BEAM DIAGNOSTICS USING BUNCH-BY-BUNCH FEEDBACK SYSTEMS IN 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 well since the early stages of the commissioning of the rings. Beam diagnostic systems that are the part of the bunch feedback systems, such as bunch current monitors, betatron-tune measurements systems, and bunch oscillation recorders, have been playing important roles in the tuning of the rings, enabling stable high-luminosity operation. The performance of these diagnostic systems and their control systems is reported.

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 achieve the very high luminosity, $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, with about 5000 bunches per ring at total beam currents of 1.1 A (HER) and 2.6 A (LER) in the design goal. At present we can store over 1030 mA in the LER, 872 mA in the HER without coherent beam oscillation and have achieved a peak luminosity of $4.49 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. For such high luminosity machines, since keeping high luminosity and accumulating large integrated luminosity is the first priority, we must control the beam conditions very precisely throughout the physics experiment. The distortion of beam optics such as betatron functions, dispersion functions, x-y coupling and chromaticity should be measured and be corrected. As the collision parameters strongly depend on the bunch current, we must control filling pattern and bunch current during the injection. With increasing beam currents, the growth rate of the coupled-bunch instability increases and unexpected beam losses due to high beam current also increases. To understand such beam behavior, recording bunch positions of all bunches before and after some events such as beam loss will help us very much. We have installed beam diagnostic systems that are the part of the bunch feedback systems to measure betatron tunes, bunch currents and bunch oscillations. The related parameter are listed in Table 1.

Table 1: 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
Harmonic number	5120	
Revolution Freq.	99.32	kHz
Damping time (L)	22/23	ms

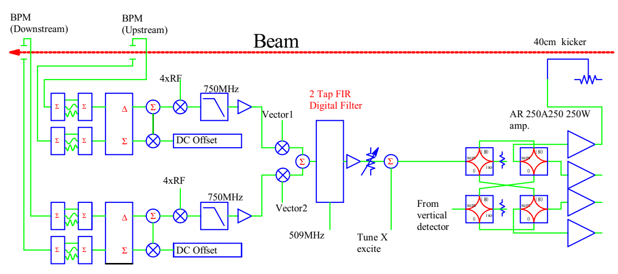

Figure 1: Block diagram of the transverse bunch feedback systems.

2 BETATRON TUNE MEASUREMENT SYSTEM

Figure 1 shows a block diagram of the transverse bunch feedback systems[1]. We use the same kickers and power amplifiers of bunch feedback systems to excite the beam. The excitation input is placed at the rear-end of the low-level circuit of the bunch feedback systems. The bandwidth of the feedback kickers and the amplifiers is from 10 kHz to 255 MHz. As the bandwidth of the system is designed wide enough to damp all the modes of oscillation, there are no limitations on kicker and amplifiers system to excite various modes of betatron oscillation. Figure 2 shows a block diagram of the betatron tune measurement system. We use a spectrum analyzer (SA) with

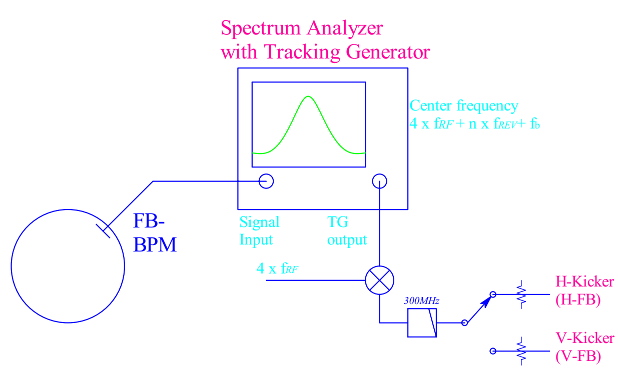

Figure 2: Block diagram of betatron tune measurement system.

a tracking generator (HP8594E) per ring to excite and detect the betatron oscillation. An output of a button electrode which is placed 45° tilted from the horizontal plane is connected to the input of the SA. The center frequency of the SA is set at the betatron frequency sideband around 2 GHz ($= 4 \times f_{rf} + n \times f_{rev} + f_\beta$), where f_{rf} is the RF frequency, f_{rev} is the revolution frequency, f_β is the betatron frequency. We can select the harmonics n from 0 (base band) up to 5119. In normal operation, we use 4th harmonic ($n = 4$), the span of the SA is set 5 kHz, resolution bandwidth (RBW) and the video bandwidth (VBW) is set 100 Hz and the sweep time is set 3 s. The output of the tracking generator (TG) of SA, which is the same frequency as the detection frequency, is down-converted to the base-band-like frequency with a special VME module which contains a DBM, a signal switch and programable attenuators. The output of the TG is down-converted to base-band-like frequency (=$n \times f_{rev} + f_\beta$) by multiplying the $4 \times f_{rf}$ signal with the DBM. We switch the output in two ways, horizontal and vertical. Each of them are connected to the feedback excitation inputs through program attenuators.

