OBSERVATION AT CESRTA OF THE REDUCTION OF THE VERTICAL BEAM SIZE OF THE LEAD BUNCH IN A TRAIN DUE TO THE PRESENCE OF A PRECURSOR BUNCH*

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Abstract

Electron cloud-induced beam dynamics is being studied at CESRTA under various conditions. These measurements make use of instrumentation for the detection of the coherent self-excited spectrum for each bunch within the train and bunch-by-bunch vertical beam size. In the position spectrum coherent betatron dipole and head-tail motion is detectable for each individual bunch within the train. These techniques are utilized to study the electron cloud-related interactions, which cause the growth of coherent motion and beam size along the train. We report on the observations of the vertical enlargement of the first bunch(es) in 30 bunch-long trains. We also report that the addition of a precursor bunch following the train of bunches and before the start of the next train can counteract the vertical enlargement of the first bunch(es) in the train. Results from these observations will be presented.

PREVIOUS OBSERVATIONS

During the study of EC buildup in the storage ring CESR as part of the CESRTA project an unusual phenomenon has been observed. The studies utilized trains, containing 30 or 45 bunches, with the total number of positrons or electrons in the train of $3.6x10^{11}$ particles. Initially the bunches were spaced 4 or 14 ns, but in subsequent studies with positrons the spacing was varied in multiples of 4 or 14 nec to a much as a 56 ns spacing. As expected, the buildup of the EC along positron trains caused the growth of coherent oscillations and the enlargement of the vertical beam size in the later bunches in these trains. The phenomenon that was unexpected, which was observed for positrons *and not for electrons,* was the enlargement of the vertical beam size and the presence of the (m=-1) coherent head-tail mode for the *first* and possibly the second bunch of the train.

Betatron tune measurements of bunches within the train and of witness bunches placed after the train observed the a tune shift from the EC, which grew in magnitude along the train and then fell approximately 200 ns after the end of the train [1]. This tune shift indicated the average integrated number density of the EC similarly grew and then dissipated as the train passed around CESR. Retarding field analyzers (RFAs), placed in various accelerator components, indicated that there was a significant EC buildup within the aluminum vacuum chamber within the dipoles and POSINST simulations for these tune shifts predicted that the dipole magnets were the primary source of the EC buildup [1]. Since there is approximately a 2 μs gap between the last bunch in the train and its first bunch, it is difficult to argue that the dipoles or drifts, studied by RFA measurements and simulation, could be trapping the EC for this duration in CESR. RFA measurements and POSINST simulations did suggest two possibilities for accelerator elements, capable of trapping of the EC for more than 2 μsec: the quadrupole and wiggler magnets [1]. Adding to this effect was the observation that a "precursor" bunch of the same charge as the other bunches within the train and placed 162 ns before the train would completely counteract the vertical blowup of the first bunch. Summarizing: in the absence of a precursor bunch, the blowup of the first bunch of the train was observed for the 4 and 14 ns-spaced bunches in positron and not electron trains. These observations caused us to consider the source of the first bunch blowup to be a long-lived EC effect, rather than effects such as impedance/wake-fields, beam loading, or a malfunction of the bunch-by-bunch beam-stabilizing feedback systems.

EXPERIMENTAL METHODOLOGY

We report in this paper about recent measurements attempting to clarify the phenomenon of the enlargement of the vertical beam size for the first bunch within a train. Instrumentation at CESRTA allows the study of the position spectrum of individual bunches within the train by observing a single button of a BPM and gating the signal to accept only the bunch being studied [2]. This gated signal is sent to a spectrum analyzer, which averages the spectrum for approximately 10 seconds. This spectrum contains horizontal and vertical dipole (D) (m=0) betatron modes at frequencies F_h and F_v, in many cases vertical head-tail (HT) (m=±1) lines at $F_v \pm F_s$ (F_s is the synchrotron tune) and occasionally horizontal HT modes. There are two x-ray beam size monitors (xBSMs) installed for the positron and electron beams [2]. These

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detect x-rays on a linear, vertical 32 pixel arrays bunch-by-bunch and turn-by-turn, which removes dipole motion before the fitting the vertical beam size σ_V of each bunch.

The most common format for a set of measurements is as follows: For a given spacing of bunches we filled each of the 30 bunches to 0.75 mA (1.2×10^{10} particles.) We might choose to vary parameters, such as the vertical chromaticity the spacing between bunches, and/or the addition and location of precursor or trailing bunches. We topped-off the beam, took spectra for five of the bunches and in parallel acquired turn-by-turn vertical beam size data for all bunches. At this point we would top off the beam and acquire the same data for the next five bunches. The set of data for all 30 bunches constitutes a data run. After examining the data online to verify its quality, we changed the experimental conditions and began a new data run. In the past, our focus was on the growth of coherent motion and the vertical beam size for bunches in the latter part of the train; these results have been documented in other experiments [3]. With our focus on the vertical size of the first bunch, we performed a different set of measurements, where we only took BPM spectra for the first 5 bunches in the train and for a precursor or trailing bunch, if there was one. This change in procedure reduced the time for each data run substantially because the xBSM measurements are relatively fast. In addition a different set of measurements was undertaken during the CESRTA run of April 2013 when we increased the number of bunches within the train, while holding the total beam current constant.

