STUDY OF TURN-BY-TURN VERTICAL BEAM DYNAMICS AT LOW AND HIGH ENERGY CESR OPERATION*

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Abstract

Presently, the Cornell Electron-Positron Storage Ring (CESR) is operated at two different beam energies: low energy (E=2GeV) for high energy physics (CESR-c), and high energy (E=5.3GeV) for synchrotron radiation production for the Cornell High Energy Synchrotron Source (CHESS). The electron and positron bunches' vertical dynamics at these two energies are vastly different, in part due to the change in the pretzel orbit, the presence of wiggler magnets at low energy, and synchrotron radiation power at two different energies. Using a 32 channel photomultiplier array and a beam position monitor (BPM), vertical beam dynamics were measured on a turn-by-turn basis during CHESS and CESR-c operation as well as dedicated machine studies time. For these studies, electron cloud effects such as vertical tune shift and vertical beam size blow-up along the electron and positron trains are quantified at these two vastly different beam energies.

INTRODUCTION

The Cornell Electron-Positron Storage Ring is operated at high energy (E=5.3 GeV) for synchrotron radiation production (CHESS) and at low energy (E=2 GeV) for high energy physics at the upsilon energy. In addition, there are plans to turn CESR into a damping ring test accelerator, CESR-TA, to study beam dynamics, such as ultra low emittance beams, e+/e- damping times, and the electron cloud instability, for the International Linear Collider damping ring. To quantify the vertical beam dynamics on a turn-by-turn, bunch-by-bunch basis for these different operating conditions, two 32 channel photomultiplier tube (PMT) arrays were installed in CESR. These can be used to measure the vertical beam dynamics for the e+/e- beams.

CHESS VERTICAL BEAM DYNAMICS

During CHESS operation there are typically 9 trains of 6 bunches of e+/e- in CESR for a total of 54 bunches. The bunches in each train are separated by 14 ns. Electrostatic separators provide a horizontal pretzel orbit in the arcs and vertical pretzel orbit in the interaction region to prevent the bunches from colliding. Calculations of the lattice properties due to the horizontal parasitic crossings predicts three-fold symmetry so that trains 1, 4, 7, and 2, 5, 8, and 3, 6, 9 have identical optical properties due to their identical horizontal parasitic crossings [1].

Parasitic measurements of the vertical beam dynamics were made during CHESS operation using the PMT array. Measurements were made at high current (top of a fill), medium current (middle of a fill), and low current (end of a fill), where bunch-to-bunch currents are fairly uniform. At each current, the vertical profile of all 54 e+/e- bunches were measured for 9k turns (~23ms total time). Each profile is fit to a Gaussian distribution to determine the vertical position and size of each e+/e- bunch.

Figure 1 shows the difference in e+/e- vertical beam size from the first bunch in the train. From these measurements we can conclude that: i) there is e- σ_y growth along the train except for bunch 6 in trains 1, 4, and 7, ii) there is significant e+ σ_y growth along the train except for train 3, 6, and 9 where σ_y decreases, and iii) a three-fold symmetry is evident in σ_y, particularly in the e+ σ_y along the train (figure 1a). Since the parasitic crossing is a horizontal effect and it's noticed in the vertical plane, coupling must occur.

