VERTICAL BEAM SIZE MEASUREMENT BY STREAK CAMERA UNDER COLLIDING AND SINGLE BEAM CONDITIONS IN KEKB

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Abstract

Beam behaviour of KEKB was studied by measurement of the beam size using a streak camera. The effects of electron-clouds and beam-beam interactions on the vertical beam size were examined in beam collision. We injected a test bunch of positrons 2 RF buckets after a bunch to enhance the electron cloud effect and changed electron beam conditions to see the beam-beam effect. The beam size was also measured in a single positron beam condition and compared with that during collision. The result of the measurement is reported in this paper.

INTRODUCTION

KEKB is a high luminosity e^+e^- collider for studying CP violation in B meson decays[1]. We have achieved the design luminosity of $10^{34}cm^{-2}s^{-1}$ in 2003 and the highest luminosity of $1.533x10^{34}cm^{-2}s^{-1}$ on March 19th, 2005. The number of filled bunches in a train is now 1389 during luminosity runs. The filling pattern is made up of bunches spaces alternately 3 and 4 RF buckets apart. In order to get higher luminosity, we tried to inject more bunches with shorter bunch spacing but could not get higher luminosity. We suspected that vertical blow-up of the beam size due to electron clouds may cause the degradation of the specific luminosity. Then we injected test bunches and compared the beam size of 2, 3 and 4 RF bucket-spacing bunches. The beam size of positron ring (LER) bunches, the bunch-by-bunch luminosity and the dipole beam oscillation of the bunches were measured under several sets of conditions. In this paper we report on the measurements of the vertical beam size measured by streak camera and of the bunch-by-bunch luminosity. The measurement of the beam oscillation is reported separately[2].

VERTICAL BEAM SIZE MEASUREMENT BY USING STREAK CAMERA

We use the synchrotron radiation (SR) from individual beam bunches produced in a weak bending magnet to measure the beam size. The streak camera (Hamamatsu C5680) is used to measure the vertical beam size, since the interferometer can not measure the bunch-by-bunch size. Narrow band light is generally used in measurements with the streak camera but we could not get enough light intensity with a band pass filter for the SR. In order to eliminate the band pass filter a reflective optics system for the streak camera, which is shown in Fig. 1, was developed instead of using a refractive optics system. Consequently we could get enough light intensity to measure the bunch-by-bunch size. The bunch-by-bunch shapes were observed as shown in Figure 2 (a). The vertical and horizontal axes indicate the time and spatial axes, respectively. The vertical beam size was evaluated by Gaussian fitting of the projection shown in Fig. 2 (b).

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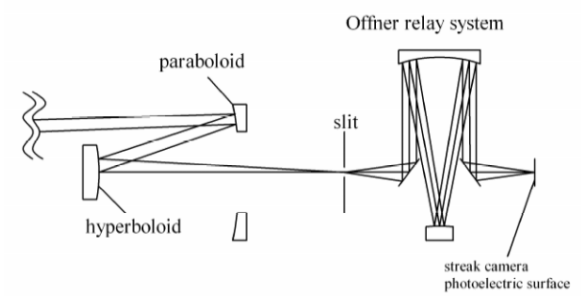
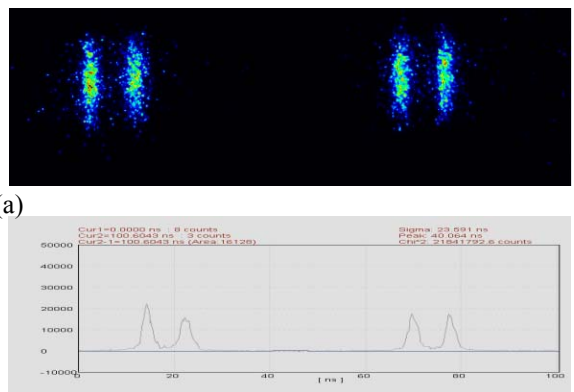


Figure 1: Reflected optical system of the streak camera.



