Coherency of the Long Range Beam-Beam Interaction in CESR *

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Introduction

Making more luminosity is the name of the game at CESR these days. Luminosity is proportional to the average beam current I, the vertical tuneshift parameter ξ_y, and inversely proportional to the vertical beta function at the interaction point β_y^*. The main thrust of our efforts is to increase the average beam current by adding more bunches, without losing ground on the other two parameters. This should work as long as the additional bunches can be kept from colliding with each other at the numerous crossing points in the arcs, and the machine hardware is capable of handling higher currents.

The main limitation to the maximum number of bunches the ring can accommodate is due to the long range beam-beam interaction that occurs when the bunches pass by each other in the arcs. Separation can be obtained at these points using electrostatically generated closed orbit distortions known as 'pretzels'. However, the pretzel distortion is proportional to $\sqrt{\beta_x}\cos\phi_x$ and so good separation can be obtained over only the portions of the ring where the cosine term is not small. If crossing points are too close to pretzel nodes the long range beam-beam interaction causes a very short lifetime for the bunches which cross there. Roughly one can collide one train of closely spaced bunches for each integer of the horizontal tune and manage to avoid crossing points near the pretzel nodes. The total length of each train must limited to some fraction of half the minimum betatron wavelength. For illustration the actual pretzel in a portion of CESR is reproduced in figure 1 together with the beam envelopes and marks at the crossing points. Here we were running with nine trains consisting of two bunches separated by 28 ns.

One may ask when does it actually make sense to increase the number of bunches, given the number and length of the trains is more or less fixed?

There are a few considerations: If the single bunch current is near or above the value for which ξ_y is saturated then luminosity will increase linearly with total beam current, independent of the number of bunches. In this case one may be able to avoid single bunch current limitations by adding more bunches.

If the single bunch current is below the saturation value then it might be better to increase the single bunch current if possible, than to add more bunches, because the luminosity will go up faster than linear. For CESR, saturation occurs at roughly 10 mA/bunch.

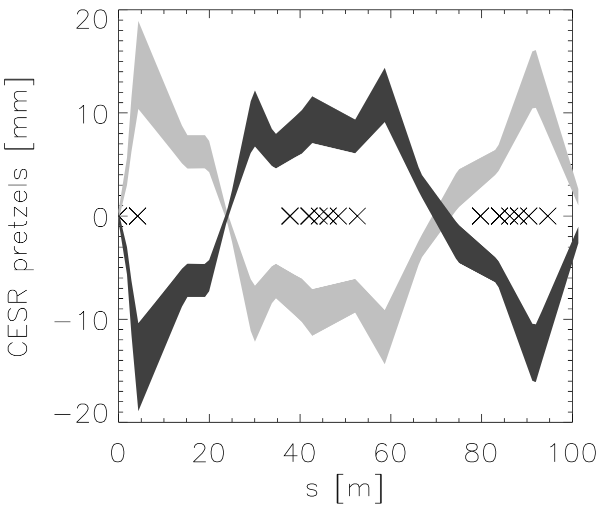

Figure 1: CESR pretzels for e^+ and e^- beams near the main interaction point are shown. The shaded regions represent the beamsize $\pm\sigma_x$.

Another consideration, which is the main topic of this paper, is if the single bunch current is limited by the long range beam-beam interaction, then it makes sense to try to add more bunches. *However if the bunches in each train are so close together that the long range beam-beam interactions from successive crossing points add coherently, the effect is the same as if the current were put into a single bunch, and there is no advantage to be gained.* A number of machine studies described below quantitatively address the question of coherency and bunch spacing.

This work on coherency follows earlier long range beam-beam studies where we evaluated various phenomenological models [1] and found that the limiting pretzel increases roughly as the square root of the bunch current.

Whether or not successive interactions are coherent is important because we always desire to reduce the size of the pretzel. Large pretzel causes reduced dynamic aperture, high radiation, poor lifetime, and may reduce ξ_y. To illustrate how the luminosity is related to the coherency of the parasitic beam-beam interactions, consider the fol-

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[1] A.B. Temnykh, J.J. Welch and D.H. Rice, *The Long Range Beam-Beam Interaction at CESR — Experiments, Simulation and Phenomenology* Proc. Particle Accelerator Conf., 2007 (1993)

lowing: Suppose we are operating at the highest possible train current I_t, with one bunch per train, and the pretzel amplitude can not be increased. We decide to divide the train current into n equal bunches. If the interactions from the new crossing points act coherently the train current will still be limited to the same value and the luminosity will be unchanged. If the interactions act incoherently we might expect that the net kick due the train current will scale with $\sqrt{n} * I_t/n = I_t/\sqrt{n}$. That is, the interaction strength will be reduced by a factor of $1/\sqrt{n}$ relative to the coherent or $n = 1$ case. This means we can increase the train current and therefore the luminosity by a factor of $\sqrt{n}$ as long as the bunches interact incoherently.

