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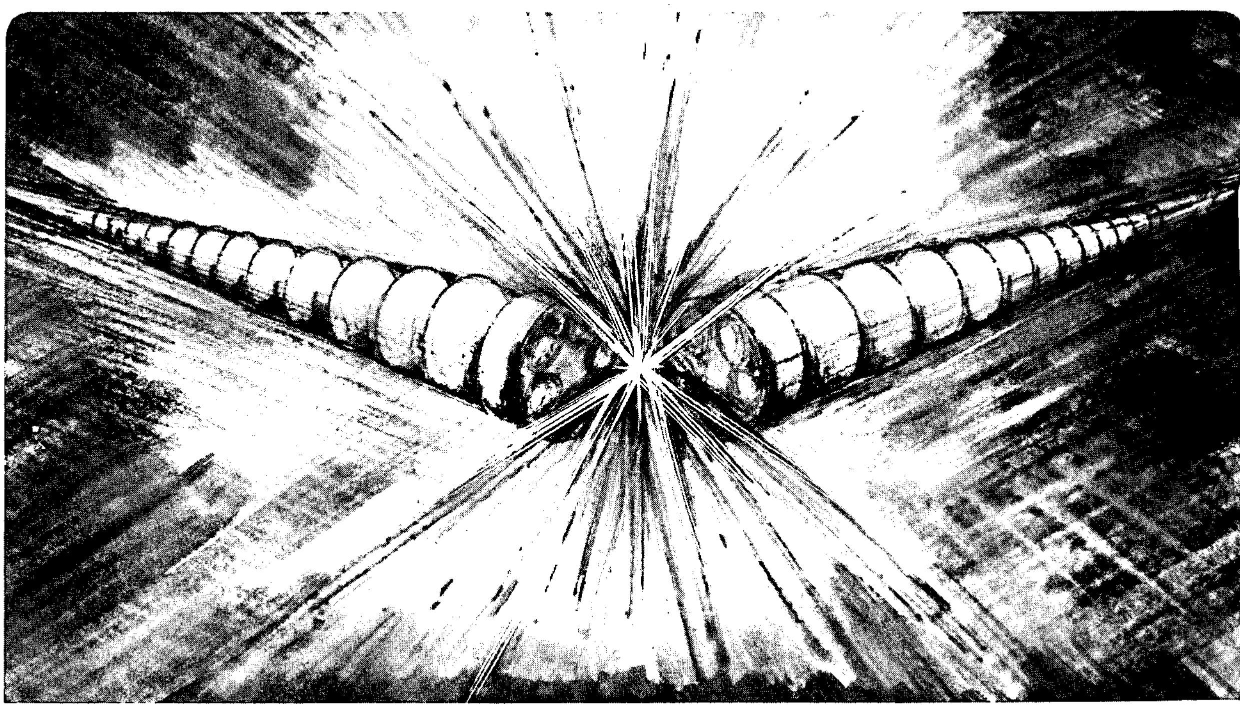

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Introduction

The attainable luminosity in an asymmetric storage-ring collider will be determined to a large extent by the physics of the beam-beam interaction. Nothing is known experimentally about the beam-beam tune shift limit under asymmetric energy conditions. The situation is complicated, since two beams with unequal energies naturally tend to behave differently. Indeed, what is often observed in computer simulations is that one beam blows up badly while the other beam suffers practically no blowup. This is a serious problem, since the significant blowup in the weaker beam imposes an unnaturally low beam-beam tune shift limit on the stronger beam.

Probably the best cure is to bring the beam-beam interaction into the "strong-strong" regime where the two beams blow up in a similar manner, reducing the beam-beam force on both beams simultaneously. In this way, putting the two beams on an equal footing as far as transverse dynamics is concerned, we might expect to reach the same maximum beam-beam tune shift limit set by nature in equal-energy colliders. A possible set of conditions to achieve such a circumstance is generally referred to as the "energy transparency conditions" [1, 2, 3]. The idea of the energy transparency conditions results from two facts:

- We know about the actual behavior of the beam-beam effect only under symmetric conditions – the beam-beam tune shift limit, ξ, in equal-energy electron-positron colliders.