(a)

(b)

Figure 2: Image on the streak camera. The bunch profile (a) and its projection to horizontal axis (b) are shown.

FILLING PATTERN

For the vertical beam size measurement of 2, 3 and 4 bucket-spacing, four LER bunches ("test bunches") were decayed from full to low current. These bunches were two successive 2 bucket-spacing bunches, a 3 bucket-spacing bunch and a 4 bucket-spacing bunch as listed in Table 1. The currents of the other bunches were kept constant at full current by continuous beam injection. Since the average beam size is controlled by beam-size feedback which adjusts the horizontal position of the HER beam at the collision point while monitoring the data of the interferometer, most bunches show a similar beam size except for the test bunches. By this method, dependence of the bunch size behaviour on the bunch spacing was observed during normal luminosity runs. We tried several filling patterns in the electron ring (HER) to estimate the electron cloud effect and beam-beam blow-up effect of the LER. The conditions for the bunches in the HER are shown in Table 2. In condition (a), the first 2 bucket-spacing bunch was not injected. In (b), all bunches were injected. The HER bunch current in (a) and (b) decayed,

as the LER bunch current did. By comparison of the measurement (a) and (b) the beam-beam effect for 2 bucket-spacing bunch could be observed. In condition (c), only the second 2 bucket-spacing bunch was injected. In (d) all four bunches of HER were injected and the bunch current did not decay but were kept to 0.8–0.9 mA/bunch.

Table 1: Filling patterns of both rings for the measurement. Cross marks and circles correspond to empty and filled buckets, respectively. The four bunches shown as solid circles labelled by bucket-spacing (2, 2, 3, 4) were measured because they can be measured by one shot of the streak camera. All measured bunches were allowed to decay.

LER		2 2 3 4 ○×●×●××○×××○××●×××○××○×××○××○×××○××●××○×××○××○
HER	a	○×××○××○×××○××○×××○××○×××○××○×××○××○×××○××○
	b	○×○×○××○×××○××○×××○××○×××○××○×××○××○×××○××○
	c	○×××○××○×××○××××××○××○×××○××○×××○××××××○××○×××○
	d	○×○×○××○×××○××○×××○××○×××○××○×××○××○×××○××○

Table 2: HER bunch condition for the filling patterns shown in Table 1 was listed for each measured bunch in LER.

LER spacing		**2**	**2**	**3**	**4**
HER condition	a	None	Decayed with LER.	Decayed with LER.	Decayed with LER.
	b	Decayed with LER.	Decayed with LER.	Decayed with LER.	Decayed with LER.
	c	None	Kept at full current.	None	None
	d	Kept at full current.	Kept at full current.	Kept at full current.	Kept at full current.

RESULT OF VERTICAL BEAM SIZE MEASUREMENT

An example of the vertical beam size for each bunch at one moment is shown in Fig. 3. The sizes of some bunches in Fig.3 were larger than others, which means individual bunches were not under control of the beam-size feedback. In order to decrease the measurement error, averaged results of 10 shots of the streak camera measurement were used in the following discussion. When the beam sizes were compared between HER conditions (a) and (b), the size of the second 2 bucket-spacing bunch in (a) was checked for whether it had the same size as that in (b). The procedure was also applied when comparing the beam sizes between HER conditions (c) and (d). In this way, the uncertainty of the measurements caused by optical tuning of the streak camera and beam stability during different HER conditions was removed.

