MEASUREMENT OF BEAM-BEAM KICK USING BUNCH-BY-BUNCH BEAM-POSITION MONITOR AT KEKB

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Abstract

This note describes an orbit measurement at the interaction point (IP) at KEKB, an asymmetric collider, where the beams collide with a horizontal crossing angle. A position offset due to the beam-beam kick was detected using a bunch-by-bunch beam-position monitor (BPM) that measured the beam position of collision and non-collision bunches independently. Varying the distance of the two beams at the IP, we found that the beam-beam kick was not symmetrical, and that the optimum collision was performed with a horizontal offset. The asymmetry was caused by changes in the beam sizes.

1. INTRODUCTION

KEKB [1,2] is a multi-bunch, high-current, electron/positron collider for *B* meson physics. The collider consists of two storage rings: the Low Energy Ring (LER) for a 3.5-GeV positron beam and the High Energy Ring (HER) for 8-GeV electrons. Both rings store more than 1,000 bunches, where the harmonic number is 5120 with an RF frequency of 509 MHz. The two beams collide at one interaction point (IP) with a horizontal crossing angle of 22 mrad.

Unlike conventional single-ring colliders, the beam parameters are different between the two rings, which makes collisions complicate. Since KEKB is operated at the horizontal betatron tune just above a half integer, the beam-beam collision changes the emittance and the beta function due to the dynamic effect. Under these situations, various parameters, such as the beam orbits, the x-y coupling, the beam sizes and the betatron tunes of both rings are optimised to perform the best collisions.

Beam-position monitors for the collision tuning have already been installed at both sides of the IP [3]. The monitors obtain an orbit change at the IP from detecting the average orbit for all bunches. The orbit at the IP is controlled with the cooperation of dipole magnets near the IP, called “iBump”; however, the orbit control is very severe and depends on the experience and skills of the operators. [4]. We have experienced that the luminosity is very sensitive for a horizontal orbit.

Therefore, it is required to investigate the beam-beam effects. A turn-by-turn beam-position monitor [5] with a gate function turns into a bunch-by-bunch monitor. The beam-beam kick can be detected from a position difference between collision and non-collision bunches. We do not need to install a position monitor near the IP region, and the monitor would not be affected by a global orbit correction.

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2. MEASUREMENT METHOD

When two beams collide with a position offset, Δx^*, they are kicked by the space charge of the opposite beam and the orbit is distorted around the ring. A position monitor located at a phase advance of $\Delta\varphi$ from the IP detects a position offset due to collision. The position offset at a detector is given by

$$\Delta X_{\mathrm{det.}} = \frac{\sqrt{\beta_{\mathrm{det.}}\beta^*}}{2 sin(\pi\nu)}\,\theta_{b-b}\,\cos(\pi\nu - |\Delta\varphi|)\,.$$

Here, $\beta_{\mathrm{det.}}$ and β^* are the beta functions at a detector and the IP, respectively and ν is the betatron tune and θ_{b-b} is the beam-beam kick angle. Assuming a rigid Gaussian bunch, the beam-beam kick for a bunch with the linear approximation is given by

$$\theta_{b-b} \approx -\frac{2\pi\xi}{\beta^*}\Delta x^*,$$

where ξ is the beam-beam parameter. Since a position offset at a detector is proportional to the beam-beam kick, we can estimate an offset at the IP, assuming a beam-beam parameter.

KEKB is usually operated with a single train of bunches followed by an empty gap. Bunches are spaced by 6 ns or 8 ns in a train. Additional bunches, called *pilot bunches*, are placed just after the train, at different location in each ring so that they do not collide with each other as illustrated in Fig. 1. We can evaluate the beam-beam effects, assuming that effects of the wakes are equal to bunches to be measured, by comparing the beam parameters of a bunch in a train with those of the pilot bunch. A beam-beam kick induces a difference in the beam position. The measurement has the following features: we do not install a detector near the IP, gain errors of a detector would cancel out due to a subtraction and the measurement would not be affected by the global orbit correction. However, an error may occur when there is a large imbalance in the intensity between bunches to be measured.

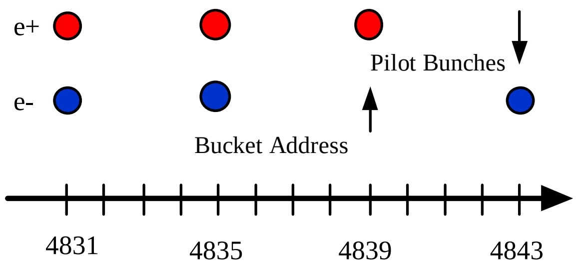
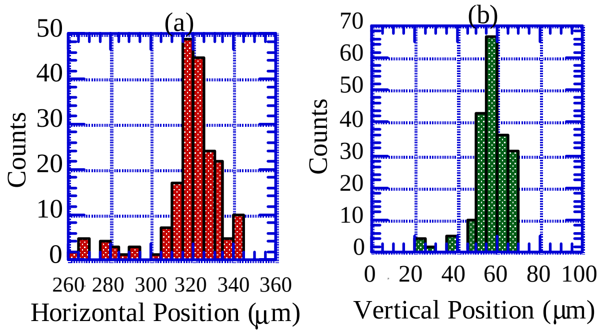


Figure 1: Configuration of bunches at the tail of a train.

