A POSITION MONITOR FOR THE ABORTED BEAM IN KEKB

N. Iida, M. Kikuchi, T.Mimashi, K. Mori and M.Tejima,
KEK, 1-1 Oho, Tsukuba, Ibaraki, 305-0801, Japan

Abstract

The beam-abort system is an important element of KEKB for the protection of sensitive components of the Belle detectors and the accelerator components from damages due to intense beams. A new beam position monitor (BPM) was installed in front of a beam dump to observe the positions of dumped beams. The BPM measures the transverse position of each bunch with a precision of 0.25 mm. By observing beam positions of whole bunches at the moment of the beam-abort, we can get useful information on the beam instabilities, as well as hint of any degradation of the abort system. In this paper we describe the BPM system, data acquisition and analysis, as well as typical examples.

INTRODUCTION

KEKB is an asymmetric double-ring collider of 3.5 GeV positrons (LER) and 8 GeV electrons (HER), filled with a current of 2.6 A for LER and 1.1 A for HER in design.

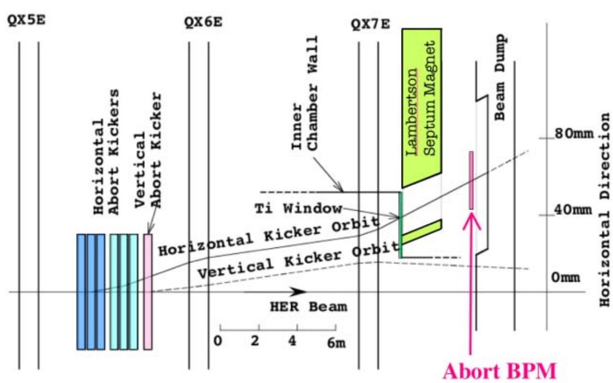

Figure 1: Schematic side view of the HER abort system. Electron beams, coming from the left side of the figure, are kicked by the horizontal kickers out of the vacuum chamber through a window located in front of a Lambertson septum magnet. The Abort BPM is installed at the entrance of the dump block. There are two quadrupoles between the vertical kicker and the Lambertson septum.

A schematic layout of a beam-abort system of HER is shown in Fig. 1. Circulating beams are kicked horizontally with two horizontal kickers. The deflected beam, exiting the ring through a thin Ti window of 1.4 mm thick, is bent downward by 75 mrad with the Lambertson DC septum magnet, and enters the beam dump[1][2]. A new BPM, called as the Abort BPM, is installed in front of the beam dump.

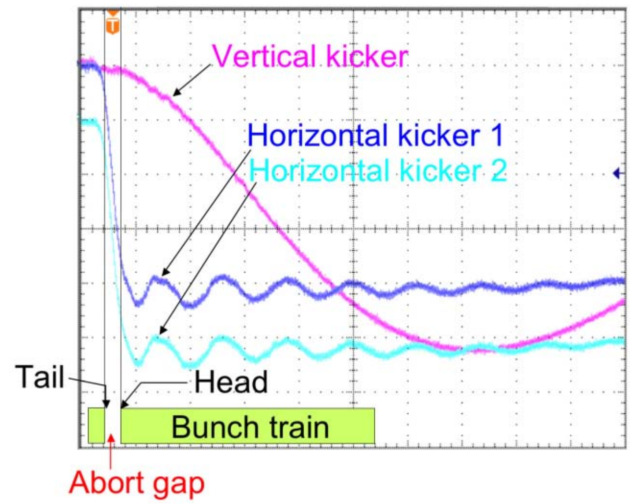

Figure 2: Current waveforms of the HER Abort kickers are shown. Scale: 2 μsec/div. in the horizontal axis and that in the vertical is 400 A/div. for the horizontal kickers and 1 kA/div. for the vertical kicker.

