BEAM-BEAM EFFECT OBSERVED IN THE KEKB

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Abstract

This report summarizes observed phenomena related to the beam-beam effects in the KEKB collider. A general performance of the beam-beam effect is described. An emphasis is put on the reduction of the specific luminosity with shorter bunch spacing.

1 INTRODUCTION

Table 1 shows a parameter list of the KEKB at the record peak luminosity. This table tells some characteristic features of the KEKB. The present KEKB is filled with beams at every 4th RF bucket. In the design[1], the number of bunches was assumed to be around 5000 which means that every RF bucket is filled with particles (except for some abort gap). In the present KEKB, the specific luminosity is decreased when the number of bunches is increased from the every 4th RF bucket case by reducing bunch spacing. The 5 RF bucket spacing pattern is inhibited at the KEKB, since this pattern induces a heating problem of the IP chamber. Although we once tried 6 bucket spacing, we could not get higher specific luminosity than with 4 bucket spacing. Therefore, 4 RF bucket spacing (∼8nsec) is the best choice at the present KEKB. The other parameters are chosen under this restriction of bunch spacing.

It is notable that the bunch currents of the present KEKB are much higher compared with the design values particularly in the HER (high energy ring). This is also a consequence of the bunch spacing restriction. To compensate this unusually high bunch current to some extent, the horizontal emittance of the HER is enlarged compared with the design. On the other hand, the LER bunch current is not so high as the HER. Until very recent operations, the luminosity did not increase with a higher LER beam current than some threshold current. It is believed that this luminosity saturation with the LER beam current arose from the beam blowup due to the electron cloud. In this situation, the LER beam current was limited by the electron cloud instability in the sense that the luminosity did not increase with a higher LER beam current. However, as a result of cumulative installations of solenoid windings in the LER, the single beam blowup from the electron cloud is not visible with the present maximum beam current. The scrubbing effect of the chamber wall also possibly contributed to suppress the blowup. The present beam current limitation comes from a heating problem in the IR region.

Another feature of the KEKB is that working points are very close to the half integer resonance particularly in the horizontal direction as is seen in the table. These horizontal tunes make the horizontal emittance large and the horizonal beta functions small to a large extent. This large emittance compensates the large bunch currents and contributes to stabilize the beams against the beam-beam effect. As is seen in the table, both of the horizontal and vertical tunes of the both rings are located above the half integer resonance, while the vertical tunes are above the integer resonance in the design. In the early days of the KEKB, the vertical tunes were above the integer resonance. In February 2001, the vertical tunes moved to above the half integer based on results of new beam-beam simulations. This change of the tunes brought some increase of the luminosity.

2 SPECIFIC LUMINOSITY AND BEAM-BEAM PARAMETERS

To assess beam-beam performance, a common way is to record the specific luminosity and the beam-beam parameters. In the following, these parameters are discussed. One thing that one should note here is that these parameters do not necessarily describe only beam-beam performance. They could be affected by other beam blowup mechanisms such as the electron cloud instability.

In Fig. 1 and 2, the specific luminosity per bunch is shown as function of a square root of a bunch current product. The specific luminosity (per bunch) is defined by a peak luminosity divided by a number of bunches and also divided by a bunch current product of the two beams. The specific luminosity should be constant, if the beam sizes do not change. The slopes in the figures mean that the sizes continuously shrink as the beam currents decrease in the course of the fills. The figures show comparisons of the specific luminosity with 3 RF bucket spacing to that with 4 RF bucket spacing. The data in Fig. 1 was taken before the summer shutdown in 2001 and that in Fig. 2 was after the shutdown. During the shutdown, additional solenoid coils of about 800m in total were installed in LER. In Fig. 1, the specific luminosity with 3 bucket spacing is much lower

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	LER	HER
ε_x (nm)	18 (18)	24 (18)
β^*_x/β^*_y (m)	0.59/0.0062 (0.33/0.010)	0.63/0.007 (0.33/0.010)
bunch current (mA)	1365 (2600)	918 (1100)
# of bunches	1223 (5000)	
bunch current (mA)	1.12 (0.52)	0.750 (0.22)
bunch spacing (nsec)	8 (2)	
bunch length (mm@MV)	5.3@6.6 (calculation)	5.5@12.0 (calculation)
ξ_x/ξ_y	0.082/0.050 (0.039/0.052)	0.073/0.041 (0.039/0.052)
ν_x/ν_y	45.512/43.566 (45.52/44.08)	44.512/41.586 (44.52/42.08)
Lifetime (min@mA)	106@1365	299@918
Luminosity ($/\mathrm{cm}^2/\mathrm{sec}$)	7.35×10^{33} (1.0×10^{34})	