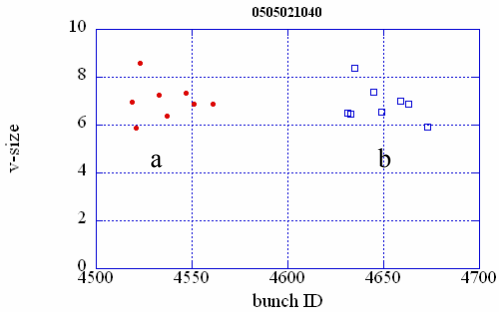


Figure 3: Vertical beam size along a bunch train. Eight bunches can be measured in one shot of the streak camera. Two shots of (a) and (b) conditions of Table 1 and 2 are shown in this figure. Bunch IDs correspond to the numbers shown in Figure 4 (4521-4663).

The bunch size depends not only on bunch spacing but also on the bunch current. The current dependence of the beam size was measured for each bunch. Fig.4 shows the results of all conditions of Table 1 and 2. In all four plots the blow-up threshold of the 2 bucket-spacing bunch is around 0.8 mA of bunch current. This is consistent with the side-band measurement of the betatron oscillation [2]. The blow-up could be caused by the beam-beam effect, the electron cloud effect, and so on.

First, the beam-beam effect is discussed. To do this, the data in (a) and (b) were compared. The sizes of the second 2 bucket-spacing bunches in (a) and (b) which were under the same beam condition were almost the same, which ensured that two measurements were done with the same optical and beam conditions. The size of the first 2 bucket-spacing bunch (solid circle) in (a) is smaller than that in (b). The difference between conditions (a) and (b) was that no counter bunch was in HER in (a) for the first 2 bucket-spacing bunch of the LER. This measurement demonstrates that the difference of the beam size was caused by the beam-beam effect.

In order to see the electron cloud effect, the measurements in (c) and (b) were examined. In (c) the first 2 bucket-spacing, 3 bucket-spacing and 4 bucket-spacing bunches had no counter bunches in the HER. Thus the measurement of these three bunches is essentially a single-beam measurement of the LER beam. The result of (c) in Fig. 4 shows that the sizes of 3 and 4 RF bucket-spacing bunches show almost no blow-up. This fact indicates that the single beam blow-up in the alternating 3 and 4 RF bucket-spacing fill pattern is suppressed. In (b) four test bunches were subjected to collision. These bunches could be influenced both by the electron cloud effect and the beam-beam effect. Looking at the result of (b) in Fig. 4, the blowup of the 2 and 3 RF bucket-spacing bunches seems larger than that of the 4 RF bucket-spacing bunch. This fact may indicate that the beam-beam blowup is influenced by the electron cloud effect. Further study is necessary to clarify the situation.

The effect of imbalance of the bunch current between HER and LER was examined in comparison with the results (b) and (d). The difference of the beam size among the four bunches in (d) is smaller than that in (b). This means that the measurement of the electron cloud effect becomes difficult due to the beam-beam effect under the imbalance of the bunch current in two rings.

