KEKB PERFORMANCE

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Abstract

This report summarizes a recent progress of the KEKB whose commissioning started on December 1st 1998. Since the commissioning of earlier period was described in other papers [1][2], this report mainly deals with the commissioning from the beginning of 2000.

1 INTRODUCTION

The KEKB B-Factory is one of second generation electron-positron colliders. It has two significant features of a “very high luminosity” and an “energy asymmetric collider”. These features come from requirements of B meson physics which studies very rare processes and aims at detecting the CP violation in the B meson system.

The design luminosity is $1 \times 10^{34}/\mathrm{cm}^2/\mathrm{sec}$. Other design parameters related to the luminosity also fit with this design luminosity. Design beam currents are 2.6A and 1.1A for the positron and electron beams, respectively. Design parameters of the horizontal and vertical beta functions at the IP for both beams are 0.33m and 10mm, respectively. Design goals of the beam-beam parameters for both beams are 0.039 and 0.052 in the horizontal and vertical directions, respectively. Beam energies are 3.5 GeV for Low Energy Ring (LER e+) and 8 GeV for High Energy Ring (HER, e-). The requirement of energy asymmetry inevitably leads us to a double ring collider. From the standpoint of machine design, this double ring feature enables a “high current-multibunch” approach like synchrotron light sources, which is vital to get to a higher luminosity. In addition to these features, the KEKB adopted a challenging scheme of a (horizontal) crossing angle of ± 11 mrad. A motivation of the crossing angle is to simplify the IR design and to suppress effect of a parasitic collision[3].

So far the design goals above have not been fully accomplished yet. Table 1 summarizes the present performance of the KEKB related to the luminosity together with the design parameters. This article describes how the present performance has been attained and what limits it.

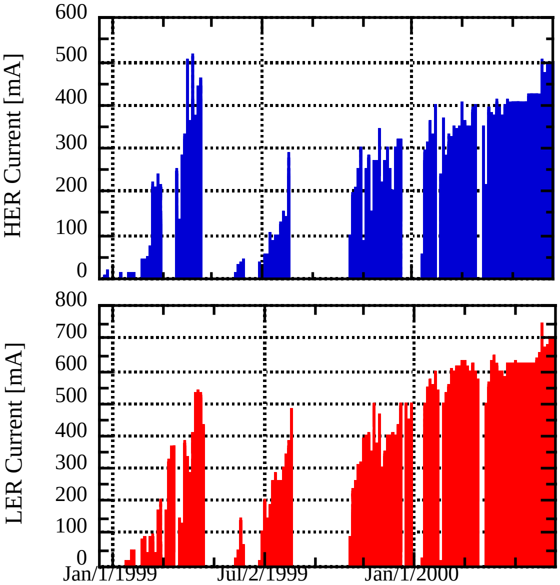

Figure 1: Histories of the beam currents.

2 PRESENT PERFORMANCE

2.1 Brief History

Fig. 1 shows histories of the beam currents. As is seen from the figure, there have been steady increases of the beam currents. The increase rates, however, were not very remarkable this year. As is described in another section, the present beam current limitation does not come from instabilities but from some hardware heating problems. Fig. 2 shows a history of the luminosity. Contrary to the case of the beam currents, we see a remarkable increase of the luminosity. The peak luminosity was $6.7 \times 10^{32}/\mathrm{cm}^2/\mathrm{sec}$ at the end of last year. The record peak luminosity of the KEKB so far is $19.2 \times 10^{32}/\mathrm{cm}^2/\mathrm{sec}$ which was recorded on May 29 2000. Actually, the peak luminosity almost tripled this year. As is discussed in the next section, this improvement in the luminosity has been brought mainly by squeezing beta functions at the IP and other optimization of the beam-beam effect. Some related parameters at this record luminosity are summarized in Table 1 compared with the design values. As shown in Table 1, β_y^* is now lower that the design.

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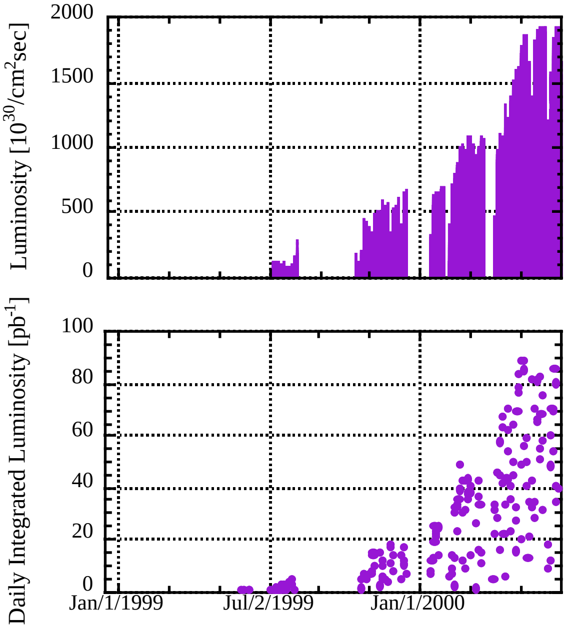

Figure 2: History of the luminosity.