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

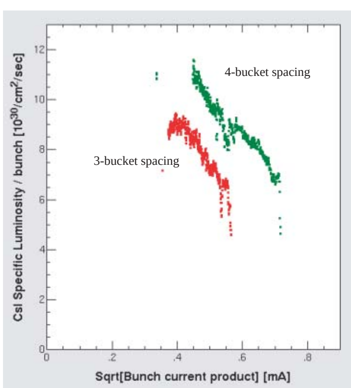

Figure 1: A specific luminosity as function of a square root of the bunch current product. The data was taken on July 11 and 12 in 2001 (before the summer shutdown). The green and red dots denote the data with 4 bucket spacing and 3 bucket spacing, respectively.

than that with 4 bucket spacing. If the beam blowup is induced purely by the beam-beam effect, the two curves in this graph should overlap. Therefore, the different behavior of the two curves indicates that a beam blowup mechanism other than the beam-beam effect plays a part in the blowup. Since the beam blowup is usually observed in the vertical direction of the LER beam, the electron cloud instability is the first candidate for this mechanism. However, even below the threshold beam current of this instability, the specific luminosity with 3 bucket spacing is much lower than that with 4 bucket spacing. Therefore, we can not attribute this difference to the electron cloud instability alone. We

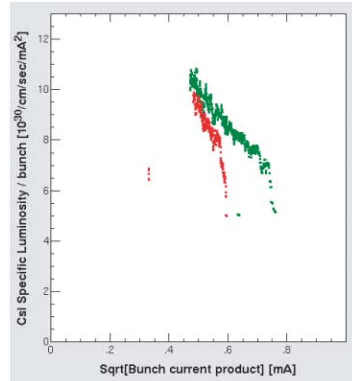

Figure 2: A specific luminosity as function of a square root of the bunch current product. The data was taken on Nov. 9 and 10 in 2001 (after the summer shutdown).

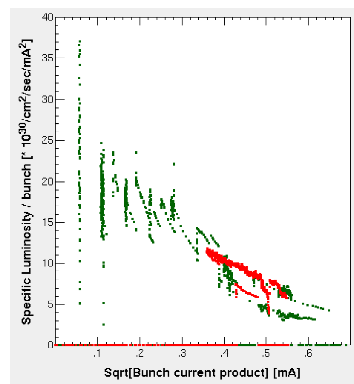

Figure 3: A current dependence of the specific luminosity with different bunch spacing of 4 bucket (red) and 24 bucket (green). These two data sets were taken in the same day (March 10 2001).

might have to consider a synergistic effect of the beam-beam effect and the electron cloud instability. Recently, E. A. Perevedentsev et al. and K. Ohmi independently proposed a model in which a coherent beam-beam instability of the head-tail type could be induced by the beam-beam effect combined with some ring impedance [4] [5]. This model might be applicable to the present case by considering the electron cloud as the impedance source. After addition of solenoid coils during the summer shutdown in 2001, the situation changed. As is seen in Fig. 2, the specific luminosity with 3 bucket spacing is much improved, while the improvement with 4 bucket spacing is small.

A more fundamental question is that the origin of the steep slopes of the curves in Fig. 1 and 2. Since the continuous beam blowup during the fill seems quite unusual compared with conventional colliders, the origin of these beam size enlargements has been controversial. There has been some doubt that the beam blowup comes not from the beam-beam effect but from the electron cloud instability. This doubt seemed to be supported by an observation that the beam blowup is mainly observed in the vertical direction of the LER. To distinguish these two effects, an experiment with longer bunch spacing of 24 RF buckets

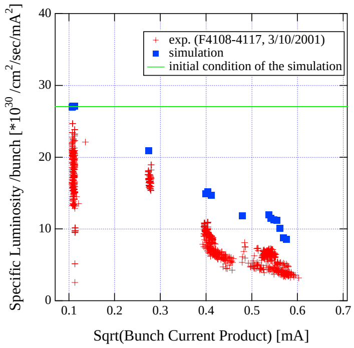

Figure 4: A comparison of a measured specific luminosity with 24 bucket bunch spacing to that from the the beam-beam simulation using a strong-strong code.