- The beam-beam interaction in the strong-strong regime is not well understood in a quantitative sense at present. The only systematic tool to understand it is provided by computer simulations. However, there is no simulation program to date that can consistently explain the experimental data, even from various symmetric machines, in a quantitative sense.

Therefore, by adopting the energy transparency conditions, one can hope to design an asymmetric collider in a "rational" way, without relying in detail on any particular theory or simulation code. Several B-Factory designs have adopted variants of the concept of energy transparency as a design guideline [1, 4, 5].

Energy Transparency Conditions

Two possible sets of energy transparency conditions have been proposed [1, 5]. The author has proposed the following set of four conditions [1] (the superscripts label the electron (-) and positron (+) beam):

- Same nominal linear beam-beam tune shift parameters:

$$\xi_{0x}^{-} = \xi_{0x}^{+}, \quad \xi_{0y}^{-} = \xi_{0y}^{+} \tag{1}$$

- Same nominal cross sectional areas at the IP:

$$\sigma_{0x}^{-} = \sigma_{0x}^{+}, \quad \sigma_{0y}^{-} = \sigma_{0y}^{+} \tag{2}$$

- Same radiation damping decrements:

$$\delta^{-} = \delta^{+} \tag{3}$$

where the damping decrement, δ, is defined as the product of the absolute radiation damping rate and the time interval between collisions.

- Same betatron phase modulations due to synchrotron motion:

$$\left(\frac{\sigma_s Q_s}{\beta_x^*}\right)^{-} = \left(\frac{\sigma_s Q_s}{\beta_x^*}\right)^{+}, \quad \left(\frac{\sigma_s Q_s}{\beta_y^*}\right)^{-} = \left(\frac{\sigma_s Q_s}{\beta_y^*}\right)^{+} \tag{4}$$

where σ_s is the rms bunch length, Q_s is the synchrotron tune, and β^* is the beta function at the IP.

The validity of these criteria is demonstrated in references 1-3 by applying a modified version of Yokoya's beam-beam simulation program to the APIARY-I lattice and showing that the two unequal energy beams maintain symmetric behavior.

The first condition equalizes the beam-beam kicks in the two rings; any remaining difference in beam dynamics must then come from the difference of beam parameters elsewhere in the rings. The second condition is necessary for complete overlap of the two beams at the IP. The fourth condition guarantees the same strength of synchro-betatron resonances, which are supposed to be a source of beam blowup. Radiation damping is an important effect that suppresses external perturbations of beams [6]. There are many experimental [7] and computer simulation results [6] that indicate the damping decrement dependence of the luminosity in symmetric colliders. In the simulations, the effect is not simply that the larger the damping rate, the larger the beam-beam limit will be. If one starts with two identical rings, and increases the damping decrement of one beam, keeping that of the other beam constant, the beam with larger damping decrement shrinks, while the beam with smaller damping decrement blows up. The luminosity will start to drop when the asymmetry of the damping decrements exceeds a certain value. Figure 1 shows an example of the luminosity L and the dynamic emittance (after blowup) as a function of the asymmetry of the damping decrement of two beams when the damping decrement of Beam+ is changed while that of Beam- is kept fixed. The main parameters used are shown in Table 1 below. In order to isolate the effect of the damping decrement, only this parameter is different in the two rings.

Table 1. Main parameters of the sample asymmetric collider used.

Parameters	*Beam+*	*Beam-*
Energy, E (GeV)	8	8
Circumference, C (m)	2200	2200
Nominal emittance, $\epsilon_{0x} = \epsilon_{0y}$ (nm·rad)	68.133	68.133
Bunch length, σ_s (cm)	1.0	1.0
Beta function at IP $\beta_x^* = \beta_y^*$ (cm)	3.0	3.0
Damping decrement, δ	—	1.643×10^{-4}
Bunch current, I_b (mA)	5.188	5.188
Synchrotron tune, Q_s	0.089	0.089
Nominal beam-beam tune shift, $\xi_{0x} = \xi_{0y}$	0.05	0.05
Betatron fractional tunes, $Q_x = Q_y$	0.72	0.72

