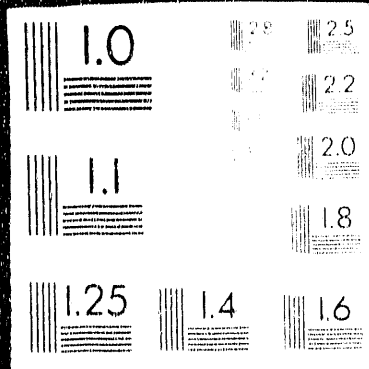


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Effects of Parasitic Beam-Beam Interaction During the Injection Process at the PEP-II *B* Factory*

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ABSTRACT

This paper is concerned with beam-beam effects during the injection process at the proposed asymmetric SLAC/LBL/LLNL *B*-Factory, PEP-II. It is shown that the parasitic beam-beam interaction can lead to a significant blowup in the vertical size of the injected beam. Simulation results for the horizontal and the vertical injection schemes are presented, and their performances are studied.

1. INTRODUCTION

For an asymmetric collider, which intrinsically consists of two separate rings, the bunches not only collide at the interaction point (IP) but experience a long-range beam-beam force on the way into and out of the IP region (where both beams travel in a common vacuum pipe). These collisions are called "parasitic crossings (PC)." The parasitic crossings has emerged as a source of far stronger beam-beam impact during the injection process at the PEP-II *B* factory [1]. In the previous design, APIARY-6.3d [2], the bunches are injected horizontally into the two rings with large horizontal offset of $8\sigma_{0x}^{ptm}$ where σ_{0x}^{ptm} is the nominal horizontal storage ring beam size at the end of the septum magnet. Then, the injected beam starts to travel around the ring oscillating horizontally for the first several damping time. We only consider the case in which injection takes place into the low energy ring (LER), while the beam in the high energy ring (HER) has already been fully stored. This configuration is expected to give the worst case with respect to the beam dynamics, since previous studies on the beam-beam interaction including the PC in APIARY-6.3d show that it is the low energy beam that mostly blows up [2]. When the injected beam arrives at the 1st PC, where the two nominal orbits are separated horizontally by about 7.6 times the nominal horizontal

beam size of the LER, it may approach the other beam far more closely than the nominal separation, or it may even strike the other beam head-on. Due to the large vertical beta function (~ 20 m), the vertical beam-beam tune shift at the 1st PC can become of the order of unity in the head-on collision case, which is larger than the normal beam-beam tune shift limit by one or two orders of magnitude. Such strong impacts may lead to a significant blowup of the injected beam and to a subsequent particle loss. We begin our study by showing the simulation results for this horizontal injection case.

2. HORIZONTAL INJECTION AT APIARY-6.3D

The main storage ring and injection parameters of APIARY-6.3d design are listed in Table 1. Here, E is the beam energy, I_b is the bunch current, ϵ_0 is the nominal emittance, β is the betafunction, and d_x and σ_{0x} are the separation distance and the nominal rms beam size at the 1st PC, respectively. We consider only the 1st PC (the one closest to the IP) on either side, because it overwhelms the others. The injection parameters are specified in square brackets. A bunch with 20% of the nominal single-bunch current is injected to the LER with a horizontal displacement $8\sigma_{0x}^{ptm}$ from the stored beam orbit. We assume that the phase advance between the injection point and the IP is 2π times an integer. We have selected the fractional tunes of the working point to be $\delta Q_x = 0.64$ and $\delta Q_y = 0.57$ for both beams.

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Table 1: The main storage ring and injection parameters of APIARY-6.3d. The parameters in square brackets are those of the injected beam at the time of injection.

	LER (e^+)		HER (e^-)	
E (GeV)	3.1		9	
I_b (mA)	1.23 [0.246]		0.848	
ϵ_{0x} (nm-rad)	92 [8.24]		46	
ϵ_{0y} (nm-rad)	3.6 [8.24]		1.8	
d_x (mm)	2.82			
	IP	1st PC	IP	1st PC
β_x (m)	0.375	1.51	0.75	1.30
β_y (m)	0.015	25.23	0.03	13.01
d_x/σ_{0x}	-	7.6 [25.2]	-	11.5

Figure 1 shows the rms sizes of the injected beam in units of the nominal storage ring beam sizes versus the turn number after the injection. The largest turn number, 10000, corresponds to about 2 radiation damping times. The characters "x" and "y" denote the relative horizontal and the vertical beam sizes, respectively, while the character "o" represents the rms bunch length in units of the nominal value. We can see that the vertical beam size reaches its peak value very quickly within approximately 300 turns. The beam blowup then damps out gradually in the following few radiation damping times. Despite the large vertical beam blowup, no particle loss out of 200 "superparticles" was found during the simulation. The high energy beam sizes, which are not plotted here, show practically no change from their nominal values.

