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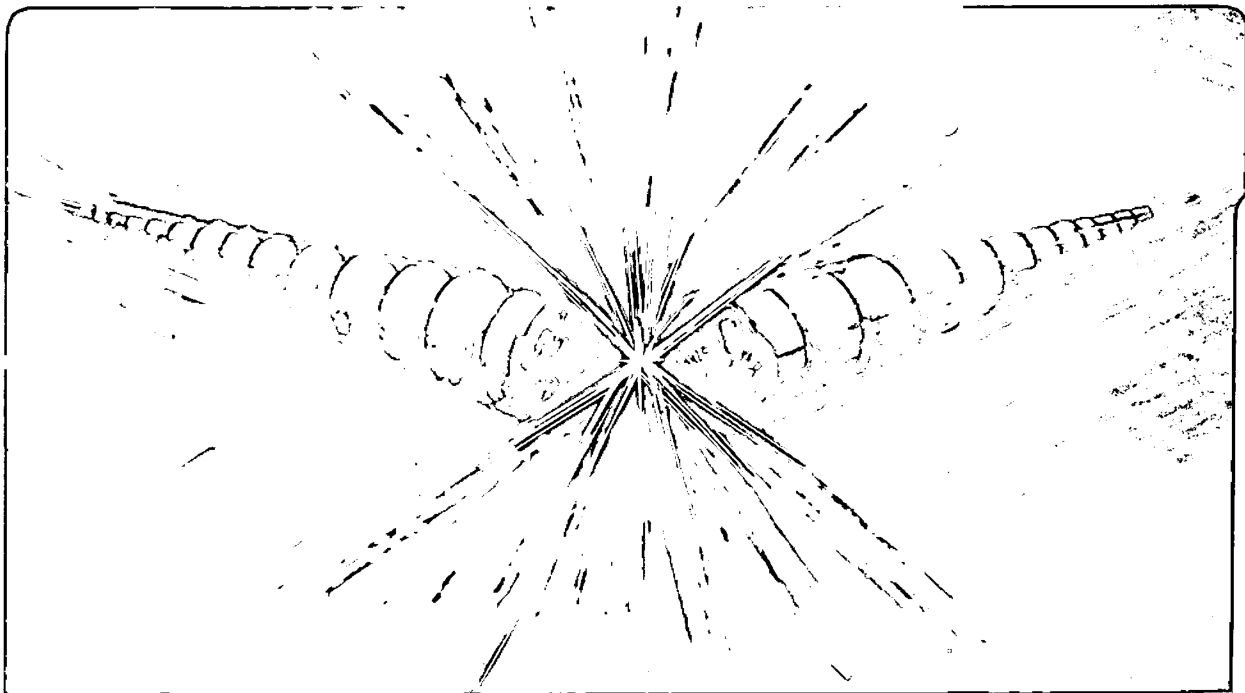



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# Beam-Beam Diagnostics From Closed-Orbit Distortion*

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1 Deceased.

# BEAM-BEAM DIAGNOSTICS FROM CLOSED-ORBIT DISTORTION *

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**Abstract**

We study the applicability of beam-beam deflection techniques as a tuning tool for asymmetric B factories, focusing on PEP-II as an example. Assuming that the closed orbits of the two beams are separated vertically at the interaction point by a local orbit bump that is nominally closed, we calculate the residual beam orbit distortions due to the beam-beam interaction. Difference orbit measurements, performed at points conveniently distant from the interaction point (IP), provide distinct signatures that can be used to maintain the beams in collision and perform detailed optical diagnostics at the IP. A proposal to test this method experimentally at the TRISTAN ring is briefly discussed. This article summarizes Ref. [1].

## 1 Introduction

Because of their two-ring structure, asymmetric B factories are likely to require more diagnostics and feedback mechanisms than single-ring colliders in order to guarantee head-on collisions. In addition to the traditional techniques, however, the independence of the two beams allows one to envisage other kinds of beam diagnostics.

In this article we investigate one such a possibility, by looking at the closed orbit distortion produced by the beam-beam interaction when the beams do not collide exactly head-on. We base this investigation on an analytic model and strong-strong multiparticle simulations. Although our discussion uses the PEP-II [2] design as an example, our conclusion is that this technique is quite a promising diagnostics tool for asymmetric colliders in general.

## 2 Analytical model for closed-orbit distortions

Under the "rigid Gaussian bunch" simplifying assumptions [3, 4], listed below, we can carry out the analytical calculation of the closed orbit. This approach illustrates the basic features of the effect and, for typical realistic parameters, is in good agreement with multiparticle tracking simulations that do not involve some of the most important assumptions. The analysis presented here follows that of Hirata and Keil [4], suitably augmented to include a closed orbit bump at the IP.

