Beam Beam Performance as a Function of β_v^* at CESR. *

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Abstract

The beam-beam tune shift parameter for beams colliding at a single interaction point was measured for several values of the vertical β minimum. We report linear tune shift parameter as a function of current for $1cm < \beta_v^* < 10cm$. Electrostatic separators are used to horizontally separate beams at all but one crossing point. The quadrupole lattice is characterized by zero dispersion at the interaction point, horizontal $\beta_h^* = 1m$, and horizontal and vertical tunes of $Q_h \sim 8.61$ and $Q_v \sim 9.64$ respectively. The two sets of measurements correspond to operation before and after the single interaction point conversion of CESR [1, 2]. The beam energy is 5.29GeV. We measured a saturated tune shift parameter ($\xi_v = \frac{2er_eL\beta_v^*}{I\gamma}$) of .021, .032, .045 ($\pm$.003) for $\beta_v^* =$ 2,5,and 10cm respectively ($\sigma_l = 1.8cm$). After removal of the north interaction region we measure $\xi_v =$ .011, .026, .0275 for $\beta_v^* =$ 1,1.55,and 1.8cm respectively.($\sigma_l = 1.97cm$)

Introduction

In a colliding beam storage ring in which there is significant variation of β_v^* over the length of the bunch we anticipate a degradation of beam beam performance. Such variation occurs if the minimum $\beta < \sigma_l$ where σ_l is the bunch length. We find in CESR that β_{min} is indeed limited by the finite bunch length.

The beam-beam tune shift parameter ξ is the measure of the linear focusing strength of the bunch of one beam on the particles of the other. ξ_v is usually calculated from luminosity assuming the crossing point coincides with β_{min} and $\sigma_l << \beta_v^*$.

$$\xi_v = \frac{2er_eL\beta_v^*}{I\gamma} \tag{1}$$

However, if one includes the finite bunch length and displacement of the crossing point (ΔS):

$$\xi = \frac{\xi_0\beta_v^*\cdot}{\sigma_l}\sqrt{\frac{2}{\pi}}\int_{-\infty}^{\infty} ds\sqrt{1+\frac{(s-\Delta S)^2}{\beta_v^{*2}}}\exp(-\frac{2s^2}{\sigma_l^2}) \tag{2}$$

[3] where $\xi_0 = \frac{N_0 r_0 \beta_v^*}{2\pi\gamma\sqrt{\epsilon_v\beta_v^*\sigma_h}}$. and ΔS is the displacement of the crossing point. Everything is a known quantity except ϵ_v. ϵ_v must be calculated from measured luminosity:

$$\sqrt{\epsilon_v} = \frac{fN^2}{4\pi\sigma_h\sqrt{\beta_v^*}L_{meas}\sqrt{\pi}\sigma_l}\int_{-\infty}^{\infty} ds\frac{\exp\frac{-(s-\Delta S)^2}{\sigma_l^2}}{\sqrt{1+\frac{s^2}{\beta_v^{*2}}}} \tag{3}$$

[3] where L_{meas} is the luminosity measured by from bhabha scatters. The geometric effect on luminosity and ξ_v is calculable numerically.

The dynamical consequences are more difficult to evaluate. Because the beam profile and β vary over the length of the bunch, the kick imparted to the counterrotating particle will depend on the arrival time of that particle. The arrival time varies with the synchrotron period and therefore longitudinal and vertical oscillations are coupled. The resulting synchrobetatron sidebands may limit the beam-beam tune shift [4]. Also, displacement of the crossing point from β_{min} will drive odd synchrobetatron resonances at low order, while only even sidebands are driven with $\Delta S = 0$.

We explore the effects of finite bunch length by varying β_v^* such that $0.5 < \frac{\beta^*}{\sigma_l} < 5$ for $\sigma_l = 1.97cm$ and $\sigma_l = 1.8cm$. [5] A similar experiment was performed earlier by D. Rice (CON 87-3 unpublished).

Machine Configuration

In order to simplify the interpretation of the results, measurements are performed with: a single collision point, fixed bunch length and synchrotron tune, transverse tunes constrained over a region $Q_h = 8.58 \pm 0.03$ and $Q_v = 9.61 \pm 0.03$, zero dispersion at the interaction point, and $\beta_h^* = 1m$. Details of each of the machine configurations from which data is drawn are summarized in table 1.

Electrostatic separators are used to establish the single interaction point criteria. Complications associated with the separation scenario and techniques to remedy them are described elsewhere [1, 2]. In any event the optics relevant to the separation are essentially unchanged throughout each set of measurements.