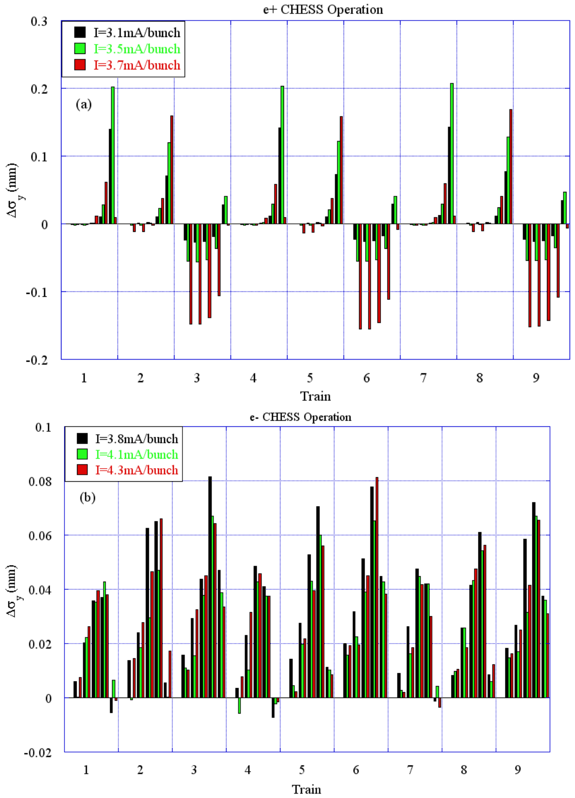

Figure 1. Vertical beam size for the (a) positron bunches and (b) electron bunches when 9 trains of 6 bunches per

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train were present in CESR during CHESS operation. The measurements were made at three different currents.

CESR-C VERTICAL BEAM DYNAMICS

Colliding beam measurements were made during CESR-c high energy physics production with 24 bunches in CESR and a bunch pattern of 9 trains with 3 bunches except for train 1 (2 bunches) and train 9 (1 bunch). During CESR-c operation, the bunches are separated in the CESR arcs with horizontal separators and they collide in the CLEO-c detector.

Using the PMT array, vertical beam size measurements were made for 10k turns. Figure 2 is the vertical beam size for the positron and electron bunches during CESR-c operation. The results show that: i) the e+ vertical beam size typically grows along the train, ii) the e- vertical beam size decreases along the train, iii) both the e+/e- vertical beam sizes increase with current, and iv) the three-fold symmetry due to the parasitic crossing is not present. During colliding beams, the beam-beam effect is significantly larger than the parasitic crossing effect (~ factor of 5) which might explain why it's not observed during CESR-c colliding beams.

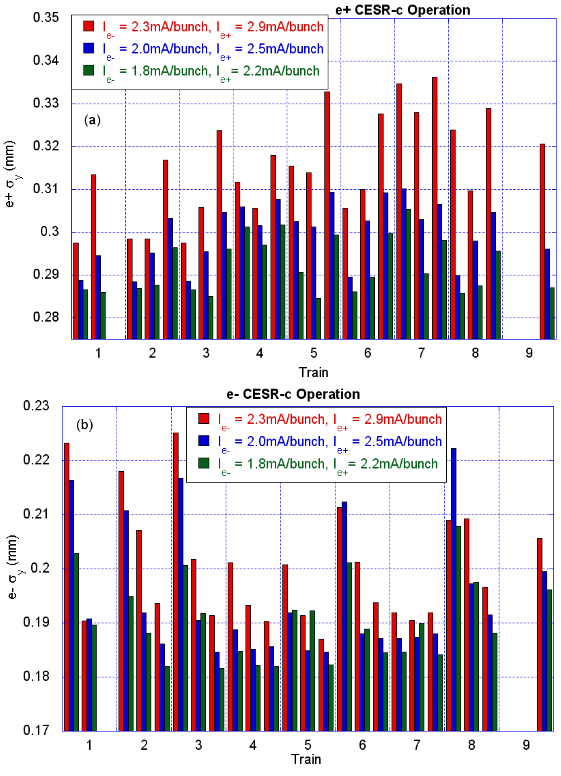

Figure 2. The vertical beam size for the (a) positron and (b) electron bunches during CESR-c high energy physics operation. The measurements were made at three different currents.

ELECTRON CLOUD MEASURMENTS AT CESR

Over the past year, a series of measurements using the turn-by-turn PMT and BPM instrumentation have been made to quantify the presence of the electron cloud in CESR. The measurements were made at the CESR-c energy (1.9 GeV) with a magnetic lattice that included 12 wiggler magnets. To characterize the electron cloud, a bunch train with up to 45 bunches with 14 ns spacing was used. By exciting the bunch train with a pulsed magnet, the tune of each bunch can be measured using the turn-by-turn BPM system.

The decay of the electron cloud can be quantified by measuring the tune shift as a function of bunch spacing. A 10-bunch train of positrons was used to generate an electron cloud and a single witness bunch was placed at various distances behind the train. Generating and witness bunches were filled to 0.75mA. The results are shown in figure 3 where the bunch tunes are plotted relative to the tune of the leading bunch in the train.

