

BEAM-BEAM STUDY ON THE UPGRADE OF BEIJING ELECTRON POSITRON COLLIDER

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Abstract

It is an important issue to study the beam-beam interaction in the design and performance of such a high luminosity collider as BEPCII, the upgrade of Beijing Electron Positron Collider. The weak-strong simulation is generally used during the design of a collider. For performance a large scale tune scan, the weak-strong simulation studies on beam-beam interaction were done, and the geometry effects were taken into account. The strong-strong simulation studies were done for investigating the luminosity goal and the dependence of the luminosity on the beam parameters.

INTRODUCTION

BEPCII, a double ring electron positron collider, is an upgrading scheme from Beijing Electron Positron Collider (BEPC) with micro- β scheme and multi-bunch collision. To perform multi-bunch collision, two rings of BEPCII will be installed in the existing BEPC tunnel.

To achieve the high luminosity in the factory class collider, high current and small beam size are necessary, and these induce strong beam-beam interaction. The successful performance of KEKB and PEP-II indicates that the beam-beam limit can be reached without any single bunch instability. This means the beam-beam interaction limits the luminosity. It is an important issue to study the beam-beam interaction in the design and the performance of such a high luminosity collider.

The beam-beam interaction on BEPCII was studied by simulation. Table 1 shows main parameters of BEPCII, which were used in the simulation. Both weak-strong and strong-strong models were adopted in the simulation. The tune scan was performed for optimizing the tune by weak-strong simulation, while the strong-strong simulation was done for investigating the luminosity goal and the dependence of the luminosity on the beam parameters. The estimation of the parasitic beam-beam effects is also given in this paper.

THE WEAK-STRONG SIMULATION

The weak-strong simulation studies were done by taking the advantages of the code BBC (Beam-Beam interaction with a Crossing angle) developed by K.Hirata[1]. BBC is a weak strong simulation code in 6-dimensional phase space including the effect of crossing angle. Although the weak strong simulation can not investigate the coherent phenomena of beam-beam interaction, it is generally used during the design of a collider.

Table 1: Main parameters of BEPCII

Energy E (GEV)	1.89
Circumference C (m)	237.53
Rev. frequency f_0 (MHz)	1.2621
RF frequency f_{rf} (MHz)	499.8
RF Voltage V_{rf} (MV)	1.5
Damping time $\tau_x/\tau_y/\tau_E$ (ms)	25/25/12.5
Total current/beam I (A)	0.91
Particle number N	4.5×10^{12}
Bunch number n_B	93
Bunch current I_b (mA)	9.8
Energy spread σ_ϵ	5.16×10^{-4}
Momentum compact α_p	0.0235
Bunch length σ_z (cm)	1.5
Tunes $\nu_x/\nu_y/\nu_s$	6.53/7.58/0.034
Emittance ϵ_x/ϵ_y (nm-rad)	144/2.2
Beta function at IP β_x^*/β_y^* (m)	1/0.015
Beam size at IP σ_x^*/σ_y^* (μm)	380/5.7
Crossing angle ϕ_c (mrad)	11×2
Piwnski angle Φ (rad)	0.435
Bunch spacing s_b (m)	2.4
Beam-beam parameter ξ_x/ξ_y	0.04/0.04

The effect of a finite bunch length was taken into account by dividing a strong bunch into 5 slices in longitudinal directions, and the weak bunch is represented by 50 randomly generated super particles, with Gaussian distribution in 6-dimensional phase space. The simulation was done for more than 5 damping time.

The tune scan was performed for optimizing the tune from the view point of high luminosity. Figure 1 shows the simulated luminosity on the tune plane (fractional part only) $\delta\nu_x \in (0,1)$, $\delta\nu_y \in (0,1)$ with crossing angle $\phi_c = 2 \times 11 \text{ mrad}$, in which the luminosity reduction factor L/L_0 is given instead of luminosity itself. The mesh size was set as 0.02, which is smaller than the synchrotron tune of $\nu_s = 0.034$. It indicates that the high luminosity region is just above the half integer in horizontal plane, and there is no significant deference between just above half integer and just above the integer in vertical plane. According to the commissioning experiences of KEKB and PEP-II [2], an above half integer vertical tune is preferable because that the orbit distortion is much stable than that of above an integer. Fig.2 gives a tune scan with

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both transverse tunes above the half integer, with much smaller mesh size. The high luminosity is expected around $\delta v_x = 0.53$ and $\delta v_y = 0.58$, and these tune values are set as designed working point.