We found that the horizontal beam size also blows up, although much more slowly, to about 3 times the nominal storage ring value, roughly within one radiation damping time. This can be explained as follows [1]. When the injected beam collides with the counter-rotating beam at the PC, particles in the injected beam receive horizontal kicks whose sign depends on whether the particle is located in the inner side or the outer side with respect to the center of the other beam in horizontal phase space. This is illustrated in Fig. 2. The result is that the beam will have a tendency to shear into an elongated shape

and eventually to spread out over a circular annulus. This leads to a damping of the horizontal baricentroid motion even though the particle amplitudes themselves have not yet been significantly damped.

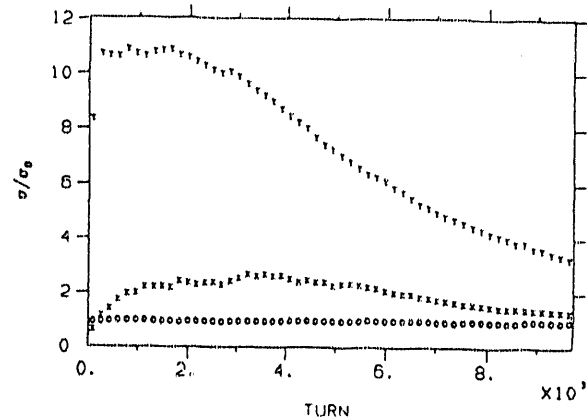


Figure 1: The time evolution of the injected beam sizes in units of the nominal storage ring beam sizes during the horizontal injection for APIARY-6.3d (x=horizontal, y=vertical, and o=longitudinal).

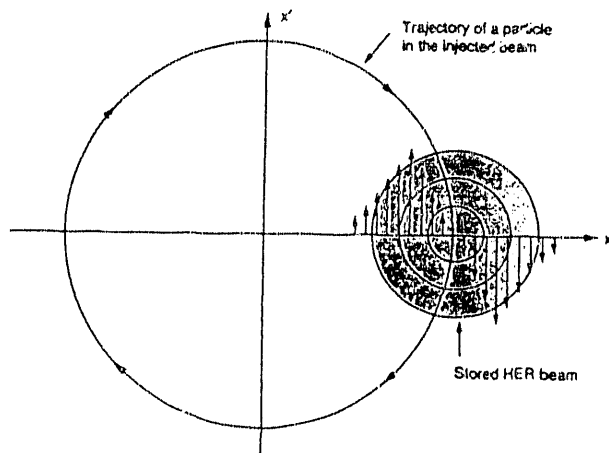


Figure 2: Schematic illustration of the parasitic beam-beam interaction in horizontal phase space.

Figure 3 shows the evolution of the baricentroid motion of the injected beam. The characters "x" and "y" denote the horizontal and the vertical baricentroid positions (in units of the nominal storage ring beam size) sampled at the IP every 172 turns, respectively. In Fig. 4, we plot the horizontal distribution of the injected beam in normalized phase space at 4000 turns or roughly at one radiation damping time after the injection. It can be seen that the phase space distribution already forms a closed

annulus due to the shearing force. Accordingly, the horizontal baricentroid position settles down at the origin as shown in Fig. 3. This process will be likely to be accelerated if the amplitude-dependent tune shift due to lattice nonlinearities are taken into account.