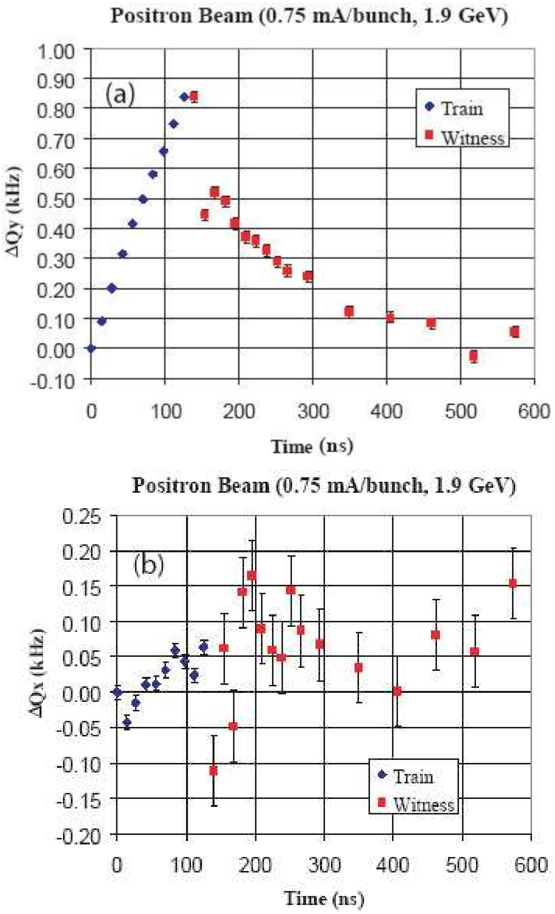

Figure 3: The positron tune shift in the (a) vertical, and (b) horizontal plane relative to the first bunch in the train. The nominal first bunch tunes were Q_x=202.7 kHz and Q_y=239.3 kHz.

We note the following: i) Using a simple model of the electron cloud interaction, the beam requires a cloud density of $\rho_e \sim 10^{11}/m^3/kHz$ to produce the vertical tune shift along the train [2]. ii) The decay time of the electron cloud is roughly 170ns. iii) The horizontal tune shift along the train is small in comparison to the vertical tune shift.

An identical measurement to the positron tune shift was made for electrons (figure 4). The results show that: i) a negative tune shift is measured which is consistent with an electron cloud acting on the beam. ii) The peak tune shift is observed at 196 ns (bunch 14) behind the lead electron bunch whereas the peak tune shift for positrons is observed at 140 ns (bunch 10) behind the lead bunch, and iii) the peak electron vertical tune shift is ~1/3 the peak positron vertical tune shift. Our preliminary conclusion from the above tune measurements is that we are seeing evidence for the electron cloud affecting the dynamics of both electron and positron beams.

Using the turn-by-turn PMT, the vertical beam size along a 45 bunch train of positrons was made over a range of bunch currents. At each current setting a 50 turn average of the vertical beam size was measured 200 times. The results displayed in figure 5 show that as the current increases the vertical beam size blow-up occurs earlier in the 45 bunch train. This is characteristic of the e- cloud.

CONCLUSIONS

At low energy (E=2GeV, CESR-c), the e+ vertical beam size tends to increase along the train, while e- vertical beam size decreases along the train. Both the e+/e- vertical beam sizes increase with current. We see no evidence of three-fold symmetry due to the parasitic crossing.

At high energy (E=5.3GeV, CHESS), a three-fold symmetry is evident in σ_y, indicating coupling between the horizontal and vertical. Both electrons and positrons show σ_y growth along the train.

During dedicated electron-cloud measurements (E=1.9GeV) for electrons, a cloud density of $\rho_e \sim 10^{11}/\mathrm{m}^3/\mathrm{kHz}$ is required to produce the observed vertical tune shift. Measurements were consistent with an e-cloud decay time of 170ns. Positron measurements of a negative tune shift were consistent with an e-cloud effect. As current increases, σ_y blow-up for positrons occurs further toward the front of a 45 bunch train, which is also consistent with an e-cloud effect. We conclude that we are seeing evidence for an electron cloud affecting both the e+ and e- beams.

