UPGRADE THE LUMINOSITY WITH DECREASING THE HORIZONTAL CROSSING ANGLE AT THE IP OF KEKB

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Abstract

In the present routine operation of KEKB, the bunch number is 1154 that is much less than the design value in each ring. The horizontal crossing angle at the interaction point (IP) is 2 × 11 mrad. The luminosity can be increased by reducing the crossing angle. Some calculation and the simulation were made in the paper.

1 MOTIVATION

In the KEKB B-Factory Design Report, the horizontal crossing angle at the IP is 2 × 11 mrad with the bunch spacing of 0.6 m. In the present routine operation, there are only 1154 bunches (5000 bunches in the design report) in each ring due to the limitation of the blowup and other instability of the beam. The present bunch spacing is 2.4 m, which is larger than the design one. It is not easy to realize 5000 bunches collision in a short time as there is no effective way to suppress the beam blowup with the bunch spacing of 0.6 m in the high current situation. Normally the luminosity with a crossing angle is lower than that of the zero crossing angle as the geometry reason. So decreasing the horizontal crossing angle at the IP maybe increases the luminosity.

2 UPGRADE THE LUMINOSITY

In the present status of KEKB, the horizontal crossing angle at the IP can be decreased, such as 5.5 mrad or 2.75 mrad; meanwhile, the enough separation at the parasitic IP's can be still kept because the bunch spacing is 2.4 m instead of 0.6 m. Then the luminosity can be increased. The calculation and the simulation with Ohmi's code of "Strong-Strong Beam-Beam Simulation" were made in the paper. The results show the gain of the luminosity is around 10% with the angle of 2 × 5.5 mrad compared with the current operation mode.

2.1 Calculation

For a collider with a half horizontal crossing angle θ at IP, if the transverse beam size $\sigma_y^* \ll \sigma_x^*$, the luminosity L can be expressed as

$$\frac{L}{L_0} = \sqrt{\frac{2}{\pi}} a e^b K_0(b)$$

where L_0 is the luminosity without geometrical effect, K_0 is a modified Bessel function, a and b stand for,

$$a = \frac{\beta_y^*}{\sqrt{2}\sigma_z}\ ;\ b = a^2\left[1+\left(\frac{\sigma_z}{\sigma_x^*}\tan\theta\right)^2\right]$$

where β_y^* is the vertical beta-function at IP, σ_z the bunch length. If $\sigma_z \ll \sigma_y^*$, the above formula can be inferred as

$$\frac{L}{L_0} \approx \left[1+(\frac{\sigma_z}{\sigma_x^*}\tan\theta)^2\right]^{-\frac{1}{2}}$$

In the KEKB B-Factory Design Report, the machine parameters are σ_z = 4 mm, σ_x^* = 33 μm, $\varepsilon_x = 1.8 \times 10^{-8}$ mrad, $\varepsilon_y = 3.6 \times 10^{-10}$ mrad, θ = 11 mrad, particles/bunch = 3.3×10^{10}, 1.4×10^{10} for LER and HER, respectively. The luminosities versus the horizontal crossing angle at the IP were calculated by the above formula, shown in Table 1.

Table 1: Calculation result for the design parameters

Crossing angle at IP	11 mrad	5.5 mrad	2.75 mrad
$(L_{angle}$-$L_{11})/L_{11}$	0 %	10.8 %	14.1 %

2.2 Simulation

The simulation results with the parameters of the design values were shown in Figure 1 and Table 2.

Table 2: Simulation result for the design parameters

Crossing angle at IP	11 mrad	5.5 mrad	2.75 mrad
$(L_{angle}$-$L_{11})/L_{11}$	0 %	14.4 %	21.5 %