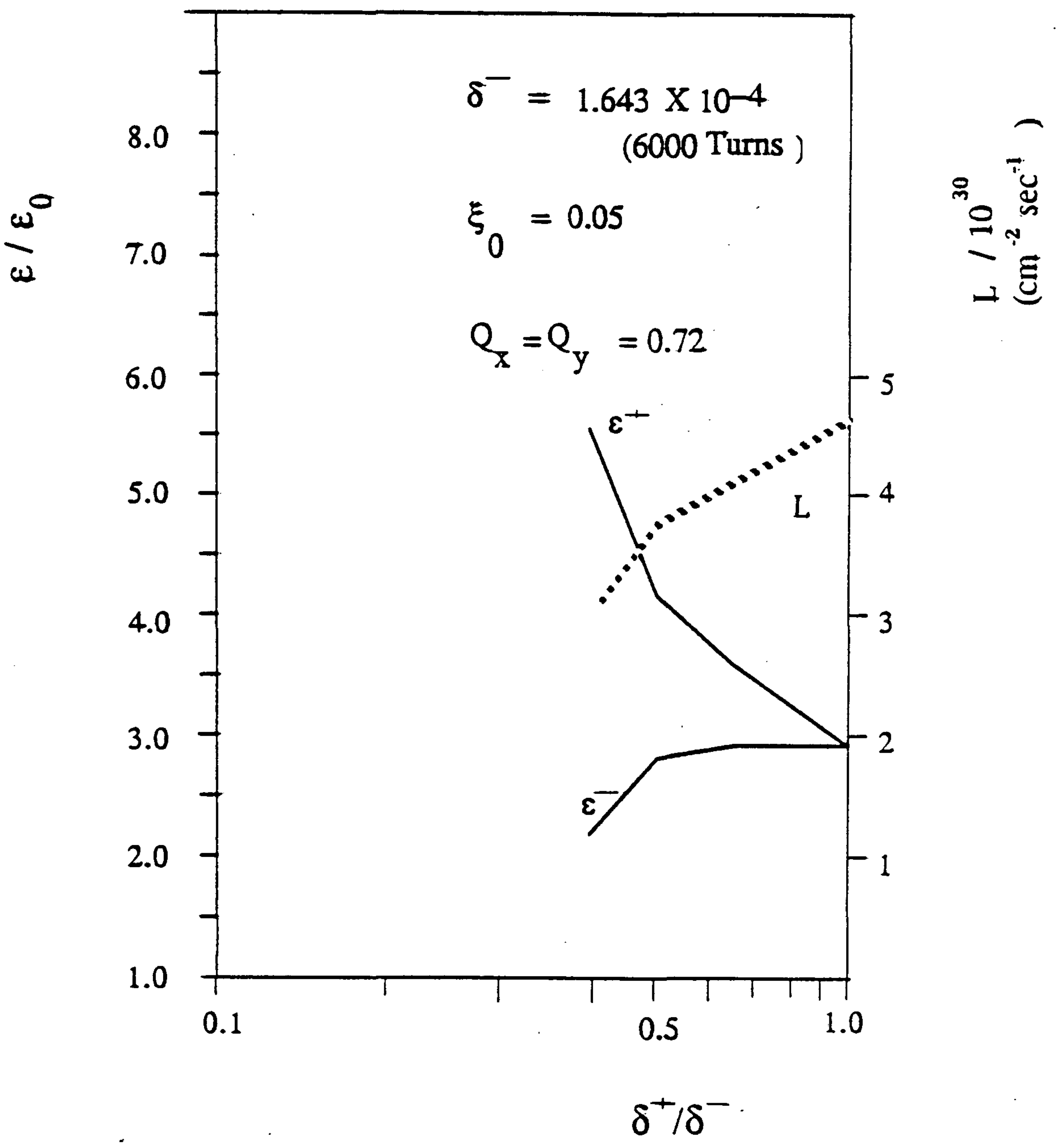


Figure 1: The luminosity L and the dynamic emittance ϵ as a function of the asymmetry of the damping decrement. Here, ϵ_0 is the nominal emittance, and ξ_0 is the nominal beam-beam parameter in the absence of beam blowup.