OBSERVATIONS

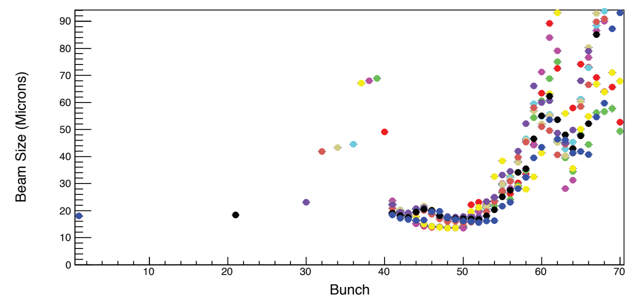
The following sections summarize the results of groups of experiments conducted over the last two years with positron trains. Unless described otherwise, the vertical and longitudinal feedback was turned off during the measurements. In all cases the coherent spectrum for a bunch having a large σ_V contained vertical HT lines.

Precursor and Trailing Bunch Studies

This set of studies explored the vertical blowup for the first bunch of the train as single bunches were placed immediately following the train (trailing bunches) or immediately in front of the train (precursor bunches.) The train employed for these measurements consisted of 30 bunches each of 1.2×10^{10} particles.

To 4 ns-spaced bunches in a train we added a single bunch of the same charge as others. When this bunch followed the train from 16 ns to 28 ns, σ_V of both the trailing bunch and first bunch of the train was large, but when it was placed 36 ns to 240 ns from the end of the train, σ_V of the trailing bunch was still large, but σ_V of the first bunch was not enlarged. The transition between these two regimes is when the trailing bunch follows the train by 32 nsec, where σ_V of the first bunch is sometimes large and sometimes not. If the trailing bunch is 24 nsec after the train and the number of particles per bunch is increased between 1.6×10^{10} to 2.4×10^{10}, σ_V of the first bunch changes from being blown up to not. If the bunch trails the train by 40 ns and the number is reduced from 8.0×10^9 to 4.0×10^9 particles, σ_V of the first bunch undergoes a transition from small to large. For these cases σ_V of the trailing bunch was large.

Studies for the placement of the trailing bunch of the 1.2×10^{10} particles after 8 ns- or 12 ns-spaced trains find that the transition between the first bunch having σ_V large or not occurs with the trailing bunch between 20 ns and 28 ns after the train. In all of these cases σ_V of the trailing bunch is larger. 8 ns-spaced trains often have more than one bunch in the front of the train with σ_V large.



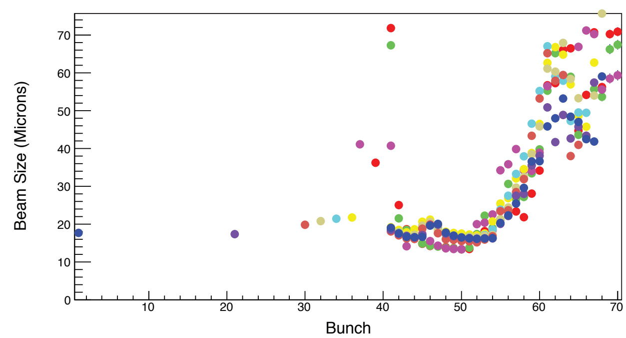


Figure 1: The vertical beam size of bunches within the train and of the precursor bunches plotted vs. their 4 ns bucket number. The train is located in buckets 41 to 70 with precursor bunches preceding the train in buckets corresponding to the following times in ns(colors are for upper plot): 4(red), 8(green), 12(pink), 16(yellow), 20(teal), 28(gray), 36(brown), 44(purple), 80(black), and 160(blue). The upper and lower plots have precursor bunches of 1.2×10^{10} and 4.0×10^9, respectively, with 1.2×10^{10} particles in bunches in train.

Next we examined bunches immediately ahead of the train with this single precursor bunch placed in locations between 4 ns and 160 ns. The number of particles in the precursor bunch at each location was studied for three intensities, 4.0×10^9, 8.0×10^9 and 1.2×10^{10}. The results for σ_V for this study are shown in Figure 1 for the highest and lowest number of particles in the precursor; not shown, the middle value of 8.0×10^9 yielded essentially the same results as for 1.2×10^{10}. In this figure the train begins at 4 ns bucket number 41 and continues through 70, and the precursor is placed in buckets from 1 to 40; the values for σ_V are overlaid in different colors depending on the location of the precursor bunch.