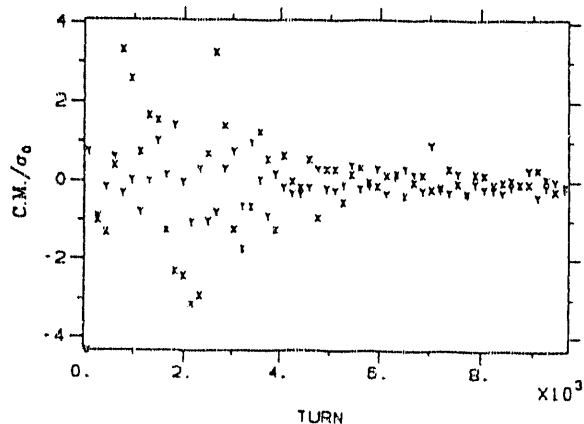


Figure 3: The time evolution of the baricentroid positions of the injected beam in units of the nominal storage ring beam sizes during the horizontal injection process (x=horizontal, and y=vertical).

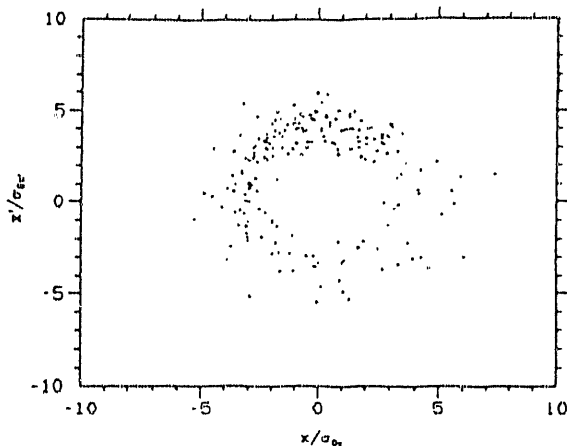


Figure 4: The horizontal distribution of the injected beam in normalized phase space after 4000 turns.

Although the resultant performance of this horizontal injection scheme would still be considered acceptable, we have explored two other injection schemes in an attempt to seek a solution that entails less blowup of the injected beam [1]. One such scheme is to inject beams vertically instead of horizontally. Obviously, this scheme prevents the injected beam from approaching the other beam at the PC closer than the nominal separation distance between the two stored-beam orbits at the PC. An-

other scheme is horizontal injection with vertical separation at both the IP and the PC by creating a temporary bumped orbit during the injection. The simulation results for both of these injection schemes show substantial improvements in terms of the blowup of the injected beam sizes. No particle loss was found in either case.

3. VERTICAL INJECTION AT APIARY-7.5

Because of these results for the injection process for APIARY-6.3d, we have adopted a vertical injection scheme in the current APIARY-7.5 design [3]. In this scheme, for geometrical reasons, the two beams cannot get closer at the PC than the nominal separation distance. The beam beam kick is accordingly much weaker on average. However, the parasitic beam-beam interaction, being a collision of the two beams at large amplitude in phase space, still tends to shear the injected beam into an elongated shape, in vertical phase space in this case. The process is accelerated as the vertical coherent oscillation of the injected beam damps away and, as a result, the distance between the two beams get shorter on average. This is a peculiar point in contrast to the horizontal injection case where the parasitic beam-beam interaction becomes weaker as the horizontal coherent oscillation of the injected beam damps away. However, the parasitic beam-beam interaction in both cases approaches the same strength in the final steady-state.

The main storage ring and injection parameters of APIARY-7.5 design are almost identical to those of APIARY-6.3d shown in Table 1 except for the separation distance d_x at the 1st PC. Now, d_x is increased to 3.498 mm from 2.82 mm, and the ratio d_x/σ_{0x} becomes 9.64. A bunch with 20% of the nominal single-bunch current is injected to the LER with a vertical displacement $18\sigma_{0y}^{ptm}$ from the stored beam orbit, where σ_{0y}^{ptm} is the nominal vertical storage ring beam size of the LER at the end of the injection septum magnet. The rest of the injection conditions follow those in the previous horizontal injection simulation.

Figure 5 shows the time evolution of the injected beam sizes in units of the nominal storage ring beam sizes. The evolution of the baricentroid motion of the injected beam is shown in Fig. 6. The largest turn number, 20000, corresponds to about 4 radiation damping times. The notations follow those in Sec. 2.

