Beam-Beam Effects Observed at KEKB

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Abstract

At KEKB, a dedicated machine experiment on crab crossing has been carried out for about 4.5 months this year. Some of the beam-beam effects observed with crab crossing, which include a beam lifetime issue, are discussed in comparison with those with a finite crossing angle of $\pm 11\mathrm{mrad}$.

INTRODUCTION

During the winter shutdown this year, a crab cavity was installed in each ring. After the installation, a dedicated machine experiment on crab crossing has been carried out for about 4.5 months. General results of the machine experiment are written elsewhere [1] [2]. In this report, characteristic beam-beam phenomena observed with crab crossing are described in comparison with those without crab crossing.

BEAM-BEAM PERFORMANCE

Beam-beam simulation

Recent beam-beam simulations showed that crab crossing or the head-on collision provides a very high beam-beam parameter $\xi_{\mathrm{y}} > 0.1$, if combined with horizontal betatron tunes very close to the half integer [3]. Figure 1 shows the comparison of ξ_{y} with the head-on (crab) and crossing angle with a strong-strong beam-beam simulation. A main purpose of the present experiment is to study if thus high beam-beam parameter predicted can be obtained in a real machine.

Achieved performance in experiment

Most of machine tuning in the experiment was done with a small number of bunches. Typical machine parameters with crab crossing are summarized in Table 1 compared with those without crab crossing. Fig 2 shows the specific luminosity per bunch with crab crossing in comparison with the crossing angle of $\pm 11\mathrm{mrad}$. The predicted specific luminosity by the strong-strong simulation is also shown. As is seen in the figure, the specific luminosity with crab crossing is higher than that without crab crossing. However, the achieved values so far are not as high as those from the beam-beam simulation. From the achieved luminosity, the beam-beam parameter was calculated. In the calculation, the hourglass effect is taken into account. As shown in Fig. 2, the highest value of ξ_y is 0.088.

Another problem with crab crossing is that storable bunch currents are not as high as those without crab crossing. A poor beam lifetime particularly in LER prevented us from storing the HER bunch current. To mitigate this problem, we tried to increase the HER horizontal emittance from 24nm to 29nm. As seen in Fig. 2, we could somewhat increase the HER bunch current with the higher emittance. However, its effect was very limited.

The achieved luminosity and the poor beam lifetime are very contradictory to the beam-beam simulation. Possible explanations for the low luminosity are discussed in anther report [1]. The lifetime problem is discussed below in connection with the asymmetry with respect to the IP horizontal offset.

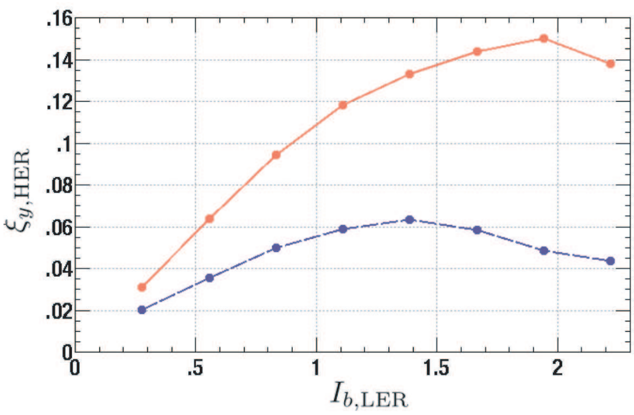

Figure 1: Enhancement of the vertical beam-beam parameter by a head-on (crab) collision (upper curve) comparing with the crossing angle of $\pm 11\mathrm{mrad}$ (lower curve), obtained by a strong-strong beam-beam simulation. Parameters are the same as the present KEKB.

Table 1: KEKB Machine Parameters.

	June 2007 with crab		Nov. 2006 w/o crab		
	LER	HER	LER	HER	
Energy	3.5	8.0	3.5	8.0	GeV
Circumference	3016		3016		m
I_{beam}	48	27	1662	1340	mA
# of bunches	50		1388		
I_{bunch}	0.94	0.53	1.20	0.965	mA
Ave. Spacing	59		2.1		m
Emittance	18	24	18	24	nm
β_x^*	80	80	59	56	cm
β_y^*	5.9	5.9	6.5	5.9	mm
Ver. Size@IP	1.1	1.1	1.9	1.9	μm
RF Voltege	8.0	15.0	8.0	15.0	MV
ν_x	.506	.510	.505	.509	
ν_y	.595	.596	.534	.565	
ξ_x	.089	.092	.117	.070	
ξ_y	.093	.084	.105	.056	
Luminosity	1.25		17.12		/nb/s