This set of experiments suggests several conclusions.

1) Precursor bunches having more than $8.0\text{x}10^9$ particles and placed in any preceding 4 ns bucket always reduces the blow up of σ_V of the first bunch. 2) For precursor bunches of $4.0\text{x}10^9$ particles as they are moved earlier in 4 ns steps from the front of the train, σ_V of the first bunch is reduced in magnitude monotonically over the first 16 ns. 3) The transition between these two regimes is when the trailing bunch follows the train by 32 nsec, where σ_V of the first bunch is sometimes large and sometimes not. If the trailing bunch is 24 nsec after the train and the number of particles per bunch is increased between σ_V decreases to the size of a single bunch. Conclusion 3) makes it difficult to argue that the effect we observe is caused by a remnant EC, which enlarges σ_V of the first bunch that passes through it and is dispersed by this bunch's passage.

Varying Spacing Between Bunches in the Train

Maintaining the same $1.2\text{x}10^{10}$ particles per bunch in 30 bunch trains, we varied the spacing between bunches to be 4, 8, 12, 14, 16, 20, 24, 28, 32, 42 and 56 ns. Enlargement of σ_V of the first bunch only occurs for spacings of 4, 8, 12 and under some circumstance 14 ns.

Varying Number of Bunches Within the Train

In another set of data runs we kept the total number of particles in the train constant at 30 x ($1.2\text{x}10^{10}$) and varied the number of 4 ns-spaced bunches in the train between 30 and 60. Figure 2 displays σ_V for all bunches for trains containing between 30 and 40 bunches; the large error bars are indicative of large dipole oscillations for those bunches. In these sets of data we observed that the enlargement of σ_V for the first bunch decreased monotonically with this enlargement disappearing for trains longer then 40 bunches.

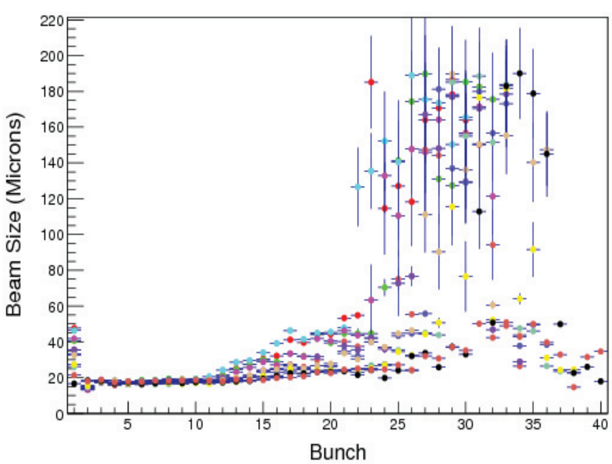


Figure 2: The vertical beam size of bunches for trains of varying lengths plotted vs. their 4 ns bucket number. The colors of the points correspond to trains of different number of bunches: 30(red), 30(teal), 32(green), 32(orange), 34(blue), 34(magenta), 36(violet), 36(tan), 38(gray), 38(yellow), 40(black) and 40(brown).

Additional Experimental Tests

We examined other potential mechanisms, which might enlarge σ_V of first bunch in 30 bunch trains of $1.2\text{x}10^{10}$ positrons having 4 ns-spacing per bunch. In the first experiment we turned on the EC solenoids wound around beam pipes for most the drift length of CESR. Other tests contained various combinations of 1) changing the vertical, longitudinal 4 ns-feedback system gains including turning them off, 2) raising the horizontal 4 ns-feedback system gain, although it was never turned off, 3) disconnecting the 14 ns modulators from the amplifier for the feedback system's stripline kickers, 4) disconnecting and terminating the drive cable to the same stripline kickers, 5) disconnecting the low level drive to the vertical shaker magnets used for tune measurements, 6) varying the vertical chromaticity and 7) a variety of combinations of the above. In all cases there was no effect on the enlargement of the first bunch in the train.

CONCLUSIONS

The set of experiments reported here were anticipated to clarify the observations of the enlargement of the lead bunch in a 30 bunch train of positrons. Since this effect is observed with two very different instruments, 1) by the presence of a coherent HT mode in the spectrum of a beam position monitor button and 2) as a blown up vertical beam size with the xBSM, we conclude there is a real dynamical effect observed for the lead bunch of the train. Based on our observations we consider it very unlikely that this phenomenon is caused by an EC. Since this effect manifests itself for positrons and not electrons, we cannot conclude this is a simple impedance/wake-field or beam-loading effect either. Since the vast majority of our measurements have studied positron trains, it is possible that this effect may be observed with electrons also, but in a difference range of parameters. That we have not studied. This may be possible if low densities of ions, the direction of passage through a structure or some equivalent mechanism modifies the dynamics for electrons. Regardless of possible mechanisms, we must conclude that further observations of electron trains under a wider range of parameters should be part of future experimental studies.

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