Beam-Beam experience at KEKB

M. Tawada, K. Akai, N. Akasaka, K. Bane*, A. Enomoto, J. W. Flanagan, H. Fukuma, Y. Funakoshi, K. Furukawa, J. Haba, S. Hiramatsu, K. Hosoyama, N. Huang†, T. Ieiri, N. Iida, H. Ikeda, T. Kamitani, S. Kato, M. Kikuchi, E. Kikutani, H. Koiso, S. -I. Kurokawa, M. Masuzawa, T. Matsumoto, S. Michizono, T. Mimashi, T. Nakamura, Y. Ogawa, K. Ohmi, Y. Ohnishi, S. Ohsawa, N. Ohuchi, K. Oide, E. A. Perevedentsev‡, D. Pestrikov‡, K. Satoh, M. Suetake, Y. Suetsugu, T. Suwada, M. Tejima, M. Tobiyama, S. Uno, Y. Z. Wu†, N. Yamamoto, M. Yoshida, S. Yoshimoto, M. Yoshioka, C. H. Yu†, F. Zimmermann§, KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken 305-0801, Japan

Abstract

KEKB has achieved the peak luminosity of 4.1×10^{33} cm^{-2}sec^{-1} and the present capability for delivering integrated luminosity is 224 pb^{-1}/day. This paper describes (1) the recent performance and the problems of KEKB and (2) the comparison of beam-beam simulations with experiments at KEKB.

1 INTRODUCTION

KEKB is a double ring electron-positron collider to study B-meson physics. One ring is an 8 GeV electron ring (HER) and the other is a 3.5 GeV positron ring (LER). The HER and LER rings cross at the interaction point (IP) with a ±11 mrad crossing angle. To study B-meson physics, which deals with very rare processes, KEKB has a high design luminosity of 1×10^{34} cm^{-2}sec^{-1} and high vertical beam-beam parameters (ξ_y) of 0.05. The general outline and overall parameters of the KEKB accelerator are given in [1].

Recently, there has been excellent progress in commissioning of the KEKB accelerator. Figure 1 shows the luminosity history of KEKB from the beginning of the commissioning with the Belle detector. The peak luminosity of 4.1×10^{33} cm^{-2}sec^{-1} was achieved and the present capability for delivering integrated luminosity is 224 pb^{-1}/day, 4.7 fb^{-1}/month. The total integrated luminosity of 30 fb^{-1} was accumulated[2]. Table 1 summarizes the present parameters which are related to the luminosity with the design parameters.

2 RECENT IMPROVEMENT OF KEKB PERFORMANCE

KEKB performance has been improved by several means: (1) installation of solenoids to LER, (2) a shift of the vertical tunes above a half integer for both rings , (3) increasing the HER bunch current after the replacement of HER movable masks to those of a new type of mask and (4) a continuos tune monitor of pilot bunch.

* visiting from SLAC, U.S.A
† visiting from IHEP, China
‡ visting from BINP, Russia
§ visiting from CERN, Switzerland

	LER	HER	unit
Horizontal emittance	18	24	nm
Beam current	885 (2600)	748 (1100)	mA
No. of bunches/ring	1154 (5120)	1154 (5120)	
Bunch current	0.77 (0.5)	0.65 (0.2)	mA
Bunch spacing	2.4 (0.6)	2.4 (0.6)	m
Bunch trains	1	1	
σ_x^*	103	123	μm
$\sigma_y^{*\,1)}$	2.9	2.9	μm
ϵ_y/ϵ_x	4.2	3.2	%
β_x/β_y	0.59/0.0065 (0.33/0.01)	0.63/0.007 (0.33/0.01)	m
$\xi_x/\xi_y{}^{2)}$	0.072/0.045 (0.039/0.052)	0.050/0.028 (0.039/0.052)	
ν_x/ν_y	45.51/44.57 (45.52/44.08)	44.519/42.517 (44.52/42.08)	
Beam lifetime	166@854 mA	210@675 mA	min.
Bunch length	5.9@8.0	6.4@11	mm@MV
Luminosity (CsI)	4.1×10^{33}	(1×10^{34})	/cm^2/sec
Luminosity records per day/ 7 days / month	224/1336/4703		/pb

Table 1: The present machine parameters and performance of the KEKB (June 13, 2001). The values in a parenthesis are the design values. 1) Vertical beam sizes of the two beams are assumed to be equal. 2) An effect of dynamic beta and dynamic emittance is not considered.