It can be seen that the vertical beam size reaches its peak value of $\sim 3\sigma_{0y}$ within approximately 1000 turns. In Fig. 7, we plot the vertical phase space distribution of the injected beam after 1000 turns. Notice the change of the scale from that in Fig. 4. Figure 7 is a typical phase space distribution at an early stage of the simulation where the injected beam is slowly sheared into an elongated shape. Since then, the vertical beam size decreases slowly in balance between two conflicting tendencies, namely, the shearing movement to increase the rms beam size, and the damping of the coherent oscillation of the injected beam to decrease it. Finally, the elongated shape is closed to a circular annulus after approximately 8000 turns which is roughly two damping times. The vertical baricentroid motion dies out at the same time. At this point, the rotational shearing movement in vertical phase space does not contribute to the change in the vertical rms beam size, and the injected beam converges monotonically toward its equilibrium sizes due to radiation damping. No particle loss was found during the simulation.

4. CONCLUSIONS

We have investigated the beam-beam effects during the injection process including the effect of the parasitic crossings, for the APIARY-6.3d and APIARY-7.5 designs of the PEP-II *B*-Factory. It was found that the strong parasitic beam-beam interaction in the horizontal injection scheme for the APIARY-6.3d design can induce a significant beam blowup in the vertical size of the injected beam, although it does not appear to lead to particle loss. The current vertical injection scheme for the APIARY-7.5 design is more comfortable since it induces a much less beam blow up and no particle loss.

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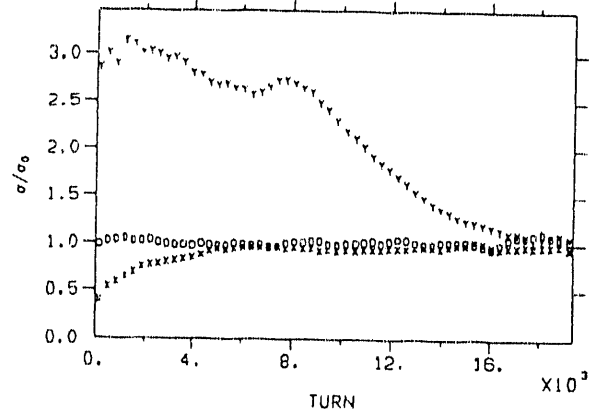


Figure 5: The time evolution of the injected beam sizes during the vertical injection for APIARY-7.5 (x =horizontal, y =vertical, and z =longitudinal).

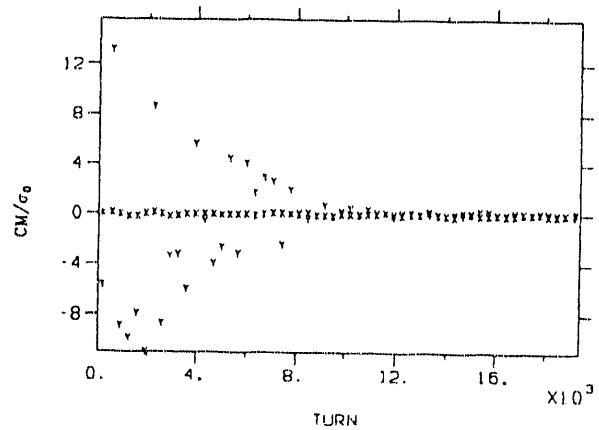


Figure 6: The time evolution of the baricentroid positions of the injected beam during the vertical injection process (x =horizontal, and y =vertical).

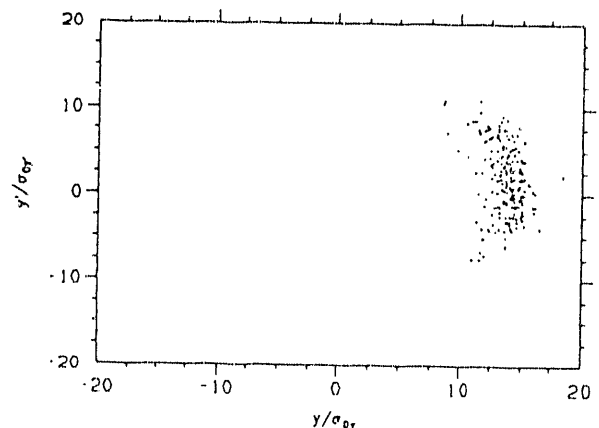


Figure 7: The vertical distribution of the injected beam in normalized phase space after 1000 turns.

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