2.2 *Beam-beam parameters*

It is shown in Table 1 that the vertical beam-beam parameter of the HER is notably low compared to the design value. This is a consequence of the following two reasons. One reason is that the bunch current of the LER is limited by the hardware heating problem in usual operations. The bunch current of the LER in Table 1 is much lower than the design. The other is a single beam blowup in the LER. This problem is also discussed in another section.

To see how seriously these problems limit the beam-beam parameter (and the luminosity), an experiment with fewer number of bunches was carried out. In this experiment, we used 188 bunches which is about 1/6 of that in the usual operation. In the experiment, the bunch current could be increased up to near the design, since the heating problem is less serious with the fewer number of bunches. In the usual operation, the bunch spacing is 4 RF buckets (8nsec) and the LER single beam blowup is serious as shown in Fig. 5. In the experiment, the bunch spacing was 24 RF buckets and the LER single beam blowup was not visible with this bunch spacing.

Table 2 shows a result of the experiment. ξ_y of the HER with 188 bunches was much higher than that with 1069 bunches. On the other hand, ξ_y of the LER got smaller than the case of 1069 bunches. This is because the HER beam is blown up in turn in this situation. Since the LER beam is apt to be blow up due to the beam-beam effect in the usual operation, most part of beam-beam tuning has been devoted to suppress the beam-beam blowup of the LER. It may be possible to suppress this HER beam-beam blowup with more beam-beam tuning and to get even higher ξ_y of the LER. With this 188 bunch operation, we obtained the luminosity of $4.04 \times 10^{32}/\mathrm{cm}^2/\mathrm{sec}$ with almost no beam tuning. This luminosity multiplied by a factor 6 is higher than the present record of the luminosity. This means that the LER single beam blowup and the beam current limitation from the hardware heatings limit the present peak luminosity seriously.

	LER	HER	
Hor. Emittance	29	30	nm
β^*_x/β^*_y	0.7/0.007 (0.33/0.010)		m
Beam Current	565 (2600)	397 (1100)	mA
# of bunches	1069 (2833)		
Bunch Current	0.53 (0.87)	0.37 (0.37)	mA
# of trains	16		
Bunches/train	74		
Bunch spacing	8 (2)		nsec
Bunch Length (calculation)	5.9@9.0	6.4@5.0	mm@MV
ξ_x	0.039 (0.039)	0.032 (0.039)	
ξ_y	0.036 (0.052)	0.018 (0.052)	
ν_x	45.51 (45.52)	44.519 (44.52)	
ν_y	44.07 (44.08)	42.176 (42.08)	
Lifetime	105@565	302@397	mim@mA
Luminosity Belle CsI	19.2×10^{32} (1.0×10^{34})		$/\mathrm{cm}^2/\mathrm{sec}$

Table 1: Present performance compared with the design. (Values in a parenthesis are the design values.)

# of bunches	1069	188
ξ_x/ξ_y (LER)	0.039/0.036	0.030/0.025
ξ_x/ξ_y (HER)	0.032/0.018	0.030/0.032
bunch current (LER)[mA]	0.53	0.70
bunch current (HER)[mA]	0.37	0.30
Luminosity [/cm^2/sec]	1.92×10^{33}	4.04×10^{32}

Table 2: Result of beam-beam experiment.

2.3 *Specific luminosity*

Fig. 3 shows a specific luminosity as function of the product of the beam currents in some typical fill. As is seen in the figure, the specific luminosity is not constant at relatively low beam currents. Since no single beam blowup of the LER is seen at the low beam current, this indicates that the beam-beam blowup is not negligible even at the low currents. The tendency for the specific luminosity to increase even at the low beam currents is reproduced by a beam-beam simulation[4].