Method and Results

The basic technique we used to study the long range beam-beam interaction was to decrease the pretzel amplitude until the lifetime of a probe bunch dropped to 50 minutes or so. The probe beam consisted of one bunch which was much weaker than the bunches in the drive beam. We would start each measurement set at the highest desirable current in the drive bunches. After the pretzel amplitude was reduced and a limiting value found, some current was removed without changing the magnetic lattice and the measurement repeated. This was done for several different configurations of main bunches and the dependence of pretzel amplitude on current was plotted.

The pretzel amplitude refers to an arbitrary coefficient by which all horizontal electrostatic separators are scaled. For convenience 2000 units is defined so that it generates a ± 2 milliradian crossing angle at the interaction point. In practice the lifetime is essentially independent of pretzel amplitude until the limiting pretzel amplitude is approach. At that point the lifetime changes very rapidly. This fact enables a fairly reproducible value to be obtained for the limiting pretzel even if the beam lifetime is not exactly the same. A typical reproducabilty is about 20 pretzel units if there are no changes to the magnetic lattice.

Tune changes and nonreproducible changes to the lattice also affect the measurement of the limiting pretzel amplitude. By optimizing the tune the limiting pretzel can often be reduced by about 100 units. Going back to the same machine configuration on a different day the limiting pretzel could be expected to be within 100 units or so. Within a machine studies session, but after cycling the lattice, the limiting pretzel data had an RMS of about 30 units.

It must be noted that we always chose bunch configurations such that there was no collision at the main interaction point. Such bunches only interact via long range beam-beam interaction. There is some reason to think that if the bunches also had a normal beam-beam interaction they would require even large pretzel as they may have larger tails generated by the normal beam-beam interaction. Thus the limiting pretzel we obtain is probably only a lower bound on an estimate of the limiting pretzel for when the normal beam-beam interaction is included.

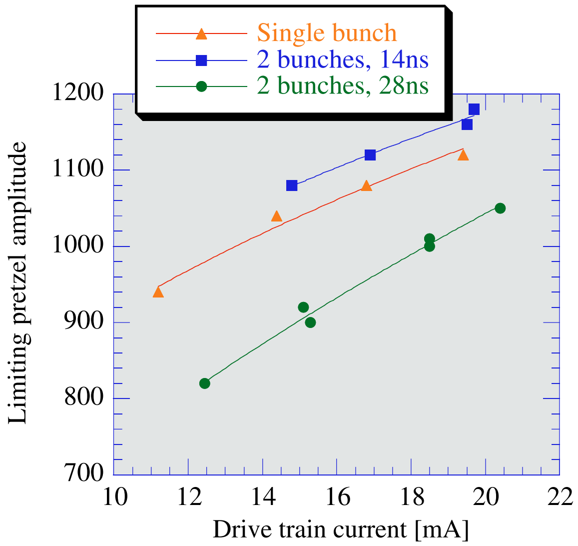

Figure 2: The measured limiting pretzel amplitude (arbitrary units) is plotted against various total drive beam currents. The drive beam consisted either of a single bunch or two bunches separated by either 14 or 28 nanoseconds.

Results from three machine studies are reported herein: In the first run we had a single bunch of electrons as the probe bunch against a drive beam of one or two bunches of positrons. The data are plotted in figure 2. The limiting pretzel amplitude obtained when the all the drive beam current is put in a single bunch is not significantly different from that obtained with the charge in two bunches spaced at 14 ns. When the spacing is increased to 28 ns significantly less pretzel was required for the same total drive beam current. In fact, for the pretzel, the limiting drive current in the 28 ns case is between 1.32 and 1.45 times larger than the in the single bunch case — comparable with a factor of $\sqrt{2}$ expected from the crude scaling law described above.

The lattice parameters for these crossing points are given in table 1. Though the bunch crossings occurs in two places on opposite sides of the ring, the lattice parameters for these places are similar. In both cases the lattice parameters for the 14 ns and 28 ns crossing points are less favourable with respect to the long range beam-beam interaction: larger β_y, more long range tuneshift, less separation distance. So any reduction of the limiting pretzel would plausibly be due to a reduction of the coherency of the vertical kicks received. Thus it appears that with 28 ns spacing there may be incoherency while there is not with 14 ns spacing.

