LONGITUDINAL BEAM STABILITY FOR CESR-c*

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Abstract

The Cornell Electron-Positron Storage Ring (CESR) operates at 1.9 GeV per beam for high energy physics collisions. To maintain high luminosity it is essential for the bunch trains to be longitudinally stable. Measurements of longitudinal stability with a single, multiple, and colliding trains have been performed using a dual sweep streak camera and are presented in this paper.

INTRODUCTION

The Cornell Electron-Positron Storage Ring (CESR) collides electron-positron bunches at energies between 1.9-2.1GeV per beam, for high energy physics in the charm/tau regime. Operating at these energy levels (CESR-c operation) began in 2003. Up to 45 bunches can be stored in CESR-c in 9 trains of 5 bunches with each bunch separated by 14ns. CESR-c presently operates with currents up to 55mA for e- and 65mA for e+, and a maximum luminosity of 7×10^{31} cm^{-2}s^{-1}.

The CESR-c luminosity is determined by the transverse beam size ($\sigma_{x,}\sigma_y$) at the interaction point in the CLEO-c detector and the e+/e- currents. The luminosity is also dependent on the longitudinal distribution and stability through the "hourglass effect" [1]. Since the bunches are tightly focused at the interaction (focal) point, longitudinal oscillations will introduce transverse divergence in the beams, causing collisions to occur outside the interaction point and degrading the luminosity. If the bunches are stable longitudinally, they will collide when the transverse beam sizes are at a minimum.

Here we compare the longitudinal stability of bunches when a single train, multiple trains, and colliding trains are present in CESR-c measured by a streak camera with/without longitudinal feedback damping [2].

STREAK CAMERA

Calibration

The dual-sweep streak camera used for these measurements has a synchroscan plug-in tuned for 142.9 MHz so that single bunches, single trains, or multiple trains can be measured. The streak camera is triggered by a timing signal synchronous with the CESR RF system and can be advanced in time steps of 81.87ps. By adjusting the streak camera trigger in time while acquiring longitudinal distributions, a time calibration of the streak camera sweep is determined (Fig. 1). The time calibration for the measurements presented in this paper is 0.199±0.005 mm/pixel.

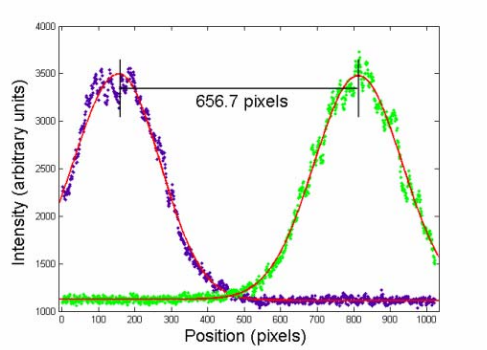

Figure 1 (color): Two longitudinal distributions separated in time by six trigger units (6x81.87ps=491.2ps) and 656.7 pixels in the streak camera sweep.

Streak Camera Image Analysis

The bunch length and longitudinal stability of single trains in CESR-c are quantified by the following analysis made on each streak camera image: i) A single Gaussian function (when measuring e+ or e- trains separately) or a double Gaussian function (when measuring both e+ and e- trains simultaneously) of the form

$$I(z)=I_0+I_1\exp\left[\frac{1}{2}\left(\frac{(z-\overline{z}_1)}{\sigma_1}\right)^2\right]+I_2\exp\left[\frac{1}{2}\left(\frac{(z-\overline{z}_2)}{\sigma_2}\right)^2\right],$$

with fit parameters I_o for the background, $I_{1,2}$ for the peaks, $\overline{z}_{1,2}$ for the mean positions, and $\sigma_{1,2}$ for the bunch lengths of the e+/e- bunches, was fit to the longitudinal profile of each bunch. (Fig. 2).

