CRABBING ANGLE MEASUREMENT BY STREAK CAMERA AT KEKB

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Abstract

 Crab cavities have been installed in the KEKB rings in order to increase the luminosity. This paper describes the measurement of a crabbing angle by streak cameras.

INTRODUCTION

The KEK B–Factory (KEKB) [1] is a high luminosity e^+e^- collider for studying B mesons and has achieved the design luminosity of $10^{34} cm^{-2}s^{-1}$ in 2003, and the highest luminosity of $1.71 \times 10^{34} cm^{-2}s^{-1}$ was achieved on Nov. 15th 2006. At KEKB the two beams collide with a finite horizontal crossing angle of $\pm$ 11mr at the interaction point (IP). In order to compensate the crossing angle at IP by tilting the bunch horizontally and thus increase luminosity, crab cavities are installed in KEKB. The beam operation with crab crossing has continued since February 2007[2], [3].

 As there is only one crab cavity installed per ring, the bunches are tilted not only in IR region but also at the emission points for the synchrotron radiation monitors (SRMs). Thus we can measure the tilt of a bunch by observing the synchrotron light with streak cameras.

 We use the synchrotron radiation from the individual beam bunches produced in a weak bending magnet to measure the beam size.   High and low energy rings (HER and LER, respectively) are equipped with their own SRMs. The light paths from the weak bending magnets to the streak cameras are 35 m and 38 m for the HER and the LER, respectively. The streak cameras (Hamamatsu C5680) whose schematic view is shown in Figure 1 were used to measure the bunch length and the bunch-by-bunch transverse beam size. Two-dimensional (longitudinal - horizontal) beam profiles were taken to measure the crabbing angle.
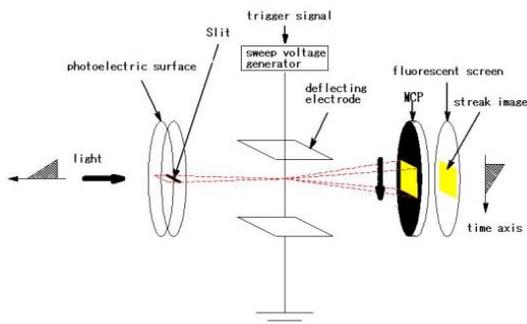
Figure 1: Schematic view of the streak camera.

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CALIBRATION

Accuracy of measurement

 The accuracy of the measurement was estimated before the crabbing angle measurement. The profile of a bunch was longitudinally divided into several pieces then the horizontal center of gravity of each piece was calculated. The tilt angle "b" of a bunch was obtained by fitting the centers of gravity H to a linear function of $H = a + b \times L$, where L is the longitudinal position of a piece. Figure 2 shows an example of a fitting result. The accuracy of the tilt was estimated by the distribution of "b" obtained from many samples and a calibration constant between pixel and length. The rms width of the "b" distribution was 0.022 with no applied voltage on the crab cavity. The width corresponds to $(3.6 \pm 0.675) \times 10^{-3}$ rad and about 10% of the expected crabbing angle at the SRM.
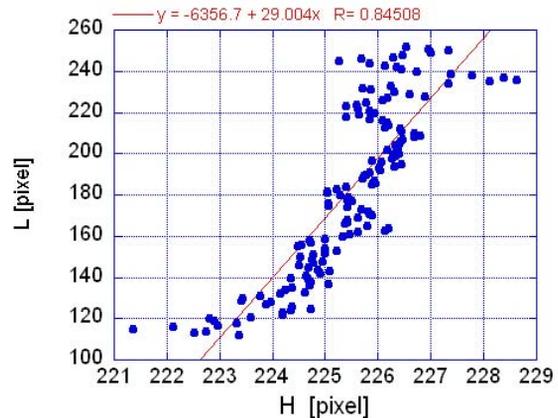
Figure 2: Fitting example of a crabbing angle of a single bunch at SRM.

Horizontal calibration

 A parallel orbit bump was set at the SR emission point for horizontal size calibration using 6 steering magnets as shown in Figure 3(a). The bump height was changed from -2 mm to +2 mm, then the center of gravity of the streak image at each point was measured. Figures 3(b) and (c) show the movement of the bunch by the bump. The movement in pixels on the CCD of the streak camera was converted to physical distance by fitting the bump height to the movement of the streak image in pixels as shown in Figure 4.

