FIRST BEAM COLLISION IN THE KEKB

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Abstract

The first beam collision study was done in the KEKB double ring collider. Beam collision conditions were found by searching beam-beam deflection curves in a trial-and-error method. From these curves, beam sizes at IP and a luminoisty was estimated.

1 INTRODUCTION

Unlike single ring colliders, special cares are needed to bring two beams into collision in double ring colliders like the KEKB. Generally speaking, there are several methods to detect beam collision. Among those methods, we have been made use of a beam-beam deflection technique, pioneered at the SLC[1], for this purpose. In this report, results of the first beam collision study are described where the beam-beam deflection method has been successfully applied to the KEKB collider to find beam collision conditions.

2 PROCEDURE OF FINDING BEAM COLLISION CONDITIONS

To establish a beam collision condition, we have to tune beams both in longitudinal and in transverse directions. As for the longitudinal direction, relative timing of the two beams have to be adjusted so that the two beams collide at the nominal collision point. As for the transverse direction, beam positions of the two beams at IP have to coincide with each other. In addition to this, beam crossing angles should be removed to ensure a stable beam collision. A vertical crossing angle is generally important. On the other hand, a horizontal crossing angle is usually less harmful and we have intentionally introduced a horizontal crossing angle of $\pm 11 mrad$ to simplify an IR design. In this beam study, however, we did not care the crossing angles and committed ourselves to the beam offset at IP.

2.1 Bassetti-Erskine formula

In analyzing data of the beam-beam deflection, we used the Bassetti-Erskine formula[2] which gives 2-dimensional beam-beam kick. This means that we ignored bunch length effects of the beam-beam interaction. With the rigid Gaussian model, the coherent beam-beam kick is given by the following expression.

$$\begin{aligned}\Delta y' + i\Delta x' &\\ = & -\frac{N_* r_e}{\gamma}\sqrt{\frac{2\pi}{\Sigma_x^2-\Sigma_y^2}}\{w(\frac{x+iy}{\sqrt{2(\Sigma_x^2-\Sigma_y^2)}}) \\ & -exp(-\frac{x^2}{2\Sigma_x^2}-\frac{y^2}{2\Sigma_y^2})w(\frac{\frac{\Sigma_y}{\Sigma_x}x+i\frac{\Sigma_x}{\Sigma_y}y}{\sqrt{2(\Sigma_x^2-\Sigma_y^2)}})\},\end{aligned}$$

where

$$\Sigma_x = \sqrt{\sigma_x^2+\sigma_{x*}^2},$$
$$\Sigma_y = \sqrt{\sigma_y^2+\sigma_{y*}^2},$$

and

$$w(z) = e^{-z^2}[1+\frac{2i}{\sqrt{\pi}}\int_0^z e^{\xi^2}d\xi]$$

is the complex error function. Here, x and y denote offsets of the horizontal and the vertical directions, respectively. r_e denotes the classical radius of the electron. Asterisks in subscripts mean that the values belong to the counter-rotating beam. When we can assume that there is an offset only in the vertical direction, the beam-beam dipole kick is expressed as:

$$\begin{aligned}\Delta y' &\\ = & -\frac{N_* r_e}{\gamma}\sqrt{\frac{2\pi}{\Sigma_x^2-\Sigma_y^2}}exp(\frac{y^2}{2(\Sigma_x^2-\Sigma_y^2)}) \\ & \times\{Erf(\frac{\frac{\Sigma_x}{\Sigma_y}y}{\sqrt{2(\Sigma_x^2-\Sigma_y^2)}})-Erf(\frac{y}{\sqrt{2(\Sigma_x^2-\Sigma_y^2)}})\}\end{aligned} \tag{1}$$

When there is an offset only in the horizontal direction, the beam-beam dipole kick is expressed as:

$$\begin{aligned}i\Delta x' &\\ = & -\frac{N_* r_e}{\gamma}\sqrt{\frac{2\pi}{\Sigma_x^2-\Sigma_y^2}}exp(-\frac{x^2}{2(\Sigma_x^2-\Sigma_y^2)}) \\ & \times\{Erf(\frac{-i\frac{\Sigma_y}{\Sigma_x}x}{\sqrt{2(\Sigma_x^2-\Sigma_y^2)}})-Erf(\frac{-ix}{\sqrt{2(\Sigma_x^2-\Sigma_y^2)}})\}\end{aligned} \tag{2}$$

where

$$Erf(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt$$

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is the error function.