We control the SA and the signal-converter module under the EPICS environment. Most of the measurements are performed automatically by clicking measure button with the sequencer program on the VME cpu (IOC). As we use the SA not on the base-band frequency, we must track the RF acceleration frequency when it has been changed. The sequencer program always monitors the RF frequency and if the change is larger than some threshold value, it require the SA to measure $4 \times f_{rf}$ frequency using the beam signal to calibrate the SA. For fine measurement of the betatron tune for the optics correction or chromaticity measurements, we transfer the measured beam response data from the SA to the host workstation to fit the data to the function.

We have also installed remote-controlled RF-switches around the SA to switch the input and excitation signals. For CW excitation of beam, we connect output of a signal generator to the excitation input. We can measure the phase advance between the tip of the final super-quadrupoles by using the turn-by-turn monitor[2]. During the physics running at high beam current, the tune-spread due to the bunch feedback and the beam-beam interaction is huge. Then it is fairly difficult to measure the betatron tune with this system. We have added a gated-bunch tune measurement system to measure a pilot-bunch's betatron tune which has no colliding partner bunch. We switch the excitation input to the gated-tune measurement system during collision[3].

3 BUNCH CURRENT MONITOR SYSTEM

In KEKB, the equalization of the bunch current is very important not only to suppress the instabilities, but also to maintain high effective luminosity with long beam lifetimes. Here, the effective luminosity means the integrated luminosity per total running time including idle time such as the injection time. To control the bunch current during the injection process, it is necessary to measure the bunch currents of all 5120 buckets and decide which bucket should be filled by the next injector-pulse within the injection interval, which is 20 ms at the maximum injection rate of 50 Hz. Figure 3 shows a block diagram of the bunch current monitor system. The bunch current monitor box in the

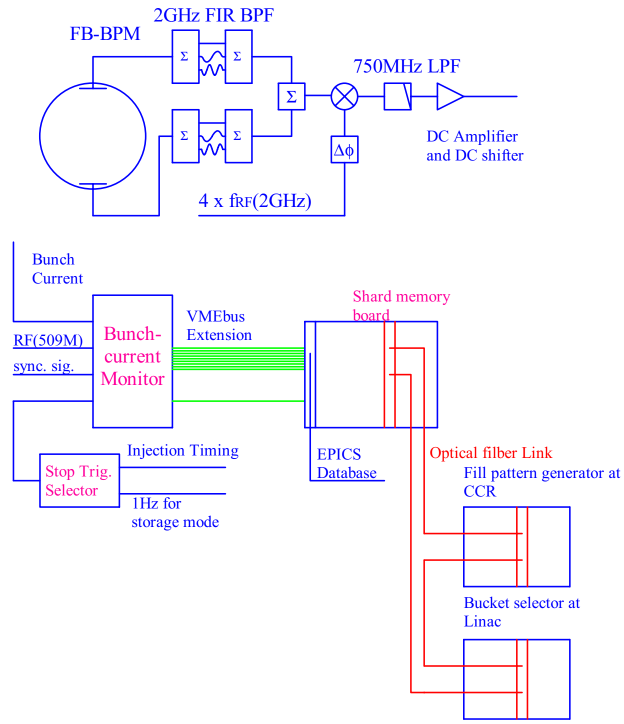

Figure 3: Block diagram of bunch current monitor system.

figure means a digital memory complex which is a special application of the digital filter board[4] used in the bunch feedback systems. Though it has 20 Mb of memory, the address space is limited to 1 Mb.

During injection, the bunch-current monitor transfers the bunch-current data triggered by the injection-kicker timing-signal. Interrupted by the trigger, the EPICS device-support of the board at first transfers the bunch-current data form the memory board to the EPICS database. After the transfer, it writes the bunch-current data on a shared memory board with the information of the current operating ring. This data triggers the bucket selector software on the IOC at the injector control building[5]. Under current environment of KEKB, it takes about 1.4 ms to complete the bunch current measurement procedure stated above. Figure 4 shows an example of HER filling pattern during a physics run measured by the bunch current monitor.