(a)

(b)   (c)
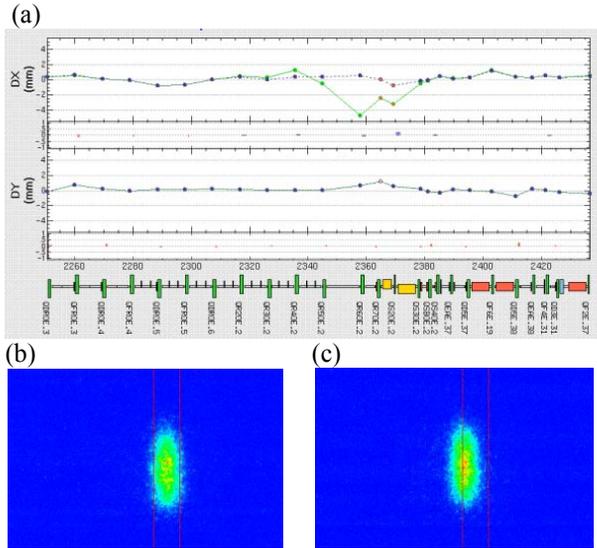
Figure 3: (a) Beam orbit at SR emission point and streak images at bump height 0 mm (b) and 2 mm (c).
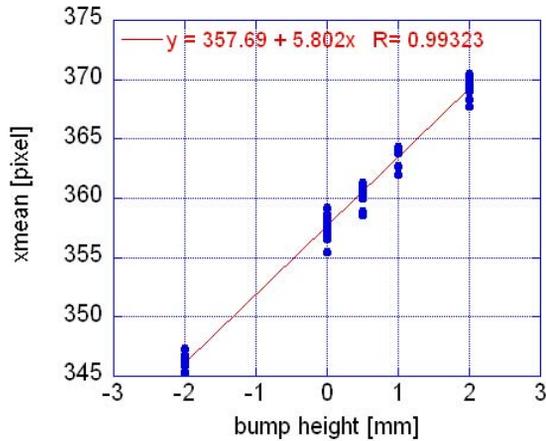
Figure 4: Horizontal unit calibration result.

Longitudinal calibration

The longitudinal (i.e. time) axis of the streak image was tuned at Hamamatsu before delivery and the accuracy of the time base is 1.95 ps, according to the inspection report from the company. It corresponds to 10% of the bunch length and is sufficient for our measurement.

We also calibrated the time axis on site as a cross check. A quartz plate of 20 mm thickness was installed in the light path to calibrate the longitudinal units. The index of refraction of quartz is 1.462 for 500 nm wavelength light. The time delay caused by the plate is 3.08 ps. The calibration constants are 4.24 and 3.16 pixels/mm for the HER and the LER, respectively. These values ar e consistent with the calibration constants by Hamamatsu photonics within 1% and 12%, respectively.

MEASUREMENT OF TILT

A single 1 mA bunch was injected into each ring after applying voltage to the crab cavities to check the crabbing

angle. Figure 5 shows the tilted bunch in the HER. The bunch tilted oppositely when the phase of the crab voltage changed by 180 degrees.

First, we checked the direction of the tilt and confirmed that both beams were tilted toward the inside of the ring at the SR emission points. Since the direction of the tilt is not changed between the SR emission point and IP according to the machine optics, the above result shows that both beams were also tilted to the inside of the ring, which means the directions of the crabbing angles are correct at the IP.
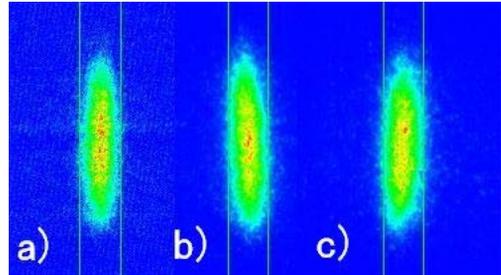
Figure 5: (a) Crab cavity voltage is 0. (b) Crab cavity is ON and a phase is 0 degree. (c) Crab cavity voltage is ON and the phase is 180 degree.

The crabbing angle of the bunch at the SRM was obtained by using the calibration constant. The results of the tilt measurements are shown in Figure 6. The two peaks correspond to the two sweep phases of the streak camera. Since a sweep frequency of the streak camera is 125MHz which is 1/4 of rf frequency of KEKB, while a bunch is on a rising side, another bunch is on a down side of the sinusoidal voltage depending on a bunch fill pattern. An example is shown in Fig. 7. The crabbing angle is the average of the two peak values. The obtained crabbing angles were 40.1 mr and 19.8 mr for the LER and the HER respectively.

Table 1: Beam optics parameter on March 8th, 2007.