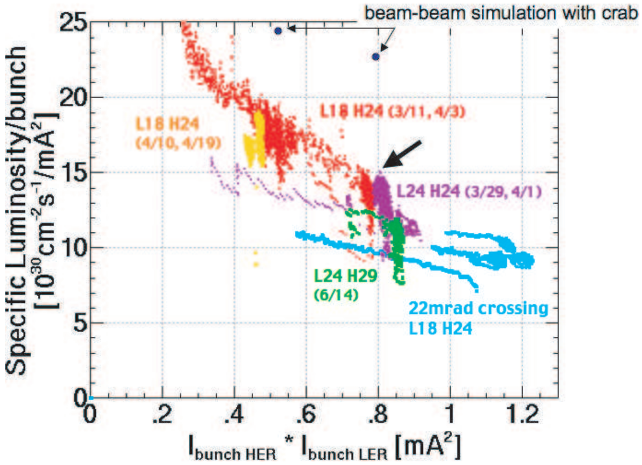

Figure 2: Specific luminosity per bunch with crab crossing comparing to crossing angle (thin blue) as a function of the product of bunch currents. We tried three different sets of the horizontal emittance; *i.e.*18nm(LER)/24nm(HER), 24nm(LER)/24nm(HER) and 24nm(LER)/29nm(HER). The highest value of $\xi_y \sim 0.088$ was achieved at the arrow. The predicted specific luminosity by the strong-strong beam-beam simulation is also shown.

OBSERVED BEAM-BEAM PHENOMENA

Beam size asymmetry with respect to horizontal offset at IP (finite crossing angle)

One of characteristic features with the finite crossing angle is that the LER beam size behaves quite asymmetrically with respect to the sign of the IP horizontal orbit offset [4] [5]. Fig. 3 shows a result of horizontal offset scans done in 2004. In this scan, we measured the luminosity, the vertical beam size of LER and the horizontal beam-beam kick as function of the horizontal offset at IP. As for the measurement of the beam-beam kick, we used two different methods. One is a method to use BPMs near IP which measure positions of colliding bunches. In this method, the sum of the beam-beam kick and the horizontal offset is obtained from the measurement. In another method, a BPM located in an arc section is used and the BPM measures positions of a colliding bunch and a non-colliding bunch separately and makes a difference between these two.

The center of collision (the zero horizontal offset) was obtained from the beam-beam kick measurements and in this scan the setting value of about -70μm gave the zero offset. As is seen in Fig. 3, there are two remarkable features. One is that the LER vertical size was very asymmetric with respect to the the horizontal offset. Another is that the zero-offset in the horizontal direction did not give a maximum luminosity. A finite value of the horizontal offset, about 50μm in this case, gave the maximum luminosity. In usual physics operation, due to these behaviors, we cannot rely on the horizontal beam-beam deflection for maintaining the optimum orbit relation of the two beams unlike the case of the vertical direction. Instead, the horizontal orbit feedback system utilizes the vertical beam size of LER for the monitor value. This feedback works by keeping the vertical beam size of LER at some target value.

The LER beam size blowup occurs with the negative sign of the horizontal offset where the LER beam is outside relative to the HER beam and the head part of the LER bunches collide with the HER bunches with a larger hor-

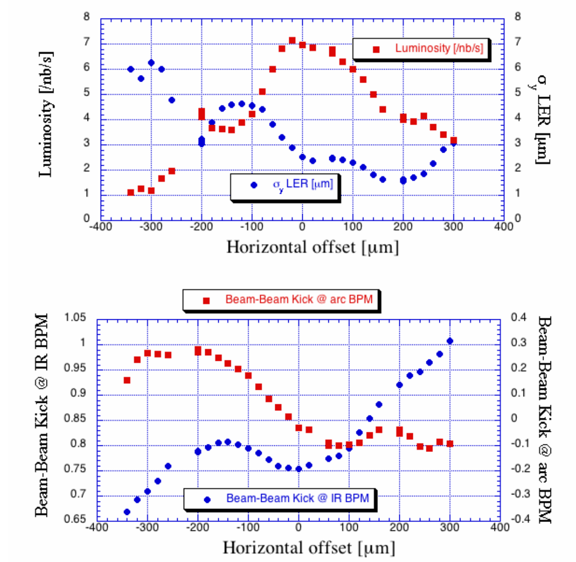

Figure 3: Horizontal offset scan done on June 9h 2004 with a finite crossing angle of ± 11mrad. Beam currents were 940mA and 1200mA for HER and LER, respectively. The number of bunches was 1289 for each ring and the averaged bunch spacing was 3.77 RF buckets. The luminosity, the LER vertical beam size and the horizontal beam-beam kick were recorded. Two different methods of the horizontal offset measurements were utilized.

izontal offset. The asymmetric longitudinal charge distribution for both beams due to impedance was suspected to be the source of the asymmetric behavior of the LER beam size. If so, it was expected that the asymmetry would disappear with crab crossing.

