored at total beam currents of 1.1 A (HER) and 2.6 A (LER) in the design goal. The commissioning of the rings started at the end of 1998 and is continuing up to now. Even at early stage of the commissioning, we have encountered unexpected very strong transverse coupled-bunch instabilities on both rings which limited the total storable currents under such low value, about 50 mA. With the progress of the operation of the transverse bunch-by-bunch feedback systems, we have successfully suppressed the instabilities and been extending the total currents. We can store over 900 mA in LER, 770 mA in HER without coherent beam oscillation and have achieved the peak luminosity of $4.0 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The bunch feedback system consists of position detection systems, high-speed digital signal processing systems with base clock of 509 MHz, and wide-band kickers fed by wide-band, high-power amplifiers. We describe here the progress and the present status of our feedback systems. Also the related beam diagnostic tools such as the large scale memory board will be shown.

2 OUTLINE OF KEKB BUNCH FEEDBACK SYSTEMS

All of the feedback equipment is installed in the Fuji crossing area as shown in Fig. 1. There are two sections of position monitors on each ring to make suitable betatron phase shift to the transverse kicker. Stripline-type kickers for transverse deflection are installed upstream of the first monitor chamber. We use two kinds of transverse kickers, a 40 cm wideband kicker up to 255 MHz and a 1.2 m lower frequency kicker for lower frequency than 1 MHz. We have also installed two of the DAΦNE type longitudinal kickers[1] only in LER, each with four input ports and four output ports.

Block diagram of the transverse feedback system is shown in Fig. 2. Major part of closed orbit distor-

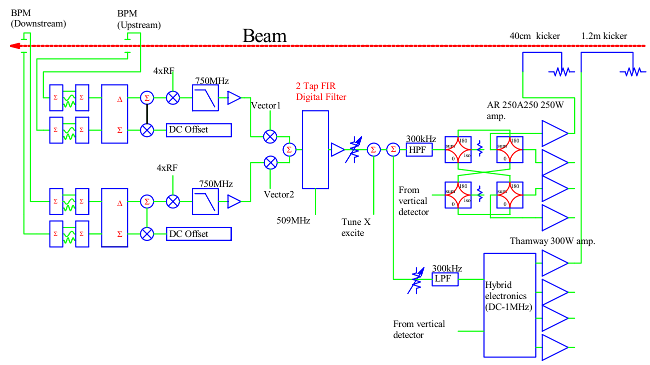

Figure 2: Block diagram of the transverse feedback systems.

tion (COD) at the BPMs is suppressed by the continuous closed-orbit correction (CCC)[2]. Residual CODs are cancelled by the local offset canceller circuit. An example of phase advance and the betatron function at the monitors and the kickers are listed in Table 1. We adjust the phase difference between the monitor and the kickers by vectorially combining the two signals from the upstream and downstream positions. The signal processing systems[3] are working as two-tap FIR digital filters. The function of the two-tap FIR filter are (1) DC component including error in the detection circuit rejection, (2) enhance the betatron tune component, and (3) digital delay to adjust the one-turn delay. The tap positions of the filters are set with (kick) $\propto$ (position data 2 turns before) - (position data 1 turn before) because the fractional part of the betatron tunes are around 0.5. The residual phase errors coming from the phase shift in the filter function are corrected with the fine tuning of the vectorially combining circuits.

Four 250W amplifiers (10 kHz $\sim$250 MHz) to drive the 40 cm kicker, and four 300 W amplifiers (5 kHz$\sim$1 MHz) to drive the 1.2 m kicker, are used for each ring. Since the performance of the wideband amplifiers below 50 kHz is not ideal, and the intintional injection error (kicker jump) has only lower frequency component, we use the lower frequency system to help the damping around the lowest mode. To equalize the two bands, we use 1st order low pass and high pass filter with the crossover frequency of 300 kHz.

