

# IMPROVED MEASUREMENT OF CRABBING ANGLE BY A STREAK CAMERA AT KEKB

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## Abstract

Crab cavities were installed in the KEKB rings in order to increase the luminosity. We measured the tilt of the bunches in the x-z plane using streak cameras. In a previous report [1], the measured tilt in the HER was 2 times smaller than the expected crabbing angle, while the LER measurement was consistent with that expected. After further studies we found that the discrepancy in measurement in HER was caused by an offset of the tilt.

## INTRODUCTION

The KEKB [2] is the asymmetric energy  $e^+e^-$  collider with a finite horizontal crossing angle of  $\pm 11\text{mr}$  at the interaction point (IP). We installed crab cavities into high and low energy rings (HER and LER) in order to compensate the crossing angle at IP by horizontally tilting the bunch, thus increase the luminosity [3].

Both rings in KEKB are equipped with diagnostics system utilizing synchrotron light. The streak cameras (Hamamatsu C5680) are used to measure the bunch length, the bunch-by-bunch transverse beam size and the two-dimensional (longitudinal - horizontal) beam profiles. The tilts of the bunches due to the crab cavities were measured by these streak cameras. From the beam optics parameters, the following tilt angles at the SRMs are expected for crabbing angle at IP of  $11\text{mr}$ :

$$\phi_{SRM(HER)} = 40.5\text{mr}, \phi_{SRM(LER)} = 42.9\text{mr}.$$

Figure 1 shows the tilted bunch in the HER measured by the streak camera. The bunch tilted oppositely when the phase of the crab voltage to the beam phase changed by 180 degree. The measurement showed that the directions of the tilt were correct in both rings. The tilt angle in the LER was consistent with the expected value calculated from the beam optics, while the tilt angle in the HER was about two times smaller than the expected value. Figure 2 shows the results of crabbing angle measurements in both rings. 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, a bunch is on a rising side and another bunch is on a down side of the sinusoidal sweep voltage as shown in Fig. 3.

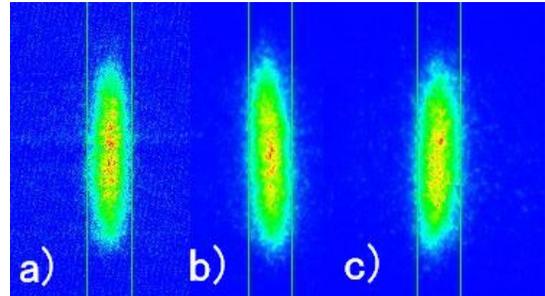


Figure 1: (a) Crab cavity voltage is 0. (b) Crab cavity is ON and a phase of the crab voltage is 0 degree. (c) Crab cavity voltage is ON and the crab phase is 180 degree.

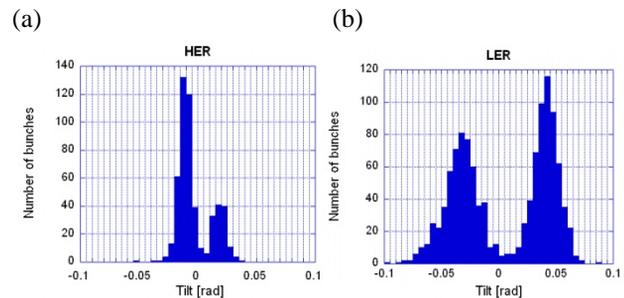


Figure 2: Distributions of crabbing angles of bunches in (a)HER and (b) LER.

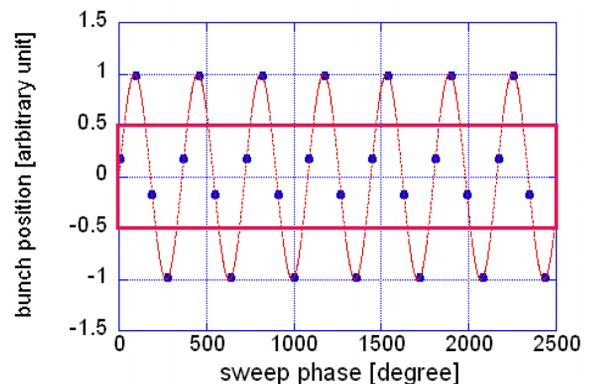


Figure 3: An example of the sweep phase of the streak camera when all rf buckets are filled by bunches. A red line is a sweeping voltage of the streak camera and blue points are filled bunches.

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### CRABBING ANGLE MEASUREMENT

In order to find out the reason of inconsistency of the measured crabbing angle and the expected value in HER, several studies were done.

#### Bunch Current Dependence

We checked the bunch current dependence of the measurement. The results are shown in Figure 4. Though a measurement error in small bunch currents is big, change of the current does not influence the measurement of the tilt. We notice that, when a crab voltage was turned off, a small offset of the tilt was seen though we expected no tilt without crab voltage.