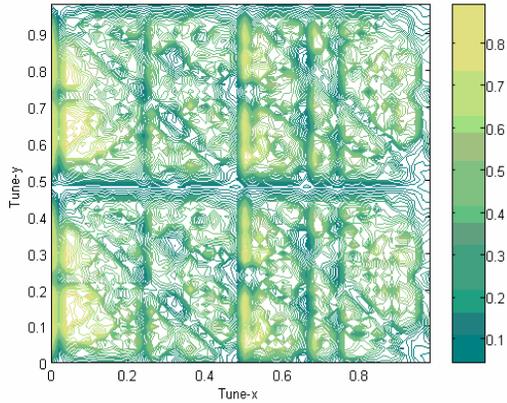


Figure 1: Luminosity survey with crossing angle of $\phi_c = 11 \times 2 \text{ mrad}$

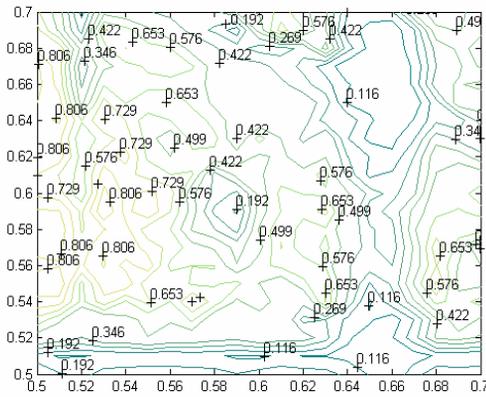


Figure 2: Luminosity survey above the half integer with a crossing angle of $\phi_c = 11 \times 2 \text{ mrad}$

3 STRONG-STRONG SIMULATION

The Simulation of Luminosity

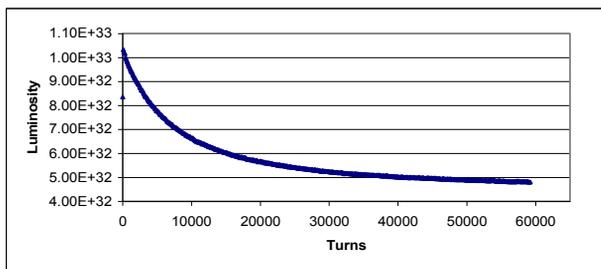


Figure 3: A simulation of luminosity for designed tune with a crossing angle of $\phi_c = 11 \times 2 \text{ mrad}$

The simulation with strong-strong model was done by using Dr. Cai's code[3], which is a 6-D code, including a finite bunch length effect and a crossing angle effect. Fig.3 shows a simulation result with design tune $\delta v_x = 0.53$

and $\delta v_y = 0.58$. After two damping time, beams almost reach their equilibrium.

From the simulation result of Fig.3, there is a large reduction of the luminosity compare with the luminosity goal of 1×10^{33} . A local tune scan shows that, much closer of the horizontal tune to half integer, much higher luminosity. This consists with the commissioning experience of KEKB and PEP-II. Fig.4 gives a slice of local tune scan, from which, one can find higher luminosity is reached at the tune of $\delta v_x = 0.51$ and $\delta v_y = 0.58$, in which the luminosity is 0.62×10^{33} . This is chosen as a new tune.

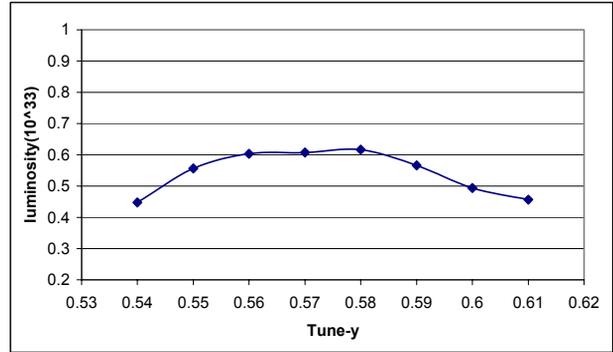


Figure 4: $\delta v_x = 0.51$, Luminosity vs. δv_y

Beam-Beam Limit

To achieve higher luminosity, larger beam-beam parameter ξ_y is preferable. However, the maximum ξ_y is limited by beam-beam interaction. Fig.5 shows the curves of luminosity vs. vertical beam-beam parameter ξ_y^2 . $\xi_y = 0.04$ is the designed value of BEPC-II. It indicates that with half crossing angle of 11 mrad, ξ_y is saturated around 0.06. From the view point of beam-beam interaction, $\xi_y = 0.05$ is reachable. The successful commissioning experience of KEKB and PEP-II shows that there is no problem to reach $\xi_y = 0.05$.

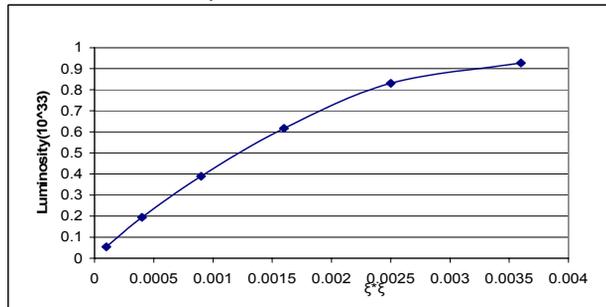


Figure 5: Luminosity vs. ξ_y^2 with crossing angle of $\phi_c = 11 \times 2 \text{ mrad}$

The Crossing Angle Dependence

For BEPC-II, the crossing angle of $\phi_c = 11 \times 2 \text{ mrad}$ is the basic requirements of interaction region. From the view point of beam-beam interaction, the crossing angle not only limits the maximum ξ_y , but also induces some additional luminosity reduction due to the geometric effects. Fig.6 shows that the luminosity reduction factor

due to finite bunch length effect and crossing angle is about 62%, while the luminosity reduction factor is 87% in head on scheme. The theoretical geometry effect, which was calculated by using a formula [1] is also given in Fig.6. The luminosity reduction with crossing angle in the strong-strong simulation is much larger than that in the weak-strong simulation.