It can clearly be seen from Fig. 1 that the unequal damping decrement causes asymmetric behavior of the beam sizes. We know that there is another report that shows a weaker damping decrement dependence of the luminosity [8]. In that calculation, however, other parameters are also changed when the damping decrement is changed in order to maximize the luminosity. Moreover, an extremely short bunch ($\sim 100\ \mu$m) is used, making the betatron phase modulation due to synchrotron motion, one possible source of beam blowup, extremely small. Therefore, the effect of the damping decrement alone is obscured, and a comparison with the present results is difficult.

Siemann and Krishnagopal have proposed a stricter set of energy transparency conditions than discussed here. They require [5]: the same products of the number of particles N and the Lorentz factor, the same beta functions at the IP, the same emittances, the same bunch length, the same synchrotron tunes, and the same fractional parts of the betatron tunes. We haven't yet studied these conditions in detail.

Discussion

At present, when there are no existing asymmetric colliders, it is not known how strictly such symmetrization conditions must be satisfied, or how much they can be relaxed in real machines. We need further work on this problem of the minimum set of requirements for the practical design of rings.

Another question is whether one could relax such strong constraints by compensating for one asymmetry with another. The answer is not straightforward. Any such compensation scheme would require a credible theory and a computer simulation program that can quantitatively predict how much asymmetry in one parameter is needed to compensate for an asymmetry in another parameter. Moreover, there is some evidence that the stability of such a delicately compensated beam-beam mode would be unpredictable [9, 10].

Let us examine a possible compensation. The idea is the following: when one beam blows up more than the other beam, one tries to equalize the beam sizes of the two beams by reducing the nominal emittance of the blown-up beam. Table 2 shows the parameters of the sample lattice used in a simulation test of this idea. The main asymmetric parameter in the two rings is the beta function. The emittances and the bunch currents are chosen so that the rms beam sizes at the IP and the nominal beam-beam parameters are equal in the two rings.

Table 2. Parameters of the sample lattice used in the simulation test of a possible compensation scheme.

Parameters	*Beam+*	*Beam-*
Energy, E (GeV)	8	3.5
Circumference, C (m)	2200	2200
Nominal emittance, $\epsilon_{0x} = \epsilon_{0y}$ (nm·rad)	68.133	136.3
Bunch length, σ_s (cm)	1.0	1.0
Beta function at IP $\beta_x^* = \beta_y^*$ (cm)	3.0	1.5
Natural beam sizes, $\sigma_x = \sigma_y$ (μm)	45.21	45.21
Damping decrement, δ	$.657 \times 10^{-3}$	$.657 \times 10^{-3}$
Bunch current, I_b (mA)	4.54	5.188
Synchrotron tune, Q_s	0.089	0.089
Nominal beam-beam tune shift, $\xi_{0x} = \xi_{0y}$	0.05	0.05
Betatron fractional tunes, $Q_x = Q_y$	0.70	0.70

The simulation result for the above configuration shows that the beam size of Beam- increases to 59.97 μm (33% blowup) while that of Beam+ increases only to 48.02 μm (6% blowup). We then reduced the nominal emittance, ϵ^-, of Beam- and ran additional simulations. The results for various values of ϵ^- are summarized in Table 3, where σ_0 and σ are the nominal and the dynamic beam sizes, respectively.