The current wave forms of the horizontal and vertical kickers measured by current transformers are shown in Fig. 2. The rise-time of the horizontal kicker is about 500 nsec. The revolution period is 10 μsec. The kicker timing is adjusted such that the head of the bunch train is located just at the end of the rise time. The aborted beams are extracted through the window and guided to the dump in the air. Since the beam size is very small ($\sim$0.6mm$\times$7.5μm) and the beam current is high, the window would not bear the temperature rise caused by the deposited energy of the beams. In order to relax the power density at the window, the vertical abort kicker sweeps the beam slowly so that the beam positions are moved about 15 mm in the vertical direction on the window in 10μsec. Furthermore to make the hot spots more sparsely distributed, the horizontal abort kickers has ringing waveform on the flat-top with amplitude of about 12 % of the kicker height. It corresponds about $\pm$3 mm at the window.

ABORT BPM

The BPM is the same type as that of LER[3][4]. The BPM chamber installed in front of the dump is shown in Fig. 3. Mapping calibration of the BPM was made with a 1.018 GHz signal at a test bench[3]. The four electrode signals (A,B,C,D) measured at the bench are normalized to h=(A-B-C+D)/(A+B+C+D) and v=(A+B-C-D)/(A+B+C+D). The horizontal and vertical positions are

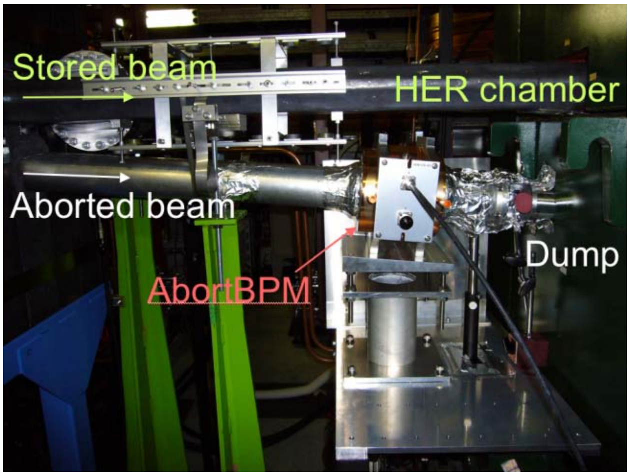

Figure 3: A picture of the Abort BPM installed in front of the dump block.

obtained by the 3rd order polynomial of h and v;

$$
\begin{aligned}
X_{pos} &= \sum_{i,j;0\le i+j\le 3} p_{ij} h^i v^j \\
Y_{pos} &= \sum_{i,j;0\le i+j\le 3} q_{ij} h^i v^j ,
\end{aligned}
\tag{1}
$$

where the coefficients, p_{ij} and q_{ij} are given by the mapping data. Signals of the four electrodes are carried through 80m-long ring-corrugated cables. An oscilloscope (DPO4102 by Tektronix Co.), is used as a signal digitizer, whose analog frequency band-width is 1 GHz and sampling rate is 5 GS/sec. Low Pass Filters (LPF's) are inserted in front of inputs of the oscilloscope for better signal to noise ratio. This LPF decrease the signal level to 30 dB at 2.5 GHz, a half sampling frequency. The BPM signals are shown in Fig. 4. The trigger signal is the abort request signal from HER. Digitized data are transferred, saved to a data storage, and analyzed in a few seconds.

ANALYSIS

RF bucket interval of KEKB is 1.96507 nsec. In ordinary operation, bunch spacings are two RF buckets at minimum, corresponding to 3.93015 nsec. In the data analysis we employed a peak-to-peak value to get the amplitude of the signal for each bunch. The data around the peak corresponding to each bunch was clipped as a partial data, and a simple maximum-minimum algorithm was applied to the partitioned data. A difficulty was that the abort-request signal, which is also used as a trigger of the oscilloscope, has a jitter of 2 nsec at maximum relative to the RF frequency. To compensate for the timing jitter, the correct timing of the last bunch was searched by scanning the clipping position automatically; the difference of the timing from a standard one should be due to the timing jitter. Fig. 4-(b) shows an