We assume that there is a single IP endowed with an orbit bump that splits the closed orbits apart by a distance $d$. It does not matter how $d$ is apportioned between the $e^+$ and the $e^-$ beams as long as the total separation of the nominal orbits adds up to $d$. For simplicity, we take this orbit separation to be purely vertical. We assume that this orbit bump is nominally closed. *i.e.*, that in the absence of the beam-beam force the orbits coincide exactly with the nominal orbits in the region "outside" the bump. Because of the beam-beam interaction, however, there is a residual closed orbit distortion everywhere in the ring. The situation is sketched in Fig. 1. We further assume that: (1) the bunches are not tilted; (2) all effects from parasitic crossings are ignored; (3) the beam sizes are independent of $d$ and have their nominal values; (4) the beam-beam interaction is treated in the impulse (thin-lens) approximation; (5) for the purpose of computing the beam-beam kick, the particle distributions are taken to be Gaussian; and (6)

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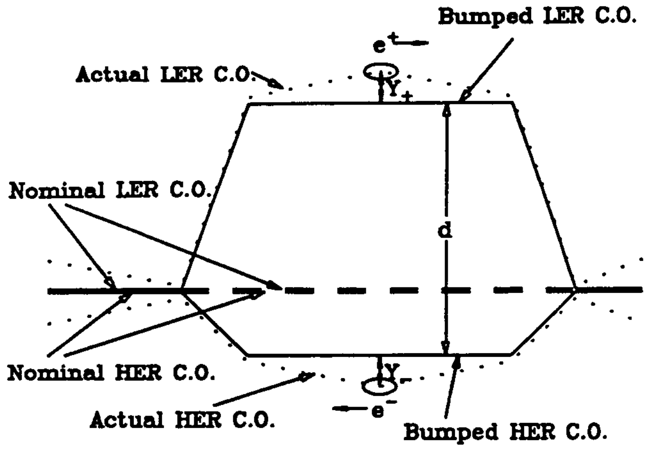


Figure 1: Elevation sketch of the vertical closed orbit bump near the IP (LER=low-energy ring, HER=high-energy ring).

the rings are represented by linear, uncoupled arcs. Assumptions (3) and (4) are removed in the multiparticle tracking simulations mentioned below.

The condition for the existence of a closed orbit yields the well-known relation between the centroid displacement at the IP and the deflection

$$Y_\pm = \tfrac{1}{2}\Delta Y'_\pm \beta^*_{y\pm} \cot(\pi\nu_{y\pm}) \tag{1}$$

with a corresponding expression for the horizontal quantities. Here the centroid displacements $Y_\pm$ are measured *relative to the bumped nominally closed orbits* (see Fig. 1). In our particular case, in which the bump displacement is assumed to be purely vertical, we look for solutions with $X_\pm = \Delta X'_\pm = 0$ (we assume that the parameters are such that there is no "spontaneous orbit separation" [4] either horizontally or vertically).

The deflections $\Delta Y'_\pm$ are computed from the electromagnetic beam-beam kick produced by the opposing bunch [3]. By combining them with Eq. (1) one finds the set of two nonlinear equations

$$\begin{aligned} Y_+ &= A_{y+}\mathrm{Im}F(0, Y_+ - Y_- + d, \Sigma_x, \Sigma_y) \\ Y_- &= A_{y-}\mathrm{Im}F(0, Y_- - Y_+ - d, \Sigma_x, \Sigma_y) \end{aligned} \tag{2}$$

where $F(x, y, \sigma_x, \sigma_y)$ is a complex [5] function[2] and $\Sigma$ and $A$ are given by

$$\Sigma_x = \sqrt{\sigma^2_{x+} + \sigma^2_{x-}}, \quad \Sigma_y = \sqrt{\sigma^2_{y+} + \sigma^2_{y-}} \tag{3}$$

$$A_{y\pm} \equiv -\frac{r_0 N_\mp \beta^*_{y\pm}}{2\gamma_\pm} \cot(\pi\nu_{y\pm}) \tag{4}$$

[2] Our definition of $F$ differs from that in Ref. [5] by complex conjugation and a factor of $2i$.

For the case $\sigma_{x\pm} \gg \sigma_{y\pm}$, a practical rule of thumb [1] for the solution is the following: the maximum orbit distortion at the IP occurs at $d \simeq 2\Sigma_y$, and is given by

$$(Y_\pm)_{\max} \simeq 2\pi\Xi_{y\pm}\Sigma_y \cot(\pi\nu_{y\pm}) \tag{5}$$

where $\Xi_{y+}$ is one of the four coherent beam-beam parameters [4],

$$\Xi_{y+} = \frac{r_0 N_- \beta^*_{y+}}{2\pi\gamma_+\Sigma_y(\Sigma_x + \Sigma_y)} \tag{6}$$

Having solved for $Y_\pm$, the closed orbit distortion at any point in the ring is given by

$$Y_\pm(s) = \frac{\Delta Y'_\pm}{2\sin(\pi\nu_{y\pm})}\sqrt{\beta^*_{y\pm}\beta_{y\pm}(s)}\cos(\phi_{y\pm}(s) - \pi\nu_{y\pm}) \tag{7}$$

where $\phi_{y\pm}(s)$ is the betatron phase advance of the observation point measured from the IP.