#### Crab Phase Dependence

We scanned the phase of the crab voltage by 360 degree and measured the tilt. Figure 5 shows the result. At the crab phase of zero degree, maximum tilt is expected. The tilt should have the minimum at 180 degree of the crab phase. This was confirmed in Fig. 5. In addition, the tilts are same at zero and 360 degree. However, the sinusoidal curve seems shifted by -0.02 radians. Change of the tilt through the whole phase scan is about 80mr that is twice of the expected crab angle, which indicates the measurement was consistent with the expected tilt.

#### Crab Input Voltage Dependence

We changed the crab voltage from 0 to 1.43MV and measured the tilt. The result is shown in Figure 6. The tilt is almost linear to the crab voltage as expected. Again the offset of the tilt of about -0.015 radians is seen at null crab voltage.

#### Streak Phase Dependence

We observed the tilts by changing the sweep phase of the streak camera. Figure 7 shows the similar behaviour of the tilt at different sweep phases.

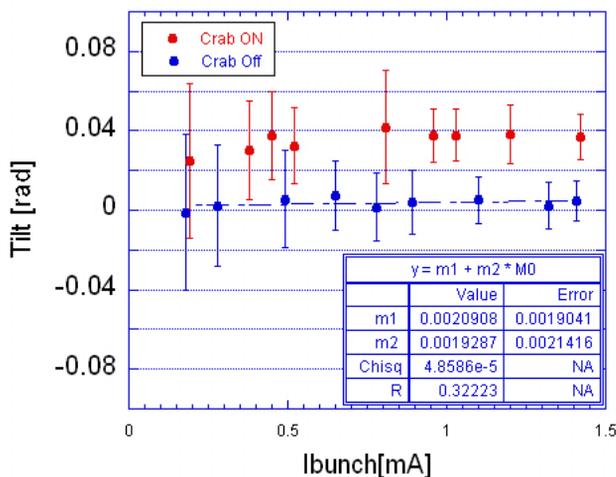


Figure 4: Bunch current dependence of the crabbing angle.

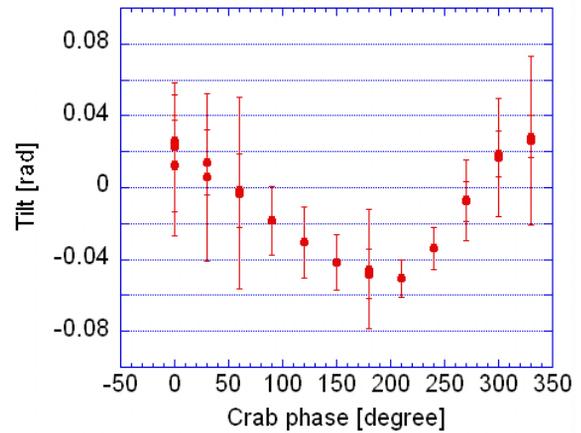


Figure 5: Crab phase dependence of the crabbing angle.

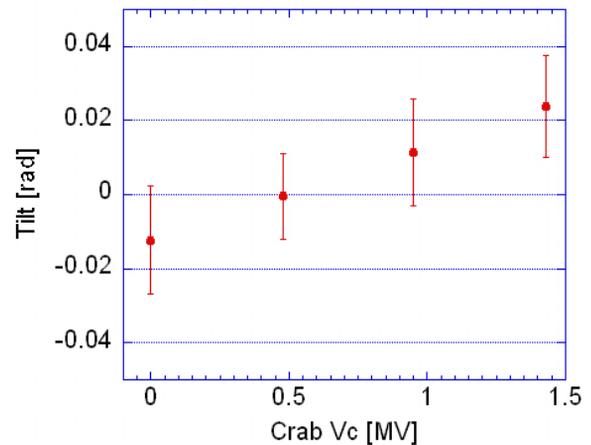


Figure 6: Crab voltage (Vc) dependence of the crabbing angle.

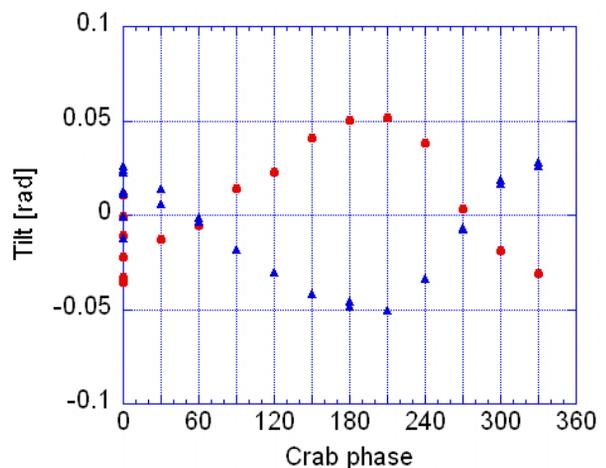


Figure 7: Crab phase dependence of the crabbing angle. The solid circles and triangles show the result for the different streak phase.

