BEAM-BEAM SIMULATION STUDY WITH PARASITIC CROSSING EFFECT AT KEKB

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Abstract

We have studied the parasitic long-range beam-beam effect at the KEKB by a strong-strong beam-beam simulation. Simulation result shows a parasitic long-range nonlinear beam-beam effect change the contour diagram of the luminosity. The luminosity degradation is observed near the half integer tune due to the dynamic beta effect.

INTRODUCTION

KEK B-factory (KEKB) is an asymmetric-energy, double ring, electron-positron collider for B physics. The 8 GeV electrons stored in a high energy ring (HER) and the 3.5 GeV positrons in a low energy ring (LER) collide at one interaction point with a finite crossing angle of 22 mrad. The large finite crossing angle scheme helps to separate the two beams quickly, which allows a small bunch spacing.

On March 2005 the highest record of luminosity, $1.53\times10^{34}cm^{-2}s^{-1}$ has been achieved. The success of surpassing the design luminosity of $1.0\times10^{34}cm^{-2}s^{-1}$ at KEKB has clearly demonstrates the advantages of the finite crossing angle scheme.

However, the bunch spacing has been chosen to be 2.4 m (8 ns) in most physics run while the designed spacing is 0.6 m (2 ns). The horizontal beam separation distance at the parasitic collision point is

$$\Delta x = \theta \times \frac{l_{sp}}{2} = 6.6mm \tag{1}$$

for the 0.6m spacing at KEKB, while the nominal horizontal beam size at parasitic collision point is

$$\sigma(l_{sp}) = \sigma_0\sqrt{1+\frac{l_{sp}^2}{4\beta^2}} = 0.1mm. \tag{2}$$

Since there is more than 60σ separation in horizontal space, the long-range beam-beam force is weak.

The shorter bunch spacing is necessary to get a higher luminosity. However the degradation of the specific luminosity by unknown reason is observed in the shorter bunch spacing.

In order to investigate whether long-range parasitic beam-beam force degrades a beam-beam performance, we have performed a strong-strong beam-beam simulation with a parasitic long-range beam-beam force. In this paper we present our simulation results.

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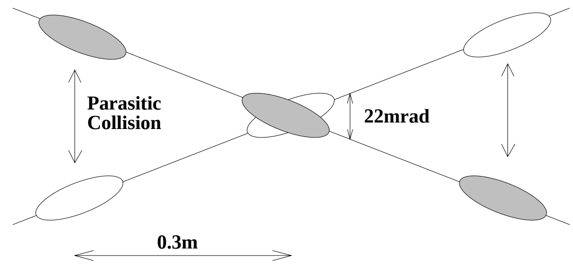

Figure 1: Schematic drawing of the parasitic collision with the finite crossing angle scheme.

SIMULATION MODEL

We are using the three dimensional beam-beam simulation code developed by K. Ohmi[1]. In the simulation, both beams are represented by 100,000 macro-particles. The transformation of the particles through the ring is calculated using a linear transfer matrix.

$$x(s+C) = Mx(s) \tag{3}$$

Beam-beam kicks for each beams at the collision point are evaluated by particle-in-cell method. Each beams are sliced longitudinally and particles are mapped on that transverse grid space according to their longitudinal positions. The two dimensional potentials for the each transverse grid are obtained by solving the Poisson equation by using a discrete fast Fourier transform.

The solution of the Poisson equation is expressed by an integral form using Green function G, The solution of the Poisson equation is expressed by an integral form using Green function G,

$$\phi(\vec{x}) = -\frac{1}{2\pi\epsilon_0}\int d\vec{x}G(\vec{x}-\vec{x'})\rho(\vec{x'}), \tag{4}$$

$$G(x) = ln|\vec{x}|$$

where ρ is the charge density distribution. The solution is obtained by convolution of the FFT of G and ρ,

$$\hat{\rho(\vec{k})} = \int d\vec{x}\rho(\vec{x})\exp(i\vec{k}\cdot\vec{x}), \tag{5}$$

$$\hat{G(\vec{k})} = \int d\vec{x}G(\vec{x})\exp(i\vec{k}\cdot\vec{x}). \tag{6}$$

$$\phi(\vec{x}) = \frac{1}{(2\pi)^2}\int d\vec{x}\hat{G}(\vec{k})\hat{\rho}(\vec{k})\exp(-i\vec{k}\cdot\vec{x}). \tag{7}$$

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In KEKB, the nominal beam-beam parameter (which is around 0.05) are relatively strong and the bunch length is comparable size with the vertical beta function. Because, in this case, the beam-beam force strongly depends on its longitudinal position, it requires many longitudinal slices. In stead of increasing longitudinal slice number, we obtain the beam-beam kick by interpolation between longitudinal slice potentials[3].

