EFFECT ON LUMINOSITY FROM BUNCH–TO–BUNCH ORBIT DISPLACEMENTS AT CESR *

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Abstract

In routine operation the Cornell Electron/positron Storage Ring, CESR, collides 9 trains of 4 or 5 bunches of electrons and positrons. The luminosity of individual bunch pairs can suffer if the transverse positions of those bunches are displaced differentially. This paper will present the results of studies of the effect of bunch–by–bunch or train–by–train variations in the luminosity by measuring (1) the deflection from the beam–beam interaction, (2) the relative positions of the bunches, and (3) the bunch dependent luminosity from the CLEO detector. Comparisons between these three methods are discussed.

1 INTRODUCTION

At CESR, the Cornell Electron/positron Storage Ring, the bunches in a beam are grouped into "trains" of closely spaced bunches with relatively long spaces between trains. This is necessary since the electron and positron beams share the same beam pipe and electrostatic separators are used to separate the beams in the arcs. By using appropriately spaced trains of bunches, the locations of the parasitic bunch crossings can be kept away from the points where the electron and positron orbits cross. The word "car" is used to denote the place of a bunch in a train. Car 1 denotes the leading bunch, car 2 the next bunch, etc. Typically in HEP 9 trains of 4 or 5 bunches are used with 14 nsec between bunches and about 224 nsec between trains. Because the number of RF buckets in CESR is 1281 which is not divisible by 9, the spacing between trains is not uniform and in practice 3 of the train–to–train spacings are larger by 14 nsec.

Given the asymmetry in the bunch spacings, it is not surprising that measurements have shown that there are differences in the vertical orbits between different bunches[3]. Possible causes for this difference include the different wakefields seen by the different bunches, asymmetries in the fields in the RF cavities, and the different kicks felt by different bunches via the long–range beam–beam interaction due to the fact that different bunches will have different parasitic crossing points. Another possible cause is voltage fluctuations, due to synchrotron radiation, in the vertical separators. The vertical separators are used to separate the beams at "L3" which is the point half way around the ring from the interaction point (IP).

The car–to–car differential orbit displacements are a concern since the maximum luminosity is achieved when all bunches follow the same orbit and all the bunches collide head–on at the IP. Since the vertical emittance is much smaller than the horizontal, the beams are more sensitive to vertical orbit differences. Measuring these vertical orbit differences is the subject of the present paper.

2 MONITORING BUNCH–TO–BUNCH ORBIT DISPLACEMENTS

There are three methods used to monitor the car–to–car orbit variations at CESR: One method uses the Beam–Beam Interaction (BBI) Luminosity Monitor[3]. The BBI Luminosity monitor shakes a bunch (or bunches) of one beam at a fixed frequency while monitoring the induced (via the BBI) oscillation amplitude of the corresponding opposing bunch. The monitored oscillations have maximum amplitude when the beams are colliding head–on. Thus, in colliding beam conditions, the vertical offset between a particular colliding pair of bunches can be measured by setting up the Monitor to shake/monitor just that pair and then varying the differential (that is, $\delta y \equiv y_{\text{positron}} - y_{\text{electron}}$) offset and noting where the monitor signal is a maximum. In practice, the differential offset is adjusted by varying the betatron phase advance within the vertical electrostatic orbit bump spanning L3. The control system "knob" that is used to vary this phase advance is called "VCROSING 7". The drawback with this method is that only orbit differences between electrons and positrons are measured, not the individual orbits themselves. The method is also relatively slow since the VCROSING 7 knob must be varied.

A second method uses the DC pedestal of the beam feedback system. This method gives the orbit of all bunches simultaneously. The drawback here is that the orbit is only obtained at the feedback monitor point which is 1.16 wavelengths from the IP. If it is assumed that there are no kicks between the monitor point and the IP, then the position at the IP may be obtained by scaling the measured positions by $\sqrt{\beta_{ip}/\beta_{fm}}$ where β_{fm} is the beta at the feedback monitor point. Another drawback is that the pedestals are current dependent and there can be bunch–to–bunch crosstalk. These issues complicate the analysis.

