Luminosity Optimization by Controlling a Beam Size Ratio at KEKB

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Abstract

KEKB B-Factory is one of second generation electron and positron colliders. The energies of the two beams are 3.5 GeV(positron) and 8 GeV(electron). In the usual beam operation of KEKB, the Low Energy Ring (LER) beam is weaker than the High Energy Ring (HER) beam. We found that the LER vertical beam size can shrink by intentionally making the HER beam size bigger and then luminosity gets higher when the LER beam is blown up due to the beam-beam effect. By making use of this mechanism, we have constructed a feedback system which keeps the vertical beam size ratio of the two beams at some optimum values where the luminosity is maximum. We found that this feedback is a very useful tool for increasing the luminosity.

1 INTRODUCTION

The KEKB accelerator is a high luminosity e^+e^- collider to generate a large amount of B mesons. The designed value of peak luminosity is $1.0 \times 10^{34} cm^{-2} sec^{-1}$ and we have currently the best recorded value of about $3.0 \times 10^{33} cm^{-2} sec^{-1}$. At KEKB, enlargement of the LER vertical beam size is the most severe obstacle for increasing the luminosity.

There are two major processes of the LER beam blowup. One is a single beam blowup[1] and the other is that due to beam-beam effect[2]. The former is induced by the photo-electrons which are emitted from the inner surface of LER beam pipe by the synchrotron radiation from the beam. The beam blowup is more likely appeared in the vertical beam size at KEKB. The latter one, the beam-beam blowup is also observed in LER. Although we sometimes observe it in the horizontal direction too, we discuss only the vertical blowup of the LER in this report. There are two reasons why the LER beam is weaker at KEKB, both of which come from the photoelectron beam blowup. One is that the present operating beam currents of KEKB heavily breaks the energy transparency condition; the HER beam current is much higher than that of LER even if we consider the energy difference of the two beam. This is because the higher HER beam current usually brings the higher luminosity whereas the higher LER beam current is less effective for increasing the luminosity due to the photoelectron blowup. The other reason is that the LER vertical beam size of collision is larger than that of HER due to the photoelectron effect. Because of this beam size difference, particles in LER feels the nonlinear beam-beam force more likely than those in HER. This also brings the LER beam-beam blowup.

We empirically know that the higher luminosity is obtained when the blowing up of the LER vertical beam size caused by beam-beam effect is suppressed by making the HER beam larger intentionally. We found that the luminosity is very sensitive to the ratio of beam sizes, $\sigma_y^{LER}/\sigma_y^{HER}$. We constructed a feedback to keep the vertical beam size ratio to an optimum target value that is obtained empirically. In this paper, the feedback system which is used for the actual beam operation, called “iSize” feedback system is described.

2 BEAM SIZE FEEDBACK SYSTEM

2.1 *HER Beam Size Control*

At KEKB, the non-interleaved sextupole scheme is adopted for chromaticity correction and many pairs of sextupole magnets are installed in the arc sections of each KEKB ring. At one of the most strong sextupole pairs in HER, an anti-symmetric bump is made by using three dipole correction magnets near them. This bump converts the horizontal dispersion to the vertical which leaks out around the whole of the ring. On the other hand, the created XY-coupling is closed in the bump and never leaks out. By this dispersion the vertical emittance is enlarged and the HER beam size can be made larger. The calculated orbits and dispersions

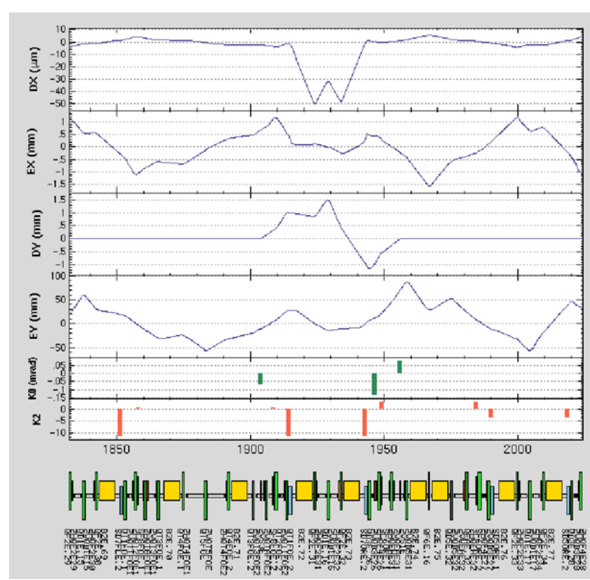

Figure 1: The orbits calculated with iSize bump height of 1mm at the pair of sextupole magnets as shown in the third graph.

around the pair of sextupoles with a bump of 1mm height is shown in Fig. 1. The emittances calculated with some iSize bump heights are shown in Fig. 2. These calculations are done with the "sad" code[3] in which a lattice for the current operations is used[4]. The iSize bump heights in the actual operation are mainly between 0mm and 2mm.

