QUASI-STRONG-STRONG SIMULATIONS FOR BEAM-BEAM INTERACTIONS IN KEKB

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Abstract

Although the strong-strong simulation is expected to give the most faithful representation of beam-beam interactions, since the calculations require a large amount of computer resources, their practical applications are severely limited. This paper presents a new method, called quasi-strong-strong simulation that method allows to efficiently calculate effects of beam-beam interactions without significantly compromising the advantages of strong-strong simulations.

1 INTRODUCTION

Traditionally beam-beam effects have been studied by many researchers with the weak-strong, the rigid Gaussian and strong-strong schemes. In the weak-strong scheme, one (weak) beam is represented by a group of macro-particles, while the other (strong) is assumed to have a rigid spatial charge distribution. During the beam collision, the weak beam is subjected to a Coulombic force due to the fixed charge distribution of the opposing beam. This force can be expressed by a Hamiltonian in a manner similar to interactions of the beam with other elements in an accelerator. Thus various effects such as reduction of luminosity due to an emittance growth related to resonances can be investigated.

In the rigid Gaussian model, the two beams are both assumed to be of a fixed Gaussian distribution. It is typically employed in studies of coherent motions of the beam barycenter. In the strong-strong scheme, the two beams are both represented by a group of macro-particles. This method allows to investigate coherent motions of bunches as well as incoherent weak-strong phenomena. If each beam is assumed to consist of 'N' macro-particles, Coulombic forces between N(N-1)/2 macro-particle pairs need to be calculated in each beam collision. This number 'N' has to be sufficiently large, so as to keep statistical effects of the bunch "macronization" on the coherent amplitude ($\sim 1/\sqrt{N}$) reasonably small. Consequently, a reliable strong-strong simulation requires a large amount of CPU resources, which frequently renders large-scale, systematic studies of beam-beam effects near impractical.

This paper presents a new method, called quasi-strong-strong simulations that has been developed by the authors. It allows to efficiently calculate effects of beam-beam interactions without significantly compromising the advantages of strong-strong simulations. Two types of quasi-strong-strong simulation for studying beam-beam interactions are shown: the first method is applied to a study on an incoherent effect, and the second methods includes an improvement that allows to study coherent effects.

2 FIRST METHOD : INCOHERENT EFFECT

In the first method of quasi-strong-strong simulation, similar to the conventional weak-strong simulation, one beam is represented by macro-particles and the other is assumed to be rigid. However, the roles of strong and weak beams are switched periodically. After a prescribed number (N_T) of collisions, the size of the hitherto weak bunch is fixed according to the latest calculation, and it becomes "strong". From then on the previously strong bunch is treated as weak, and the calculations are conducted for the next N_T revolutions until. Then a another switching of strong vs. weak beams is made and the simulation is continued.

If N_T equals 1, i.e. if the switching is done at each collision, this method is almost equivalent to strong-strong simulation with Gaussian approximations. Therefore, the calculated coherent amplitude of particles is subjected to a statistical error of $O(1/\sqrt{N})$, where N is the number of macro-particles. However, if the switching is done at a reasonably large value of N_T, by accumulating the data in a strong-weak mode of calculations for this period, the statistical fluctuation of the coherent motion is significantly reduced. The value of N_T should be larger than the inverse of fractional tune and be less than radiation damping time.

This method has been applied to studies of beam-beam effects of KEKB. Since the damping time at KEKB is 7000 turns, the N_T has been set to 500 turns. The weak beam is represented by 50 macro-particles. The strong beam is assumed to have a rigid Gaussian distribution determined by the beam envelope matrix [1]. In the simulation synchro-beam interaction [2] is used to represent beam-beam forces. Effects of the crossing angle are included[3]. For each collision the macro-particles in the weak beam are tracked and their beam envelope matrix is updated. The final coordinates of each macro-particle in a collision are recorded for tracking them through a revolution. After N_T turns of collision / revolution cycles, the assignment of weak and strong beams is switched, and the simulation continues.

Fig.1 shows vertical beam size of electron and positron beams in each step. We consider two cases, that is, one is the case that the damping time of LER is equal to that of HER, and the other is that of LER is twice of that of HER. The damping time is controlled with a damping wiggler. The beam sizes become to equal each other in the case of the same damping time for the both rings. In the different damping time, the positron beam which has a larger damping time blows up about twice in emittance. In both case, the luminosity was 1.4×10^{34} cm^{-2}. This suggests that the beam blow up comes from a vertical tail[4].

