COMPARISON OF BEAM-BEAM SIMULATION WITH EXPERIMENTS AT THE KEKB

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Abstract

The KEK B-factory (KEKB) is high luminosity electron-positron two ring collider and has high beam-beam parameter. To achieve such a high luminosity, it is important to study beam-beam effect. Newly, a beam-beam simulation code, which is based on a strong-strong model, was developed by K. Ohmi[3] to study beam-beam effect. For operation parameters of KEKB, we have carried out beam-beam simulations. In this report, we try to compare the results of the beam-beam simulations with the experiments. The simulation results are in good agreement with the experiments.

1 INTRODUCTION

The KEKB consists of two separate rings: 8 GeV electron ring (HER) and 3.5 GeV positron ring (LER)[1]. To study B quark physics, which is very rare process, KEKB has the high designed luminosity of 1×10^{34} $cm^{-2}sec^{-1}$ and the high beam-beam parameter of 0.05 for both rings.

Beam-beam simulations, which is based on weak-strong model showed that the beam-beam parameters of 0.05 are attainable if there is no machine errors and we choose operational tunes carefully[1]. In other words, to achieve high luminosity, it is important to correct machine errors which is relevant to beam-beam effects and choose tunes for higher beam-beam parameters.

Newly, a strong-strong simulation code was developed by K. Ohmi[3] to study beam-beam effect. In that simulation, both of the colliding beams are represented by macro-particles. The electro-magnetic fields of each relativistic beam are obtained by solving the Poisson equation for the charge distribution of the macro-particles. On each turn, the electro-magnetic fields are calculated for each beam, and then these beams are allowed to interact with each other through the fields. A transformation of the collided bunch across one revolution through the ring is calculated by using a beam transfer matrix. The effects of radiation damping and quantum excitation are included in this code.

We have carried out simulations for the KEKB parameters which were used in operation and compared these results with experiments. In these simulations, both beams are represented by 100,000 macro-particles and for which 5 longitudinal slices are used. The macro-particles are tracked for 45,000 turns. A 64×128 mesh with horizontal and vertical sizes of 20 $\mu m\times$0.4 μm was used, respectively. No error was included in these simulations.

Due to the fast progress in computing power, the strong-strong simulation becomes feasible. But this still requires a large amount of computer resources. It takes about 5 days on the Unix workstation of AP3000 (Sun) or 4 hours on the supercomputer of SR8000F1 (Hitachi) under above conditions.

2 COMPARISON OF SIMULATION WITH EXPERIMENT

Table 1 shows the paramters of the KEKB operations at present.

Table 1: Machine parameters of the KEKB. () is the designed value.

	LER	HER	unit
Horizontal emittance	29	30	nm
β_x/β_y	0.7/0.007 (0.33/0.01)	0.7/0.007 (0.33/0.01)	m m
Beam current	565	397	mA
No. of bunches/ring	1069 (2833)	1069 (2833)	
bunch current	0.53 (0.87)	0.37 (0.37)	mA
No. of trains	16	16	
No. of bunches/train	74	74	
Bunch spacing	8 (2)	8 (2)	nsec nsec
Bunch length	5.9@5.0	6.4@9.0	mm@MV
ξ_x/ξ_y	0.037/0.036	0.030/0.018	
	(0.039/0.052)	(0.039/0.052)	
ν_x/ν_y	45.51/44.07	44.519/42.176	
	(45.52/44.08)	(44.52/42.08)	
Lifetime	105@565	302@397	min@mA
Luminosity (CsI)	1.92×10^{33}		$/cm^2/sec$
	(1×10^{34})		

2.1 Luminosity History

The luminosity of KEKB have been limited by the several problems: (1) LER single beam blows up. (2) Heating of the movable masks for suppressing the detector beam background. (3) Heating of the vacuum bellows of the interaction point (IP). (4) Beam blow-up due to the beam-beam effect. (5) Beam current limitation from the instabilities of the LER and HER. (6) The beam background for the detector. The history of the KEKB commissioning, the luminosity optimization and the present performance of KEKB will be summarized by [4]. As the horizontal tune of LER was decreased, the peak luminosity was gradually increased and reached to the luminosity of $1.94\times10^{33}cm^{-2}s^{-1}$. The horizontal/ vertical beta functions of IP were reduced to the 0.7 m/ 7 mm at March 2000.

Figure 1 shows the luminosity tuning history from December 1999, the geometrical luminosity and the beam-beam simulation result. The tendency of the simulation result is in good agreement with that of the experiment.