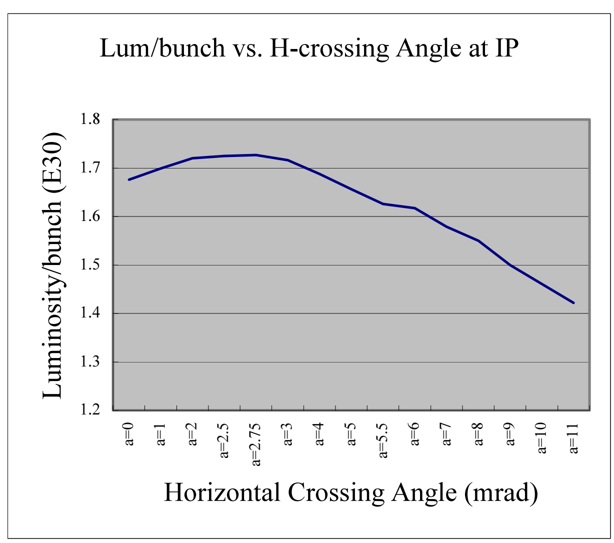

Figure 1: Simulation for the design parameters

We can see that the luminosity with a horizontal crossing angle of 5.5 mrad can be increased over 10%, compared with the case of the horizontal crossing angle of 11 mrad. Of course, if the angle can be reduced further, the luminosity can be increased more. In the present status of KEKB, the horizontal crossing angle of 2.75 mrad is no problem for the optics and the beam-beam interaction at the parasitic IP's as the bunch spacing is large. Then the luminosity can be increased around 20%. But it's sure that the bunch number will be increased in the near future. We should leave the margin for this.

Some simulations for the different operation parameters of KEKB were made. The crossing angle of 5.5 mard was chosen in the simulation. In this case, the current bunch number can be doubled in the future operation. The parameters are the routine operation values from the February to May in 2001. It contained the situations of the vertical tunes above and below the half integer. They all show that the luminosity can be increased and the results are interesting (See Figures 2-5 and Table 3).