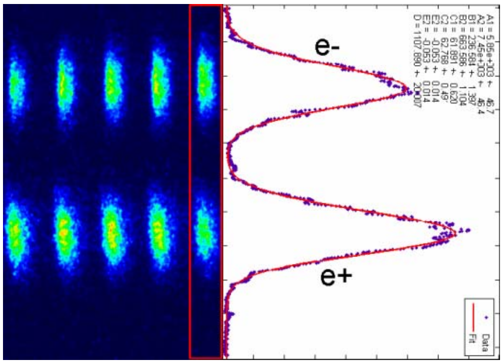

Figure 2 (color): A single streak camera image of an e- (top) and e+ (bottom) train. Summing up the pixels horizontally in the red rectangle gives the longitudinal distribution (5th bunch for this figure) to which a Double Gaussian function is fit.

ii) The center of charge for each train (e+ or e-) in each image calculated by

$$Z_{cm}=\frac{1}{n}\sum_{i=1}^{n}\overline{z}_i$$

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where n is the number of bunches in each image and $\bar{z}_i$ is the mean location, determined from the Gaussian fit, of the i^{th} bunch in the train. iii) The longitudinal deviation from the center of charge for the i^{th} bunch in the train , δ_i , is determined by

$$\delta_i = \bar{z}_i - Z_{cm} .$$

A positive δ refers to the bunch arriving late with respect to the center of charge.

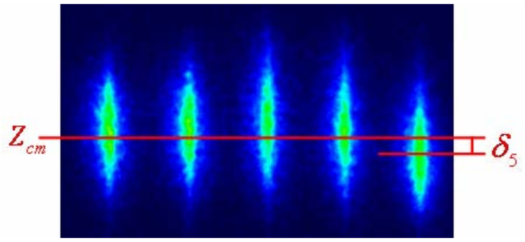

Figure 3 (color). A five bunch train streak camera image with the center of charge, denoted as Zcm, and 5^{th} bunch deviation, δ_5 , from the center of charge.

CESR-c MEASUREMENTS

The following measurements were made during CESR-c operation when machine studies time was available.

CESR-c Single Train

The longitudinal stability of a single train of five bunches was measured at several beam currents. At the currents of 1, 2, 3, and 4 mA/bunch, between 50 and 200 streak camera images were taken with the longitudinal feedback turned on and off.

At the current of 1mA/bunch (Figs. 4) we conclude that: 1) the longitudinal single train motion is unchanged with feedback on or off. The longitudinal deviation is typically ±1mm of mean value. 2) The bunch length along the train is constant. The CESR-c model zero current bunch length is given by

$$\sigma_z = \frac{\alpha c}{2\pi \nu_s}\left(\frac{\sigma_E}{E}\right) = 11.5\text{mm}$$

where $\alpha = 1.13\times10^{-2}$, $\sigma_E/E = 8.5\times10^{-4}$, and the measured synchrotron tune of $\nu_s = 40$ kHz. The measured value is within 10% of the CESR-c model.

As the bunch current increases the following observations are made: i) with the longitudinal feedback turned on, the bunch length along the train is constant but grows with current. The longitudinal deviation remains at ±1mm . ii) With the longitudinal feedback turned off, the bunch length along the train increases. In addition, above the bunch current threshold of 2mA/bunch, the longitudinal oscillation amplitude grows with current which is a signature of a longitudinal instability (Fig 5). At 4mA/bunch the oscillation amplitude is ~±7mm from the center of mass. With respect to the mean position of bunch 1, the longitudinal oscillation amplitude of bunches 4 and 5 increase with current (Fig. 6).