3. BUNCH-BY-BUNCH BPM

A bunch-by-bunch beam-position monitor system is installed at two locations in each ring. A common detector is used for the two beams. A beam signal picked up by button electrodes is processed in parallel. A gate [6] following a low-pass filter (LPF) selects a specific bunch with a pulse-width of 6 ns. The on/off isolation of the gate is more than 60 dB at 1 GHz. A beam pulse is filtered by a band-pass filter with a center frequency of 509 MHz. An I/Q (in-phase and quadrature phase) demodulator working at an RF frequency of 509 MHz gives two orthogonal detected signals to sampling ADCs with a memory. The amplitude of the beam pulse is given by two signals in orthogonal phase, V_{sin} and $V_{\cos}$. The beam position can be obtained from a difference-over-sum algorithm using four amplitudes corresponding to each electrode. The relative bunch intensity is obtained by summing up the four amplitudes. On the other hand, the phase difference between the beam signal and the reference RF can be given from the ratio $V_{sin} / V_{\cos}$.

A bunch signal selected by the gate is sampled every revolution of 100 kHz and the beam position and the phase are calculated turn by turn. The reproducibility of averaged values over 32,000 data was obtained with a stored beam. The histograms are shown in Fig. 2. The standard deviations of the positions are about 10 to 15 μm over 200 data; note that the measurement includes a stability of the beam itself. On the other hand, the standard deviation of the phase is 0.05 degrees, corresponding to a time resolution of 270 fs.



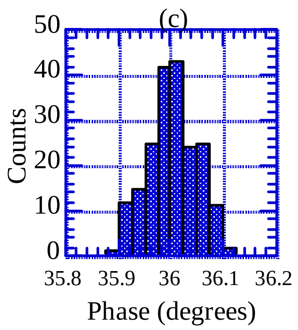


Figure 2: Reproducibility of the measured average positions, (a) and (b), and the phase, (c).
(a): Arg=318.6, Std=15.5
(b): Arg=56.9, Std=9.1
(c): Arg=36.00, Std=0.05

4. MEASUREMENT

4.1 Measurement during Physics Run

A position offset is obtained from subtracting the position of the pilot bunch from that of a collision bunch located next to the pilot bunch. The LER-2 monitor was used for detecting a horizontal offset of the positron beam and the LER-1 was used for the vertical detection, since they were placed in a suitable phase advance from the IP.

Before measuring the collision bunches, the positions without collisions were measured. There was a position difference between two bunches of about 5 μm horizontally and of 20 μm vertically. These values were caused by the wake and/or an error of the detectors and subtracted from data measured with the collision. A position offset due to the beam-beam kick was measured during usual physics runs. Figure 3-(a) and (b) show the position offsets as a function of the LER beam current; (a) measured in a relatively high-luminosity run and (b) measured in a relatively low-luminosity run. Though both cases run with the same number of bunches and with almost the same beam current, there was a difference of 35 % in the specific luminosity. We notice in Fig. 3-(a) that the horizontal position offset changes from –100 to –150 μm, depending on the LER beam current. An offset of –150 μm is equivalent to an offset of -61 μm at the IP, assuming $\xi_x = 0.07$. In Fig. 3-(b), the horizontal position offset scatters at high beam current and is larger than that in Fig. 3-(a) as a whole, which may be related to a lower luminosity. Some unknown parameters might have changed between the two runs. These results indicate that the optimum luminosity is obtained with a negative horizontal offset. We may notice a small dip in the horizontal position offset at the beam current of 1100 to 1200 mA, which corresponds to scanning a tuning knob at the IP. The vertical position offset is almost zero and constant in both cases.

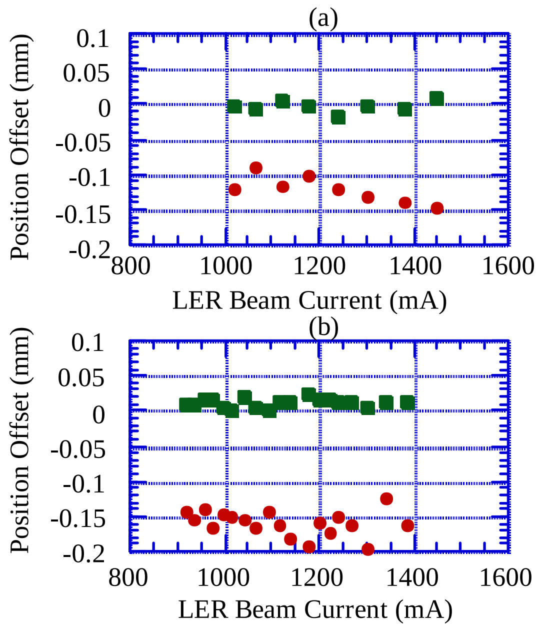


Figure 3: Horizontal (dots) and vertical (squares) offsets as a function of the LER beam current, (a) measured in a relatively high luminosity run, where a luminosity of 10.5×10^{33} /cm^2/sec was obtained, and (b) measured in a relatively low luminosity run, where the maximum