Though we have prepared a wideband longitudinal feed-

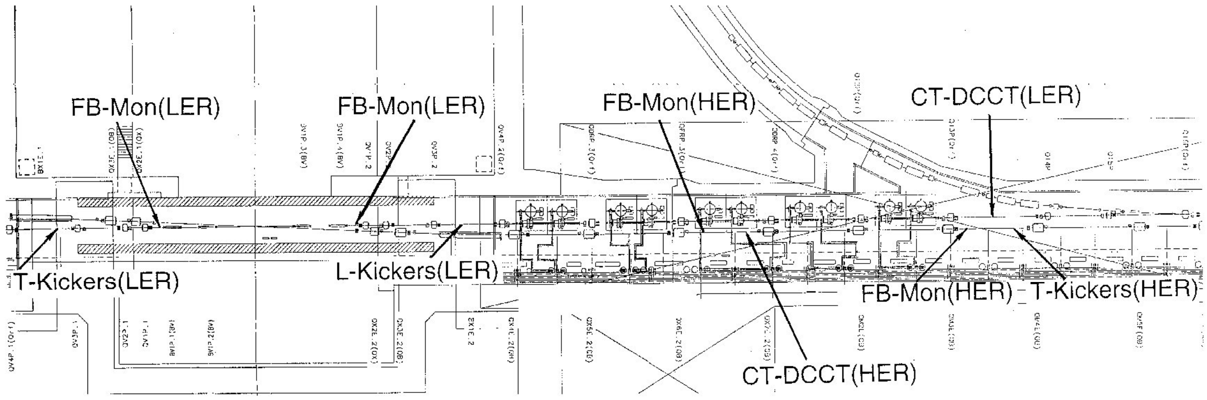

Figure 1: Location of the feedback equipment at the Fuji crossing area. Positrons come from left side and electrons come from the right side. All the final feedback amplifiers are installed under the crossing bridge.

Table 1: Feedback related parameters of KEKB.

Ring	LER/HER	
Energy	3.5/8.0	GeV
Circumference	3016.26	m
Bunch current	0.76/0.67	mA
Betatron tune	45.53/43.58 (LER)	
	44.52/41.62 (HER)	
RF voltage	6.0/11.0	MV
RF Frequency	508.887	MHz
Damping time (L)	22/23	ms
Betatron functions	β_x/β_y	
BPM1	21m/21m	LER
	19m/16m	HER
BPM2	21m/21m	LER
	30m/8m	HER
Kickers	23m/7m	LER
	33m/14m	HER
Phase advance	$\Delta\nu_x/\Delta\nu_y$	
BPM1 - BPM2	65°/65°	LER
	88°/107°	HER
Kicker - BPM1	18°/48°	LER
	10°/12°	HER

back system, we have encountered no longitudinal instability except RF-noise induced one. We have, therefore, not used them up to now.

3 EXPERIENCE WITH THE FEEDBACK SYSTEMS

In the early stage of the commissioning of the feedback systems[4], we had operated the systems with a very simplified scheme because both the feedback systems and the accelerator had not been well understood. We had used only the wideband kicker systems to escape from the complexity concerning the equalization of overlapping bands. The digital filter worked as a simple digital delay, not as a two-tap filter. With this mode of operation, we had several difficulties:

- Unexpected power saturation at the final power amplifiers. As the residual offsets of detector depends on both the bunch current and beam phase shift due to beam loading, it is impossible to cancel out the offset with the analog circuit. The saturation reduced the dynamic range of the feedback system and restricted the gain of the system to be lower than expected.
- Longer damping time at the injection. As the shunt impedance and the maximum power of the wideband system is limited, the amplifiers always saturate at the injection period due to injection bump error. The system worked as the bang-bang damping scheme during injection and the performance was reduced greatly.

With changing the function of the digital filter from the simple delay mode to 2 tap FIR mode, position offsets between the bunches has been completely cancelled out. We have increased the feedback gain without be annoyed by the saturation at the amplifiers. The huge shake during the injection is now suppressed well with adding the lower frequency system with equalizing the wideband system, though the gain balances between the two systems are still troublesome.

We have measured the damping rate of the horizontal oscillation during injection using the bunch oscillation recorder (BOR)[3]. Figure 3 shows an example of damping of horizontal oscillation during injection of HER with total current around 730 mA. Present setting of feedback damping time at maximum beam current is 0.2 ms (horizontal:H) and 0.8 ms (vertical:V) in HER, 0.2 ms (H) and 0.4 ms (V) in LER.