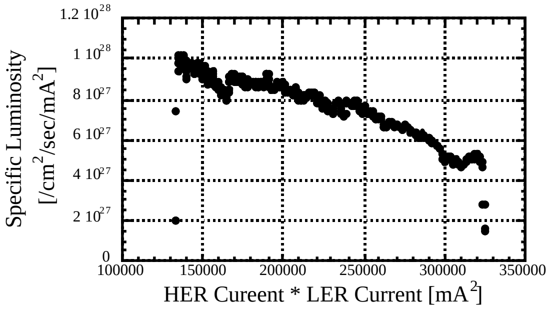

Figure 3: Specific luminosity.

	typical	record	design	
Charge$^{*)}$ (e-)	1	2.0	1.28	nC
Charge$^{*)}$ (e+)	0.5	0.82	0.64	nC
Inj. rate (e-)	2	4.3	6.4	mA/sec
Inj. rate (e+)	0.7	1.7	3.2	mA/sec
Inj. effic. (e-)	60	~ 90	100	%
Inj. effic. (e+)	40	~ 90	100	%
Mode switch e+ $<->$ e-	2	2	2	min.

*) at the end of LINAC

Table 3: Performance of the beam injection.

2.4 Integrated luminosity

The daily integrated luminosity in Fig. 2 is that recorded by the physics detector(Belle). The delivered luminosity by the KEKB accelerator is about 10% higher than the recorded one. The total integrated luminosity from the beginning of the KEKB is 5104 pb^{-1} as of June 15 2000.

Beam injection performance is one of the factors which affect the integrated luminosity. Table 2 summarizes the present performance of the beam injection. In the usual operation, bunch charges at the end of the injector linac (LINAC) are near its design values. Injection efficiencies are rather poor. This is partially because the ring acceptances are severely restricted by movable masks which are used for suppressing the Belle beam background. With the present KEKB injection systems, it is not possible to inject the two beams simultaneously. It takes 2 minutes to switch LINAC from the e+(e-) mode to the e-(e+).

3 ROAD TO PRESENT LUMINOSITY

3.1 Working point

A relatively extensive tune survey was done in the middle of last year. We found that a region near the design tunes gave a relatively good luminosity. However, the design tune itself did not bring the best luminosity last year[5]. Fig. 4 shows a history of luminosity improvement. Only some turning points for the luminosity jump are plotted. Also shown in the figure are histories of the horizontal and vertical tunes for the LER. The HER tunes are more or less the same as those of the LER. Roughly speaking, lower horizontal and vertical tunes give better results. The best luminosity in the figure is achieved with almost the same tunes as the design. The tune search in Fig. 4 was done in trial and error ways in daily tuning. The best tune found this way is coincided with the design tune which was determined from a strong-weak beam-beam simulation[3]. In Fig. 4 the luminosity from a new strong-strong beam-beam simulation[7][4] is also shown. The effectiveness of the design tunes are also confirmed by the new simulation. Moreover, the measured luminosity is roughly reproduced by the simulation. Therefore, we have now more confidence in predictive power of the beam-beam simulation.

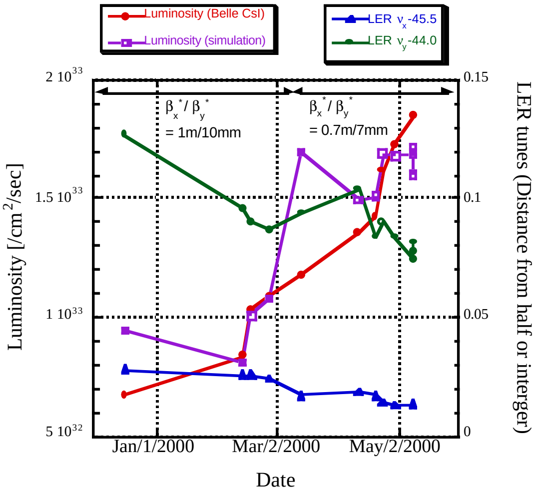

Figure 4: History of the luminosity improvement.

3.2 Squeezing β^*_x/β^*_y

As shown in Fig. 4, we squeezed β^*_x/β^*_y of both rings from 1m/10mm to 0.7m/7mm in the middle of March this year. Just after squeezing, we did not see much increase in the luminosity. However, the luminosity was raised gradually after that and the record peak luminosity of the KEKB so far was recorded with these beta values. At the beginning of June, β^*_x/β^*_y of both rings were successfully squeezed to 0.5m/6mm. However, we did not see any increase of the peak luminosity but we did see even some significant decrease in spite of relatively intensive efforts on the luminosity tuning. We have not understood the reason for this decrease. Since β^*_y is comparable to the bunch length, shortening of the bunch length may be needed to raise the luminosity by squeezing the beta functions further.