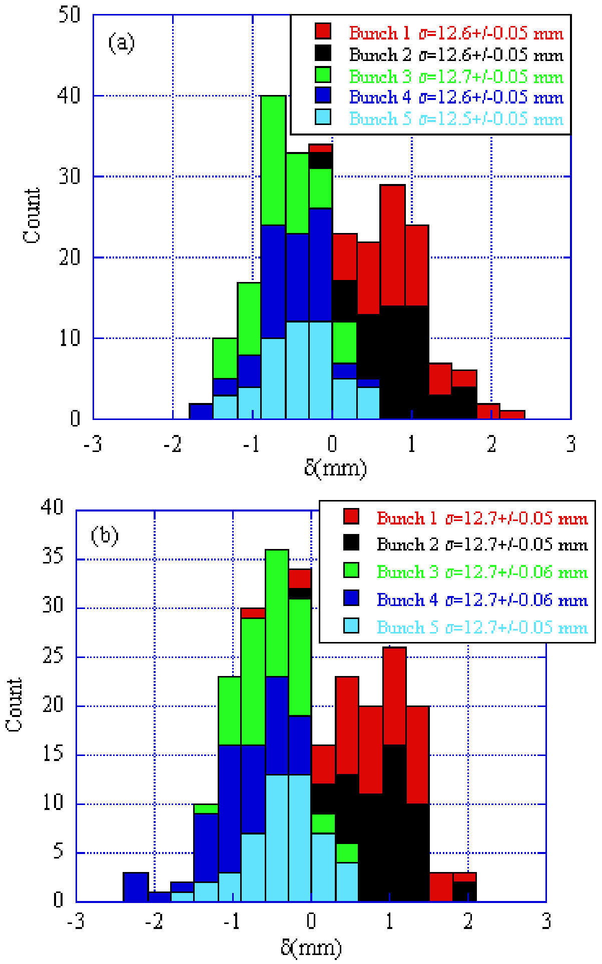

Figure 4 (color): The longitudinal deviation from the center of charge for a five bunch train with 1mA/bunch with the longitudinal feedback (a) on and (b) off.

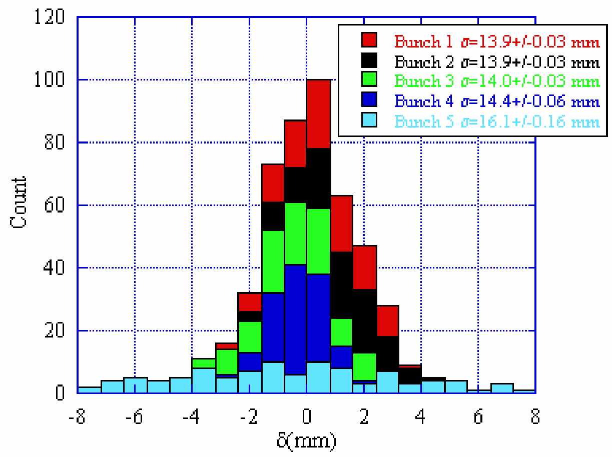

Figure 5 (color): The longitudinal deviation from the center of charge for a five bunch train with a current of 4mA/bunch with longitudinal feedback turned off.

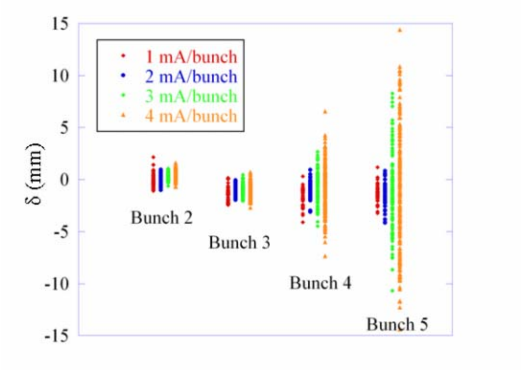

Figure 6 (color): The longitudinal deviation with respect to bunch 1 for I=1, 2, 3, and 4 mA/bunch with longitudinal feedback off.

CESR-c Multiple Bunch Trains

As with the single train measurements, we studied longitudinal stability with 9 trains of positrons with 5 bunches per train present in CESR-c at currents of 0.5, 1, and 1.5mA/bunch with the longitudinal feedback on and off. We can conclude from these measurements that: i) the bunches are longitudinally stable, the bunch length is constant along the train, and the bunch length grows with current with longitudinal feedback turned on. ii) A longitudinal oscillation appears at ~1mA/bunch with longitudinal feedback turned off. The instability signature is the same as the single train instability but at a lower current per bunch. iii) The oscillation amplitude is ~±5mm at 1.5mA/bunch.