Long range beam-beam force for the parasitic collision is calculated by using a Basseti-Erskine formula[2]. We are using two methods to estimate beam-beam force, (i) soft target and (ii) fixed target method. In a soft target method, beam sizes are updated every turn . On the other hand, the beam size given by simulation without parasitic collision are used in the fixed target method. If necessary, a few iterations are repeated to determine the fixed beam size. In both method, parasitic kicks are applied every turn and two method gives us the same result. And we have assumed the drift space between parasitic point and collision point. Simulation parameters are listed in Table 1.

Table 1: Simulation parameters table of KEKB

	LER	HER
Energy	3.5 GeV	8 GeV
emittance	18 nm	24 nm
bunch population	7.9×10^{10}	5.9×10^{10}
bunch spacing	2.4 m	2.4 m
ν_s	-0.0249	-0.0217
β_x^*/β_y^*	59/0.52 cm	56/0.65 cm
σ_s	7.3 mm	6.7 mm
xangle	0.022	0.022
Circumference	3016 m	3016 m
Harmonic number	5120	5120
transverse damping time	40 ms	40 ms
Energy spread	7.3×10^{-4}	6.7×10^{-4}

We use the supercomputer (Hitachi SR8000) at the KEK computing research center. It has 100 node and each node has 12 G Flops (peak). Typically, it takes about 8 hours for 3 radiation damping time calculation using $128 \times 256 \times 5$ grids with horizontal and vertical mesh size of $10\mu m \times 0.25\mu m$. Two 32-nodes jobs are available for parameter scan with Message Passing Interface (MPI) library.

SIMULATION WITH PARASITIC EFFECT

The figure 2 shows evolution of the luminosity per bunch as a function of turns with 0.6m, 1.2m, 1.8m and 2.4m bunch spacing, respectively. The horizontal and vertical tune is 45.505 and 43.535 for LER and 44.513 and 41.582 for HER, respectively. There is no difference in the luminosity between the bunch spacings.

The figure 3 (a), (b) and (c) show the contour diagrams of the luminosity per bunch for KEKB-LER without a parasitic collision, 1.8m and 2.4m bunch spacing, respectively as a function of the horizontal and vertical tune. The colored makers show the history of the working point at KEKB-LER. The horizontal tune became to closer to the half integer. The present working point is (45.505, 43.535), which is found by the try and effort of commissioning group members, and is a good agreement with beam-beam simulation result.

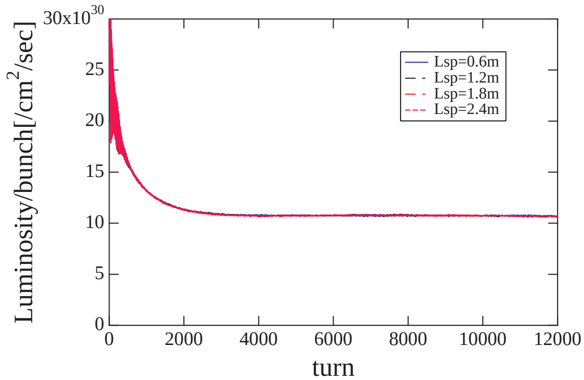

Figure 2: This figure shows the luminosity per bunch as a function of turns at KEKB with 0.6m, 1.2m, 1.8m and 2.4m bunch spacing.

The figure 3 (b) is almost similar to (c). The large degradation of the luminosity near the half integer is observed. When the horizontal tune is close to the half integer, the horizontal beta function of the collision point will be squeezed due to the dynamic beta effect. And the beam size at the collision point will be smaller. On the other hand, the beta function of the parasitic collision point will be increased and the beam size will be larger. This enlargement of the beam size at the parasitic collision point causes the degradation of the luminosity near the half integer tune.

And the good working region of (45.504, 43.545) without parasitic seems to moved to the lower vertical tune. It is not clear why the shift of the good working region occurs.

SIMULATION FOR SUPERKEKB

The SuperKEKB is a future upgrade plan of KEKB. The detail of SuperKEKB is shown in a letter of intent for SuperKEKB[4]. The figure 4 shows the contour diagram of luminosity per bunch as a function of transverse tune without parasitic effect for SuperKEKB. The peak luminosity of $8 \times 10^{31} cm^{-2}s^{-1}$ per bunch is obtained at the tune of (0.503,0.543) by the beam-beam simulation. It corresponds to the luminosity of $4 \times 10^{35} cm^{-2}s^{-1}$ for 5000 bunches.