luminosity was 7.0×10^{33} /cm^2/sec. The offset data in this figure are corrected using values without the collision.

4.2 Experiment with iBump Scan

The iBump makes an orbit bump of the electron beam to control the distance between the two beams. The iBump height was scanned to investigate the beam-beam effects, while the vertical orbit and the betatron tune were kept constant by feedbacks. The global orbit correction was off, to avoid any interaction with the iBump control.

Figure 4 indicates variations in the horizontal position offset at the detector and in the luminosity, as a function of the horizontal iBump height. The measurement started from a large positive height, where the electron beam orbited outside and the positron beam was fixed inside. The position offset of the positron beam indicated a negative value of about –120 μm, which corresponded to a position offset of –115 μm at the IP, assuming ξ_x=0.03. Reducing the distance by the iBump height, the luminosity increased and the position offset approached zero. However, the position offset was not zero, even when the maximum luminosity was obtained. Upon reducing the iBump height further, the position offset moved to the positive side and the luminosity reduced rapidly. We understand that the two beams exchange their positions. When the iBump height moved again in the reverse direction, we found differences in the luminosity and in the position offset at the same iBump height. We confirm that the optimum collision exists with a position offset of -50 to -70 μm.

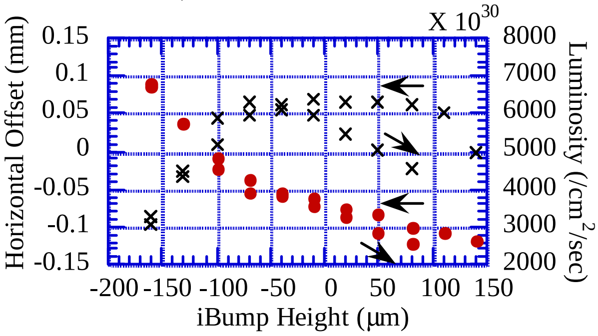


Figure 4: Horizontal position offset (dots) and the luminosity (crosses) as a function of the iBump height, measured with a bunch current of 0.78 mA (LER) and 0.66 mA (HER). The offset data were corrected using values without any collision. The arrows indicate the direction in the iBump height.

5. DISCUSSION

The horizontal offset and the luminosity are presented as a function of the iBump height as shown in Fig.4. We find that they are not symmetrical for the iBump scan. The beam size might be changed during a scan. Actually, we observed variations of the beam sizes not only in the horizontal direction, but also in the vertical direction. When the iBump height was positive, the size of the electron beam was larger than that of the positron, which suggested that the positron beam was stronger than the electron beam at the positive height region. When the iBump height was negative, the relation in the sizes was reverse. We found that the positron vertical size increased rapidly at a negative height. The effective vertical beam size, defined by $\Sigma_y = \sqrt{(\sigma_y^+)^2 + (\sigma_y^-)^2}$, is also asymmetric, as shown in Fig. 5, where the minimum size corresponds to the maximum luminosity. Moreover, the horizontal size of the electron beam rapidly decreased at the negative height region, which may enhance the horizontal beam-beam kick and the horizontal offset of the positron beam. These phenomena in the sizes reflect the asymmetry in the luminosity and in the horizontal beam-beam kick. However, a simulation did not indicate any asymmetry in the luminosity for a horizontal scan [7]. The effects of the crossing angle and the electron cloud are unclear. A shift in the waist is suspected [8]. The studies should be continued.

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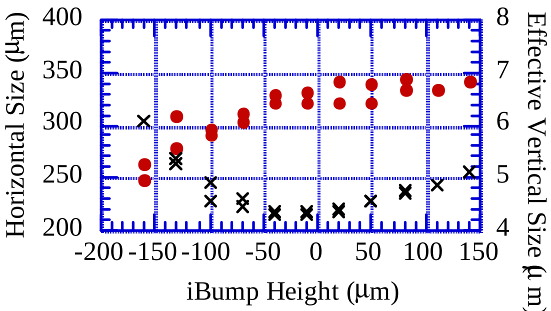

Figure 5: Horizontal size of the electron beam (dots) and the effective vertical beam size (crosses) as a function of the horizontal iBump height. The sizes were not calibrated.

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