The third measurement method uses the luminosity as determined by the CLEO detector. This method does not give offsets directly but, coupled with the other methods, gives a cross–check of the results. CLEO determines the overall luminosity by means of bhabha and $\gamma\gamma$ events in the crystal calorimeter[1, 2]. A more detailed breakdown of the luminosity can be obtained by using the tracking–based bunch finder in barrel bhabha events, which provides timing resolution at the few nanosecond level, to determine

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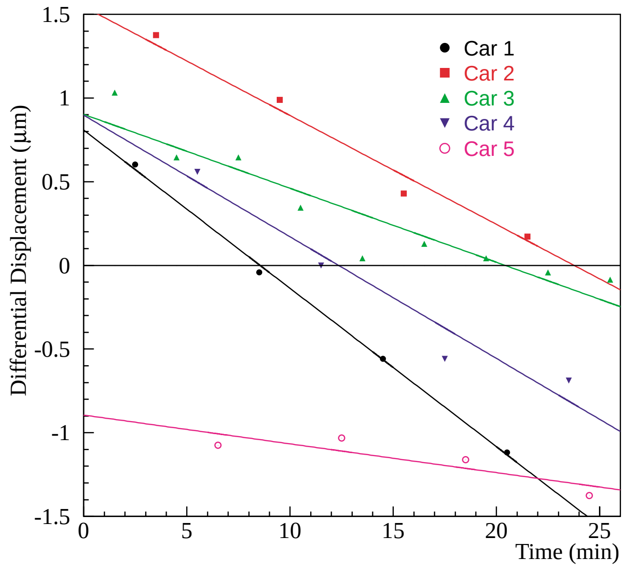

Figure 1: The vertical differential displacement for head–on collisions as a function of time as determined by maximizing the BBI Luminosity Monitor signal. Car #1 refers to the 9 leading bunches in the 9 trains, etc. The lines are linear fits to the data. The zero of the vertical axis is arbitrary.

the luminosity associated with collisions between specific cars in CESR. The primary limitation of this technique is that the car–by–car bhabha statistics corresponds to only hundreds of counts per hour at instantaneous luminosities of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. For this reason, we presently monitor a run-averaged specific luminosity for collisions in individual cars which is defined as:

$$\ell_i = \frac{N_i}{\sigma_{cleo} \int_{run} \sqrt{I_{+,i}(t) I_{-,i}(t)}\, dt}\ , \qquad (1)$$

where N_i is the observed number of bhabha events for car i collisions, $I_{+,i}$ and $I_{-,i}$ are the instantaneous positron and electron currents for their respective cars, and σ_{cleo} is the effective cross-section for the CLEO detector to observe the bhabha scattering process.

3 CURRENT DEPENDENCE

Not too surprisingly, it has been found that the differential vertical displacements vary with current. Figure 1 shows the differential displacement as a function of time (that is, current) over the course of an HEP run. In this case there were 9 trains of 5 bunches. The data was obtained by varying VCROSING 7, and using the BBI Luminosity monitor to see where the cars collided head–on. The Monitor was first set up to monitor all the car 1 bunches (this gives an average of the observed bunches), and after the maximal VCROSING 7 setting was determined the Monitor was set to look at all car 2 bunches, etc. The VCROSING 7 number was converted into μm using the theoretical calibration giving the beam displacement at the IP as a function of VCROSING 7.

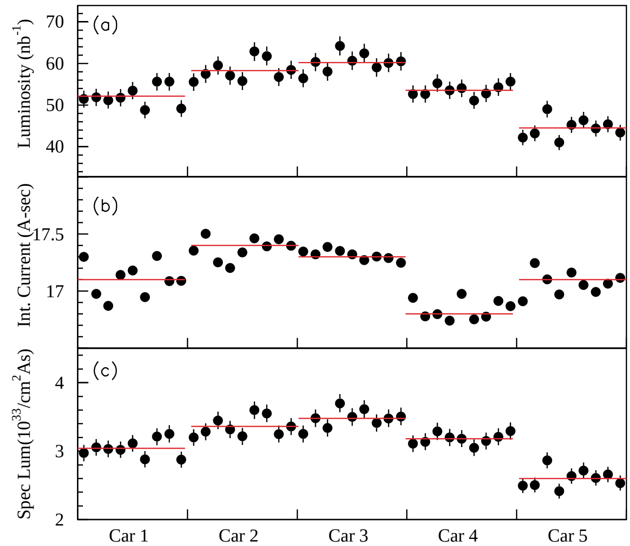

Figure 2: The (a) integrated luminosity, (b) integrated current, and (c) run-averaged specific luminosity of an HEP run where there were 9 trains of 5 bunches. The points represent the performance for individual cars while the lines indicate the average over all trains for each car.

Figure 1 shows that there is a general shift in the differential positions of the cars during a run. This is consistent with the observation that the machine operators need to vary VCROSING 7 over a run to maximize the luminosity. In the figure the lines are linear fits to the data and are solely meant to be guides for the eye. The lines all have a similar slope except for car 5 where there is little variation in the differential displacement. Why the car 5 bunches, the last bunches in the trains, should show a radically different behavior is not understood at this time. The approximately 2 μm variation between the extreme bunches corresponds to about $0.5\,\sigma_y$, where σ_y is the vertical beam size at the IP.