REFERENCES

[1] J. Crittenden et al., "A study of the effect of beam-beam interactions on CESR optics," proceedings of PAC2005.

[2] K. Ohmi, et al., "Study of Coherent Tune Shift Caused by Electron Cloud in Positron Storage Rings," Proc. of the 2nd APAC, Beijing, China, 2001.

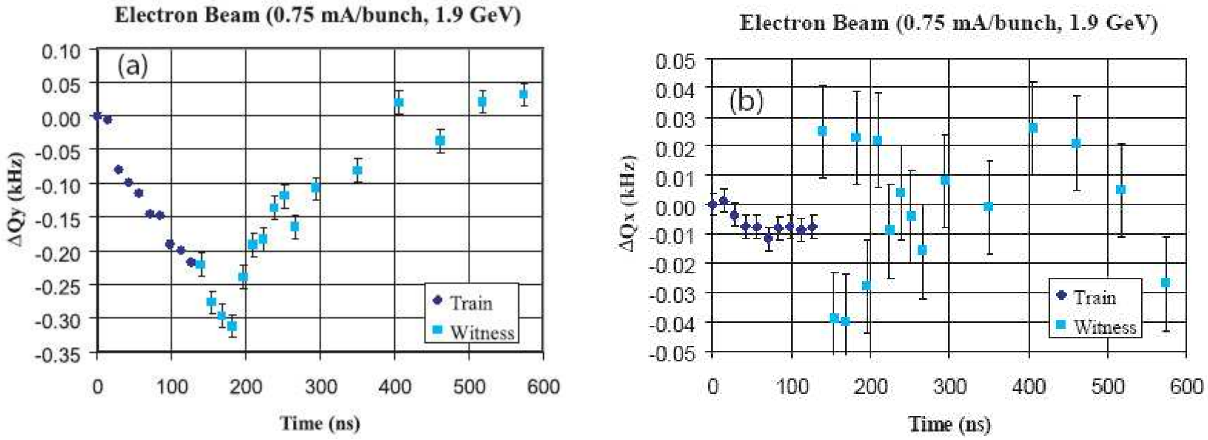

Figure 4: The electron tune shift in the (a) vertical, and (b) horizontal plane relative to the first bunch in the train. The nominal first bunch tunes were Q_x=203.7 kHz and Q_y=241.4 kHz.

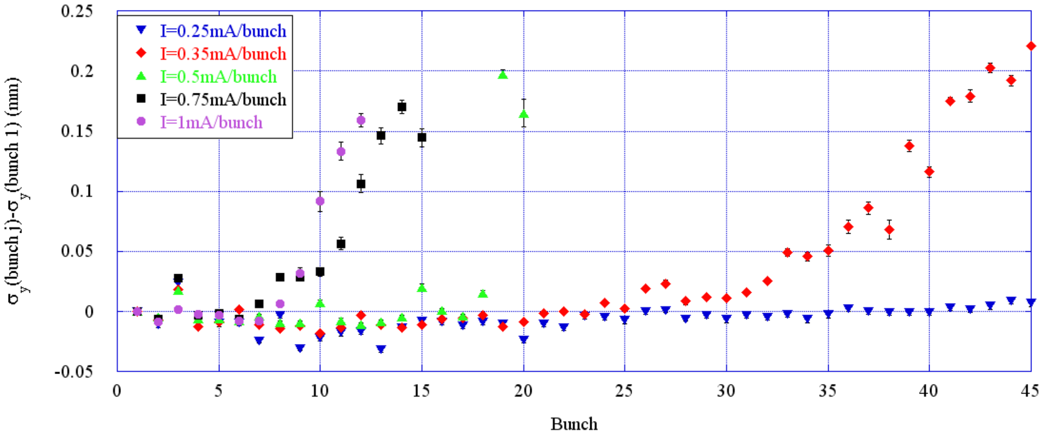

Figure 5: Onset of a vertical beam size instability for trains of 45 positron bunches as a function of bunch current. For the measurements shown, each point corresponds to the average of 200 single bunch beam size fits where each fit was carried out on a 50-turn average of the PMT array signals.