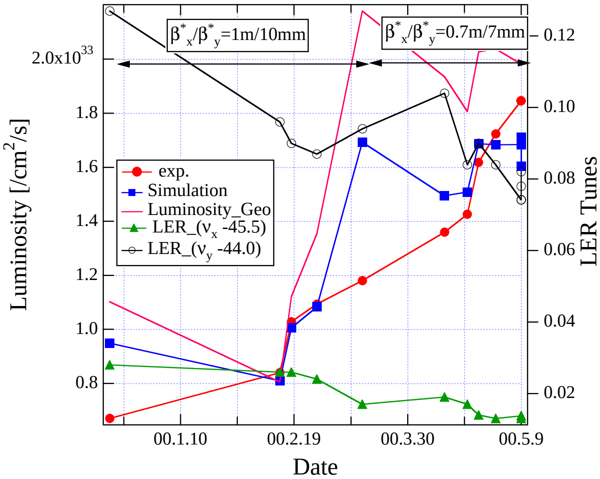

Figure 1: Luminosity history. The filled circle is the experimental peak luminosity, which was measured by the CsI luminosity monitor, the solid line is the geometrical luminosity and the filled box is the simulation result. The filled triangle and white circle is the horizontal and vertical tunes of LER.

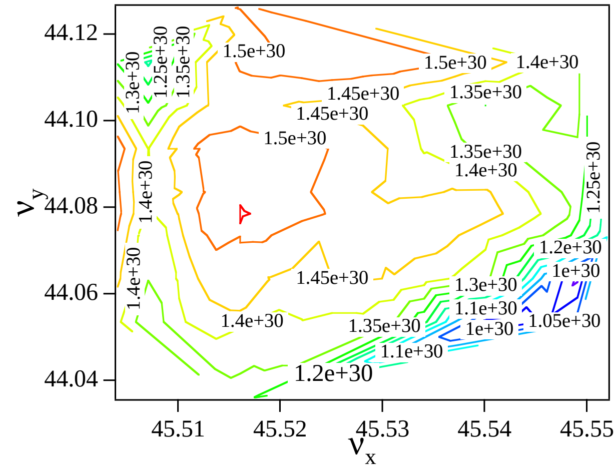

Figure 2: The result of LER tune survey by the strong-strong beam simulation around the present working point. The value on this graph is the luminosity for single bunch at the bunch current of 0.37 mA for HER and 0.58 mA for LER, respectively. The present LER working tune is ν_x~45.52, ν_y~44.08.

2.2 LER tune survey

The present LER working tune (ν_x~45.52, ν_y~44.08) were found out by trial and error around the design point. Usefulness of the tunes is estimated from three viewpoints: (1) injection efficiency, (2) beam instability (beam lifetime) and (3) luminosity. We have noticed that the luminosity is very sensitive to the LER horizontal tune. So, we have carried out the small tune survey of LER by the strong-strong simulation. The result was shown in the Figure 2. This is almost in good agreement with the experiences of the commissioning. There are slightly differences of the LER vertical tune with the result of the strong-weak simulation[1].

2.3 Waist Scan

The waist search is an important tuning procedure in the KEKB operation. The scan is done by changing strength of quadrupole magnet near the IP, where the betatron phase advance from the IP is almost $\pi/2$, which means that the modulation in the beta functions is almost localized around the IP and observing the luminosity and the beam sizes of each beam. The luminosity was measured by the CsI luminosity monitor and the beam sizes of both rings were measured by the synchrotron light interferometers[5]. Because it takes a long time to search waist point and the each current of HER and LER is changed, in this report, we use a specific luminosity, which is defined as (the measured luminosity [$cm^{-2}s^{-1}$])/1×10^{30}/(HER bunch currents [mA])/(LER bunch currents [mA])$\times$1000 in stead of the luminosity.

A typical result of the waist scan in LER is shown in Figure 3. The specific luminosity of the experiment and the simulation are plotted. The vertical beam sizes of the experiment and the simulation are shown in Figure 4. The beam blow up effect is not included in these calculations.

The luminosity curve of the simulation is similar to the experiment. The vertical beam size of the experiment is bigger than the simulation a little.

