

STUDY OF BEAM-BEAM ISSUE FOR KEKB CRAB CROSSING

K. Ohmi, J. Flanagan, Y. Funakoshi, N. Iida, H. Koiso, A. Morita, Y. Ohnishi, K. Oide, Y. Seimiya
KEK, Tsukuba, Japan

Abstract

Collision with crab crossing has been examined since February 2007 in KEKB. We target twice higher luminosity using the crab cavity. However the luminosity is still lower than the target. The luminosity degrades high bunch current and beam lifetime shortened. We discuss the reasons why the luminosity degrades in the crab crossing.

INTRODUCTION

In KEKB, crab cavity has operated to boost-up the luminosity performance. The crab cavity is considered to work to increase the luminosity twice. Betatron resonances excited by odd order terms of the dynamic variable is eliminated by the symmetry in the head-on collision, and horizontal motion is integrable for the operating point close to the half integer.

Figure 1 shows the comparison of the specific luminosity measured and simulated in KEKB. Large blue and black dots show the specific luminosity given by the strong-strong simulation (BBSS) for the head-on collision and the crossing collision with 11 mrad, respectively. Light blue dots are measured luminosity for the crossing collision. Red and other (yellow, violet, light green) dots are measured luminosity for crab crossing collision in several operating conditions. The specific luminosity is as high as that given by simulation for the head-on collision for low current $I^2=0.3 \text{ mA}^2$, but degrades at high current $I^2=0.9 \text{ mA}^2$. The current product can be achieved $I^2=1.25 \text{ mA}^2$ in the crossing collision, while 0.9 mA^2 for the crab crossing due to a short lifetime. The figure show that the measured luminosity distribute a line $L_{sp}=27-17I^2$. When horizontal emittance is changed, another line is drawn. The offset and gradient are high and steep for small horizontal size. The light blue line is similar as a line with an emittance $b_x e_x = \sigma_x^2 + (q\sigma_z)^2$. Now it seems to face a beam-beam limit independent of the collision scheme.

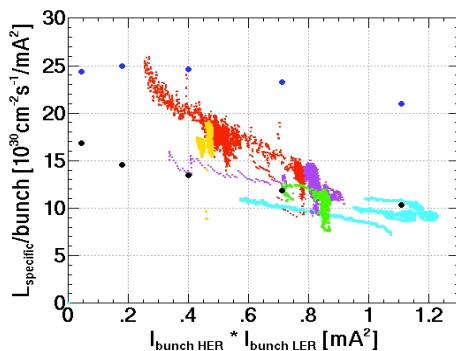


Figure 1: Specific luminosity as a function of the current product.

There are many mechanisms to cause degradation of the luminosity performance. The mechanisms, which we recognize, are summarized as follows,

1. Linear coupling at IP
2. Fast noise
3. Beam-beam halo
4. Touschek life couple to beam-beam
5. Nonlinearity of lattice
6. Wake force acting crabbing beam

Linear coupling is discussed in [1]. 2nd mechanism has been discussed in [1,2]. Beam-beam halo and Touschek effect under the beam-beam interaction were discussed in [3]. We discuss effects of lattice nonlinearity in this paper. 6-th was not more serious than the strong head-tail instability for non-crabbing beam.

LATTICE NONLINEARITY: WEAK-STRONG BEAM-BEAM SIMULATION ON SAD

Lattice nonlinearity may affect luminosity performance, because the tune spread due to the beam-beam interaction is so big that the spread overlaps resonances induced by the lattice nonlinearity. Several signs, in which nonlinearity affects luminosity, have been observed in KEKB.

1. Existence of Golden orbit
2. Luminosity performance depended on something run by run, even though IP parameters were tuned hardly.
3. Integer part of tune affected the luminosity performance.
4. Beta distortion in wiggler section made worse the luminosity.

We study the effect of lattice nonlinearity using a weak-strong simulation on SAD; a 3D weak-strong beam-beam module was implemented in SAD.

Nonlinearity is induced by errors in KEKB, because nonlinearity of each sextupole magnet is cancelled by the non-interleaved sextupole scheme in the ideal lattice. The vertical emittance is induced by the errors. Position errors of sextupole are generated randomly in SAD. It is enough to consider the position errors, since linear and nonlinear characteristics of the lattice result from orbit distortions in sextupole magnets. Amplitudes and seed of errors are chosen so that the emittance coupling (e_y/e_x) is 1%.