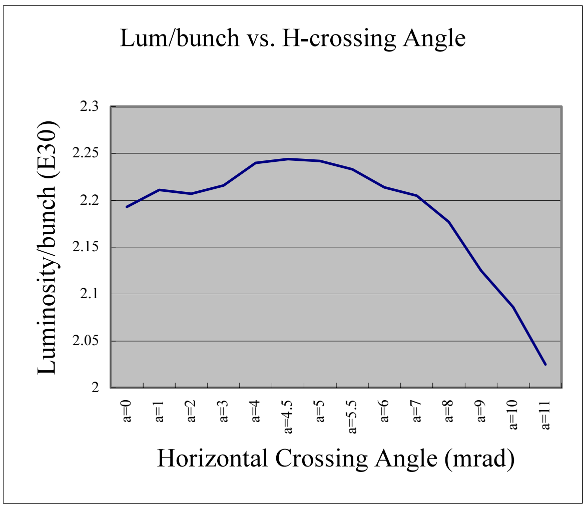

Figure 2: Simulation for parameters of March

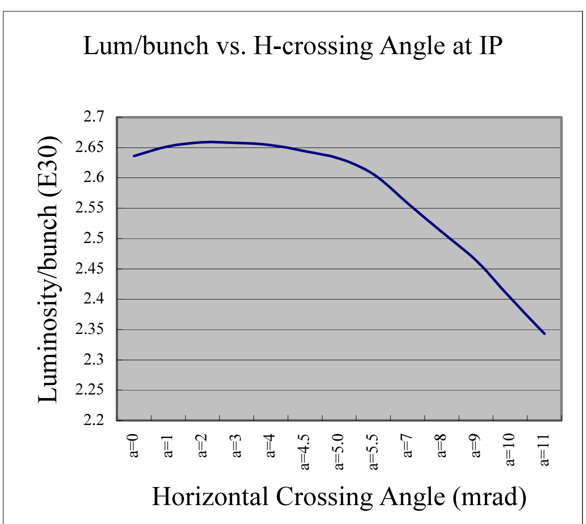

Figure 3: Simulation for parameters of April

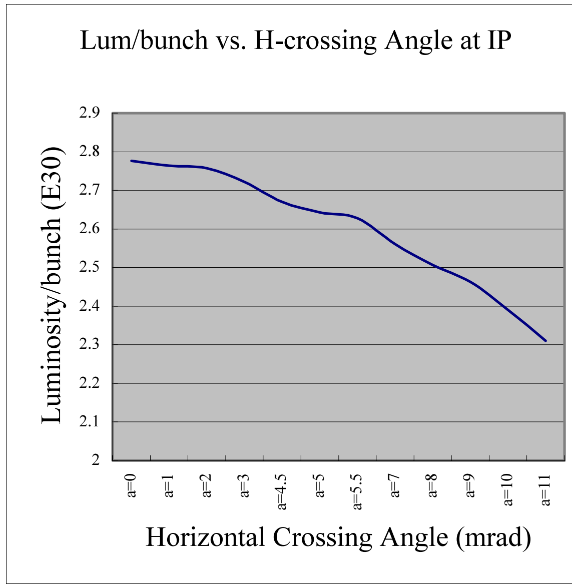

Figure 4: Simulation for parameters of May

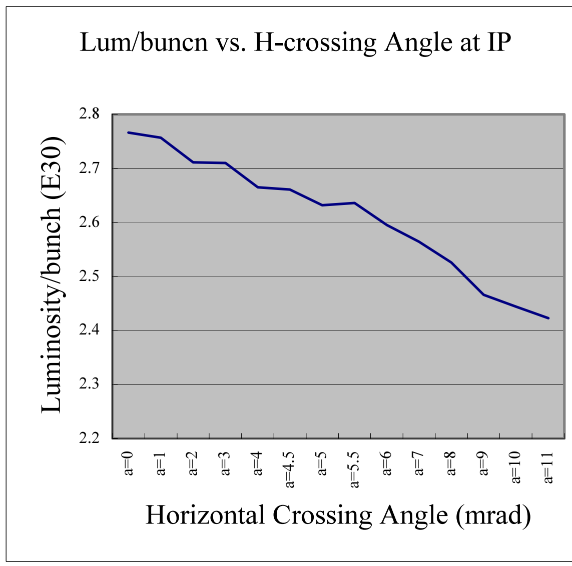

Figure 5: Simulation for parameters of February

Table 3: Simulation results with the angle of 5.5 mrad

Month	Feb.	March	April	May
Lum. increment	8.8 %	10.7 %	11.2 %	13.8 %

After decreasing the horizontal crossing angle to 2 × 4.5 mrad, the simulation of the tune scan for the operation parameters of April (Table 4) was made (see Fig. 6). It shows that the stable working region with the high luminosity is large enough. It is kept almost same as that of 11 mrad.

There is another merit for the beam instability with decreasing the angle. In the routine operation, the beam-beam blowup happened sometimes. Maybe the synchrotron-betatron coupling instability is one of the reasons. So changing the crossing angle may improve the synchrotron-betatron coupling instability.

Table 4: Parameters of KEKB in April of 2001

	LER	HER
Horizontal Emittance	18 nm	24 nm
Beam current	770 mA	530 mA
Number of bunches	1153	1153
Bunch current	0.67 mA	0.46 mA
Bunch spacing	2.4 m	2.4 m
Emittance ratio ε_y / ε_x	3.5 %	2.6 %
Beta function at IP β^*_x / β^*_y	59/0.7 m	63/0.7 m

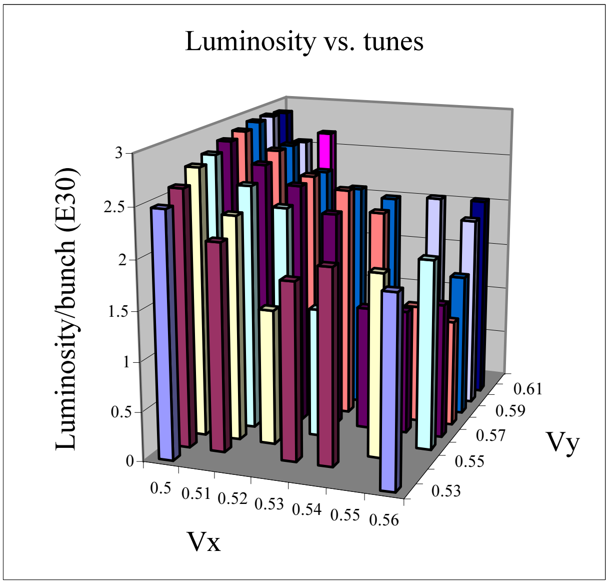

Figure 6: Tune scan for parameters of April

3 OTHER MACHINES

KEKB and PEP-II have been operating around two years. There are still no effective ways to suppress the beam blowup when increasing the bunch number up to the design value. PEP-II chose the way of "by 2" mode in the design report. That means the bunch spacing is 2 RF buckets. But the bunches were spaced every three buckets when the highest luminosity was gained at the end of last year. In this year, this kind of pattern was still used in the routine operation. It is also difficult to get the higher luminosity by increasing the bunch number to the design value in PEP-II.

In CESR, the experiment of changing the crossing angle was ever done in 1991 and 1992. The tune shift with the angle was measured as the Table 5.

Table 5: Tune shift vs. crossing angle in CESR

Crossing angle	Tune shift
0 mrad	0.03
2.4 mrad	0.024

The result showed that the tune shift and the luminosity were reduced with the angle's increasing from 0 to ±2.4 mrad.

4 CONCLUSION

It's not easy to fill beams one by one with the stable operation status in the KEKB in a short time. Before installing the crab cavities, it is worthy trying to decrease the horizontal crossing angle if there is no limitation of the hardware. The angle of 5.5 mrad is suggested here as the machine is still allowed to increase the bunch number to 2,500.

Of course, decreasing the angle is not the final way to upgrade the luminosity, as the total beam current and bunch number must be reached the design values at last. But now we still have time to make this kind of machine study in the present status.

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