SUMMARY

We have studied the parasitic effect at the current KEKB parameter. Simulation show long-range beam-beam force changes the contour diagram of the luminosity. The degradation of the luminosity near the half integer tune is observed due to the dynamic beta effect at the parasitic col-

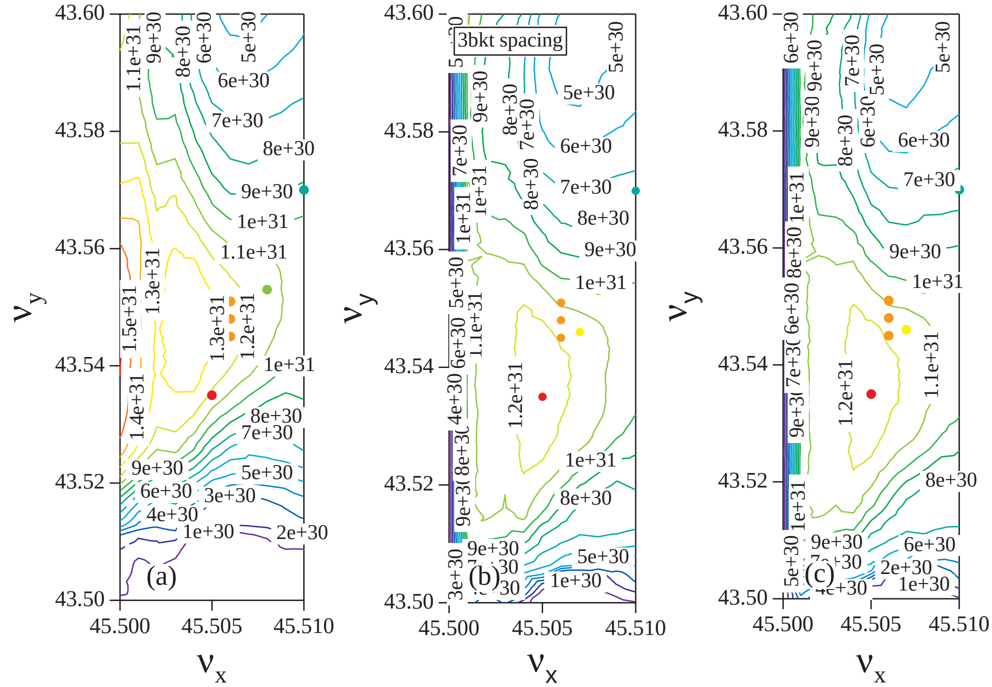

Figure 3: Each graph shows the contour plot of the luminosity/bunch ($/cm^2/s$) for KEKB-LER (a) without parasitic collision and (b) 1.8m bunch spacing (c) 2.4m bunch spacing. The colored makers show the history of the working point at KEKB-LER. The present working point of LER (ν_x/ν_y) is 45.505/43.535.

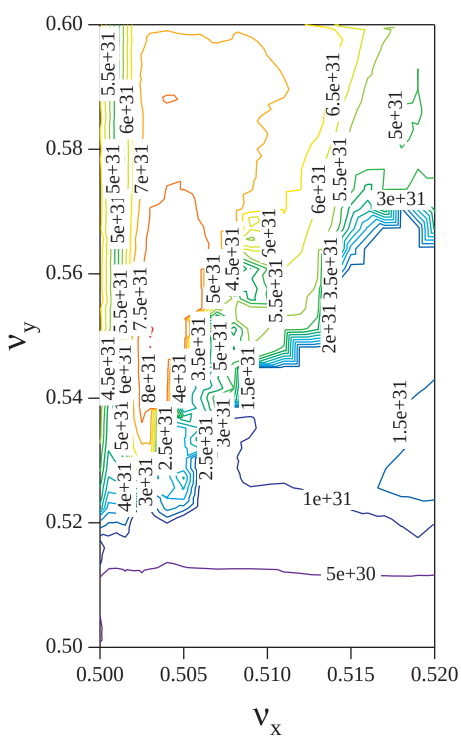

Figure 4: This figure shows the luminosity contour plot without parasitic effect for SuperKEKB.

lision point. Particle lost are observed at the early stage of the simulation with parasitical collision. Lifetime issue should be studied.

We have performed a tune survey simulation for SuperKEKB without parasitic effect. The peak luminosity of $8 \times 10^{31} cm^{-2} s^{-1}$ per bunch is obtained by the beam-beam simulation.

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REFERENCES

[1] K. Ohmi, Phys. Rev. E **62** 7287 (2000).

[2] M. Basseti and G. Erskine, CERN ISR TH/80-06 1975.

[3] K. Ohmi et. al., Phys. Rev. ST **7** 104401 (2004).

[4] Letter of Intent for KEK Super B Factory, KEK Report 2004-4, June 2004.

[5] Y. Cai et. al., in this proceedings (MOPC006)

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