2.1 Installation of solenoid to LER

A vertical beam blowup has been observed in LER since early operation. The main characteristics of the blowup are explained by single-beam head-tail instability caused by an electron cloud. About 4600 solenoids were installed to LER in order to suppress the electron cloud. Its total length is about 1.23 km and about 40 % of the ring circumference was covered by solenoid field. The calculated field strength was 45 Gauss at the center of the solenoid when the maximum current of 5 A was applied. Figure 2 shows the luminosity as a function of the bunch current product with and without solenoid field.

The averaged vertical beam size over all bunches are

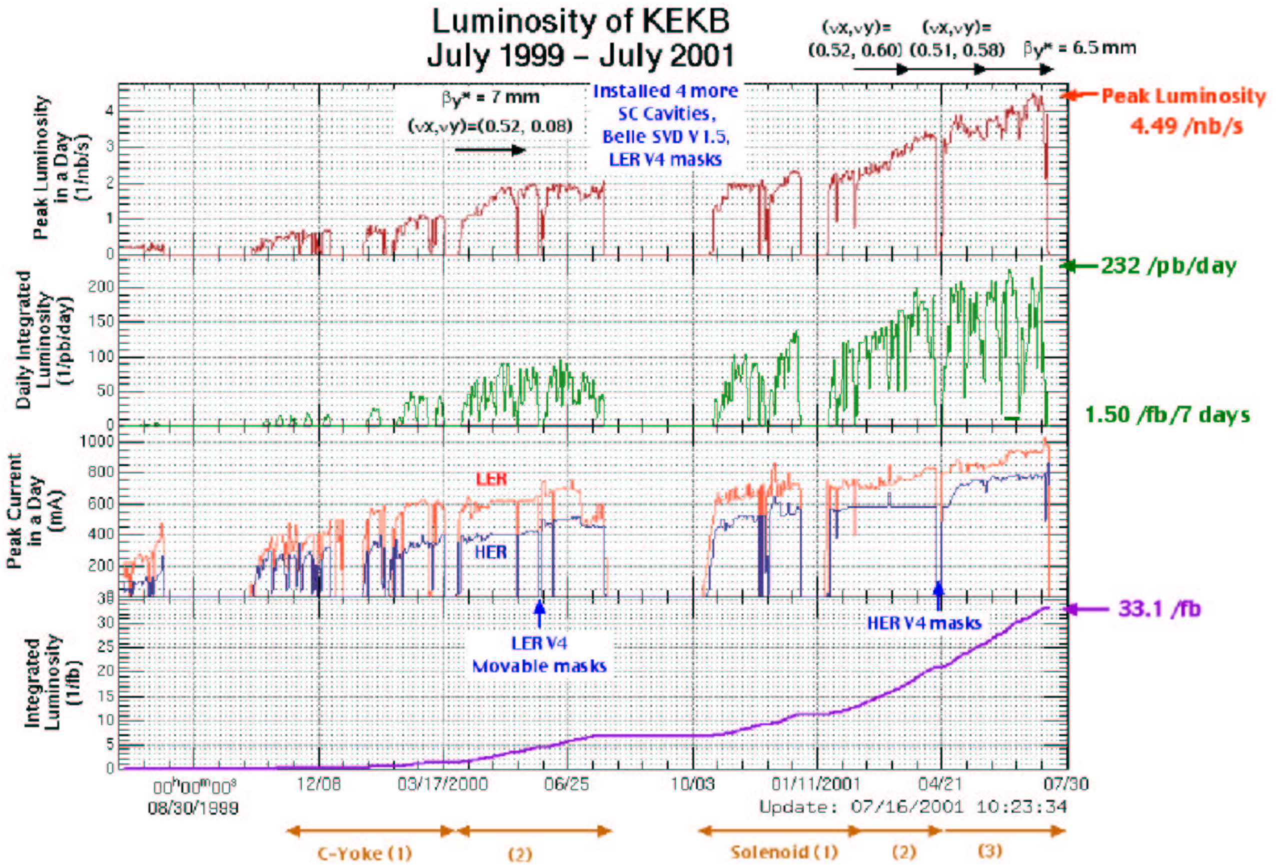

Figure 1: This figure shows the luminosity history from the beginning of the commissioning with Belle detector (July 16, 2001).

measured by a synchrotron radiation interferometer [3]. The beam size is transformed from the source point of the synchrotron radiation to IP. The threshold current of blowup was also increased when solenoids were excited[4]. The problem is improved but not solved yet. The vertical beam size is still large at the higher beam current than 700 mA with 1154 bunch mode.