Beam lifetime asymmetry with respect to horizontal offset at IP (with crab crossing)

Fig. 4 shows a result of the horizontal offset scan done on May 28th 2007 with crab crossing. Since the beam lifetime decreases with higher bunch currents, the scan was done with rather smaller bunch currents compared with that in 2004. Again, the zero-offset was detected by measuring the beam-beam kick. It was remarkable that the asymmetry in the LER beam size was not observed with crab crossing. The luminosity peak coincided with the zero-offset point. It seems that this drastic change of beam behavior to the horizontal offset indicates realization of an effective head-on collision. As a result of this drastic change, we can not utilize the size feedback for controlling the horizontal offset with crab crossing. Instead, the beam-beam kick measured by using IR BPMs is utilized for the orbit feedback with crab crossing.

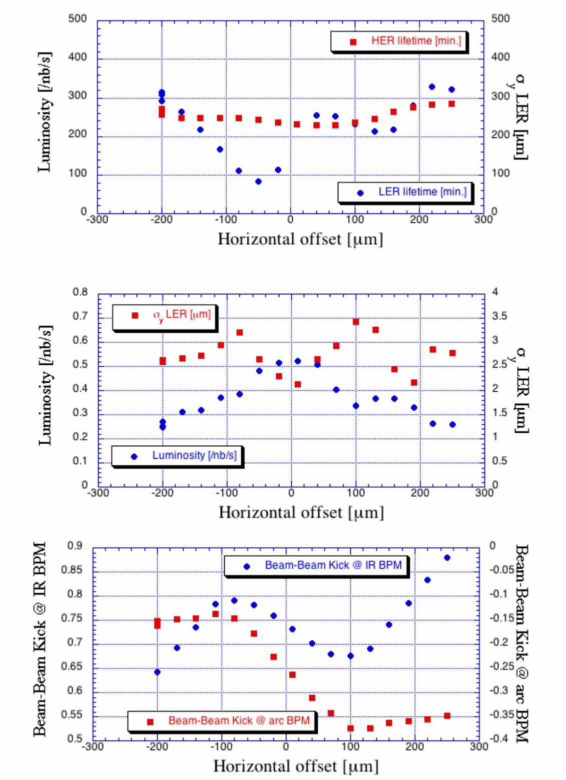

Figure 4: Horizontal offset scan done on May 28h 2007 with crab crossing. Beam currents were 40mA and 90mA for HER and LER, respectively. The number of bunches was 99 for each ring and the averaged bunch spacing was 49 RF buckets. In addition to the luminosity, the LER vertical beam size and the horizontal beam-beam kick, beam lifetime of both beams was recorded.

The beam lifetime is one of the most serious issues with crab crossing. As seen in Fig. 2, the product of the bunch currents could not reach the value with the crossing angle of $\pm 11\mathrm{mrad}$. This situation is not reproduced by the strong-strong beam-beam simulation. In addition, there is a mystery with the lifetime issue. As seen in Fig. 4, the LER beam life is very asymmetric to the horizontal offset. We have not yet understood the mechanism of the the lifetime decrease nor the lifetime asymmetry. Here, we summarize some observations on the lifetime asymmetry.

- The lifetime asymmetry appears at high bunch currents. With a higher LER bunch current, the HER lifetime shows asymmetric behavior. The asymmetry is a very universal and tough feature with crab crossing and always appear in either of the beams at higher bunch currents. The asymmetry does not depend so much on the betatron tunes or other machine parameters.
- The horizontal offset scan in Fig. 4 was done by making orbit bumps in HER. A similar scan can be done by changing the LER orbit or changing the collision point (we can make a horizontal offset with a shifted collision point by making use of the designed crossing angle). We found that the asymmetric nature did not change with different methods of making the offset. It seems that only the geometrical position relation at the IP determines the beam lifetime.
- When the asymmetry is observed, we intentionally enlarged the vertical size of the stronger beam by making a dispersion bump. However, the asymmetry did not change. It seems that this indicates that the vertical beam-beam tail is not responsible for the lifetime decrease.

Dynamic aperture is suspected to be responsible for the lifetime decrease, although a usual tracking with the beam-beam kick does not reproduce the asymmetry. We tried to explain the asymmetry with lattice non-linearity from some machine errors or from IR quadrupole magnets, which are not included in the usual tracking. However, we have not yet succeeded in explaining the asymmetry with plausible values of non-linearity. We need more studies on this issue.

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