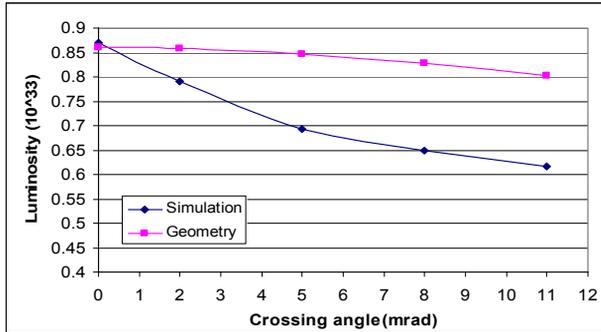


Figure 6: The luminosity as a function of crossing angle. Both the simulation results and theoretical results are given.

The Way to Higher Luminosity

Due to the finite bunch length effect and crossing angle effect, the simulation luminosity of $0.62 \cdot 10^{33}$ is lower than the design goal. The possible ways to increase the luminosity are: increasing the bunch current, decreasing β_y of IP as well as bunch length, and increasing the bunch number and total beam current, etc. Fig.7 shows

the simulation results with $\xi_y=0.04/0.05$, $\beta_y^*=\sigma_s=1.2\text{cm}/1.5\text{cm}$. Simulation result shows that when the vertical beam-beam parameter was increased to 0.05, and β_y^* and bunch length were decreased to 1.2cm, the simulation luminosity is more than $1 \cdot 10^{33}$. In this case, the total beam current is increased by 25%.

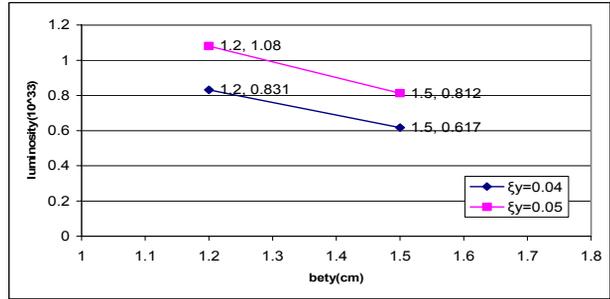


Figure 7: The luminosity vs. β_y^* & ξ_y

THE PARASITIC BEAM-BEAM EFFECT

There are 8 parasitic crossings symmetrically located on either side of the IP. The incoherent tune shift Δv_x and Δv_y experienced by a particles at the center of the bunch from a parasitic IP were estimated by Tennyson's formula [4]. Table 2 gives an estimation of the parasitic beam-beam effects for different injection pattern, in which, d is the separation between two beams at parasitic IP, and Δs is the distance from IP to parasitic IP.

Table 2: The parasitic beam-beam tune shift for different injection pattern

E(GeV)	1.89						
I _{bunch} (mA)	9.8(N _{bunch} =4.84e10)						
Φ _{crossing} (mrad)	11*2						
NO _{pc}	±1	±2	±3	±4	±5	±6	±7
Δs (m)	0.3	0.6	0.9	1.2	1.5	1.8	2.1
d(mm)	6.6	13.2	19.8	27.8	41.2	57.1	73.0
β _x	1.09	1.36	1.81	2.71	5.26	9.53	15.08
β _y	6.02	24.02	54.02	88.52	88.82	79.08	69.91
Δv _x (10 ⁻³)	-0.15	-0.046	-0.027	-0.020	-0.018	-0.017	-0.017
Δv _y (10 ⁻³)	0.81	0.81	0.81	0.67	0.31	0.14	0.077
Injection patten: By 4	ΣΔv _x (10 ⁻³)		-0.04		ΣΔv _y (10 ⁻³)		1.34
Injection patten: By 3	ΣΔv _x (10 ⁻³)		-0.088		ΣΔv _y (10 ⁻³)		1.90
Injection patten: By 2	ΣΔv _x (10 ⁻³)		-0.166		ΣΔv _y (10 ⁻³)		3.24
Injection patten: By 1	ΣΔv _x (10 ⁻³)		-0.59		ΣΔv _y (10 ⁻³)		7.25

SUMMARY

The simulation studies with weak-strong and strong-strong models show that: setting the horizontal tune close (above) to half integer is a good choice to get the higher luminosity; the luminosity reduction factor due to finite bunch length effect and crossing angle effect is about 62%, while it is about 87% in head on scheme; the beam-beam parameter of $\xi_y=0.05$ can be reached. The parasitic beam-beam effect was preliminarily studied.

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