2.2 Tune Survey and Continuous Tune Monitor

We have moved to the vertical tune above the half integer for both rings at February, 2001. The reason is as follows. (1) The closed orbit at the tune above the half integer is not so sensitive to the machine errors as that with a tune just above the integer. (2) The strong-strong beam-beam simulations have predicted a tune region above the half integer would bring a better luminosity[5].

The machine stability was also improved by the continuos tune monitor of pilot bunches. This monitor can measure the tune during both injection and physics time by using un-collided bunches.

2.3 HER current

The movable mask is a device that cuts off spent electrons/positrons just near the beam orbit and reduces background of a detector. Sixteen movable masks were installed for each ring of KEKB. Heating problems of movable masks have limited the stored beam currents for HER. New movable masks have been designed employing RF technologies for HOM damping[6].

After replacement of the HER movable masks to a new type[7] at April, 2001, we could increase the beam currents gradually.

3 PRESENT LUMINOSITY LIMITATION AND PROBLEM AT KEKB

The luminosity of KEKB has been limited by the several problems. (1) Installation of the solenoids to suppress the electron cloud instability has improved the problem as described before but not resolved it completely. (2) It turned out that the LER single beam blowup is sensitive to the filling pattern. We have tried various filling patterns to increase the number of bunches. But we could not get higher luminosity than that with 4 rf bucket spacing. (3) The total beam current is limited by the heating of vacuum components due to the synchrotron radiation or HOM. And the bunch current is also limited by the heating of the HOM damper of the superconducting cavity for HER. (4) beam background for Belle detector.

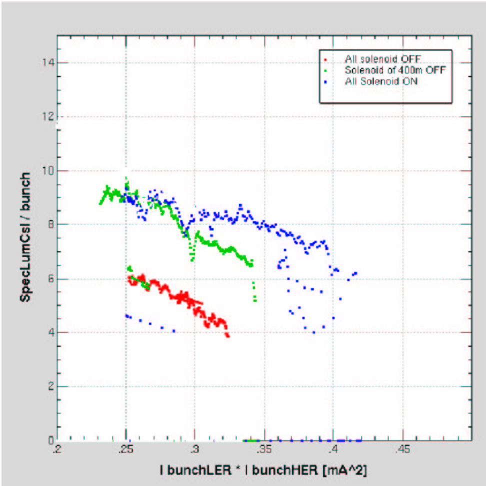

Figure 2: Specific luminosity per bunch as a function of the bunch current product in the case of all solenoid OFF(🔴), solenoid of 400 m OFF(🟢) and All solenoid ON(🔵)
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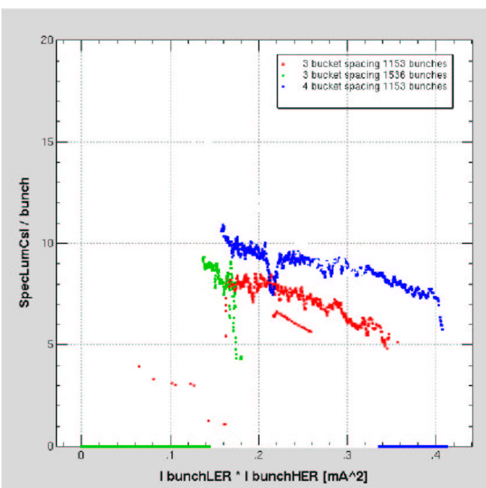

Figure 3: The data for the 3 rf bucket (🔴,🟢) spacing pattern show lower specific luminosity than that for the 4 rf bucket (🔵) pattern.

3.1 *"Egure" problem*

Sudden drops of the luminosity, so called "Egure" at KEKB, are frequently observed. Figure 4 shows a typical "Egure" pattern. The "Egure" accompanies the LER horizontal beam size growth. (sometimes accompanies vertical beam size growth.) When "Egure" is occurred, we make the horizontal beam separation ($\sim$ 50 μm) for short time and then the luminosity is recovered.

F. Zimmermann have explained that "egure" problem comes from a significant tune dependence and the existence of flip-flop solutions for head-on collisions by evaluating a simplified linear model of beam-beam interaction[8].