2.2 Longitudinal

The collision point can be shifted by changing relative beam timing between LER (low energy ring) and HER (high energy ring). We adjusted an RF phase of LER so that relative timing of an LER bunch and an HER bunch at the BPM's agrees with a design value. Beam timing was observed by monitoring signals from a BPM nearest to IP with an oscilloscope. The BPMs are located at positions where it can detect timing of both beams.

2.3 Horizontal

We observed a horizontal beam-beam deflection with scanning horizontal orbit offsets at IP. The scan was done by changing the RF phase of LER by making use of a design horizontal crossing angle of $\pm 11 mrad$.

The beam-beam deflection was detected by measuring orbit change at BPM's beside quadrupole magnets named "QC2" where betatron phase advances from IP are almost $\pi/2$. A beam-beam kick is obtained from the following expression.

$$\Delta x' = \frac{\Delta x_{QC2R}}{\sqrt{\beta_x^* \beta_{xQC2R}}} + \frac{\Delta x_{QC2L}}{\sqrt{\beta_x^* \beta_{xQC2L}}}$$

Here, L and R denote the left side and right side viewed from the ring center, respectively. As shown in the formula, we took sum of these two BPM's to cancel out an effect of orbit drifts. A horizontal orbit offset at IP found from the scan was removed by making an orbit bump.

2.4 Vertical

A vertical collision condition was searched by scanning a size of an orbit bump made in one of the rings. Beam-Beam deflection was detected by measuring orbit change at BPM's beside quadrupole magnets named "QCS" where betatron phase advances from IP are almost $\pi/2$. A beam-beam kick is obtained from the following expression.

$$\Delta y' = \frac{\Delta y_{QCSR}}{\sqrt{\beta_y^* \beta_{yQCSR}}} + \frac{\Delta y_{QCSL}}{\sqrt{\beta_y^* \beta_{yQCSL}}}$$

To avoid an effect of orbit drift, we took sum of these two BPM's. The scan was continued until we obtained a deflection pattern which characterizes a beam-beam kick.

3 RESULTS OF COLLISION STUDY

3.1 Longitudinal

Beam collision timing was observed by monitoring signals from one of the electrodes of the BPM closest to IP under the condition that a single bunch is stored in each ring. First, RF buckets of the bunches was adjusted so that the bunches collide roughly at the nominal collision point. And then, beam collision timing was adjusted finely by changing an RF phase of LER. An amount of phase adjustment was 7 degree in this study. Since resolution of the timing measurement was around $10 \sim 20 psec$, an error of the tuning was considered to be less than 3mm ($10 psec$).

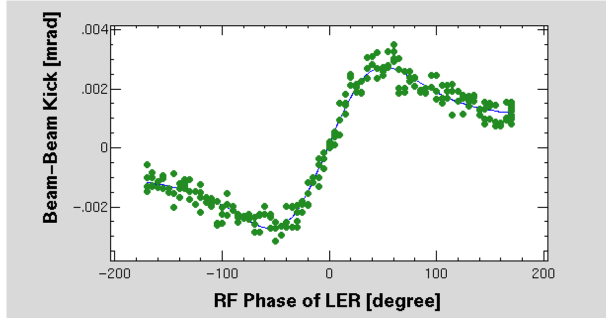

Figure 1: Horizontal Beam-beam scan with large vertical offset.

3.2 Horizontal

The collision study has been done twice. One was done in a single bunch mode and the other was with multibunch beams. Thereinafter in this report, we will only mention about the multibunch beam collision study most recently performed. Typical machine parameters relevant to the present study are summarized in Table 1. Figure 1 shows a typical result of the horizontal (RF phase) scan. In this case, there remained a relatively large vertical offset. The deflection curve was fitted by formula (2) to find a horizontal offset. To remove the horizontal offset, a horizontal orbit bump was made in LER. This process was repeated several times until the center of the curve coincides with the nominal RF phase (-7 degree in the present case). This iteration was needed since the beam-beam kick itself makes some orbit changes and we did not take this effect into account.