In normal operation for physics run, we fill the beam every 4th buckets (8 ns spacing) with the gap space for beam abort kicker, with total bunch number of 1155 per ring. Under this fill pattern mode, the growth time of the instabilities in the LER are less than 0.5 ms in horizontal, about a few ms in vertical. In the HER, the growth time is about a few

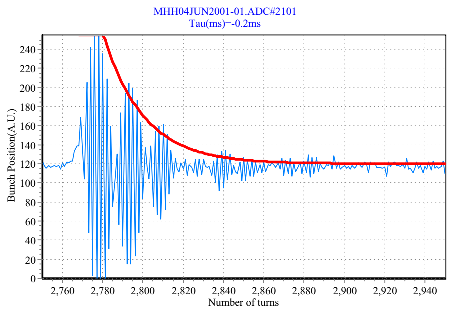

Figure 3: Feedback damping of injection oscillation (horizontal) at the HER at current of 730 mA.

ms for both horizontal and vertical planes. For the machine development, we have also tried several special filling patterns, such as (11001100· · ·), (101010· · ·) or (100100· · ·), where 1 means bucket filled while 0 means empty bucket. Though the growth rate of the instability for several patterns are comparable or higher than the feedback damping rates and not easy to accumulate beam up to higher currents, the feedback system has shown much better performance than design. Figure 4 shows an example of special filling pattern (4 ns spacing) at the transient-domain analysis of the instability, before and after switching off/on the horizontal feedback system. While switching off the horizontal feedback system in 41 ms, the beam current reduced from 650 mA to 390 mA within a few ms and the tail part of the bunch trains were lost. The analysis of thie growth by using the BOR shows very quick growth less than 0.5 ms and some broad modes around lowest modes.

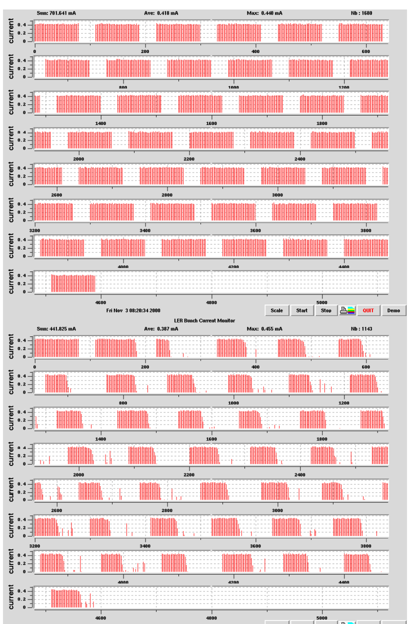

Figure 4: Special filling pattern before (upper) and after (lower) switching off/on the feedback.

The growth rate of the instabilities for both rings including normal filling pattern of 8 ns spacing are much faster than the expected ones in the design stage. Candidates of such instability source are photo-electron induced instability in the LER, fast beam-ion instability in the HER but not confirmed yet. To investigate the cause of sudden beam loss during operation, we are now testing the beam loss trigger systems to record the beam behavior just before the beam loss with BORs. An example of growth of vertical oscillation just before the beam loss of HER is shown in Fig. 5.

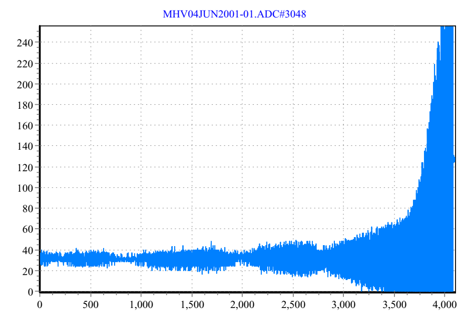

Figure 5: Growth of vertical osciillation just before the beam loss of HER.

4 SUMMARY

The transverse bunch-by-bunch feedback systems for KEKB rings have been contributing to both the commissioning of the rings and the operation of the colliding experiment beginning from early stage of the commissioning up to present, about 2.5 years operation. The damping time of around 0.2 ms (20 turns) have been achieved under the stable operation of the feedback systems.

To increase the luminosity, we will continuously try to increase both the beam current and the total number of bunches. Experiments of special filling patterns suggest the existence of large impedance source in the ring. The feedback systems and the analysis tools such as the BOR with transient-domain analysis or the beam loss trigger will continuously play important roles.

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