3.3 IP beam diagnostics and corrections

Since the KEKB is a double ring collider, the IP beam diagnostics and corrections are much more complicated and then much more important compared to the case of conventional single ring colliders. We have to take care of (1) IP orbit offset, (2) (vertical) crossing angle, (3) waist points, (4) IP x-y coupling and (5) IP dispersion.

Our method to detect the IP offset is based on the beam-beam scan observing the beam-beam deflection[5]. We have an orbit feedback system to maintain the zero-offset condition once found[6]. This system makes orbit bumps at the IP both in the horizontal and vertical directions based on information from the BPMs of the two beams around the IP. The repetition rate of the feedback is 2 or 3 seconds which is restricted by the speed of orbit measurements by the BPMs. A detection of the vertical crossing angle is done as a part of the beam-beam deflection scan. The beam-beam scan in the horizontal direction is done by scanning the collision point. The vertical crossing angle is detected as an asymmetric pattern of the vertical beam-beam kick during the horizontal scan[5]. A removal of the vertical crossing angle can be done by removing this asymmetric pattern. The orbit feedback system also takes care of the crossing angle condition. Coinciding the waist points of the two rings and the collision point is also an important tuning item[5]. A simulation shows that the IP x-y coupling combined with the crossing angle is harmful for the beam-beam interaction[7]. A trial to measure the IP x-y coupling by using a pair of single-pass BPMs near the IP is in progress[8]. In the usual operation so far, optimum x-y coupling parameters at the IP are searched by manipulating skew quadrupoles to maximize the luminosity in a trial and error method. The IP dispersion is corrected in the usual dispersion correction process as is described below. All these corrections mentioned above are directly connected to the luminosity and accumulation of these corrections played an important role in increasing the luminosity.

3.4 Beam size ratio

In the usual operation of the KEKB, the LER beam is apt to be blown up. In some situation where the LER beam is seriously blown up due to the beam-beam effect, the luminosity is raised by enlarging the HER beam size intentionally. When we make the HER beam size be enlarged gradually, the LER beam shrinks and the luminosity gets higher. At some optimum ratio of the vertical beam sizes, the luminosity gets the maximum. To maximize the luminosity, it is important to look for the optimum ratio of the beam sizes and to keep it. We have constructed a feedback system for the purpose of keeping the ratio constant. This feedback controls the HER beam size by making an orbit bump, which creates a vertical dispersion around the ring, at a pair of sextupoles.

3.5 Optics corrections

Since the KEKB uses the unusual tunes which are very close to the integer or half-integer resonance as shown in Table 1, optics corrections are important to narrow the stop bands of the resonances. In addition to the global beta corrections, global x-y coupling corrections, global dispersion corrections and continuous close orbit corrections (CCC) are done in the KEKB[9]. The global x-y coupling and global dispersion corrections are important in the sense that decreasing the zero-current emittance contributes to the increase of the luminosity. An injection efficiency is also improved by these corrections. In the global dispersion correction process, the vertical dispersion at the IP is also corrected. We found that this is very important to raise the luminosity. Since the x-y coupling and dispersion corrections are done by making orbit bumps at pairs of sextupoles, it is very important to keep the close orbits the same. CCC is always running during the operation with the repetition time of 20 or 30 seconds. For the closed orbit correction, it is important to remove offsets of BPMs. Offset measurements for all BPMs were done by using beams[10]. The measurements were done basically by detecting changes of closed orbits when changing strength of quadruple magnets beside BPMs.

4 PERFORMANCE LIMITATIONS

4.1 Beam current limitation

In the present KEKB, beam instabilities do not limit the beam current so far as the bunch-by-bunch feedback system works well and the vertical chromaticity of the LER is rather large. The current limitation of the present KEKB come from heating problems of two types of hardware components. Main problems come from the following two types of components. One is movable masks which are vital to cut off the beam tail and suppress the detector background. The other is bellows near the IP. The first version of movable masks has basically two serious problems[11]. One problem is that the masks have no effective damper for trapped modes, although the Q-value of the major trapped mode amounts to several thousand. The other problem is that sliding shield fingers of the masks are too weak and intense field of the trapped modes can easily heats up or melts the fingers. Once the fingers are broken, the field of the trapped modes strays out of the chamber and results in additional heatings of other components such as bellows. Fragmentations of the broken fingers can be seeds of arcing at other places. With these original masks, we experienced four times vacuum leaks. In the second version of the movable masks, we improved the strength of the shield fingers and the cooling power. No damper for the trapped mode was installed in this version. We found that the serious synchrotron oscillations were induced due to their high-Q trapped modes depending on the mask head position. We gave up using this type of masks in the operation.