4 BBI MONITOR VERSUS CLEO

Figure 2 shows the integrated luminosity, current, and run-averaged specific luminosity (as defined in Eqn 1) for a recent run. We observe a substantial variation in the luminosity performance between cars. Roughly speaking, this relative performance can be divided into two categories:

1. A lifetime component due to the fact that the integrated current in each car is not equal. This is expected since the environment of each car as it passes around the ring is different from its companions.

2. A specific luminosity component. This component may arise from variations in the overlap between the electron and positron bunches as well as variations in bunch size.

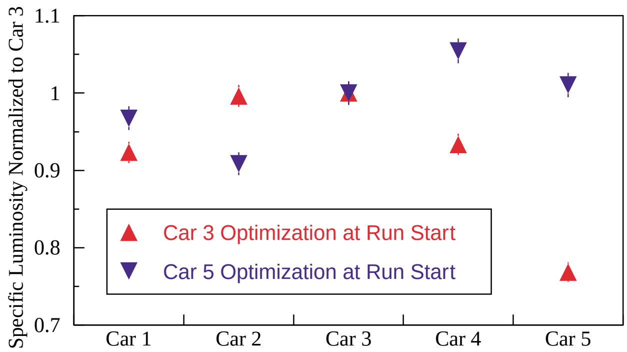

Figure 3: The car by car performance (averaged over all trains) when the electron-positron differential vertical displacement was adjusted at the start of the run to maximize the BBI luminosity signal for car 3 and car 5.

In order to verify the effects of differential vertical displacements on the specific luminosity observed by CLEO, a pair of runs were taken where the vertical orbits were adjusted at the start to optimize the BBI signal for car 3 in one instance and car 5 in the other instance. After the initial adjustment, the runs were allowed to continue for roughly 30 minutes without further tuning intervention. Figure 3 shows the relative specific luminosities that were obtained normalized to car 3. The two curves are in reasonable agreement with our attempt to optimize specific cars given the expected drift in optimum vertical displacement during each run.

In both Figures 2 and 3 we see that the typical variation between the specific luminosity of the best and worst car is typically 15-25%. If this were strictly due to the cars failing to collide head-on (that is, ignoring effects such as beam blowup), the necessary displacements would be given from the bunch overlap formula $\mathcal{L} = \mathcal{L}_0 \exp[-(\delta y)^2/4\sigma_y^2]$. Thus it would require displacements δy in the range 0.8–1.1 σ_y in order to account for the specific luminosity variations. This suggests that the poor specific luminosity of the worst bunch is likely due to a combination of effects, such as a blowup of the beam envelope, in addition to a simple vertical displacement of electrons relative to positrons.

5 FEEDBACK POSITIONING

The feedback system has been modified to permit the use of the vertical feedback kicker to deflect the orbit bunch-by-bunch[4]. This tool has been using in conjunction with a VCROSING 7 scan to determine the average differential vertical position of a particular bunch in all trains which give the best beam-beam luminosity deflection. In figure 4 an example is given of a measurement of the relative differential electron–positron vertical positions before and after installing a bunch-by-bunch deflection through the vertical kicker. The differential positions are displayed relative to those of car 1. After the initial measurement cars 2, 3, and 4 had the electrons and positrons deflected in an opposite sense to those in cars 1 and 5. Car 2-4 differential positions

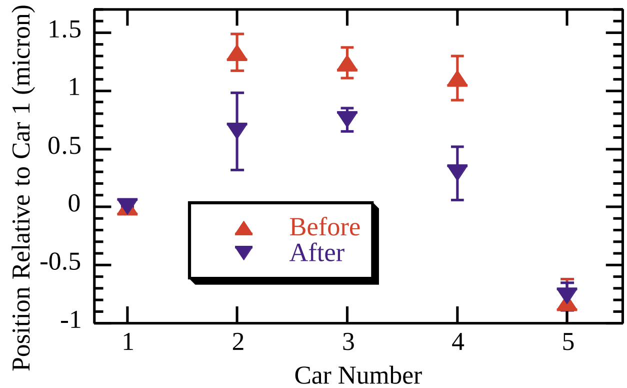

Figure 4: Positron - electron differential positions averaged over all trains relative to the average bunch 1 differential position before and after adjusting the vertical positioning of all bunches using the feedback system's kicker.

were reduced 0.5 to 0.6 microns relative to car 1 as was expected.

6 CONCLUSION

The data from a number of sources clearly shows that there are orbit variations between bunches and that this variation has a significant affect on the obtained luminosity. Work is continuing to refine the measurements and to establish the cause of the variations. Even if the source of the variations cannot be eliminated, the feedback system holds the promise of allowing for the elimination of the orbit differences.

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