Figure 2 shows specific luminosity curve as a function of the current product for a lattice with errors. Here the simulation is done for the head-on collision: i.e., crossing angle and crab cavity is not considered. The bunch length given by SAD, 4.7 mm, is used in the simulation. Three

blue lines in the figure correspond to the specific luminosities for head-on and crossing collision given by the strong-strong simulation, and the measured specific luminosity fitted in Figure 1. Red points are given for only putting errors. The x-y coupling and dispersion at IP are not cared; namely $r1=-0.009$, $r2=-5.3e-4$, $r3=-0.27$, $r4=0.56$, $hy=-8.2e-5$ and $hy'=0.023$ are induced by the errors at IP in this example. It is well-known that the coupling errors at IP degrade the luminosity performance. In KEKB, the x-y coupling and dispersions at IP are corrected everyday: that is, they are scanned to optimize the luminosity. To realize the situation, coupling and dispersions at IP are matched to be zero on SAD. Since the IP matching reduces emittance coupling, larger errors than the first one are put to keep the 1% emittance coupling. Pink points are given after the IP correction. Errors degrade the luminosity performance, but the coupling correction at IP renovates it. IP coupling correction is one of important issue for luminosity performance.

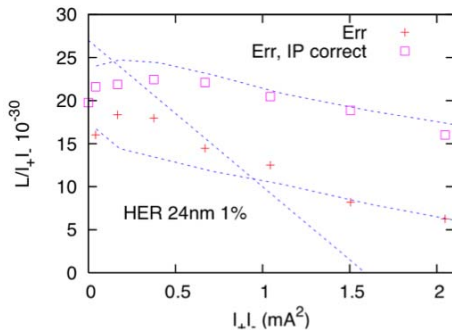


Figure 2: Specific luminosity given by a weak-strong simulation including lattice nonlinearity. Effect of coupling correction at IP.

We next discuss effects of crabbing beam. Installing a crab cavity in SAD, beam-beam collision with a crossing angle is simulated. Figure 4 shows the specific luminosity with considering crossing angle and crab cavity. Red points are given for no crossing or no crab cavity as the reference. The difference from pink points in Figure 3 is longer bunch length, 7mm. Green points are given for the case that a crab cavity is put in the lattice and correct only IP coupling and dispersion. The luminosity is degraded strongly after the IP correction. We have to notice that when x-y coupling exists at crab cavity, a vertical tilt appears at the IP. Pink points are given for further correction of coupling at crab cavity. The luminosity is recovered but still middle of red and green points. In KEKB one crab cavity is used per ring, therefore the bunch turns in the ring with tilting in horizontal. The tilt may pick-up nonlinear force along the ring[4]. Light blue points are given for the local crab scheme, in which two crab cavities are installed the straight section with IP on SAD. Coupling at IP and crab is corrected again. The luminosity is similar to that for the single crab cavity. This means crabbing only near IP section affect the

luminosity degradation. We have not understood the mechanism yet.

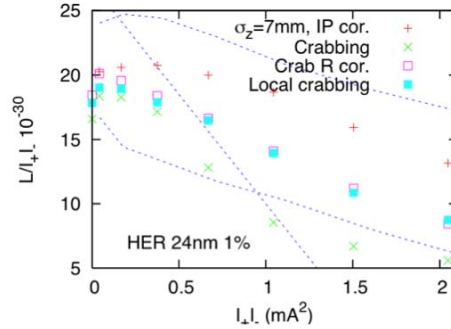


Figure 3: Specific luminosity given by a weak-strong simulation including lattice nonlinearity. Effect of crabbing beam.

MEASUREMENT: TUNE SCAN OF BEAM SIZE

A tune scan of the beam size was carried out to study the nonlinearity of lattice [4]. Tune is scanned along n_x from 0.52 to 0.7 with 0.002 step. The scan is performed for $n_y=0.58, 0.60, 0.62, 0.64$ and 0.66. Optics correction is performed for every tune point. Figure 5 shows the scan result. Differential resonance and its synchrotron sidebands $n_x - n_y + kn_s = n$ were seen. A strong beam loss was observed near $n_x = 0.66$. A beam loss was observed near $n_y = 0.66$ in HER, but was not observed in LER. The measurement was done with the crab cavity ON. The measurement was also performed with zero crab voltage, with the result that any differences were not found. Good or bad of the optics correction affected the stop-band of linear resonance, but did not affect the sidebands.

The beam size scan also shows the regular synchro-beta resonance at $2n_x - n_s = n$, though it is not seen in this figure. These resonances, which are caused by the chromaticity, can affect the beam-beam performance.