Two controllers of changing the HER vertical beam size is mentioned in this section.

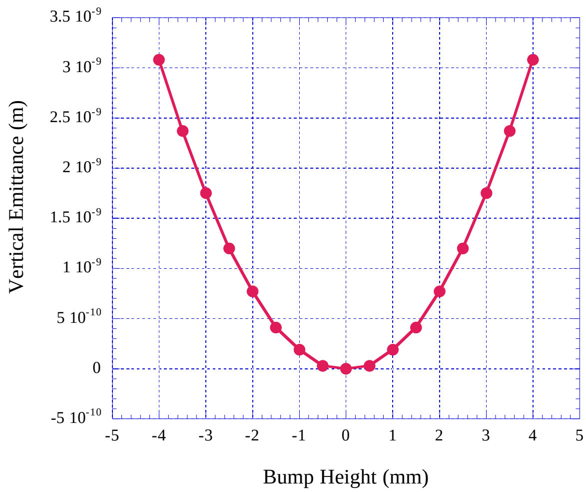

Figure 2: The emittances calculated with some iSize bump heights.

2.2 iSize Controllers

Feedback The feedback routine uses a ratio $\sigma_y^{LER}/\sigma_y^{HER}$ as an input parameter. The aim of the feedback is to keep the ratio around a target value. The beam sizes are measured by Synchrotron Radiation Monitors(SRM's)[5] which are located at the arc sections of both rings. The SRM can take data at about 5Hz which are averaged every five data. Measured beam sizes are transferred to those at the interaction point. The iSize feedback obtains the beam size of each ring at about 1Hz. However calibrations for absolute values of beam sizes are under study now. Based on the ratio, a bump height is determined.

The blue line at the lower right of Fig. 3 shows a hyperbolic curve fit with the plots and the red line indicates the target value for σ_y^{HER} which is calculated σ_y^{LER} divided by the target ratio. The bump height to be set is obtained as an intersection point of the two lines. The actual bump height change is decreased by multiplying a damping factor. This factor is necessary for stabilizing the feedback action. The typical damping factor is about 0.01. The bumps are made by the dipole magnets exclusively used for the iSize controllers.

Trend graphs of parameters used for the iSize feedback on one day are shown in Fig. 3. The beam currents were about 740mA and 580mA for HER and LER, respectively. At the beginning of these graphs the iSize bump height was

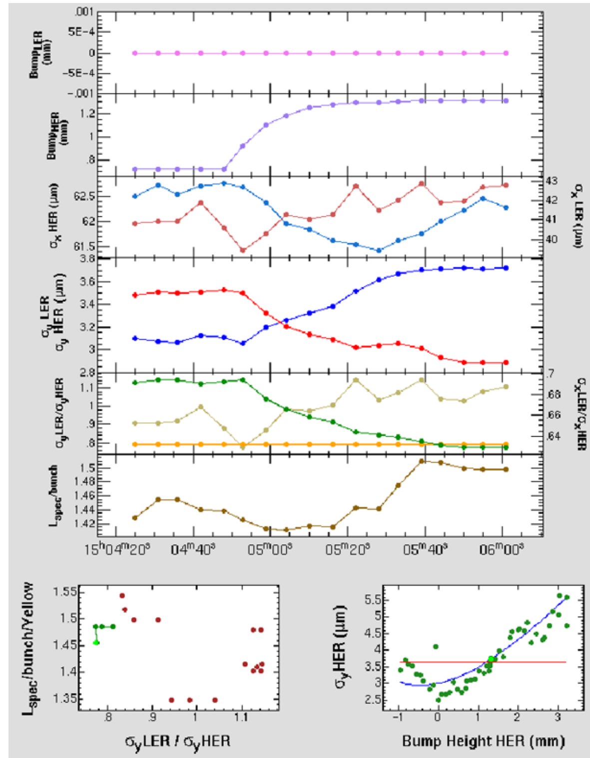

Figure 3: The top two trend graphs correspond to the iSize bump heights for LER(not used here) and HER. The middle two correspond to σ_x and σ_y. The red and blue lines express those of LER and HER for each direction. The fifth graph shows the vertical size ratio(green line) and the target value(yellow line). The bottom shows luminosity measured by a CsI calorimetry in the BELLE detector. The lower left and right of the figure show correlations of luminosity with the ratio and σ_y^{HER} with the bump height, respectively.

set at an value far from an optimum and the feedback was intentionally turned off. At the time of 15h04m45m the feedback was turned on and the bump height gradually increased. The HER vertical size enlarged and on the contrary the LER shrank. Simultaneously the vertical size ratio of LER to HER approached to an optimum target value of 0.8. When the ratio reached the target value at 05m40s, the luminosity recorded the maximum value. It took about one minute from turning on the feedback. The response of the feedback depends on the machine tuning situation.