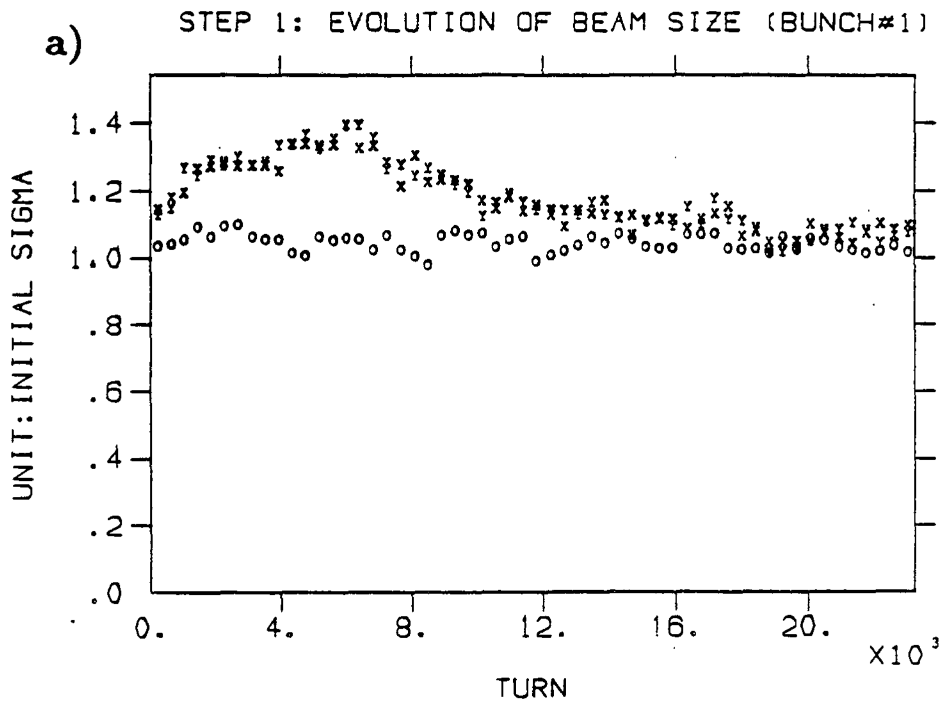
Table 3. Simulation results for five different emittances of Beam-.

Emittance, ϵ^- (nm·rad)	σ_0^+	σ_0^-	σ^+	σ^-
81.76	45.21	35.02	48.61	57.73
95.39	45.21	38.42	49.12	59.65
109.0	45.21	40.44	48.6	61.1
122.6	45.21	42.89	48.75	56.15
136.3	45.21	45.21	48.02	59.97

It can clearly be seen from Table 3 that the dynamic beam sizes of the two beams depend very weakly on the nominal Beam- emittance. This is because the dynamics of the beam-beam interaction tends to make up the difference between the equilibrium and the nominal beam sizes no matter what the nominal emittance is. The dynamic beam size in the beam-beam limit is a result of the beam-beam interaction determined by all the other parameters. It is not a free parameter that may be controlled by changing its nominal value. This result agrees with observations at PEP, where the dynamic vertical beam size is seen to remain nearly constant when the x-y coupling of the beams is changed to reduce the nominal vertical beam size (in an attempt to improve the luminosity). For this reason, the suggested compensation scheme using the beam size or the emittance as a free parameter does not appear to work in this parameter regime. Of course, we have not yet studied the plausibility of other possible compensation schemes, involving more or different parameters, so no statement can be made about the efficacy of compensation schemes in general.

There is another worthwhile point to be mentioned here. Figures 2(a) and (b) show the time evolution of beam sizes of Beam+ and Beam-, respectively, for the case of $\epsilon^- = 81.76$ nm·rad in Table 3, up to 24000 turns corresponding to 16 damping times. In this particular case of large asymmetry of the nominal beam sizes, 16 damping times was necessary to reach the true equilibrium. When the asymmetry is smaller, for example as in the third case in Table 3, only several damping times are needed to reach equilibrium. In the plot, Beam+ and Beam- are denoted as bunch # 1 and bunch # 2, respectively. The points x, y and o represent the horizontal, vertical, and longitudinal beam sizes, respectively, in units of their nominal rms sizes. Each point represents the average over 400 turns. There is some beam blowup, on the order of 10% , in the first 400 turns in both beams, so that the plotted points start from around 1.1. At the beginning, Beam- blows up while Beam+ suffers almost no blowup. They appear to be in a steady state. However, after about 8000 turns Beam- shrinks to nearly its original size while Beam+ blows up; this is the true equilibrium state. If the simulation were halted at 8000 turns, the results would be misleading. This example clearly indicates the need to be very careful in conducting computer simulations and interpreting their results.

a)



b)