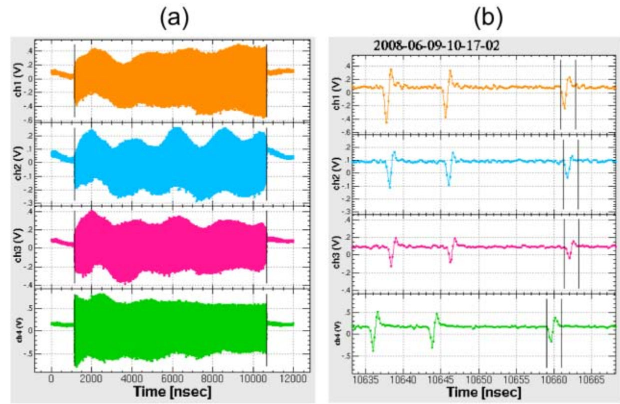

Figure 4: Voltages from four electrodes from the Abort BPM are shown. (a) Signals of the four electrodes on an oscilloscope. (b) Enlarged view around the tail of the bunch train. Bunch-by-bunch signal is clearly seen. Two black lines bracket the last bunch to compensate the timing jitter.

enlarged part of the tail bunches in the train. It can be seen that the signal of the last bunch is properly partitioned.

The data points around the peak of each bunch are only several points. We interpolated the data to obtain the peak-to-peak value, using a $\sin x/x$ interpolation method[5].

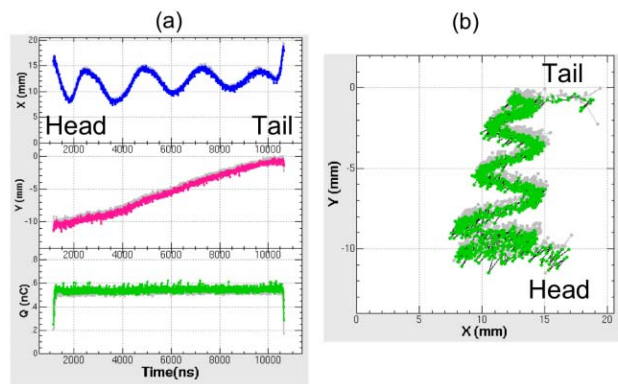

Figure 5: The horizontal axis of (a) is time (nsec) from a trigger signal, the vertical axes are, from top to bottom, the horizontal and vertical bunch positions (mm) and bunch currents. Two-dimensional position plots are shown in (b). The origin is the center of the BPM chamber.

Fig. 5 shows measured position plots. The horizontal displacement at the BPM with respect to the stored beam is 49 mm, while the amplitude of the ringing pattern seen in the figure is about 6 mm; 12 % of the magnitude of the displacement. This number is consistent with the waveform in Fig. 2. The gray points behind the color dots in Fig. 5 show the data of a “reference abort”; a specific beam-abort for which no instabilities are expected. We fit the reference positions as a function of the time. The fitting curves are shown in Fig. 6 as red lines. Taking difference from the reference abort, we can diagnose the beam oscillations just before the instant of aborts.

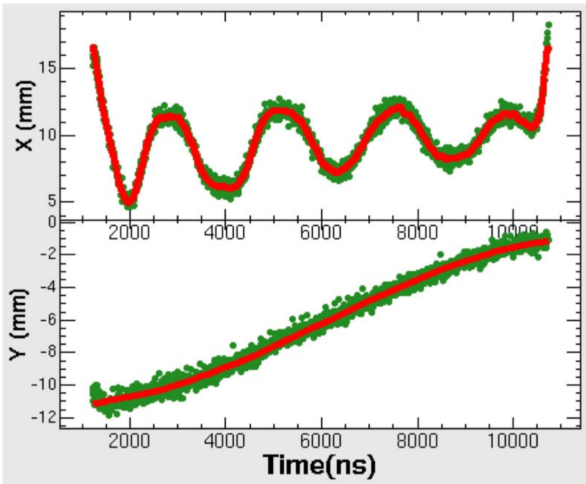

Figure 6: Red lines are the fitted curves to the horizontal and vertical positions versus the time of the "reference abort" beam. The horizontal positions are fitted by a spline interpolation. The vertical positions are fitted by a sin function.

