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SIMULATION OF ELECTRON CLOUD INDUCED INSTABILITIES AND EMITTANCE GROWTH FOR CESRTA*

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Abstract

We present results of a series of studies obtained using the simulation program CMAD [1] to study how electron clouds affect the dynamics of positron beams in CesrTA. The study complements ongoing experiments dedicated for studying the same phenomena. The simulation involves tracking positrons through the CesrTA lattice and simultaneously computing the force exerted, due to space charge of the electrons, on each of the tracked positrons. The electrons themselves are allowed to evolve under the influence of the positrons. Several results bear close resemblance to what has been observed experimentally.

INTRODUCTION

The dynamics of positrons in the presence of electron clouds is being studied systematically through experiments and simulations for CesrTA. Currently we have performed simulations for 512 turns corresponding to CesrTA parameters, which has a synchrotron tune of 0.055. This translates to about 50 synchrotron periods, which is sufficient for studying headtail oscillations but not so for studying slow emittance growth at low cloud densities. While the task of performing longer simulations is currently in progress, we have been able to get several interesting results with 512 turns that have shown similar behaviors already observed at CesrTA.

VARIATION OF CLOUD DENSITY

In this section, we show results of a study made with varying cloud densities. In observations, we typically use 30 to 45 bunches in a train. Depending upon its properties, each bunch creates a certain amount of cloud and as a result the lagging bunches experience a higher cloud density compared to the leading ones. CesrTA instrumentation has the ability to observe the turn by turn position and the beam size of each of the bunches. CMAD tracks a single bunch and so in order to simulate the effect of different bunches along the train, we need to perform a set of independent calculations with varying prespecified cloud densities. The cloud densities seen by the different bunches can be estimated from build up codes. CMAD starts with a uniform distribution of electrons while work is underway to have the program be able to use any distribution as an initial condition.

In these simulations, particles are tracked across the full CesrTA 2.08GeV lattice, where each element of non-zero length in the lattice consists of a cloud-beam "interacting point". Thus, the simulation takes into account the variation of the beam size all around the ring. The bunch had 96 slices, and the charge from each slice was distributed over a 128 × 128 grid, with 300000 macro particles (positrons) and 100000 macro electrons. The bunch current used was 1mA, corresponding to 1.6×10^{10} positrons. The bunch length was 12.2mm, vertical emittance was 20pm and horizontal emittance 2.6nm. The relative energy spread was 8.12×10^{-4}. The betatron tunes were 14.57 (horizontal) and 9.62 (vertical). The synchrotron tune was 0.055. The chromaticities were 0.6 (horizontal) and 2.3 (vertical) in units of $dQ/(dp/p)$. Overall, care was taken to match the parameters as closely as possible to the machine conditions that existed during the time of observations. In this paper, we discuss only the vertical motion of the beam particles, which are far more sensitive to perturbations given the dimensions of the beam.

Figure [1] shows the spectrum of the centroid motion of the bunches under varying cloud densities. We see that the betatron tune is gradually shifted with increasing cloud densities. The synchrotron sidebands are clearly noticeable, indicative of headtail motion. We also see that the betatron tune splits with one component remaining at the "unshifted" tune. This is likely because the outer beam particles experience less of a cloud effect as the electrons begin to get pinched toward the center of the beam. This splitting has not been observed in experiments, which is likely because in simulations, the extent of the cloud and the grid boundary is truncated at 20 times the beam size, while in reality the cloud extends much further. In such a case the outer particles would also see a significant cloud effect. We are currently working toward a more realistic model to account for the density evolution of the cloud during the bunch passage.

Despite the drawbacks in the model, we already see several features observed in experiments [2] reproduced here. The spectrum shows sidebands spaced by a synchrotron tune with the height of the sidebands rising with increased electron density. In addition, we see higher order sidebands become more visible with increased cloud density. The first order sidebands are indicative of the so called $m = \pm 1$ modes while the second order ones are a consequence of the $m = \pm 2$ modes. The higher modes become more prominent with increased cloud densities, both in simula-