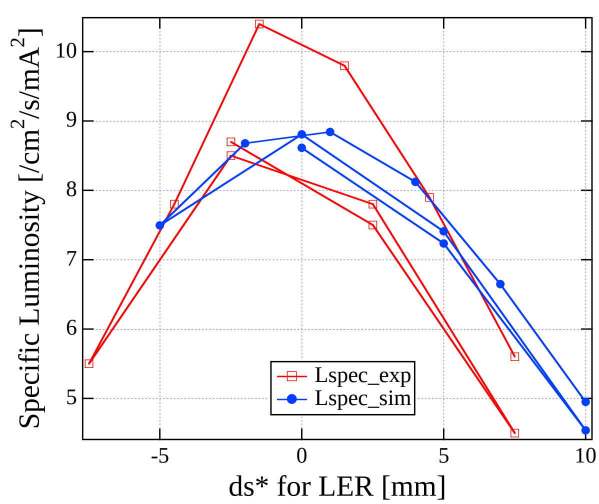

Figure 3: Typical example of waist Scan of LER. The measured specific luminosity (box) and the simulation result (black circle) are shown. The points were connected by solid lines in order of the measurements. Each simulation was carried out at the current which is corresponds to each measurement

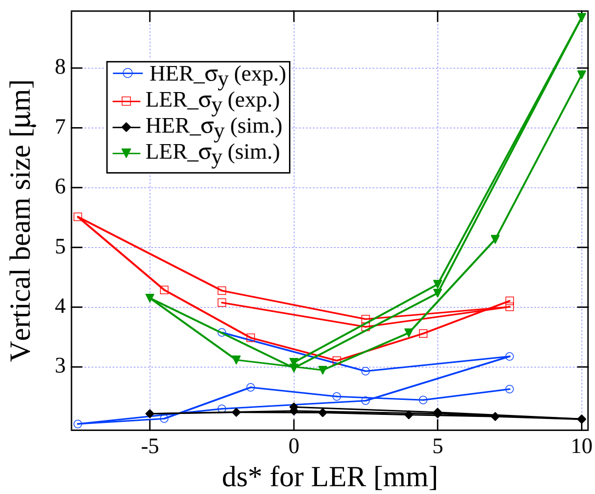

Figure 4: The measured vertical beam sizes for LER and HER and the simulated vertical beam sizes for LER and HER are shown. The points were connected by solid lines in order of the measurements

2.4 *The current dependence of the specific luminosity*

As the currents of both rings are decreased, the specific luminosity is slightly increased. Figure 5 shows the specific luminosity of the experiment and the simulation as a function of the product of HER currents and LER currents. There is a difference between the experiment and the simulation.

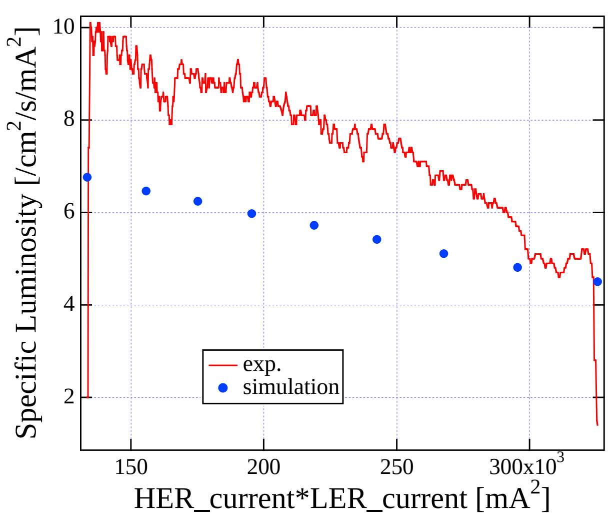

Figure 5: The specific luminosity of the experiment and the simulation are shown as a function of the product of HER currents and LER currents.

3 SUMMARY

We have carried out the beam-beam simulation, which is based on strong-strong model, at the KEKB operation parameters. This beam-beam simulation is very useful and important to study the beam-beam effect.

The simulation results are almost in good agreement with the experiments. But the luminosity of the simulation is entirely smaller than the experiments. Some of the assumed parameters, e.g. the vertical emittance may not be correct. We must check these parameters as possible as we can do.

The KEKB has successfully stored over 700 mA for LER and 500 mA for HER. The luminosity of KEKB has been increased up to the value of $1.94\times10^{33}\text{cm}^{-2}\text{s}^{-1}$. The decrease of the horizontal tune of LER is effective to obtain that luminosity. To achieve the designed luminosity, we will continue to investigate the beam-beam effect.

Now the beam blow-up problem of LER, which is probably due to the photoelectron instability, is serious to obtain higher luminosity. This code can be applied to the interactions between the positron beams and the photoelectrons.

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