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RECENT RESULTS FOR THE DEPENDENCE OF BEAM INSTABILITIES CAUSED BY ELECTRON CLOUDS AT CESRTA DUE TO VARIATIONS IN BUNCH SPACING AND CHROMATICITY*

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Abstract

At the Cornell Electron-Positron Storage Ring Test Accelerator (CesrTA) experiments have been studying the interaction of the electron cloud (EC) with 2.1 GeV stored electron and positron beams. These experiments are intended to characterize the dependence of beam–EC interactions on various beam parameters, such as bunch spacing and vertical chromaticity. Most experiments were performed with 30 or 45-bunch trains, at a fixed current of 0.75 mA/bunch. Earlier experiments with positrons had varied the bunch spacing between 4 and 56 ns at three different vertical chromaticity settings. More recent measurements have included electron-bunch trains to contrast the build up of EC between electron and positron beams. The dynamics of the stored beam was quantified using: a gated Beam Position Monitor (BPM) and spectrum analyzer to measure the bunch-by-bunch frequency spectrum of the bunch trains; an x-ray beam size monitor to record the bunch-by-bunch, turn-by-turn vertical size of each bunch within the trains. We report on recent observations from these experiments and additional studies, using witness bunches trailing 30 or 45-bunch positron trains, which were used for the generation of the ECs.

OVERVIEW

In 2008 the storage ring CESR was converted to operate as a test accelerator CesrTA, capable of studying EC effects in the presence of trains of positron or electron bunches[1]. Some of the efforts at CesrTA included the study of the dynamics of bunches within a train of 30 to 45 bunches due to the EC, which grows along the train. One effect of the EC on a stored positron beam is a net focusing force allowing the shift of the betatron tunes of bunches, measured with a bunch-by-bunch beam position monitor system (CBPM)[2], to estimate the density of the cloud along the train. EC can also cause unstable motion in later bunches in the train, detectable by the amplitude of spectral lines from a BPM at frequencies representing different modes of oscillation (e.g. dipole and head-tail) for each bunch within the train[3]. The interaction of bunches with the EC can enlarge the vertical emittance, measured using a bunch-by-bunch x-ray vertical beam size monitors (xBSM)[4]. In addition stripline kickers and deflecting RF cavities were employed to excite coherent motion in the bunches.

In this paper we present results from three of the most recent sets of observations of EC dynamics at 2.1 GeV. The first set of measurements calibrates the chromaticity control knobs for our experimental conditions in CESR and their effect on the coherent damping of beam motion. The second set compares the overall stability of later bunches within the trains containing 30 electron bunches vs. different spacings between bunches with equivalent earlier observations using positron bunches. The final measurements provide a preliminary look at recent witness bunch studies, where a train of positron bunches is used to generate EC and a probe bunch is placed after the train to explore the effects of the EC. All measurements were undertaken in CESR using a set of optics labelled, CTA_2085MEV_XR20M_20091205. Bunch-by-bunch transverse and longitudinal dipole feedback was available; feedback was always employed during injection and it was either disabled or reduced during measurements as describes in each section below. The tunes of CESR are shown for electrons and positrons in Table 1. The tunes were chosen to avoid placing any of the bunches in the train on a resonance.

Table 1: Betatron Tunes for First Bunch in Train

Beam	$\mathbf{Q_x}$	$\mathbf{Q_y}$	$\mathbf{Q_s}$
Positron	14.580	9.615	0.064
Electron	14.558	9.611	0.064

COHERENT DAMPING RATES

The ability to adjust the coherent damping rates of transverse modes of oscillation is an important tool during beam dynamics studies. Damping rates can be controlled in two different ways: by changing the chromaticity of the beam or by varying the gains of the transverse and longitudinal dipole feedback systems. In CESR the chromaticity is adjusted by software, which takes the change in the control setting by an operator and translates this into increments or decrements of the set points for the 77 independently-powered sextupoles and then linearly ramps to these new settings. The coefficients to translate an increment for either vertical/horizontal chromaticity control knobs (called XQ1/XQ2) to the commands for