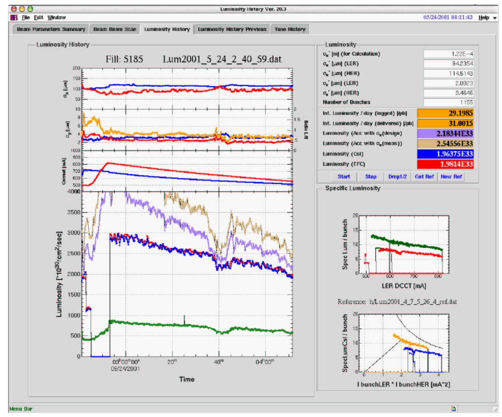

Figure 4: This figure shows a typical "Egure" pattern.

4 BEAM-BEAM SIMULATION

Newly, a strong-strong beam-beam simulation code was developed by K. Ohmi[9] to study beam-beam effect. In that simulation, both of the colliding beams are represented by macro-particles. The electron-magnetic fields of each relativistic beam are obtained by solving the Poisson equation for the charge distribution of the macro-particles. At each turn, the electron-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 are quantum excitation are included in this code. The machine errors can be included.

We have carried out simulations for the KEKB parameters which were used in operation and compared these results with experiments. A 64$\times$128 mesh with horizontal and vertical sizes of 20$\times$0.4 μm mesh was used, respectively. Both beams are represented by 100,000 macro-particles, typically. The macro-particles are tracked for 45,000 turns. Due to the fast progress in computing power, the strong-strong beam-beam simulation becomes feasible. But it still requires a large amount of computer resources.

Figure 5 shows the longitudinal slice number dependence of specific luminosity. Although the slice number should be bigger than 20, but we usually used 5 longitudinal slices due to the limited computing resources. Even if longitudinal slice number is 5, the simulation results are in reasonable agreement with measurements qualitatively in many cases. For a simulation for one tune point, it takes about 5 days on the Unix workstation of AP3000 (Sun) and about 4 hours on the supercomputer of SR8000F1 (Hitachi), which have 12 GFLOPS for each node under above conditions.

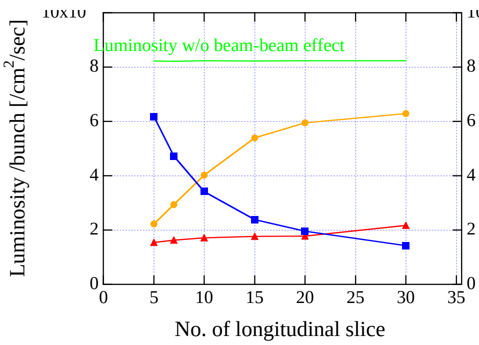

Figure 5: Longitudinal slice number dependence of specific luminosity. They were tracked for 20,000 turns, respectively. The yellow filled circle is(●) is the luminosity per bunch, the red filled triangle (▲) and the filled box (■) is the vertical beam size of LER and HER, respectively.

4.1 Tune Survey

Since the luminosity at KEKB is sensitive to the tune, the tune survey is a very important tuning issue. We have shifted the vertical tunes above a half integer for both rings as described before.

The beam-beam simulation without errors shows that ν_x ~45.51, ν_y ~44.64 is the best point in that area(the upper graph of Figure 6). We have tried to the LER vertical tune of 44.64 several times. But the luminosity with that tune is lower than that with the present working point(ν_x ~45.51, ν_y ~44.57), which is found by a trial and error method.

The simulation with the error of vertical crossing angle explains the lower luminosity at the tune of ν_x ~45.51, ν_y ~44.64 is caused by machine error(the bottom graph of Figure 6).

4.2 Specific luminosity versus current product

Beam-beam effects cause an increase in vertical beam size and subsequent decreases in specific luminosity. Figure 7 shows the simulation of the specific luminosity versus the beam current products. The measured bunch current and bunch length are also used as input parameters for simulations. The simulation is in good agreement with the experiment.

4.3 Vertical emittance dependence of Luminosity

As shown in the Figure 8, the beam-beam simulation predicted that (1) the vertical emittance of HER can be optimized to get a higher luminosity and (2) the vertical emittance dependence of the luminosity for KEKB is stronger than that for the case of zero-crossing angle.