Based on the experiences above, we have been developing three different types of masks which solve the trapped mode problems in different ways[11]. Two types of them were installed in the LER at the end of May and are being tested with beams. So far the new types of masks work well. Since the masks in the LER were replaced by the new types at the end of May, we could increase the beam current to some extent as is seen in Fig. 1. Before replacing the masks, we continued to use the original masks. To lower the Q-values, the shield fingers of the masks were intentionally removed. With the original masks, only the

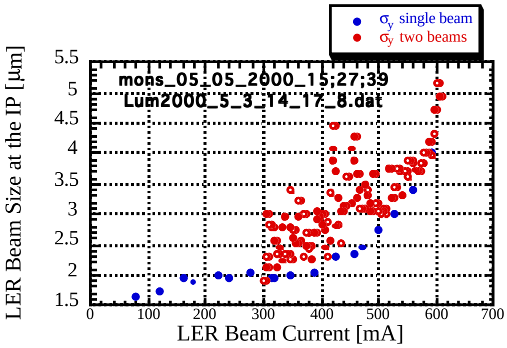

Figure 5: Current dependence of the LER beam size (single beam and two beams).

fill pattern of the 4 RF bucket spacing could be used in the usual operation. All other bucket spacing resulted in serious heating of the masks.

After the heating problems of the movable masks were solved, the beam current limitation comes from the heating of the IR bellows due to the higher order mode. This heating is sensitive to the bunch length and bunch currents. Due to this problem, we can not shorten the bunch length of the LER. During this summer shutdown, the IR bellows will be replaced with the new type which improves its cooling power thoroughly.

4.2 *LER single beam blowup*

Fig. 5 shows a current dependence of the LER beam size both in the single beam and the two beam cases. The beam sizes in the figure is values at the IP which is translated from the measurement point by using the design optics. Every 4th RF bucket was filled with a beam except for a 10% abort gap and some train gaps in both cases. As we can see from the figure, there is a serious beam blowup dependent on the beam current even in the single beam case. The present understanding for this single beam blowup based on phenomelogical observations and some beam studies[12] is that the blowup is induced by a single bunch instability in an environment of a photoelectron cloud[13]. Since the photoelectron cloud is built up by the successive passage of bunches, the blowup occurs only in the multibunch operation. From the chromaticity dependence of the beam blowup, the strong head-tail instability seems to be responsible for the beam blowup[12]. To cure this single beam blowup, we installed a large number of so-called “C-York” magnets in the LER. A C-York magnet is composed of two button-shaped permanent magnets and a C-shaped iron york. The number and configuration of the C-York magnets have been upgraded step-by-step. In the present configuration, the C-York magnets are attached on the vacuum chamber in every 10cm of the drift space in the arc section (they cover about 50% of the whole arc). The magnets are installed both inside and outside of the chamber so that they generate quadrupole field. To cancel out the effect of the field seen by the beam, the polarity of the magnets was inverted in every 20cm. The vertical magnetic field at the chamber wall was 250 G. It was expected that the magnetic field confined the photoelectrons around the chamber wall and the beam blowup was suppressed. However, the C-York magnets brought no remarkable improvement in the blowup except for the case of a long bunch spacing, although a simulation predicts effectiveness of the C-York magnets. We have not yet understood the reason why the effect of the C-York magnets is so weak. We are now planning to install solenoid magnets instead of the C-York magnets in this summer shutdown.

4.3 *Beam-beam blowup*

The beam-beam blowup has been considerably improved by the method described in this article. However, there is still some beam-beam blowup even at relatively low beam currents as is seen in Fig. 3 and 5. Also in the strong-strong beam-beam simulation, the blowup at the low beam current is reproduced even if there is no optics errors[4]. The simulation also shows that the luminosity is increased even with this beam-beam blowup by using lower vertical emittance. This may suggest that we should go for a lower emittance optics.

4.4 *Detector beam background*

After several modifications at the summer 1999, the background level in the BELLE detector has been somewhat comfortable. Thanks to steady improvement of vacuum condition, substantial background rate can be kept within tolerable level while the total beam current of the KEKB has gradually been increased since the last October. Recent daily dose in a typical collision operation amounts 600 rad nearby the silicon vertex detectors (SVD) and an occupancy in the inner most layer of the SVD is as small as 3 Currently a potential problem for a higher beam current operation is a large leakage current and high occupancy rate in the inner three layers of the cental drift chamber. They are expected to be reduced by a new mask to be installed in QCS in this summer.

5 REFERENCES

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