RECENT PROGRESS OF KEKB

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Abstract

We have been making efforts to raise the specific luminosity at high bunch currents. By using skew sextupole magnets newly installed at KEKB, the peak luminosity was increased by about 15 %. The beam lifetime issue was studied in relation to the luminosity degradation. The beam-beam simulations have been done to identify the reason for discrepancy between the simulation and the experiment. The pulse-to-pulse switching injection to three rings has been completed, which has enabled much faster beam tuning with the constant beam currents.

INTRODUCTION

In this reports, we summarize the machine operation of KEKB after the summer shutdown in 2008. A status report before this was written elsewhere [1]. We have continued to carry out machine operation with crab crossing. The most important task with crab crossing is that we achieve a high luminosity predicted by the beam-beam simulation. While the beam-beam simulations predict that the luminosity with crab crossing is twice as high as that w/o crab crossing, the achieved specific luminosity with crab at high bunch currents had been only about 20% higher than w/o crab crossing so far. Based on lots of trials and errors with beams, we have narrowed possible causes for this discrepancy down to the following ones.

- A short beam lifetime prevents us from reaching better machine parameters?
- Machine errors can not be sufficiently compensated by the usual tuning knobs?
- Off-momentum optics play some role?
- The beam-beam simulations miss something?

In this report, we describe present performance and some recent progress at KEKB mainly related to the above items.

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Table 1: Comparison of KEKB Machine Parameters with and without crab crossing.

	May 2009 with crab		**Nov. 2006** w/o crab		
	LER	HER	LER	HER	
Energy	3.5	8.0	3.5	8.0	GeV
Circumference	3016		3016		m
I_{beam}	1595	1125	1662	1340	mA
# of bunches	1585		1387		
I_{bunch}	1.00	0.71	1.20	0.965	mA
Ave. Spacing	1.8		2.1		m
Emittance	18	24	18	24	nm
β_x^*	150	150	59	56	cm
β_y^*	5.9	5.9	6.5	5.9	mm
Ver. Size@IP	0.84	0.84	1.8	1.8	μm
RF Voltege	8.0	13.0	8.0	15.0	MV
ν_x	.503	.508	.505	.509	
ν_y	.570	.580	.534	.565	
ξ_x	.120	.099	.117	.071	
ξ_y	.120	.089	.108	.057	
Lifetime	120	213	110	180	min.
Luminosity	19.64		17.60		/nb/s
Lum/day	1.334		1.232		/fb

PERFORMANCE OF KEKB

Fig. 1 shows 10-year history of the KEKB luminosity and beam currents. As of May 05 2009, the Belle detector accumulated an integrated luminosity of 906.2 fb^{-1}. Very recently, a remarkable luminosity increase was brought by using skew sextupole magnets installed in the winter shutdown. A new peak luminosity record of 1.964 $\times 10^{34} cm^{-2}s^{-1}$ was made on May 6 2009. By the recent improvement, the peak luminosity with crab crossing exceeded that without crab crossing for the first time. The higher peak luminosity with crab crossing was realized with much lower beam currents than without crab crossing. Table 1 shows the latest machine parameters of KEKB compared with those before installation of the crab cavities. Fig. 2 shows the specific luminosity as function of the bunch current product. In the graph, the present sta-

