STRONG-STRONG SIMULATIONS FOR SUPER B FACTORIES II

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Abstract

Super B factories are designed with very low emittance and very low beta function at the interaction point. The two beams collide with a large crossing angle, thus the overlap area of the beams is limited at a small part of their length. We have developed a beam-beam simulation for B factories. Our previous work was performed using Gaussian approximation and/or partial particle in cell (PIC) method. We have finished to develop full strong-strong code using the shifted Green function technique.

INTRODUCTION

In very high luminosity B factories, SuperKEKB and SuperB, collision with a large horizontal crossing angle makes possible to reduce the overlap area to $\sigma_x/\sigma_z\phi$ ~1/20 of entire bunch. It results that vertical beta function can be squeezed to the similar range of the overlap area, $\beta_y \sim \sigma_x/\phi$, where ϕ is a half crossing angle. Development of beam-beam simulation based on the strong-strong model is reported in this paper.

Collision with a crossing angle is regarded as that between tilt beams on x-z plane moving opposite direction (along s or –s axis) as shown in Figure 1, because the translation of x direction is compensated by Lorentz transformation with v_x=csinϕ [1]. Electro-magnetic field is formed in the perpendicular plane for s axis. Two beams are divided into many slices in longitudinal, and the field is calculated slice-by-slice at the collision points of combinations of two slices. If we use an ordinary method of particle in cell, very wide grid space, where two beam slices occupy, is necessary. For beam-beam interaction, it is enough to consider electro-magnetic field near one beam formed by the other beam. Shifted Green function [2] is helpful for the interaction between separated beam slices. Since the overlap area is 1/20 of entire bunch, a bunch is divided into 200 slices and 200x200=40,000 PIC calculations are performed per collision between two bunches.

We show some preliminary results of the code in this paper. Synchro-beta resonance due to the beam-beam interaction in the collision scheme is discussed.

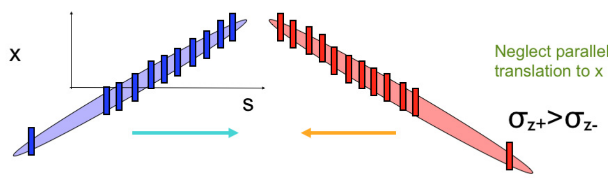

Figure 1: Schematic view of beam-beam collision with a large Piwinski angle, $\sigma_z\phi/\sigma_x$ ~20.

BEAM-BEAM FORCE CALCULATED BY SHIFTED GREEN FUNCTION

The 2-D Potential of an area where separated from a constant offset $\mathbf{r}_0$ is calculated by the shifted Green function as follows,

$$\phi(\mathbf{r}) = -\frac{Nr_e}{\gamma}\int d\mathbf{r}' G(\mathbf{r}-\mathbf{r}'-\mathbf{r}_0)\rho(\mathbf{r}'+\mathbf{r}_0). \quad (1)$$

The Green function should be defined in the area $(-\Delta x-x_0,-\Delta y-y_0)<\mathbf{r}-\mathbf{r}'-\mathbf{r}_0<(\Delta x-x_0,\Delta y-y_0)$. The Green function table G_{ij} is assigned as follows,

$$f(x_{i+}-x_0,y_{i+}-y_0)-f(x_{i+}-x_0,y_{i-}-y_0)-f(x_{i-}-x_0,y_{i+}-y_0)+f(x_{i-}-x_0,y_{i-}-y_0) \quad (2)$$

$$f(x_{i+}-2\Delta x-x_0,y_{i+}-y_0)-f(x_{i+}-2\Delta x-x_0,y_{i-}-y_0)-f(x_0-2\Delta x+x_{i-},y_{i+}-y_0)+f(x_{i-}-2\Delta x-x_0,y_{i-}-y_0) \quad (3)$$

$$f(x_0+x_{i+},y_0-2\Delta y+y_{i+})-f(x_0+x_{i+},y_0-2\Delta y+y_{i-})-f(x_0+x_{i-},y_0-2\Delta y+y_{i+})+f(x_0+x_{i-},y_0-2\Delta y+y_{i-}) \quad (4)$$

$$f(x_0-2\Delta x+x_{i+},y_0-2\Delta y+y_{i+})-f(x_0-2\Delta x+x_{i+},y_0-2\Delta y+y_{i-})-f(x_0-2\Delta x+x_{i-},y_0-2\Delta y+y_{i+})+f(x_0-2\Delta x+x_{i-},y_0-2\Delta y+y_{i-}) \quad (5)$$

$$\text{where } f(x,y)=\int dxdyG(\mathbf{r})=-3xy+x^2\tan^{-1}(y/x)+y^2\tan^{-1}(y/x)+xy\log(x^2+y^2) \quad (6)$$

$$x_{i\pm}=(i-1\pm 0.5)\Delta x/N_x \qquad y_{j\pm}=(j-1\pm 0.5)\Delta y/N_y$$

Eq.(2)-(5) show G_{ij} for (i=1, N_x, j=1,N_y), (i=N_x+1, 2N_x, j=1, N_y), (i=1, N_x, j= N_y+1, 2N_y), (i= N_x +1, 2N_x, j=N_y+1, 2N_y), respectively, so as to satisfy the periodic condition for 2Δx and 2Δy. The collision module using the shifted Green function is added to a strong-strong beam-beam simulation code, BBSS [3].