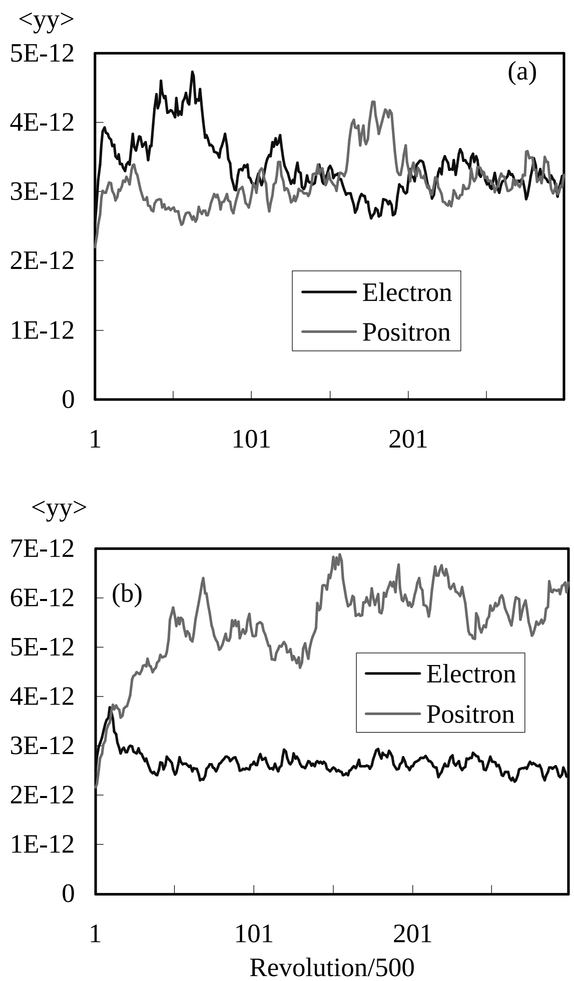

Fig.1 Vertical beam size for each switching. (a) Both rings have equal damping time (with wiggler). (b) LER have twice larger than HER (without wiggler).

Table 1 Parameters of KEKB

	LER	HER
Energy(GeV)	3.5	8
Emittances (nm)	18/0.36	18/0.36
Bunch length (cm)	0.4	0.4
Damping time (τ_x(ms))	80-40	40
Betatron tunes	45.52/45.08	47.52/43.08
Synchrotron tunes	0.01-0.02	0.01-0.02
Beta of IP(m)	0.33/0.008	0.3/0.008
Beam current(A)	2.6	1.1
Particles /bunch	3.3×10^{10}	1.4×10^{10}
Crossing angle (mrad)	11x2	
Design luminosity(cm^{-2}s^{-1})	1×10^{34}	

3 SECOND METHOD : COHERENT EFFECT

The second method takes the dipole motions of the strong beam into account on the conventional weak-strong method. In this scheme while the macro-particles in the weak beam feel the force from strong beam with Gaussian distribution, effects of the same coherent force on the strong beam is also considered. The kick that is received by the strong beam is recorded, and the strong beam is tracked through the ring for the next revolution accordingly.

Fig.2 shows the dipole oscillation of the weak and strong beams that has been obtained from a simulation with this method. The figure shows there is no dipole oscillation for our operating tune. The other hand it is seen that when the vertical tune is close to 0.5, a strong coherent oscillation (so-called pi-mode) is induced.

This method will be a good approximation for studying a coherent motion in the weak-strong limit. When the both beams are strong, it may be very similar to calculations with a strong-strong simulation with a rigid Gaussian model. However it will be important that the framework of this method permits a straightforward extension to include more complex interactions such as synchro-beam and crossing angle effects. If this is done, it will be possible to investigate coherent modes which couple to synchrotron motion.

We considered only dipole motion of strong beam. Higher order coherent motions are neglected, although in principle they can be also taken into account.

Similar technique has been applied to studies of beam-photoelectron interactions[5] and is also very powerful for studying ion instability issues, that is, the two beam instability[6]. In these cases, the weak-strong limit seems to be satisfied.

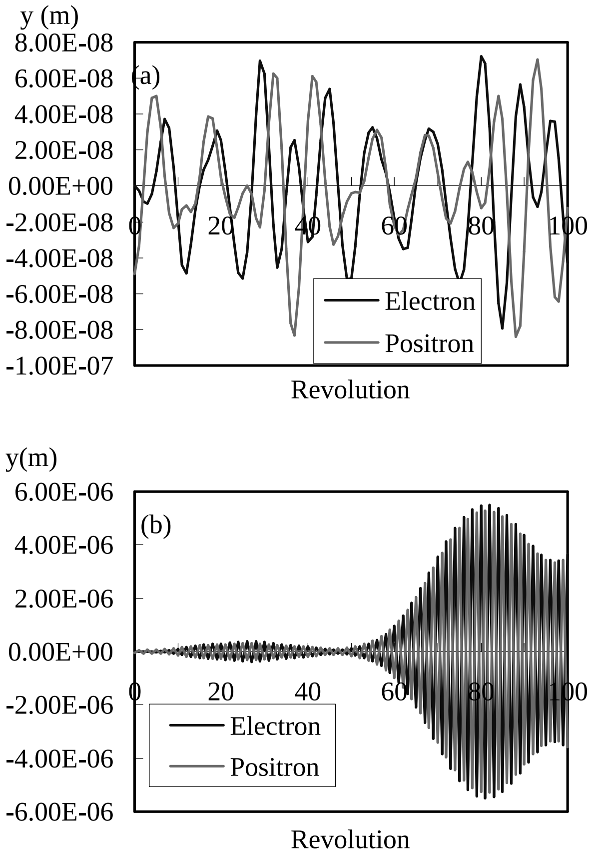

Fig.2 Vertical coherent amplitudes. (a) ν_x=0.52, ν_y=0.08, (b) ν_x=0.52, ν_y=0.48.

4 SUMMARY

Attempts have been made to circumvent the gap between the exact strong-strong scheme and weak-strong and rigid Gaussian model with these two method. The important point is to the phenomena separate into coherent dipole and incoherent effects. The concept is the same for considering rigid Gaussian and weak-strong schemes. We expect the idea is good approximation for real beam-beam phenomena, though it is difficult to know whether it is reliable until performing exact strong-strong simulation. It is interesting that one dimensional strong-strong simulation[7] shows consistent results with this idea.

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