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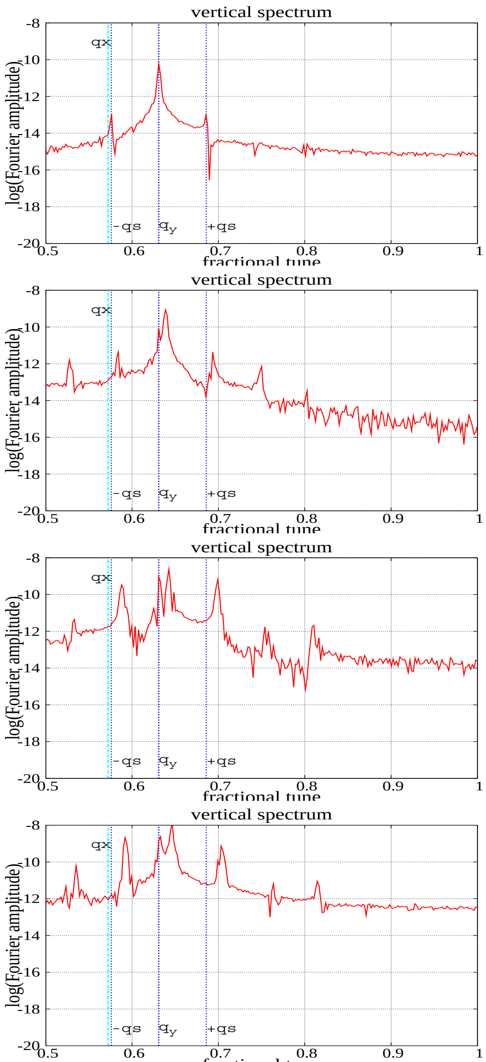

Figure 1: Spectrum of vertical bunch motion for varying cloud densities. From top to botton (a)6e10 (b)3e11 (c)6e11 (d)8e11 electrons per m^3.

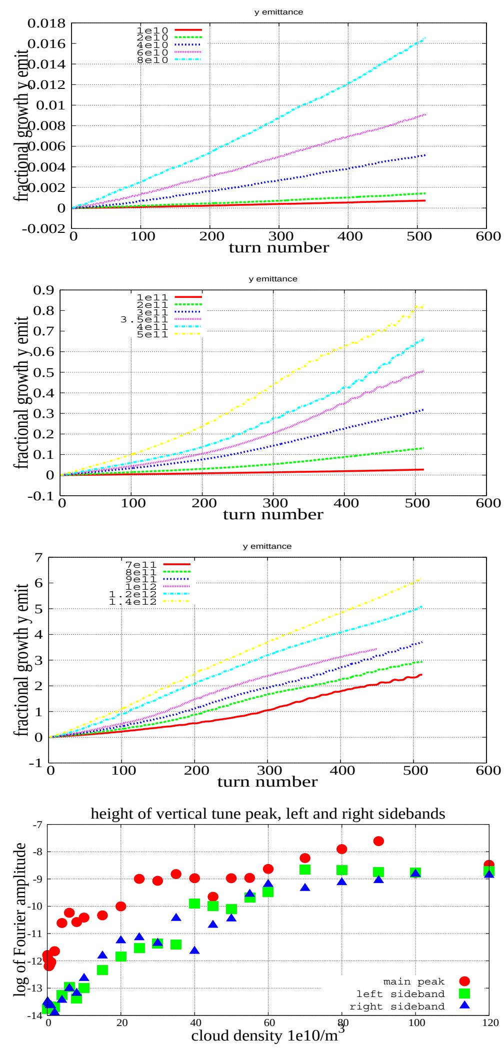

Figure 2: Emittance growth rate for varying cloud densities and a summary of sidebands heights along with the betatron peak heights.

tions and observations.

Figure [2] shows the emittance growth of the bunch. We clearly see that the emittance growth rate increases with increased cloud density. This correspondence between increase in sideband height and beam emittance has been observed at similar cloud densities. The cloud density for the observed conditions are estimated by comparing tune shift calculations obtained from build up simulations and measured tune shifts [3].

VARIATION OF INITIAL VERTICAL EMITTANCE

Our next study consists of varying the initial vertical beam emittance. In this study, we used a cloud density of $3 \times 10^{11}/m^3$ electrons and increased the vertical beam size by a factor of 2,3,4 and 5 respectively. All other parameters were identical to those mentioned in the previous sections. The simulation results clearly show that the beam motion is more stable as initial size increases. This is apparent in the spectrum of the vertical motion of the beam where as shown in Fig [3], the height of the synchrotron sidebands are suppressed as the initial vertical beam emittance increases. A similar trend is seen in the fractional emittance growth rate of the different bunches. In principle, one would expect the motion to be more stable for a beam that is more spread out.