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$\beta_v^*(cm)$	1.	1.55	1.8	2.	5.	10.
$\beta_h^*(m)$	1.	1.	1.	1.	1.	1.
$\eta_h^*(m)$	0.	0.	0.	0.	0.	0.
Q_v	9.63	9.63	9.63	9.63	9.63	9.63
Q_h	8.56	8.56	8.56	8.6	8.6	8.6
Q_s	.056	.056	.056	.068	.068	.068
Q_v'	-31.3	-24.7	-22.7	-25.7	-18.7	-16.8
Q_h'	-16.7	-16.7	-16.8	-18.8	-19.1	-19.1
ϵ_h	.23	.22	.219	.245	.244	.243
$\sigma_l(cm)$	1.97	1.97	1.97	1.8	1.8	1.8
$\eta_v^{peak}(cm)$	5.	5.	5.	10.	10.	10.
$\Delta S(mm)$	5.	5.	5.	7.	7.	7.

Table 1: Optics and machine parameters

Compensation of the coupling generated by the experimental solenoid is achieved in CESR by a combination of rotations of IR quadrupoles and thin skew quads. In so far as IR quad strengths are varied to change β_v^*, so is the solenoid compensation. The measurements before and after the single interaction point conversion are distinguished with respect to solenoid compensation. The number of pairs of IR quads available to rotate increased from two before to three after the conversion. The ability to rotate three pairs permits exact compensation of the coupling in a region in which there are no bending magnets.

Experimental Procedure

Optics designed to yield the β^* of interest and otherwise constrained to satisfy the requirements discussed above are generated by an optimization procedure. Errors in the linear lattice are determined by measuring the variation of the transverse tunes as a function of the strength of each of the 100 CESR quadrupoles. Resolution is at the level of $\frac{\Delta\beta}{\beta} < 5\%$ and therefore the uncertainty in β^* is about 5%. The absolute orbit errors are less than $\pm 2mm$ in both planes.

Relative horizontal displacement of the beams at the collision point associated with the separation scheme are corrected by independent adjustment of the horizontal separators. In the data collected before the single interaction point conversion skew quads in regions of horizontal separation are used to minimize differential vertical displacement at the IP. After the conversion vertical separators were made available as a tuning aid. The measured displacements at the interaction point are less than $15\mu m$ horizontally and less than $3\mu m$ vertically prior to the conversion as compared to $10\mu m$ horizontally and $0.3\mu m$ vertically after the conversion. In all cases the relative displacement is ultimately based on the results of tuning to optimize luminosity.

The machine is globally decoupled (skew quads are adjusted to eliminate the normal mode tune split on the coupling resonance) and the residual vertical dispersion is measured to have peak values $\eta_v^{peak} < 10cm$ for runs before and $\eta_v^{peak} < 5cm$ for runs after the machine conversion. In addition the local coupling was measured after the conversion to be $\bar{C}_{12} \sim 1\%$ [6].

Results

Each set of conditions was tuned for between 4 and 8 hours to optimize luminosity. Quantities that were optimized in terms of luminosity and lifetime include transverse coupling (via skew quads), electrostatic bump closure (separator voltages), chromaticity, and transverse and longitudinal tunes. The transverse tunes were varied over a range of$\pm$.015. The optimum was recorded for each configuration.

Luminosity was recorded over a range of beam currents. The current limit was generally characterized by a flip flop instability and short lifetimes. An effort was made to keep the currents and beam sizes the same for e^+ and e^- beams. Luminosity measurements are based on the Bhabha rate into low angle high rate luminosity monitors as well as wide angle counters. Synchrotron light CCD profile monitors yield a measure of beam sizes. The splitting of the normal modes of the coupled beams is observed with spectrum analysers.

Figures 1 and 2 show the beam beam tune shift as a function of current for each configuration. Because of the qualitative difference in the measurements in configurations before (Figure 1) and after (Figure 2) the single interaction point conversion, the results are treated separately. The largest tune shift parameter measured in each configuration is plotted as a function of the corresponding β^* in Figure 3. The tune shift ξ is computed in both the zero bunch length, zero displacement limit and for the measured bunch length and displacement according to (2) and (3). There appears to be some dimunition of ξ_{sat} with decreasing $\beta^* v$ even after removing geometrical effects.

Summarized in table 2 are the maximum tune shift parameter results for each configuration with and without geometrical corrections (eqs. 1-3) in columns 2 and 4 respectively. [5] The corresponding tune shift based on the normal mode splitting is indicated as well. $\xi_v = \frac{(\cos\mu+\delta\mu)-\cos\mu}{2\pi\sin\mu}$ where $\delta\mu = 2\pi\frac{Q_v^\pi - Q_v^0}{1.245}$ [7, 8]. The maximum ξ_v increased with β_v^*. The $\xi_v = .045$ is the same as the largest measured in CESR. The data do not clearly show the saturation of the tune shift parameter in all of the configurations. The qualitative difference in the measurements before and after the machine conversion indicate the sensitivity to systematics that are poorly understood and controlled.