After removing the vertical offset (see below), the horizontal scan was done again. Figure 2 shows a result. Again the defelection curve was fitted by formula (2). From the fit, a horizontal beam size was estimated as shown in Table 1. We should note that the estimated value include some error, since we have not yet estimated the effect of the orbit change due to the beam-beam kick.

3.3 Vertical

After the horizontal beam offset was removed, a vertical beam-beam scan was done to search for an optimum collision condition by scanning a size of an orbit bump made in HER. A result of the search is shown in Fig. 3. As is seen in the figure, a relatively large offset of 0.73mm was observed. The vertical beam size was estimated by a fit using formula (1). Again we should note that the estimated beam size includes some error from the beam-beam kick itself.

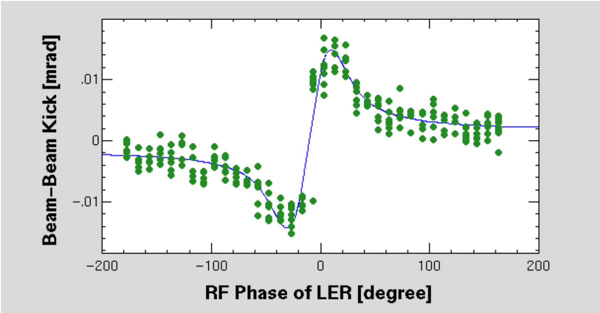

Figure 2: Horizontal Beam-beam scan without vertical offset.

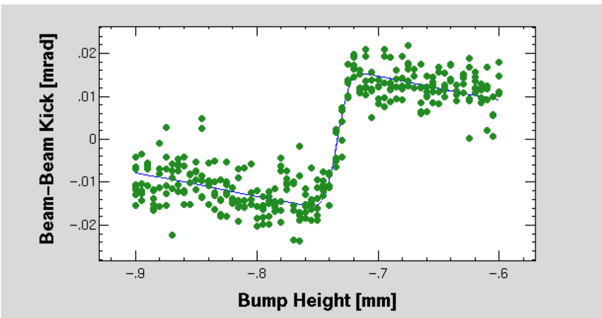

Figure 3: Vertical Beam-beam deflection.

3.4 Luminosity

From the horizontal and vertical beam sizes estimated from the deflection data, a luminosity was estimated to be around 1.7×10^{31} with an assumption that the two beam collide head-on. After removing the orbit offsets in both horizontal and vertical directions, a physics detector (BEAST) took data. Although beam collision was confirmed by events taken with EFC (Extremely Forward Calorimeter) in the BEAST detector, we could not make quantitative comparison due to a low event rate.

Table 1: Machine parameters used in the study

	HER	LER	
β_x^*/β_y^*	1/0.01		m
Beam current	13	65	mA
Number of bunches	200	200	
Beam size (Σ_x/Σ_y)	278/5.6		μm
Lifetime	40	200	$mim.$
Estimated luminosity	1.7×10^{31}		$/cm^2/sec$

4 SUMMARY AND FUTURE PLAN

A fine tuning on a collision timing was done by measuring a time difference of two beams. An error of the tuning was considered to be less than 3mm (10psec). A horizontal orbit offset at IP was measured by scanning an RF phase of LER. An offset was removed by making an orbit bump in LER. A vertical beam-beam scan was done by scanning a size of an orbit bump made at IP in HER. A relatively large vertical offset of 0.73 mm was observed. From the beam-beam deflection curves, beam sizes at IP and a luminosity were estimated. The first multibunch beam collision was done on 25th March with an estimated luminosity of $1.7 \times 10^{31} cm^{-2} s^{-1}$. We will do more precise analysis on the beam-beam deflection including a self-consistent orbit change due to a beam-beam effect.

The next step of the study is to keep the beam collision condition once found. For this purpose, we are preparing a special orbit feedback system also based on the beam-beam deflection technique.

5 REFERENCES

[1] P. Bambade and R. Erickson, SLAC-PUB-3979 (1986).

[2] M. Bassetti and R. Erickson, CERN-ISR-TH/80-06 (1980).