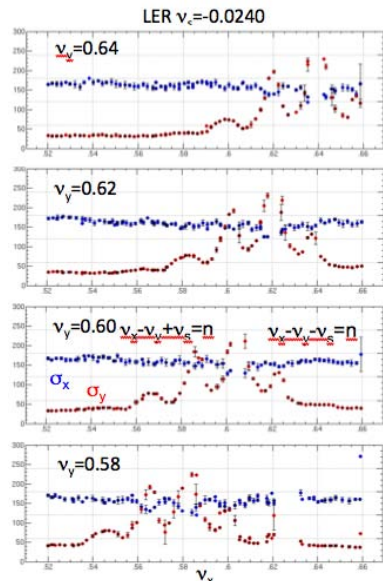


Figure 4: Horizontal (blue) and vertical (red) beam sizes in the tune space.

MEASUREMENT: OFF-MOMENTUM OPTICS

The chromaticity is defined as a tune variation for a momentum deviation. Here the chromaticity should be extended to discuss the coupling synchro-beta resonances. We parameterise the 4x4 revolution matrix to represent x-y coupling as follows [6]

$$M = RM_0R^{-1}$$

where M_0 is revolution matrix for the decoupled betatron motion. R , which characterizes the x-y coupling, is expressed by

$$R = \begin{pmatrix} r_0 I_2 & -S_2 R_2' S_2 \\ -R_2 & r_0 I_2 \end{pmatrix} \quad R_2 = \begin{pmatrix} r_1 & r_2 \\ r_3 & r_4 \end{pmatrix}$$

The chromaticity can be defined as

$$M(\delta) = M(0) + M_1 \delta + M_2 \delta^2 + \dots$$

where $M(d)$ should be a symplectic 4x4 matrix. The best way to satisfy the symplectic condition is to parameterize the matrix with momentum expansion of Twiss parameters, n , a , b , r . The ordinary chromaticity for n , a , b contributes $2n_x - kn_s = n$ resonances. Twiss parameters related to the coupling synchro-beta resonances are defined by

$$r_i \Rightarrow r_i(\delta) = r_{i0} + r_{i1} \delta + r_{i2} \delta^2 + \dots$$

Twiss parameters, coupling chromaticity, are measured by applying momentum shift for beam, where RF frequency shift of ± 400 Hz / 500 MHz are applied. Figure 5 shows measured chromaticity for b , r_1 and r_4 . The data are fitted 3-rd order polynomial. All of Twiss parameters were measured. $b(d)$ is plotted at the top picture. Red points are given by measurement, while blue points are given by a model lattice of LER on SAD. This SAD model, without error, does not give coupling chromaticity. The centre and bottom plots are given for r_1 and r_4 in HER and LER. To discuss the synchro-beta resonance, the transformation should be symplectic in 6 dimensional phase space. Hamiltonian formalism based on the measured chromaticity is developed in [7].

SUMMARY

We discussed the luminosity degradation with focusing the lattice nonlinearity. A weak-strong beam-beam simulation with SAD presented a degradation of luminosity up to a point. However we have not

understood how SAD presented the degradation. Tune scan gave information of our lattice. Dominant resonance was synchro-beta sidebands. Chromaticity related to the synchrotron resonances was measured. The effect of the chromaticity is being studied.

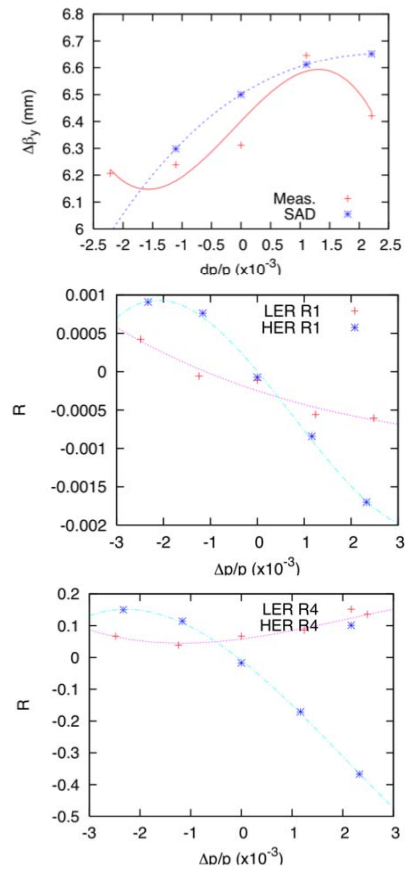


Figure 5: Examples of measured chromaticity, b , r_1 and r_4 .

REFERENCES

- [1] M. Tawada and K. Ohmi, in this proceedings.
- [2] K. Ohmi et al., Proceedings of EPAC06.
- [3] K. Ohmi, proceedings of e+e- Factories 2008.
- [4] A. Temnykh, proceedings of e+e- factories 2008.
- [5] M. Zobov, private communications.
- [6] K. Ohmi et al., Phys Rev. E49, 751 (1994)
- [6] Y. Seimiya and K. Ohmi, to be published.