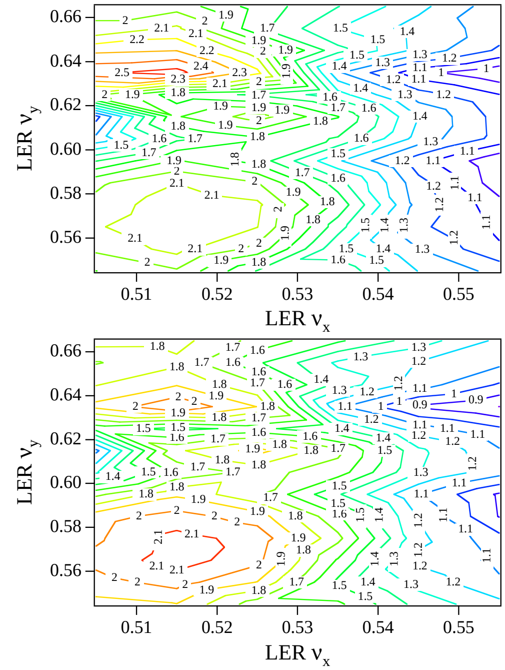

Figure 6: The result of LER tune survey by the strong-strong beam-beam simulation without errors (Top graph) and with the error of the vertical crossing angle of 0.1 mrad (Bottom graph).

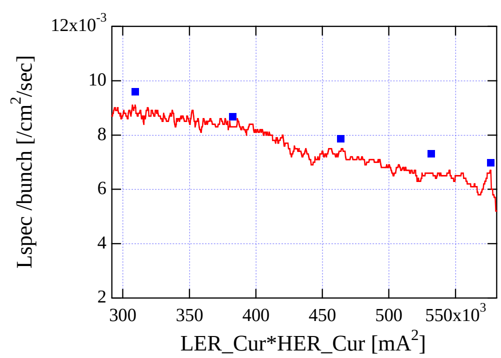

Figure 7: Specific luminosity/bunch as a function of the current products. The red solid line is the experimental result(May 2, 2001, Fill 4811) and the blue filled box (■) is the simulation result. The longitudinal slice number is 10 in this simulation.

The vertical emittance feedback system is realized by so-called "iSize" feedback system at KEKB[10]. At one of the strongest non-interleaved sextupole pairs in the arc section of HER, an anti-symmetric bump is made by three dipole correction magnets. This bump converts the horizontal dispersion to the vertical. It leaks out around the whole of the ring. The created xy-coupling is closed in the bump. This dispersion enlarges the vertical emittance. " iSize" system at KEKB works well.

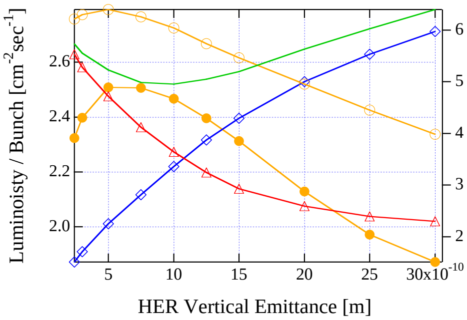

Figure 8: Vertical emittance dependence of luminosity. Vertical beam size of LER(△), HER(◊), and Σ(blue solid line), Luminosity with a crossing angle of ± 11 mrad (●), Luminosity without a crossing angle(○).

5 SUMMARY

The peak luminosity of 4.1×10^{33} cm^{-2}sec^{-1} was achieved at KEKB and the present capability for delivering integrated luminosity is about 4.7 fb^{-1}/month. Installation of the solenoids to suppress the electron cloud instability has improved the situation but not resolved the problem. The machine stability has been improved by moving to the tune above a half integer and the continuos tune monitor of pilot bunches. The beam-beam simulation is in reasonable agreement with measurement in many cases.

6 FUTURE PLAN

(1) Since KEKB has a crossing angle, a shorter bunch length is favorable for a geometrical luminosity reduction. But we are afraid that the shorter bunch for HER may cause more heating of HOM dampers. Anyway, we will try to do machine study to shorten the LER bunch length.

(2) As we mentioned above, installation of the solenoids to suppress the electron cloud instability has improved the problem but not resolved it. During this summer shutdown, we will add more solenoid to LER.

(3) The injection rate for positron beams is 1.5 mA, which is the design value. We will try to introduce the two-bunch acceleration in order to minimize injection time. This plan would almost double the injection rate, and the injection time would be reduced by 1/2.

7 ACKNOWLEDGEMENTS

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