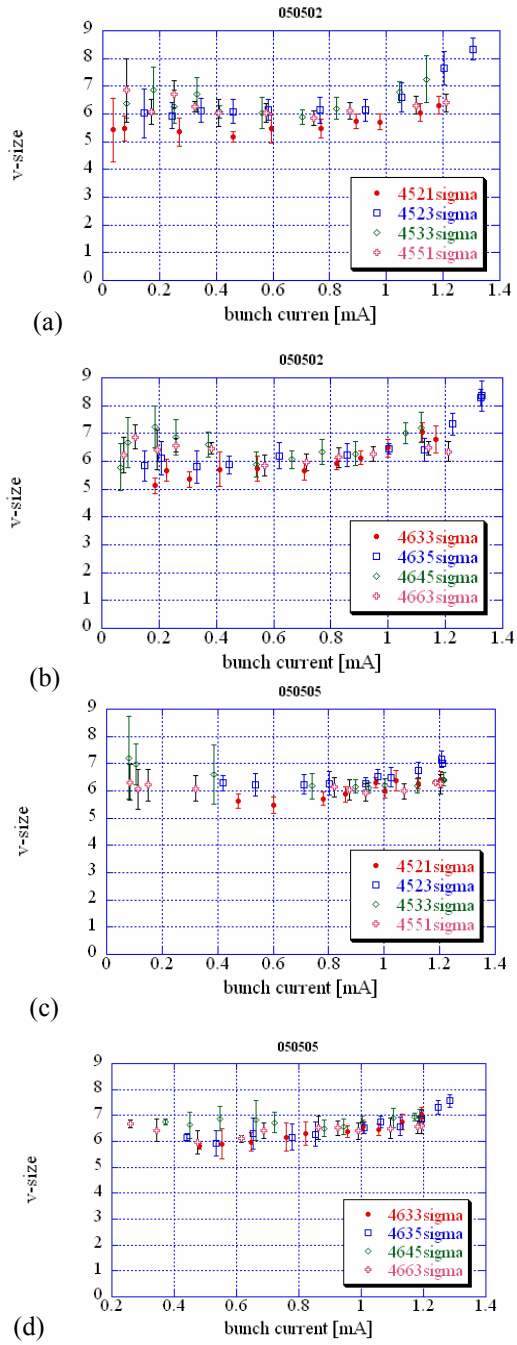


Figure 4: Vertical beam size measured by the streak camera. a)-d) correspond to HER conditions a)-d) in Tables 1 and 2. Solid circles are the sizes of the first 2 bucket-spacing bunch, open squares denote the second 2 bucket-spacing bunch, open diamonds denote the 3 bucket-spacing bunch and the cross denotes a 4 bucket-spacing bunch.

COMPARISON WITH LUMINOSITY MEASUREMENT

The bunch-by-bunch luminosity was measured at the same time as the size measurement using lead glass and a PMT which are installed near the beam pipe just downstream of the QC2RP Magnet. It detects recoil electrons of radiative-Bhabha scattering emitted at the zero-degree angle and deflected to the outside by the magnetic field of QC2RP.

Fig.5. shows the result from HER condition (d) in Tables 1 and 2. The slope of the luminosity growth of the 2 bucket-spacing bunches changed around 0.8mA while that of the 4 bucket-spacing bunch did not show such a change. This is consistent with the beam size slope in Figure 4 (d). We need more careful study on the inconsistency between bunch size and luminosity of the 3 bucket-spacing bunches.

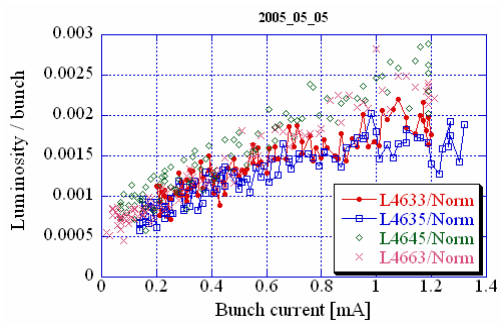


Figure 5: Bunch by bunch luminosity in HER condition d) in Table 1 and 2. The symbols are the same as in Figure 4.

SUMMARY

The behaviour of the vertical beam size in the KEKB LER was measured by streak camera. The enlargement of the beam size by the electron cloud and the beam-beam effect was measured in 2, 3 and 4 bucket-spacing bunches by changing the beam condition in the HER. In higher bunch currents under the collision, the 2 and 3 RF bucket-spacing bunches showed the blow-up of the beam size which can be caused by the electron cloud and/or the beam-beam effect. When the bunch current was unbalanced between HER and LER, the electron cloud effect could not be observed clearly. Bunch-by-bunch luminosity depended on the bunch spacing. The difference of the luminosity between 2 and 4 bucket-spacing bunches is consistent with that of the beam size measurement. The detailed relationship between the beam-beam effect and the electron cloud effect will be studied in the future.

REFERENCES

[1] KEKB Accelerator Papers, Nucl. Instrum. Meth. A499 (2003).

[2] "Betatron sidebands due to electron clouds under colliding beam conditions." J. Flanagan PAC05