	HER		LER	
	β_H	ν_H	β_H	ν_H
Crab	173.958	11.2497	62.2000	10.2500
SRM	25.8721	35.3621	24.1507	21.3905
IP	0.8	44.5108	0.84	45.5090

(a)   (b)
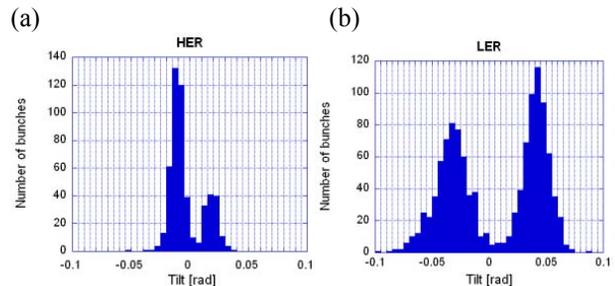
Figure 6: Distributions of crabbing angles of (a) the HER and (b) the LER.
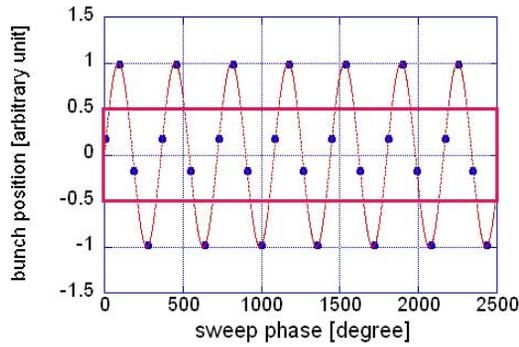
Figure 7: An example of the sweep phase of the streak camera when all rf buckets are filled by bunches. Red line is a sweeping voltage of the streak camera and blue points are filled bunches.

The expected tilt angle at the SRM, ϕ_{SRM}, can be calculated from the crabbing angle at the IP ϕ_{IP} as:

$$\frac{\phi_{SRM}}{\phi_{IP}} = \sqrt{\frac{\beta_{SRM}}{\beta_{IP}}} \frac{\cos(\pi\nu - |\psi_{crab} - \psi_{SRM}|)}{\cos(\pi\nu - |\psi_{crab} - \psi_{IP}|)}$$

where Ψ_{crab}, Ψ_{SRM}, and Ψ_{IP} are the betatron phases at the crab cavity, SRM and IP respectively, β_{SRM} and β_{IP} are the horizontal beta functions at SRM and IP and ν is the horizontal betatron tune. From the beam parameters tabulated in Table 1, the following tilt angles at the SRMs are obtained for ϕ_{IP} of 11mr:

$$\phi_{SRM(HER)} = 40.5 mr,$$

$$\phi_{SRM(LER)} = 42.9 mr.$$

Comparison between the measured and expected crabbing angles shows that while the measured crabbing angle in the LER is consistent with the expected value, the measured crabbing angle in HER is a factor of 2 smaller than the expected value.

In order to confirm the calibration method, several checks of the measurement were done at the HER as follows:

- Calculated tilt was almost the same whether one bunch is divided into 10 pieces or into all longitudinal pixels.
- Horizontal calibration via orbit bump was done with the crab voltage both ON and OFF. The results were consistent within 10%.
- A vertical calibration via orbit bump was done by rotating a light transfer mirror. The result showed a 30% difference of the calibration constant from that of the horizontal calibration. We think that the difference was caused by the deformation of the SR extraction mirror. The mirror deformation in the vertical direction is larger than that in the horizontal direction.
- Linearity of the orbit bump with respect to the movement of the streak image was checked by setting a small bump of about the beam size. It

was consistent with the data from larger bump step sizes.

- In order to check the optics, the readings of the BPMs which are located both sides of the SR emission point were compared with the calculated beam positions from the optics parameters when the phase of the crab voltage was changed by 90 degrees. They were consistent within 10% as shown in Table 2.
- Focusing mirrors of SR light in HER and LER were exchanged since the focal lengths of the mirrors differ by a factor of two. The results of the tilt measurement were consistent each other before and after the exchange.
- The core length of the HER source magnet is 2.9 m which is much longer than that of the LER. The position of the emission point of SR may have a deviation from the design value, for example, by an alignment error of a beam duct because of the large magnet length. The location of the emission point was measured by orbit bumps. The result shows that the correction to the expected crabbing angle due to the position error of the emission point is about 10 % which does not explain the discrepancy between the measured and the expected crabbing angles.

Table 2: Comparison of calculated and measured orbit at BPMs near SR emission point

		Calculated orbit [mm] @ crab phase π/2	BPM [mm] @ crab phase π/2
HER	BPM1	1.9614	1.8265
	BPM2	3.8756	3.5105
LER	BPM1	0.42369	0.81093
	BPM2	3.0648	3.2103

SUMMARY

The tilts of the bunches due to the crab cavities were observed with the streak cameras in both the HER and the LER of KEKB. The measurement showed that 1) the directions of the tilt were correct in both rings, 2) the tilt angle in the LER was consistent with the expected value from the beam optics and 3) the tilt angle in the HER was about two times smaller than the expected value. Inconsistency of the measured crabbing angle with the expected value in HER is under study.

REFERENCES

[1] KEKB Accelerator Papers, Nucl. Instrum. Meth. A499 (2003).
[2] K.Oide et al., "Compensation of the Crossing Angle with Crab Cavities at KEKB", in these proceedings.
[3] H. Koiso et al., "Beam Operation with Crab Cavities at KEKB", in these proceedings.