The optimum target values are obtained by a trial and error method. The target value is changed as a function of the LER beam current as shown in Fig. 4. At the higher beam current, the LER beam blowup is severer and the bump gets higher.

"Tool" We have one more controller named "iSize Tool" also using iSize bump. This tool moves iSize bump height little by little and observes luminosity changing at each point. The bump height of the next step is determined so that the highest luminosity is expected from the past

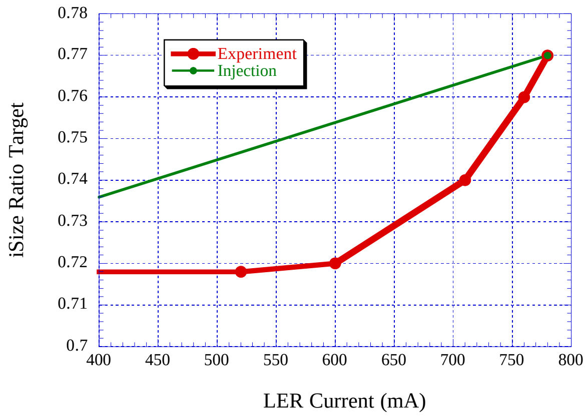

Figure 4: The target value is changed according the the LER beam current. The red line is used for BELLE experiment and the green one is for injection time.

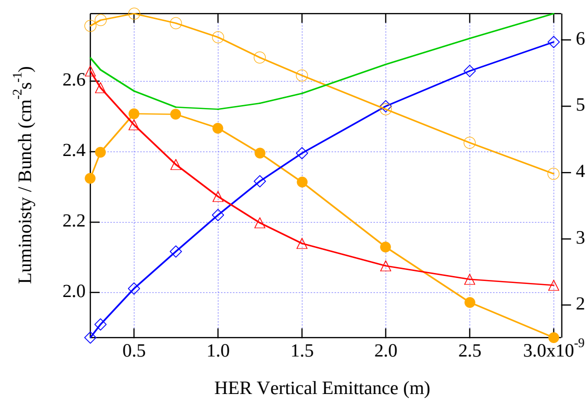

Figure 5: This figure shows Luminosity(yellow•), σ_y(red △(LER), blue ◇ (HER)) and Σ_y(green-) for crossing angle of 22mrad and Luminosity(yellow ∘) for zero-crossing angle as a function of HER vertical emittance.

two data. The calculation is done with a one-dimensional Downhill Simplex method. This tool is useful when the machine is stable. However it has two weak points, one is that the measurement of luminosity is slow(about 0.1Hz) and the other is that it is easy to be disturbed by the other collision tunings. This tool is mainly used as an auxiliary tool of iSize Feedback when the SRM does not work well for some reasons.

3 SIMULATION

If there is no iSize feedback system, the weaker beam would be blown up and the luminosity would be lower. To see the effectiveness of iSize feedback system, we have performed beam-beam simulations for the present working parameters of KEKB with a code developed by K. Ohmi [6][7].

	LER	HER	unit
Energy	3.5	8.0	GeV
ϵ_x	18	24	nm
ϵ_y/ϵ_x	2 (1)	(controlled by iSize Feedback) (1)	 %
β_x/β_y	0.63/0.007	0.8/0.007	m
bunch current	0.66 (0.87)	0.50 (0.37)	mA
Bunch length	5.5@6.0	5.7@11.0	mm@MV
ν_x/ν_y	45.518/44.063	44.525/42.135	

Table 1: Parameters for the simulations. The values in () are the designed values.

The simulation parameters are shown in Table 1. Fig. 5 shows the luminosity and the vertical beam sizes of both rings as a function of the HER vertical emittance in the cases of crossing angle of 22mrad (KEKB) and 0mrad. The highest luminosity is obtained around the minimum value of Σ_y. And the HER vertical emittance dependence on the luminosity for KEKB is stronger than that for the case of zero-crossing.

We can not compare directly the results of simulation with actual measurements from some reasons. One reason is that the simulations only deal with the beam-beam blowup and we take no account of the LER single beam blowup. Another reason is that a calibration of the SRM is not complete yet. However, it is qualitatively shown by the simulations that there is an optimum value of HER emittance for luminosity.

4 CONCLUSION

We found that the luminosity strongly depends on the vertical size ratio of LER to that of HER. The iSize controller is a very important tool for KEKB to get a high luminosity. In actual beam operation, iSize feedback is always turned on. The simulation also shows that the luminosity maximum is realized at an optimum value of the vertical size ratio.

5 REFERENCES

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