An experiment to observe this phenomenon has been conducted at CesrTA which revealed some interesting features. Unlike what the simulations showed, we did not see a significant variation in the measured beam spectrum when the initial emittance was altered. At the same time, X-ray beam size measurements revealed that the beam size equilibrated to a similar value for all initial beam emittance settings. Thus, it was clear that under the given conditions the initial beam size did not play a crucial role in the final

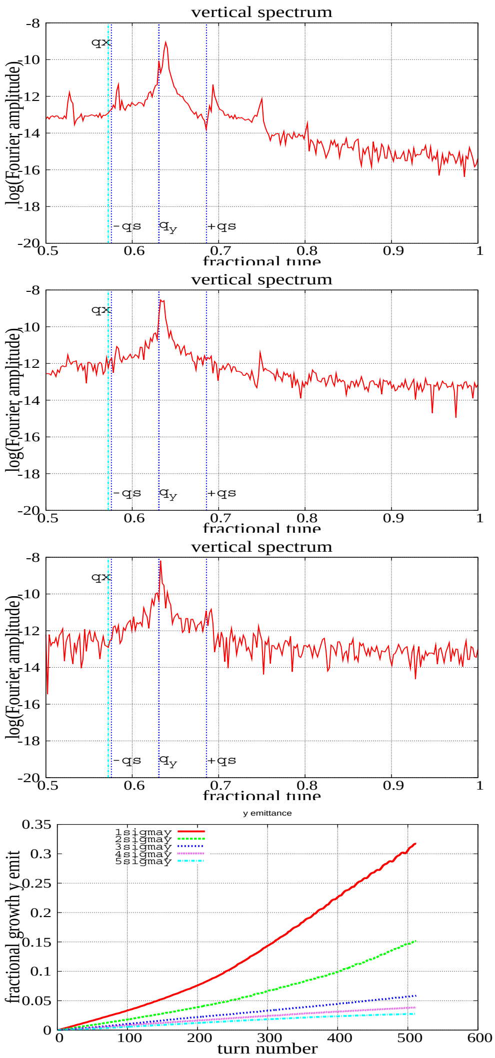

Figure 3: Spectrum of vertical bunch motion and fractional emittance growth rates for varying initial vertical emittances.

beam emittance and what is being observed in simulations is a transient effect. The simulated emittance growth already shows that the fractional growth rate increases with decrease in initial beam size. We need to repeat these studies for a much larger number of turns and confirm they all saturate to a more or less equal final emittance.

VARIATION OF BUNCH LENGTH

In this section we show the results of a study on how the dynamics of the bunch is affected with change in bunch length. It has been determined through analysis [4] that bunch instability increases with increase in the number of oscillations electrons under go during a bunch passage. A quick calculation reveals that the number of oscillations scales as square root of bunch length for a given bunch charge. Thus, our results are consistent with theory, ie, increased emittance growth rate with increased bunch

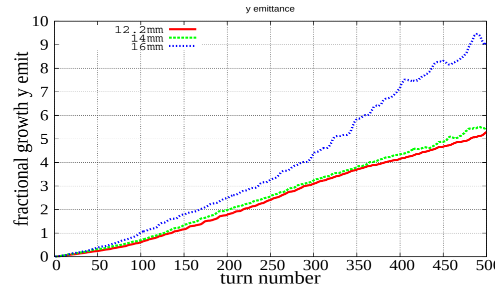

Figure 4: Vertical emittance growth rate for various bunch lengths.

length. In principle this phenomenon may be observed at CesrTA by changing the RF voltage and thus altering the bunch length. In this study, the cloud density was fixed at $3 \times 10^{11}/m^3$ electrons. The bunch length was increased from the nominal value of 12.2mm to 14mm amd 16mm. The synchrotron tune was adjusted accordingly. We did not study the spectrum for this case. Besides, the chromaticities were set to zero in this study, which results in a rather high emittance growth rate. Values of all other parameters were identical to those used in the previous sections. Hence the results for this study are as yet preliminary.

CONCLUSION

We have made considerable progress in being able to simulate electron effects over the dynamics of the beam using CMAD. The current set of results show features very similar to what has been observed at CesrTA. Several improvements of the model are underway. We hope that we will be able to obtain better quantitative agreement with observations in future. In addition to improving the model, we need to perform perform calculations for sufficient number of turns so that we are able to observe a saturation in the emittance growth rate. This would help eliminate transient effects since observations are always made when a quasi steady state condition has reached. On the other hand, it would be interesting to study the possibility of observing transient effects in experiments although this would be very difficult to achieve.

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