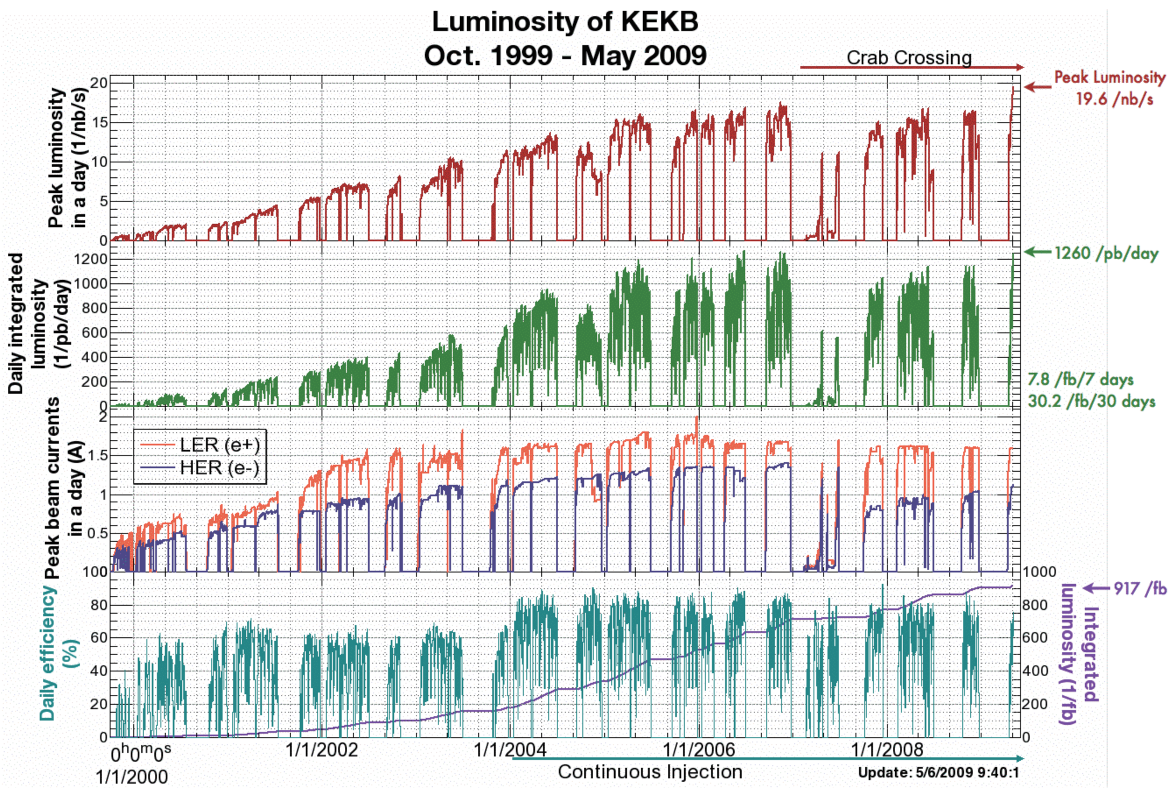

Figure 1: Ten-year history of KEKB.

tus of KEKB is summarized. Both the data during physics run (3.06 RF bucket spacing) and that in the machine study (24.5 or 49 spacing) are plotted. Although there exists a small difference between short and long spacing, the difference is as much as 10%. The data with the chromatic coupling tuning is also plotted (black color) and is about 15% higher than w/o that tuning (cyan). We tried two different values of β_x^* of 0.8m and 1.5m. The motivation of the large β_x^* of 1.5m is to mitigate the lifetime problem shown below. The beam-beam simulation predicts a very large difference with the different β_x^*. However, the achieved luminosity is almost the same and the almost all data is aligned on the constant beam-beam parameter of 0.08 or 0.09. By enlarging β_x^* up to 1.5m and reducing the β_x at the crab cavities, for which we changed wiring of quadrupole magnets around the LER crab cavity during the summer shutdown, high bunch currents up to 1.5mA^2, which is the design bunch current product of SuperKEKB, became possible. In this condition, we compared the specific luminosity with crab on to that with crab off. The data of green (crab on) and blue (crab off) shows only 20 % difference, while the calculated geometrical loss due to the crossing angle is about 11%. In the graph, the results of the beam-beam simulation are also plotted. The two lines correspond to different β_x^* of 0.8m and 1.5m with a global x-y coupling w/o the beam-beam of 1%. The discrepancy between the simulation and the experiment is still large. However, we need further study on the specific luminosity at high bunch currents with the tuning of the chromaticity of x-y coupling which has been newly developed.

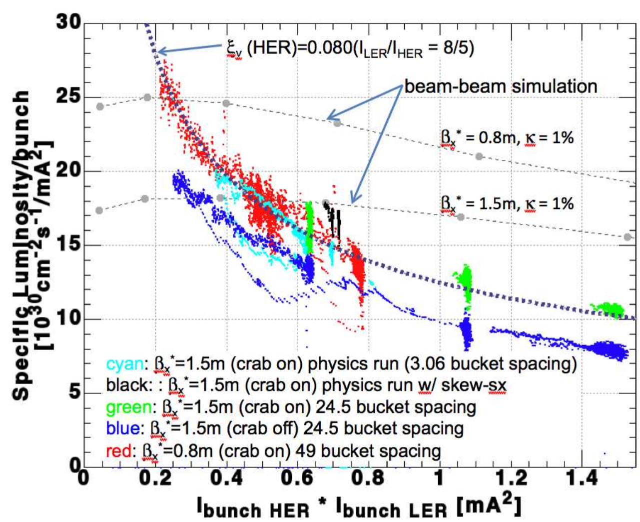

Figure 2: Comparison of specific luminosity between the beam-beam simulation and the experiment. Also shown is the comparison between data of crab on and off.