Above measurements indicate that the reason why only half of expected crabbing angle was observed at HER was due to the offset of the tilt which was not taken into account in the previous measurement. A remaining question is what is the source of the offset.

**STREAK CAMERA CALIBRATION**

Since the offset may be caused by the streak camera we calibrated the streak cameras by a following procedure.

A laser diode (LD) was driven by the sinusoidal wave of a synthesizer with the frequency of 508.88MHz. Through a pulse formation circuit, a light pulse whose width is about 40 - 50ps FWHM was obtained. A sweep trigger of the streak camera with repetition frequency of 125 MHz was obtained by a 1/4 frequency divider of the 508.88MHz signal. The signal of the LD was put to the streak camera through a light attenuator. A slit in front of the streak camera was replaced by a fiber input adapter. At first, horizontal (H) sweep was turned off. Only vertical (V) sweep was operated. Changing the delay of the vertical sweep, the image position on the screen was moved from top to bottom. The horizontal position of the image slightly shifted to left as the image moved from top to bottom, namely the V sweep was inclined with respect to the principal axis. A slant was not depended on the sweep ranges. For the H sweep a change of the slope was within 1pixel in HER and about 10 pixels in LER and no dependence on the sweep range and the position was found for the slope.

Then we checked the streak track with the double sweep. Figure 8 shows an example of HER measurement. Two measurement windows separated vertically were set on the screen and the difference of the horizontal peak positions of a light pulse in two windows was measured in the sweep range of 100ns in H direction and 400ps in V direction. The result showed that the slant of the sweep line depended on the horizontal position of the sweep and the slant was different even between the main and the return sweep. Table 1 shows the difference of the peak position for each vertical sweep.

For the camera in HER the slant was large. For the camera in LER the slope was large. In other words the effect of the offset to a tilt of the bunch is big in HER. As shown in Table 1, the slant became large from left to right on the screen. The difference of one pixel of peak position in Table 1 introduces the slant error of the vertical sweep of 0.0019 radians. If we used the most right position of the screen, the offset is expected to be 0.013 radians. It can explain almost the offset that we measured at the previous section.

**CONCLUSION**

The tilts of the bunches due to the crab cavities were observed with the streak cameras in both HER and LER of KEKB. The tilt angle in HER looked 2 times smaller than expected value in previously reported measurement [1], where we did not apply the correction of offset of the tilt. This time we measured the offset value using the crab

cavity voltage and phase scan. The offset is almost explained by the characteristic of the streak camera. This work showed that we can precisely measure the tilt angle of the bunch if we calibrate the offset using the data of the tilt in null crab voltage.

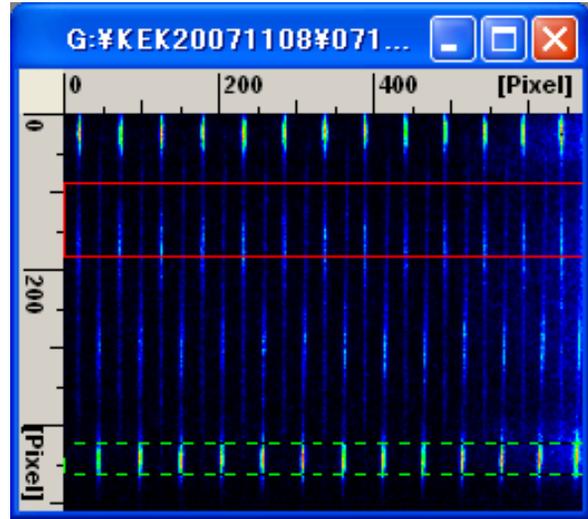


Figure8: The streak image with the double sweep.

Table 1: The horizontal position dependence of the peak difference of the HER streak camera image. The unit is pixel.

Pulse light No.	1	2	3	4	5	6
Peak Difference of main sweep	2	2	3	3	4	4
Peak Difference of return sweep	-2	-1	0	0	0	-1
Pulse light No.	7	8	9	10	11	12
Peak Difference of main sweep	5	5	6	7	6	7
Peak Difference off return sweep	0	0	0	0	0	0

**REFERENCES**

- [1] H. Ikeda et al., "Crabbing angle measurement by streak camera at KEKB", PAC07, p4018
- [2] KEKB Accelerator Papers, Nucl. Instrum. Meth. A499 (2003).
- [3] Y. Funakoshi et al, "Performance of KEKB with crab cavities", EPAC08, (2008) p1893.