Shorter bunch spacing was the topic of the second machine studies. In this case a single drive bunch was compared against two drive bunches with spacings of 4, 8, and 14 ns. The results are not reproduced here but show no significant differences in the limiting pretzel as a function

	β_x [m]	β_y [m]	ϕ_x [deg]	ϕ_y [deg]	s [m]
West crossing pts					
0 ns	29.1	6.7	0	0	32.6
14 ns	19.4	11.9	5.0	13.5	26.9
28 ns	12.0	19.5	13.0	21.4	21.0
East crossing pts					
0 ns	32.0	13.5	0	0	34.6
14 ns	23.2	18.3	4.4	7.7	29.5
28 ns	16.3	24.1	10.9	13.4	24.7

Table 1: Crossing points lattice parameters for different spacings of two bunches within a single drive train.

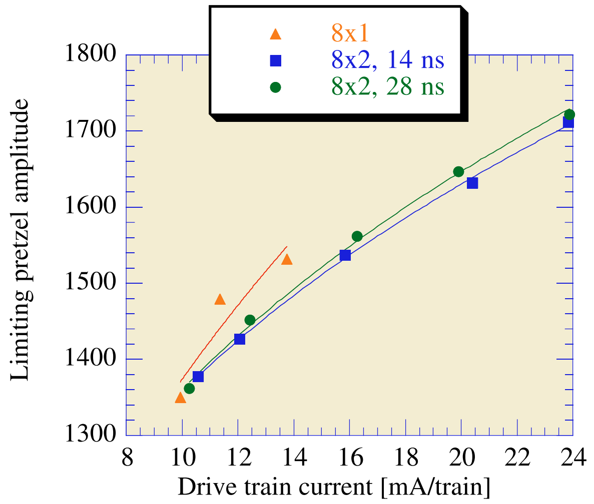

Figure 3: Limiting pretzel amplitude versus total beam current for three configurations of drive beam 8 trains of: 1 bunch, 2 bunches separated by 14 ns, and 2 bunches separated by 28 ns.

of total beam current for the various bunch configurations. All are within 100 pretzel units. Thus the parasitic interactions appear to be coherent.

The last machine studies concentrated finding the effects of multiple interactions. Results from a drive beam consisting of 8 trains of single bunches are compared with results obtained from 8 trains of two bunches spaced either 14 or 28 ns. See figure 3. There was no significant difference between the limiting pretzels for the 14 or 28 ns spacing. However, the single bunch trains required substantially more pretzel over a limited and fairly low current range. Here it is not clear if the interactions are coherent.

In none of cases was the vertical beam size noted to change substantially. Beam size was observed to grow when exploring smaller currents and likewise smaller pretzels. In the current regime of interest reduced lifetime

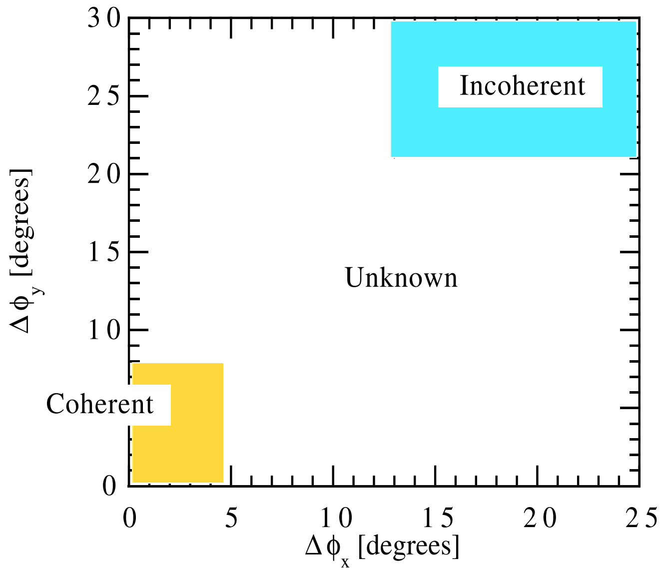

Figure 4: Regions of coherent and incoherent interactions are identified in when plotted against the horizontal and vertical phase advance between successive crossing points.

was the first deleterious effect observed when reducing the pretzel.

Discussion

It is natural to expect the limiting pretzel amplitude to depend on whether or not kicks are coherent. If the betatron phase advance between successive crossing points is small enough there is little if any cancelation: the kicks add coherently producing the same effect as if they were received at the just one point. Given the results from the 1 train studies we can make a map in the horizontal and vertical phase advance plane showing where incoherent and coherent interactions have been seen (figure 4).

Horizontal phase advance between successive crossing points is a critical factor as it determines the number of σ_x of separation between the beams. We have observed repeatedly that a change in the separation distance of less than σ_x can produce very dramatic changes in the lifetime. Given subsequent crossing points where the separation at one point is say $6\sigma_x$ and the separation at the other is $5\sigma_x$, it would be consistent with the observations if the $6\sigma_x$ point had essentially no effect on the lifetime. In this case coherency could not be observed.