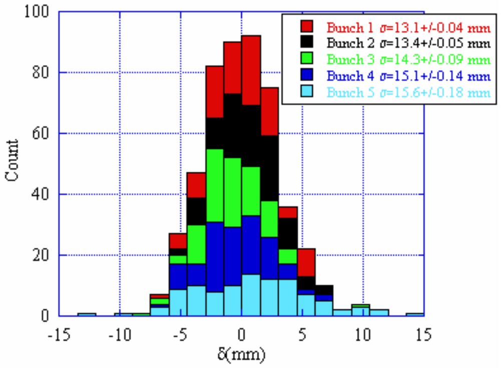

Figure 7 (color): The longitudinal deviation from the center of charge for a five bunch train with a current of 1.5mA/bunch with the longitudinal feedback turned off

CESR-c Collisions

Parasitic measurements of the longitudinal stability during CESR-c colliding beams were made on both electrons and positrons. The measurement consisted of taking 200 streak camera images just after CESR was topped off (I=1.8mA/bunch) and just before it was topped off (I=1.4 mA/bunch).

During high energy physics collisions it's evident that: (i) the bunch length is constant along the train and does not change appreciably over the small current range measured. (ii) The longitudinal deviation is ~±2mm, two times larger than with a single beam. The oscillation amplitude does not change over the small current range measured. (iii) Bunches at the front of the train arrive late and bunches at the end of the train arrive early compared to the center of charge. (iv) The CESR-c model zero current bunch length for colliding beams is σ_z=11.8mm due to a change the synchrotron tune. The measured value is 5% larger than the CESR-c model predicts.

SUMMARY

For single trains, multiple trains, and colliding beams, the bunch length along a train is constant over all current ranges measured with longitudinal feedback on. As current increases, bunch length increases. With feedback off, bunch length increases along the train for single and multiple trains. Longitudinal bunch oscillations >±1mm are present in single train measurements with current >2mA/bunch, up to ~±7mm at 4mA/bunch. Oscillations also occur in multiple train measurements at 1mA/bunch and higher currents, up to ~±5mm at 1.5mA/bunch. Bunch length growth along the trains and longitudinal bunch oscillations are signatures of a longitudinal instability. The instability is present for single and multiple train operation but only with feedback off. With feedback on, the single and multiple trains' longitudinal bunch oscillations are ~1mm. With colliding beams, the oscillations increase by a factor of two.

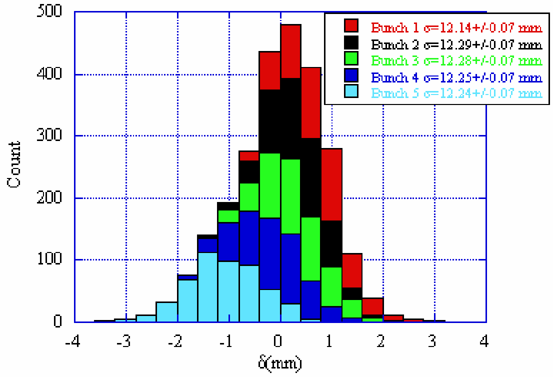

Figure 8 (color): The longitudinal deviation from the center of charge for a five-bunch e+ train in CESR-c during high energy physics collisions when I=1.8mA/bunch. The deviation profile at low current is remarkably similar.

ACKNOWLEDGMENTS

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REFERENCES

[1] S. Milton, "Calculation of how the ratio $\beta^*/\sigma_{\text{Bunch Length}}$ affects the Maximum Luminosity Obtainable: the `Hourglass Effect," Colliding Beam Note 89-1, Ithaca, 1989.

[2] J. Sikora *et al.,* "Longitudinal feedback at CESR," PAC1999, New York, Mar. 1999.