An intensity losses at the head of a train are observed. It is considered that some bunches in the head of a train are placed in the rising portions of the waveform of the horizontal kicker, and lose some part of the intensity before property dumped.

Fig. 5-(a) also shows the beams in the tail lose their intensity. It is considered that the tail bunches are placed in the very beginning of the rising portion of the horizontal kickers and receive small kicks but never extracted in one turn. After one turn the bunches receive kicks properly at the horizontal position, however, slightly opposite to the window, because the horizontal tune is very close to a half integer. This position deviation at the window is the reason of the intensity loss.

ABORTED BEAM EXAMPLES

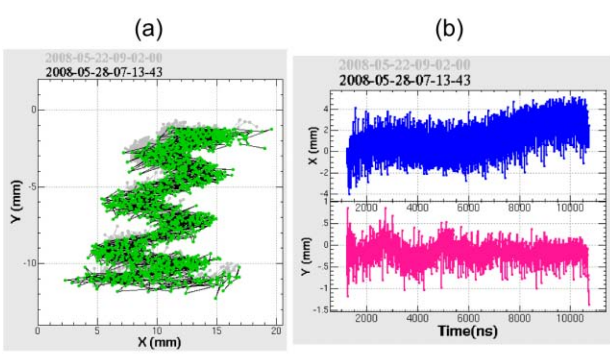

Figure 7: Measured positions of aborted beam due to beam-losses are shown. (a): the transverse positions. (b): the difference from the reference positions.

Typical examples of aborted beams observed with the Abort BPM are shown in Fig. 7. In this example, an abort request was issued by one of loss monitors which are distributed around the KEKB tunnel[6]. Fig. 7-(b) shows the difference from the "reference abort", for which no instability is to be expected. We observe that the horizontal positions of bunches are widely scattered. By Fourier-analyzing the bunch positions, it is shown that the bunches have high-order mode of the transverse coupled-mode.

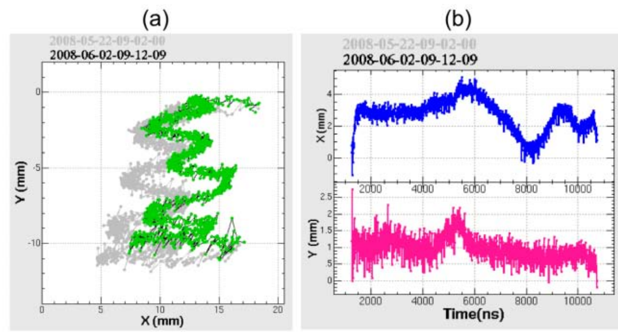

Figure 8: Measured positions of aborted beam caused by a breakdown of Crab cavity. (a): the transverse position at the Abort BPM. (b): the position difference from the "reference abort".

Another example is shown in Fig. 8. In this case, abort request was issued by the breakdown signal of a Crab cavity. We observe that the beams were shaken horizontally by a sudden power-outage of the crab mode in the cavity.

In the other case, we found a faulty thyratron switch of the abort kicker. Sometimes it was observed that the horizontal position of aborted beam was about 3 % lower than the normal position and the switching time was faster about 200 nsec. This is an indication of a breakdown of the thyratron. We exchanged the thyratron and have never observed the phenomena.

CONCLUSION

We have installed a beam position monitor for the HER of KEKB. It is useful for diagnostics of the aborted beam and is a good tool to get information how the abort is occurred. It is also useful to check the abort system itself.

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