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each sextupole power supply are a function of the selected accelerator optics for CESR. Since the software controls are incremental, the relationship between the zeroes for the control and chromaticity must be measured. This is accomplished by driving both the horizontal (H) and vertical (V) shaker magnets to observe the betatron tunes (Q_x, Q_y) using CESR's tune tracker system[5], which has two phase loops each locked to one of the tunes of a single bunch. Chromaticities, defined as $Q' = \partial Q/\partial\delta$ (δ is the fractional change in energy), are computed from the slope of the best-fit lines for the change in betatron tune as the RF cavity frequency is varied in 7 steps. Typical measured uncertainties for the x/y chromaticities were ±0.20/0.36. Subsequently Q_x' and Q_y' are fit vs. XQ1 and XQ2 to yield for positron conditions,

$$\begin{pmatrix} Q'y \\ Q'x \end{pmatrix} = \begin{pmatrix} 0.00949 & -0.00077 \\ -0.00035 & 0.00921 \end{pmatrix} \begin{pmatrix} XQ1 \\ XQ2 \end{pmatrix} + \begin{pmatrix} 0.75 \\ 0.44 \end{pmatrix}$$

and for electron conditions,

$$\begin{pmatrix} Q'y \\ Q'x \end{pmatrix} = \begin{pmatrix} 0.00911 & -0.00063 \\ -0.00028 & 0.00930 \end{pmatrix} \begin{pmatrix} XQ1 \\ XQ2 \end{pmatrix} + \begin{pmatrix} 1.68 \\ 0.12 \end{pmatrix}$$

The sextupole distribution was designed to have the on-diagonal elements in the matrix equal to 0.01 and the off-diagonals equal to 0, close to the measured values.

The coherent damping rates for vertical dipole (D) and head-tail (HT) modes were observed using the drive-damp technique, which excites the mode of oscillation by driving a shaker magnet for approximately 1 msec and then measuring the oscillation decay time[3]. (To drive the HT mode it is also necessary to continuously produce a longitudinal oscillation by exciting the RF system's phase.) The damping time is defined as the time during which the oscillation amplitude falls by one e-fold; the damping rate is the inverse of the damping time. At fixed beam current the damping rate is linear with chromaticity over a large range and the best fits to these lines at 1 mA ($1.5\mathrm{x}10^{10}$ particles) per bunch for the D modes are

$$\alpha_v = \left(14.4\,\mathrm{sec}^{-1}\right)Q'_y\left(\frac{I_b}{1\mathrm{mA}}\right) - 0.32\,\mathrm{sec}^{-1} \quad \text{for electrons}$$

$$\alpha_v = \left(14.9\,\mathrm{sec}^{-1}\right)Q'_y\left(\frac{I_b}{1\mathrm{mA}}\right) - 0.61\,\mathrm{sec}^{-1} \quad \text{for positrons},$$

for the HT modes for electrons are

$$\alpha_v^{HT} = \left(9.54\,\mathrm{sec}^{-1}\right)Q'_y\left(\frac{I_b}{1\mathrm{mA}}\right) - 0.32\,\mathrm{sec}^{-1} \quad -1\ \text{HT mode}$$

$$\alpha_v^{HT} = \left(10.81\,\mathrm{sec}^{-1}\right)Q'_y\left(\frac{I_b}{1\mathrm{mA}}\right) - 8.6\,\mathrm{sec}^{-1} \quad +1\ \text{HT mode},$$

and earlier fits for the HT modes for positrons are

$$\alpha_v^{HT} = \left(21\,\mathrm{sec}^{-1}\right)Q'_y\left(\frac{I_b}{1\mathrm{mA}}\right) + 4\,\mathrm{sec}^{-1} \quad -1\ \text{HT mode}$$

$$\alpha_v^{HT} = \left(17\,\mathrm{sec}^{-1}\right)Q'_y\left(\frac{I_b}{1\mathrm{mA}}\right) + 33\,\mathrm{sec}^{-1} \quad +1\ \text{HT mode}$$