Figure 2 shows collision between 2nd e+ and 2nd e- bunch slices. Bottom left and right pictures plot particle distributions and potentials, respectively. Figure 3 shows beam distribution and potential along y=0. Potential induced by electron are calculated in the area where positrons exist, vice versa. Macro-particles of 2,000,000 are used. Each slice contains 10,000 particles in average. Since the radiation excitation is 2% of the beam size, the macro-particle statistics (1%) is acceptable. The peak of potential coincides the peak of the distribution. Since the bunch length of positron σ_{z+}=6mm is slightly longer than electron bunch σ_{z+}=5mm, positron bunch is outside (positive x) of electron bunch even the collision of 2nd slices.

Figure 4 shows collision between 2nd e+ and 199nd e- bunch slices. The separation between two slices is around 1mm, while the horizontal size is σ_x~10 μm.

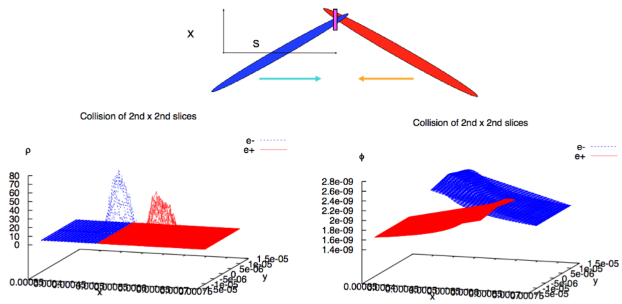

Figure 2: Collision between 2nd e+ and 2nd e- bunch slices. Top picture is a sketch of the collision. Bottom left picture plots particle distributions and right picture plots potentials, where electron and positron slices represented by blue and red, respectively.

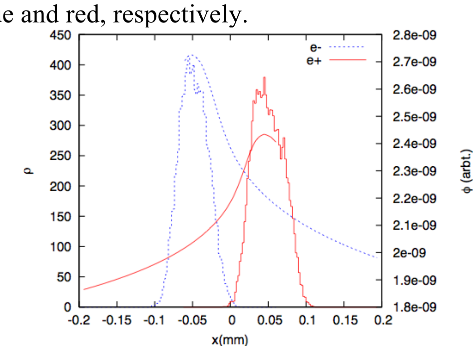

Figure 3: Beam distributions and potentials along y=0.

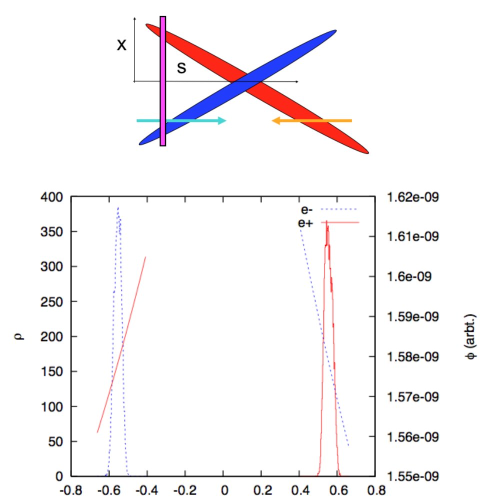

Figure 4: Collision between 2nd e+ and 199th e- bunch slices. Top picture is a sketch of the collision. Bottom picture plots particle distributions and potentials along y=0.

These results make sense for the collision scheme. The potentials are interpolated along z=s-ct to satisfy 6 dimensional symplectic condition [3]. The calculation time is 1 hour per collision in the present KEK super computer. Multi-turn tracking is being performed for the test. Figure 5 shows the luminosity and beam size in 300 turn. The turn number is small compare than the radiation damping time 4000-7000 turns in the present simulation. The luminosity degradation is 10% or more for no crab waist, while is slight for crab waist. The similar behavior is seen in simplified strong-strong simulations [5]. The luminosity degradation 10% is not disaster. Vertical beam size increase is seen in the bottom picture. The increase is not seen with crab waist scheme.