CHROMATICITY OF X-Y COUPLING

It has been shown that the chromaticity of the x-y coupling at IP could reduce the luminosity largely through the beam-beam interaction, if the residual chromatic coupling is large [2][3]. While even an ideal lattice has such a chromatic coupling, the alignment errors of the sextupole magnets could make a large chromatic coupling. It has been thought that this kind of chromatic couplings is one of the candidates that bring the serious luminosity degradation with crab crossing. Parallel to trials to measure such chromatic couplings directly, we introduced tuning knobs to control them. For this purpose, we installed 14 pairs of skew sextupole magnets (10 pairs for HER and 4 pairs for LER) in last winter shutdown. The maximum strength of the magnets (bipolar) is $\mathrm{K}_2 \sim 0.1/\mathrm{m}^2$, and $\mathrm{K}_2 \sim 0.22/\mathrm{m}^2$ for HER, and LER respectively. The tuning knobs were introduced to the beam operation on May 2. The luminosity increased promptly and the peak luminosity was raised from 1.680 $\times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ to 1.964 $\times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ so far. The luminosity gain by these knobs is about 15 %.

BEAM LIFETIME ISSUES

We often encounter the situation that the beam-beam related beam lifetime is unexpectedly short at high bunch currents, which is not predicted by the simulation, and the lifetime is improved by making a small horizontal offset at IP which may bring some luminosity degradation. An amount of the offsets for saving the lifetime depends on the bunch currents. We suspected that this current dependent offset could make the steep slope of the specific luminosity. In autumn 2008, we finally found out the mechanism of the lifetime decrease. Physical aperture at the crab cavities was responsible for the short lifetime. Due to the large dynamic beta beating and the dynamic emittance effect by the beam-beam force with the horizontal tune very close to the half integer, the horizontal beam sizes of both beams at the crab cavities were very large. However, it turned out that the luminosity degradation due to this effect is 10% at most at the bunch current product of $1.5\mathrm{mA}^2$

BEAM-BEAM SIMULATION

A recent progress in the beam-beam simulation is that the effect of the longitudinal wakefield to the beam-beam effects has been investigated by Y. Cai [4]. Instead of summing up all ring impedance sources, a simple broadband impedance model was used. The parameters of the model were determined so that the measured beam profiles at various beam currents are reproduced. It turned out that almost no effect on the luminosity is given by the wakefield. The simulation also confirmed the main results by K. Ohmi who predicted that crab cavities would lead to an increase of the luminosity by a factor two [5]. As a by-product of this study, it was shown that the microwave instability occurs in LER at the operation bunch current of 1.0mA. The energy spread increases by 20 % at 1.0mA. This was shown by the simulation first and then confirmed by the data analysis of physics events. The threshold of the instability is unexpectedly low compared with the estimation in the phase of the KEKB design. This seems to indicate that the impedance from CSR, which was not considered in the KEKB design, is very important. However, the luminosity predicted by the beam-beam simulation is not affected much by this instability.

Another topic of the beam-beam simulation is on effectiveness of usual knob tuning. In usual luminosity tuning, tuning on the x-y coupling and vertical dispersion and its slope at IP is done. These parameters for both rings (12 parameters in total) are searched by parameter scans one by one or using the downhill simplex method. This kind of tuning is very important at KEKB and without this parameter search, the peak luminosity could be less than half of its maximum value. This method of the parameter search has been simulated by the beam-beam simulation by M. Tawada. The simulation showed that the achievable luminosity could be around 60 % with starting the machine errors corresponding to 4 or 5 tuning units of these 12 parameters, which are not very large in the tuning situation. Therefore, there still remains a possibility that we can not reach as the high luminosity as the beam-beam simulation predicts with the usual tuning methods, if the machine errors are some large. We are now trying to measure the x-y coupling at IP directly by using single pass BPMs.

PULSE-TO-PLULSE SWITCHING INJECTION

The e+/e- linac at KEK provides 4 rings (KEKB LER, KEKB HER, PF and PF-AR) with beams. In the original scheme, every time when we switch the injector mode for different rings, all machine parameters had to be reloaded, since the beam energies of these rings are different. The switching time was more than 30 seconds. We have been trying to shorten the switching time. In April 2009, we finally succeeded the pulse-to-pulse switching injection to 3 rings (KEKB LER, KEKB HER and PF) [6], which is an extreme of fast switching. Owing to this scheme, the machine parameter scan at KEKB has become much faster with constant beam currents stored in the rings and it has become possible to find out better machine parameters much quickly than before. Another motivation of the introduction of fast switching of the injector mode is related to the beam lifetime issue. We expected that we could explore machine parameter space which had not been accessed to due to short beam lifetime before and that we could find better parameter sets which bring a higher luminosity. Although this kind of better machine parameters have not been found in this manner so far, we still expect that this method will become useful in the situation that the luminosity and beam lifetime are a trade-off.

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