The measured damping rates for both species are fairly similar for the D modes as expected, but the damping rates for electron HT modes appear to have about one half the slope vs. XQ1 as the positrons. Although the damping rates for both species do not need to be the same (e.g. due to the different directions,) the factor of two difference in slope vs. Q'_y between the two beams is larger than anticipated. These damping rate calibrations are essential for the analysis of data in the next section.

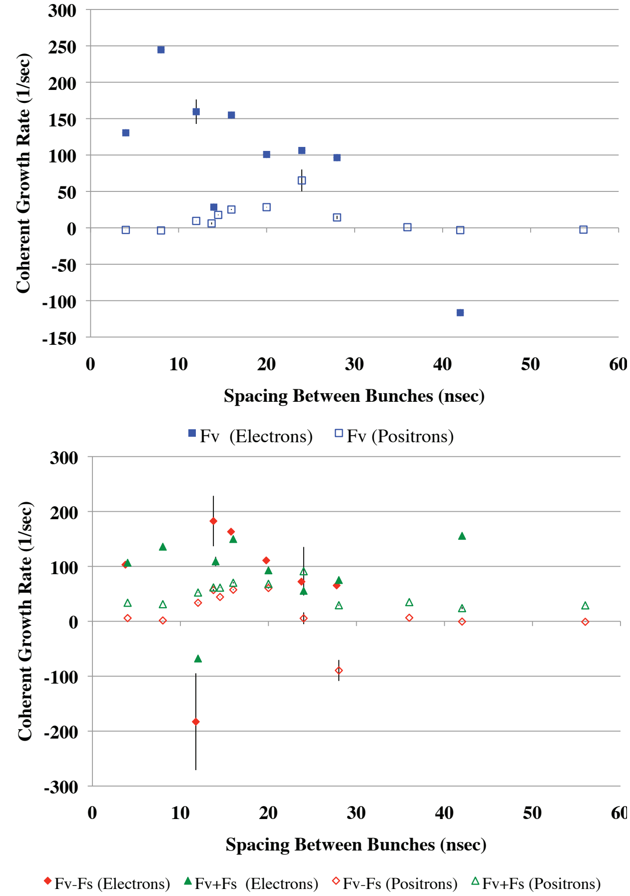

Figure 1: Coherent growth rates for electrons (solid markers) and positron (open markers) for 30 bunch trains vs. the spacing between bunches for the vertical dipole mode (upper plot) and head-tail modes (lower plot.).

STABILITY OF TRAINS OF BUNCHES

Measurements were undertaken with trains of 30 electron bunches of 0.75 mA ($1.1\mathrm{x}10^{10}$ particles) per bunch where both the spacing between bunches and XQ1 were varied. The sets of measurements are to compare with earlier ones, using positron bunches with variable spacings[6]. The data for both sets were taken with vertical feedback off and low levels of horizontal and longitudinal feedback. We measured the position spectrum of individual bunches within these trains by observing a single button of a BPM and gating the signal on the bunch being studied[3]. The signal is routed to a spectrum analyzer, which averages for approximately 10 seconds, giving a spectrum containing horizontal and vertical D (m=0) betatron modes at frequencies F_h and F_v, vertical HT (m=±1) lines at F_v±F_s (F_s is the synchrotron tune) and occasionally horizontal HT lines. Over some range of XQ1 settings, amplitudes of the D and HT lines

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decrease as the command increases. For a given bunch spacing we observed the spectra at 3 vertical chromaticity settings, chosen to span a range where the amplitude of at least one of the HT modes for bunch 25 was roughly the same as at other bunch spacings. (Bunch 25 is generally one of those exhibiting unstable motion.) By interpolating within the sets of measurements we obtain approximately the same spectral D and HT mode amplitudes for the least stable bunches in the train. This allows us to quantify the coherent instability strength from the change in growth rate as the spacing between bunches within trains change.