β_v^*	$\xi_v(\sigma_l = \Delta S = 0)$	ξ_v from Π split	ξ_v
1cm	.011 ±.003	.022 ±.005	0.022
1.55cm	.029 ±.003	.034 ±.005	0.044
1.8cm	.032 ±.003	.034 ±.005	0.045
2cm	.021 ±.003	.02 ±.002	0.028
5cm	.032 ±.003	.032 ±.002	0.034
10cm	.045 ±.003	.048 ±.002	0.046

Table 2: Tune shifts computed from measured normal mode splitting and measured luminosity with eqs. 1-3. In column 2 ξ_v is computed in the limit $\sigma_l = \Delta S = 0$. In column 4 σ_l and ΔS are from table 1.

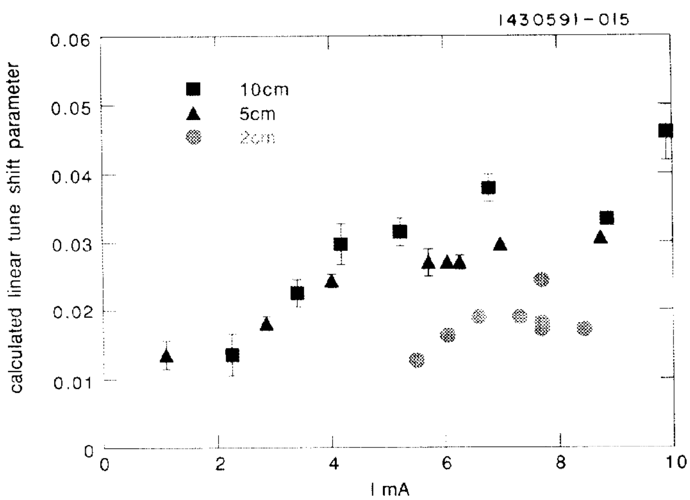

Figure 1: ξ_v measured prior to the single interaction point conversion.(set 1)

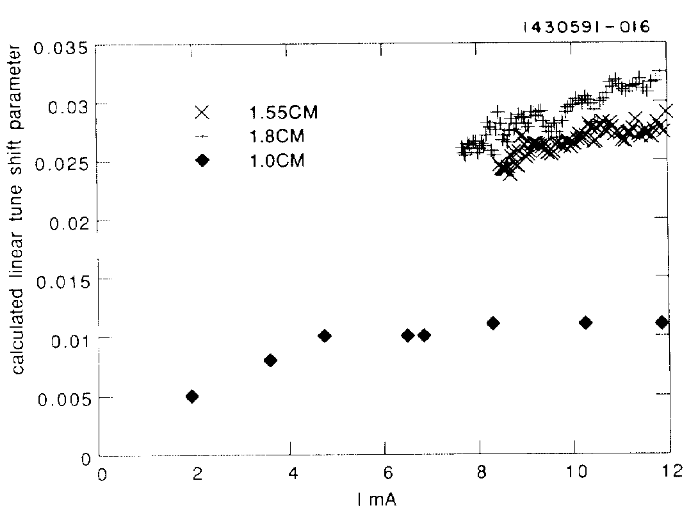

Figure 2: ξ_v measured after the single interaction point conversion.(set 2)

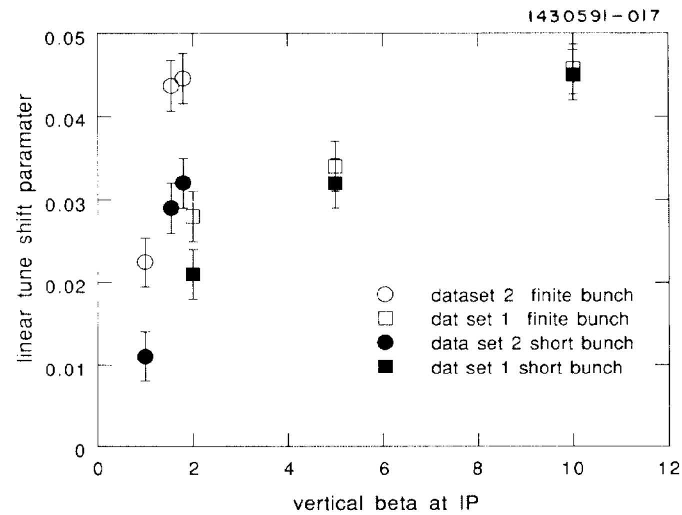

Figure 3: Highest ξ_v measured vs. β_v^*. The first and second data sets are represented by squares and circles respectively. Hollow points show ξ_v calculated including finite bunch and ΔS.

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