## 3 Application to PEP-II

The result of solving Eqs. (1–2) for nominal values of PEP-II parameters [2] is shown in Fig. 2 (nominal means here in the absence of the beam-beam interaction). Also shown are the results from strong-strong multiparticle tracking simulations, which include thick lens effects for finite bunch length, synchrotron motion, radiation and quantum excitation, and transverse beam blowup due to the beam-beam interaction. The simulation was carried out with Yokoya's code [6] with 200 superparticles per bunch for five damping times. The relation $Y_+ = -Y_-$ seen in these results is one consequence [1] of the approximate transparency symmetry [7] satisfied by the nominal parameters.

## 4 Discussion of experimental feasibility

While the closed orbit distortion is quite small at the IP, it is amplified considerably at the beam position monitors (BPMs). One can estimate [8] the rms value of the orbit distortion and the measurement error of the angular deflection at the IP by making the following assumptions: (a) equal BPM errors for all BPMs, (b) equal beta functions $\hat\beta$ at the BPMs and (c) random average betatron phases at the BPMs. One then obtains, from Eqs. (1) and (7),

$$\frac{Y(\mathrm{BPM})}{Y(\mathrm{IP})} \simeq \frac{\sqrt{\hat\beta/\beta^*_y}}{\sqrt{2}\cos(\pi\nu_y)} \tag{8}$$

$$\sigma(\Delta Y') \simeq \frac{2\sqrt{2}\sin(\pi\nu_y)}{\sqrt{\beta^*_y\hat\beta}}\frac{\sigma_{\mathrm{BPM}}}{\sqrt{N}} \tag{9}$$

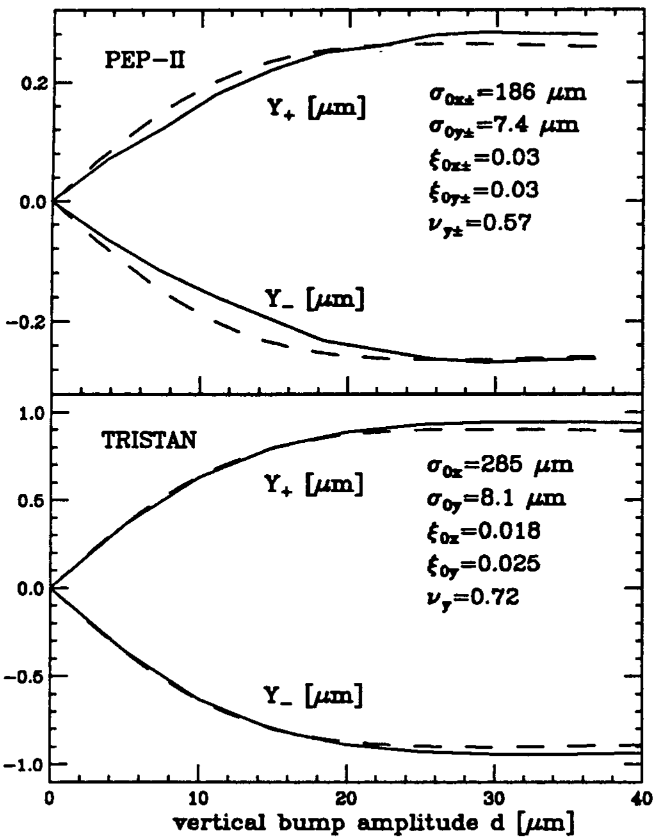


Figure 2: Beam-beam induced orbit offset at the IP for PEP-II and TRISTAN. Solid: multiparticle simulations; dashed: result from solving Eqs. (1–2) for nominal parameters.

where $N$ is here the total number of BPMs and $\sigma_{\rm BPM}$ is the rms measurement error of each BPM. Using $\hat{\beta} = 30$ m, the resultant amplification factor for PEP-II is $Y({\rm BPM})/Y({\rm IP}) \simeq 45$.

A proposal [9] has been put forth to test these ideas experimentally at TRISTAN. Results of the corresponding calculations [1] are also shown in Fig. 2. The effect is larger for TRISTAN than for PEP-II mostly because the tune is further away from the half-integer (*cf.* Eq. (5)). Assuming $\hat{\beta} = 20$ m, $N = 100$ and $\sigma_{\rm BPM} = 5\,\mu$m, which are typical for TRISTAN, we obtain $Y({\rm BPM})/Y({\rm IP}) \simeq 25$. The resultant estimate for the error for $\Delta Y'$ is $\sim 1\,\mu$rad, and the error by which the orbit displacement $Y$ at the IP can be determined is $\sim 0.2\,\mu$m, which is small compared to its maximum value ($\sim 1\,\mu$m) and to the rms beam height at the IP ($\sim 8\,\mu$m). This error is probably dominated by power supply jitter [8].

This kind of precision makes the beam-beam deflection method quite promising in its applications to IP spot size determination, as well as to feedback systems that maintain the beams in collision.

The method can also be examined in the frequency domain [1]. The $\sigma - \pi$ frequency split can then be used as an additional diagnostic tool.

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