The methods for analyzing this data were explained in detail earlier[6]. It consists of using fits for the change in amplitudes of the D and HT modes for the most unstable bunches in the trains vs. XQ1 to determine an effective V chromaticity setting (and growth rate) for each mode, which would make the average spectral amplitude of each mode the same for all bunch spacings. Figure 1 shows the results of the analyses of both the electron and positron beams for D and HT modes, where the change in growth rate is plotted vs. the spacing between bunches. Note that not all bunch spacings have growth rates for all three modes for both species; this is caused by the mode spectral amplitudes either being too small or too close to a larger spectral peak. There are error bars plotted for all points in the graphs, but these do not represent the full statistical uncertainties for the points. Rather they are only the uncertainty when determining the growth rate using the variation in spectral amplitudes vs. XQ1; i.e. if the amplitudes change only slightly as the XQ1 changes, the growth rate is poorly characterized. Both D and HT analyses show that coherent modes for the electron beams tend to be less stable, especially for bunch spacings less than 24 nsec. This suggests that EC may provide some form of damping for coherent motion within the train. The large variation in D mode damping rates for electron beams also suggests a short-range instability mechanism such as wakefields may be present.

WITNESS BUNCH MEASUREMENTS

Extensive observations were made using 30 and 45 bunch-long positron trains to generate an EC at the end of the train and then placing a witness bunch (with different delays after the train) to measure its D and HT mode oscillation amplitudes, its vertical beam size and any variation in size from turn-to-turn. Transverse and longitudinal feedback was employed to stabilize bunches within the train, and this feedback could be turned on or off for the witness bunch and the first bunch in the train during measurements. (The difference in vertical tune shifts between the first bunch in the train and the witness bunch helps estimate an average EC density for the ring.) As part of these studies we varied the vertical chromaticity, the unperturbed vertical beam size of all bunches and the current per bunch (for the bunches in the train and the witness bunch). This data is in the process of being analyzed. An example of some results is found in Figure 2, which plots the vertical beam sizes of each bunch in the train, averaged over all witness bunch measurements, and the witness bunch with vertical feedback on for all bunches and a vertical chromaticity of -0.53. Note the beam size grows for later bunches within the train; it decreases for witness bunches as they are delayed from the end of the train, indicating the decay of EC.

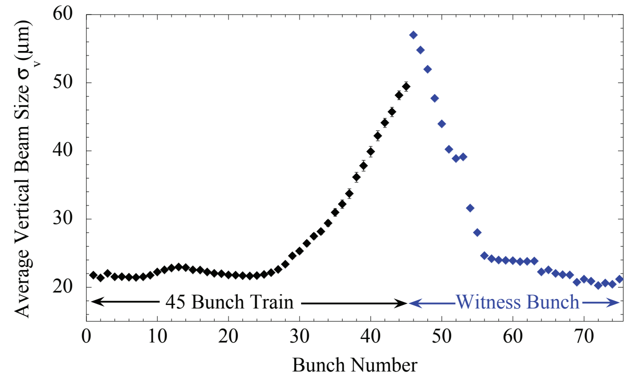

Figure 2: Vertical beam size for 45 bunch trains with 14 nsec-spaced bunches and followed by a witness bunch, located in one of the14 nsec-bunch slots from 46 to 65. All bunches contained 7.5x10^9 particles.

ANALYSIS PLANS AND CONCLUSIONS

Immediate plans focus on the comparison of the witness bunch data via a simulation of the positron witness bunch's dynamics in the presence of EC. For the measurements of train stability, at this time there are no programs capable of a fully self-consistent model of the beam's dynamics from EC for 30 bunch trains of variable spacings. In the future when such simulations are possible this data may provide a useful benchmark.

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