4 BUNCH OSCILLATION RECORDER

The transient behavior of the beam just after closing/opening of the feedback loop reveals many important characteristics of the coupled-bunch motions as well as the performance of the feedback systems. This powerful method of analyzing instabilities is known as the transient

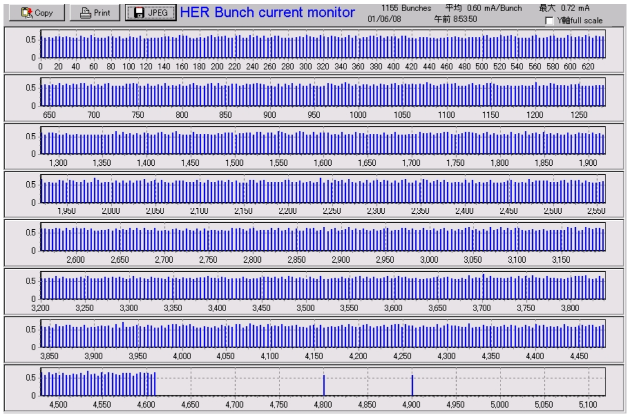

Figure 4: Example of the filling pattern during a physics run at HER. The bunch space was 4 ns.

domain analysis of beam. We have prepared six large-scale memory boards (BOR: Bunch Oscillation Recorder) for all planes of the both rings. The capacity of the memory is 20 Mb, which corresponds to record 4096 turns (41 ms) of data for all 5120 buckets in KEKB. The input of the memory board is almost the same as that of the two-tap FIR filter complex in the bunch feedback system except the amplifier's gain from the detector to the board.

For the transient-domain analysis, we use the feedback on/off signal as the trigger signal to stop the BOR. If we want to measure the growth transient of the instability, we at first turn-off the feedback signal with a fast RF-switch and after 41 ms, we restore the feedback signal and generate the stop signal to the BOR. On the other hand, to measure the damping time, for example, damping of the injection oscillation, we use the injection trigger which excite the injection kicker to stop the BOR. Figure 5 shows an example of damping of horizontal oscillation during injection of the HER with a total current around 730 mA.

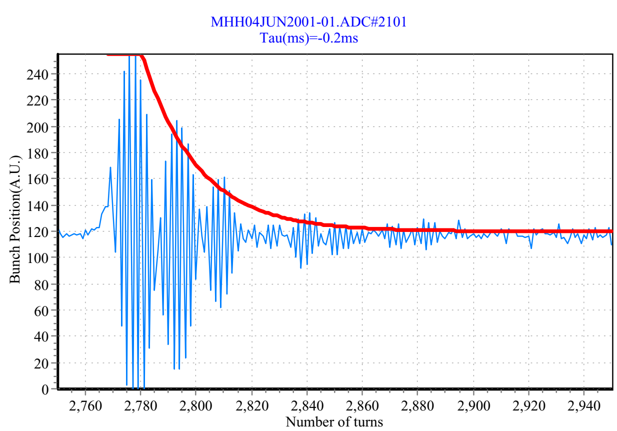

Figure 5: Feedback damping of injection oscillation (horizontal) in the HER at current of 730 mA.

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 the growth of vertical oscillation just before beam loss in the HER is shown in Fig. 6.

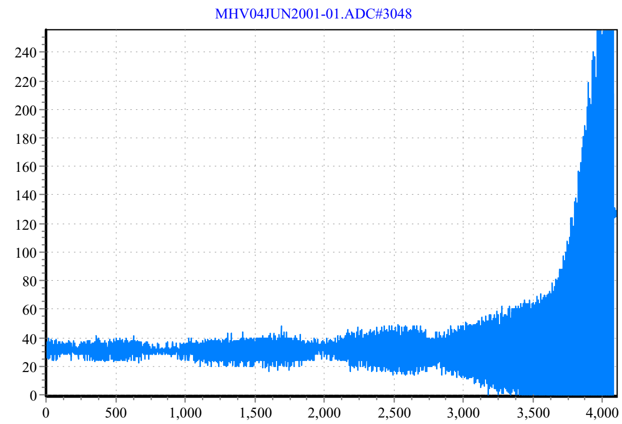

Figure 6: Growth of vertical oscillation just before beam loss in the HER.

5 SUMMARY

We have installed beam diagnostic systems that have very close connection to the bunch feedback systems. It is possible to measure the betatron-tunes very easily with enough precision. The continuous beam excitation for all planes is also possible, enabling us to measure special measurements of beam optics.

The bunch current monitor systems and the bunch oscillation recorders are special applications of the digital filter technologies developed for the bunch feedback systems. We can equalize the bunch filling pattern using the information from the bunch current monitor. The information is also used to check the bunch-by-bunch luminosity data.

By using the bunch oscillation recorder, we can identify the mode of instability with the transient-domain analysis. The beam behavior just before the beam loss helps us to find the cause of the loss.

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6 REFERENCES

[1] M. Tobiyama, et al., in proceedings of PAC2001.

[2] Y. Ohnishi, et al., in proceedings of EPAC2000, p.1537.

[3] T. Ieiri, et al., in proceeings of HEACC2001.

[4] M. Tobiyama and E. Kikutani, Phys. Rev. ST Accl. Beams 3,012801(2000).

[5] E. Kikutani, et al., in proceedings of icalepcs 99, p.280.