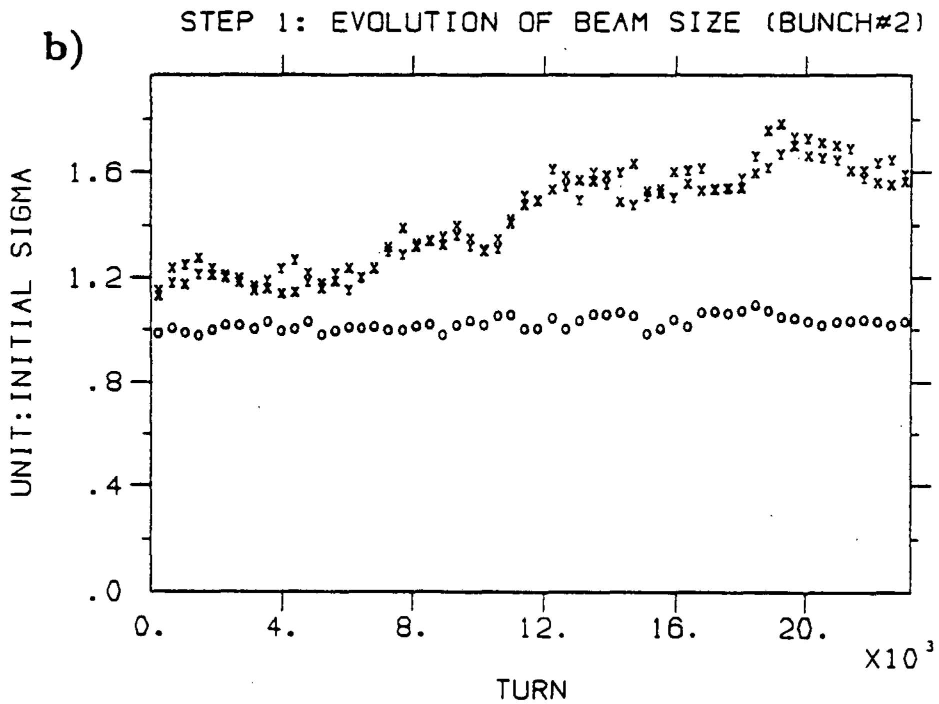


Figure 2: The time evolution of beam sizes of (a) Beam+ and (b) Beam-, respectively, for $\epsilon^- = 81.76$ nm·rad, up to 24000 turns. The points x, y and o represent the horizontal, vertical, and longitudinal beam sizes, respectively, in units of their nominal rms sizes.

Conclusions

We have studied the idea of symmetrizing both the lattice and the beams of an asymmetric collider, and have discussed why this regime should be within the parametric reach of the design in order to credibly ensure its performance. We have also examined the effectiveness of a simple compensation method using the emittance as a free parameter and shown that it does not work in all cases. At present, when there are no existing asymmetric colliders, it seems prudent to design an asymmetric collider so as to be similar to a symmetric one (without relying on a particular theory of the asymmetric beam-beam interaction that has not passed tests of fidelity). Nevertheless, one must allow for the maximum possible flexibility and freedom in adjusting those parameters that affect luminosity. Such parameter flexibility will be essential in tuning the collider to the highest luminosity.

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References

[1] Y. H. Chin, Lawrence Berkeley Laboratory Report LBL-27665, August, 1989. Presented at *the XIV Int. Conf. on High Energy Accelerators*, Tsukuba, Japan, August, 1989 (to be published).

[2] *Feasibility Study for an Asymmetric B Factory Based on PEP*, Lawrence Berkeley Laboratory Report LBL PUB-5244, October, 1989.

[3] *Investigation of an Asymmetric B-Factory in the PEP Tunnel*, Lawrence Berkeley Laboratory Report LBL PUB-5263, March, 1990.

[4] K. Oide, private communication on the KEK B-Factory design in Japan.

[5] S. Krishnagopal and R. Siemann, CESR Report, CLNS 89/96, 1989.

[6] S. Myers, in *Nonlinear Dynamics Aspects of Particle Accelerators, Lecture Notes in Physics* **247**, (Springer-Verlag, Berlin, 1985), p.176.

[7] J. Gareyte, in *Proc. of the Third Advanced ICFA Beam Dynamics Workshop on Beam-Beam Effects in Circular Colliders*, edited by I. Koop and G. Tumaikin (INP, Novosibirsk, May, 1989), pp.135-139.

[8] J. L. Tennyson, these proceedings.

[9] M. Furman, in *Proc. of the Third Advanced ICFA Beam Dynamics Workshop on Beam-Beam Effects in Circular Colliders*, edited by I. Koop and G. Tumaikin (INP, Novosibirsk, May, 1989), pp.52-57.

[10] P. J. Channell, these proceedings.

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