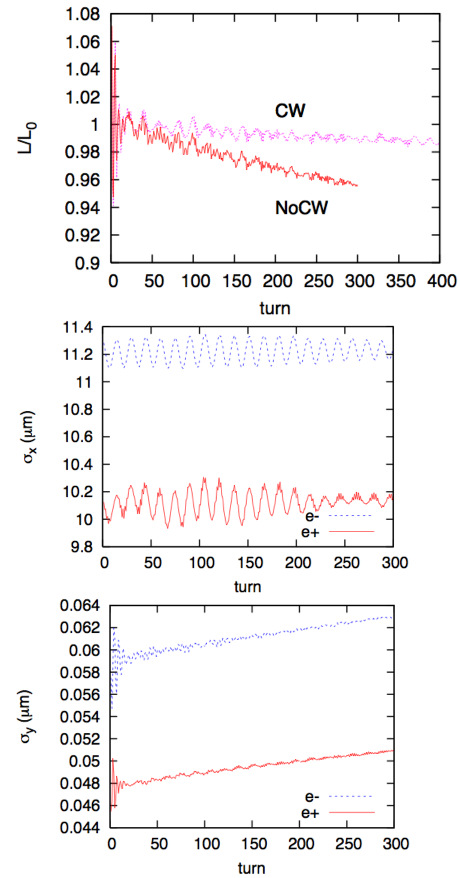

Figure 5: luminosity and beam size evolution in 300 turns.

Longer term simulation than several radiation damping time should be done. The computer is revised in this September 2011. We hope the simulation speed faster.

SYNCHRO-BETA RESONANCE STUDIED BY THE STRONG-STRONG SIMULATION

Very strong synchro-beta resonances in this collision scheme are seen using the weak-strong simulation. Figure 6 shows luminosity behavior in transverse tune space. Since synchrotron tune is ν_s=-0.025, the resonances $2\nu_x+2\nu_s$=int and $2\nu_x+4\nu_s$=int are seen. Though crab waist is not adopted in this simulation, qualitative feature does not depend on the crab waist. The resonances attract attention, because our operation point is assumed horizontal tune 0.52~0.53 as a result of a dynamic aperture optimization [4].

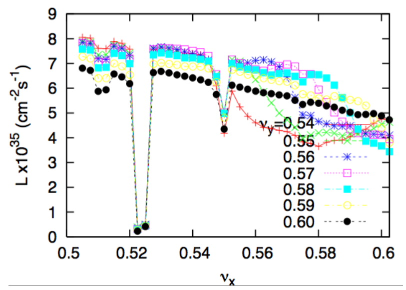

Figure 6: Luminosity v.s. horizontal tune.

Strong-strong effects, namely coherent motions for the synchro-beta resonances, have to be studied. Fully strong-strong simulation discussed above has been shortage of power for the consuming simulation time yet. Simplified strong-strong simulation, which is combination of the particle in cell calculation and Gaussian approximation, is adopted at present [5]. Figure 7 shows luminosity evolution for three tunes. Very strong luminosity loss is seen for ν_x=0.525, but both sides of the horizontal tune, 0.520 and 0.530, are safe; L=7x10^{35} cm^{-2}s^{-1}, thus the resonance is not serious. Figure 8 shows coherent motion of e+ and e- beams; correlation of x and z. The correlations for e+ and e- beams are inphase each other.

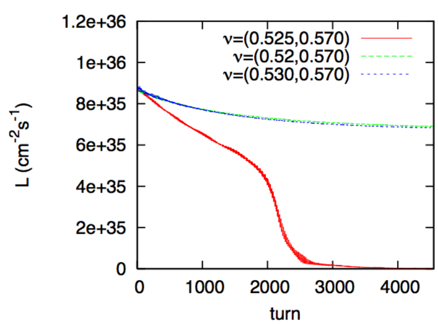

Figure 7: Luminosity evolution for three operating points.

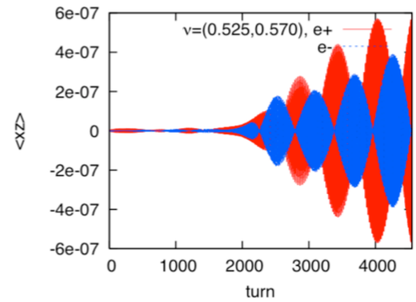

Figure 8: Evolution of x-z correlation <xz>.

SUMMARY

A strong-strong simulation code using the shifted Green function method is being developed for study of the beam-beam effect in Super B factories. Potential of beam-beam interaction with far distance is given well. Long term simulation will be performed in new KEK supercomputer.

Coherent synchro-beta resonance of the two colliding beams is very strong in the collision with large crossing angle. The resonance can be avoided by choice of operating point. Sufficient distance from the resonance should be kept because of the very strong effect.

REFERENCES

[1] K. Hirata, Phys. Rev. Lett. 74, 2228 (1995).
[2] J. Qiang et al., Phys. Rev. ST-AB 5, 104402 (2002).
[3] K. Ohmi et al., Phys. Rev. ST-AB 7, 104401 (2004).
[4] H. Koiso et al., in this proceedings.
[5] K . Ohmi, proceedings of IPAC10, TUPEB013.