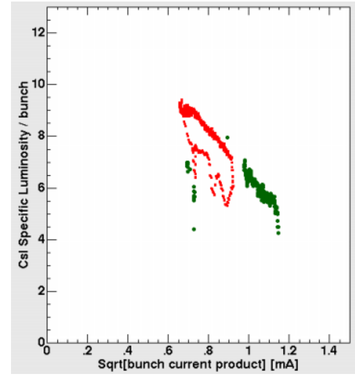

Figure 5: Specific luminosity with higher beam currents. The red and green dots denote an usual physics run with 4 bucket spacing and an experiment with 24 bucket spacing, respectively. The LER and HER beam currents in the experiments were 300mA and 183mA at maximum, respectively.

was done. With this bunch spacing, the effects of the electron cloud should be much smaller. In this experiment, we observed the luminosity with beam currents lower than in usual physics operations. The result is shown in Fig. 3. As shown in the figure, the specific luminosity with 24 bucket spacing is almost the same as that with 4 bucket spacing. This result indicates that the beam blowup in the beam current region of the usual physics run is originated not from the electron cloud instability but from the beam-beam effect. This explanation is also supported by a beam-beam simulation. In Fig. 4, a result of the beam-beam simulation by using a strong-strong simulation code[3] is also shown. Although a quantitative agreement between the simulation and the experiment is not so good, the simulation reproduces the tendency of the beam current dependence of the specific luminosity. Fig. 4 also shows that the specific luminosity does not become constant even at a very low beam current and this is also supported by the simulation. As for the reason of the strong current dependence of the specific luminosity, we suspected that it may come from the crossing angle. However, even when we temporarily turned off the crossing angle in the simulation, the current dependent was still there. After that we suspected that the horizontal tune close to the half integer resonance may bring the strong current dependence. However, the simulation result did not change very much with tunes which are off from the resonance. Therefore, we have not yet understood the origin of the strong current dependence of the specific luminosity. There still remains one more question. The above conclusion is that the main mechanism of the beam blowup with 4 bucket spacing is the beam-beam effect. On the other hand, with 3 bucket spacing, another mechanism (or the synergistic effect) plays some role. These two conclusions seem somewhat contradictory. This question is still controversial.

The beam-beam parameters are commonly used as an index of beam-beam performance. The beam-beam parameters at the record peak luminosity are also shown in Table 1. The horizontal beam-beam parameters are calculated with the design emittance, since no serious horizontal blowup is observed. Due to the large dynamic emittance effect, the actual horizontal tune shifts are much smaller than the beam-beam parameters in the table [2]. This may be the reason why the unusually high horizontal beam-beam parameters are possible at the KEKB. The vertical beam-beam parameters are calculated from the measured luminosity on the assumption that the vertical beam sizes of the two beams are equal. We believe that this assumption is more or less valid, since we rely on the beam size feedback system [6] for maximizing the luminosity in the usual operation. The“hourglass” effect from a finite bunch length and degradation of the beam-beam parameters due to a finite crossing angle are also considered. As for the bunch length, 7mm is assumed. The vertical beam-beam parameter of the HER is somewhat lower than the design. During the summer shutdown of 2002, we will reinforce the cooling power of the IR radiation masks. After that we expect that more beam current can be stored in the rings. Recently, we made an experiment for the purpose of examining the beam-beam effects with higher bunch currents. The result of the experiment is shown in Fig. 5 together with a data of a usual physics run. As is seen in the figure, the specific luminosity with higher bunch currents is on the extension of the line corresponding to the usual operation. We observed no serious lifetime decrease even with the higher bunch currents. With still 4 bucket spacing, we can expect a higher luminosity with higher beam currents.

3 REFERENCES

[1] KEKB B-Factory Design Report, KEKReport957, June 1995.

[2] Y. Funakoshi et al., ”Factories 2001”, Ithaca, 2001.

[3] K. Ohmi et al., Phys. Rev. E49 751, 1994.

[4] E. A. Perevedentsev and A. A. Valishev, Phys. Rev. SPECIAL TOPICS4 024403, 2001.

[5] K. Ohmi, private communication.

[6] N. Iida et al., HEACC 2001, Tsukuba, March 2001.