STATUS OF ELECTRON CLOUD DYNAMICS MEASUREMENTS AT CESRTA*

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Abstract

The study of electron cloud-related instabilities for the CESRTA project permits the observation of the interaction of the electron cloud with the stored beam under a variety of accelerator conditions. These measurements are undertaken utilizing automatic and semi-automatic techniques for three basic observations: the measurement of tune shifts of individual bunches along a train, the detection of the coherent self-excited spectrum for each bunch within a train and the pulsed excitation of either the betatron dipole or head-tail mode for each individual bunch within the train, followed by the observation of the damping of its coherent motion. These techniques are employed to study the electron cloud-related interactions in a number of conditions, such as trains of bunches with low emittance and spaced by as little as 4 ns between bunches. We report on the most recent observations and results.

INTRODUCTION

To study electron cloud (EC) effects in the presence of trains of positron or electron bunches, the Cornell electron storage ring CESR has been configured as a test accelerator CESRTA [1]. An electron cloud can focus the stored beam, so the density of the cloud along the train may be inferred from the betatron tunes of bunches. The cloud can cause unstable motion in later bunches in the train, visible in the amplitude of spectral lines at frequencies representing different modes of oscillation (e.g. dipole and head-tail) for bunches within the train. The interaction of the beam with cloud can enlarge the vertical emittance, as measured by the vertical beam size of each bunch. Instruments are in place to study these effects for the CESRTA program, including the bunch-by-bunch beam position monitor system (CBPM)[2], position detectors to measure the tunes and detect the internal modes of oscillation, vertical beam size monitors and beam kickers.

MEASUREMENT METHODS

The observations described in this paper utilize several different measurement techniques, which are described in greater detail elsewhere[3]. There are two methods for betatron tune shift observations along the train at higher bunch currents. The first method, which we call the "pinged" method, observes the tunes for all bunches by triggering a ferrite magnet with a 2.5 μs pulse and uniformly deflecting all of the bunches. The second method, called the "single bunch" method, uses a stripline kicker, driven by a swept frequency generator, to excite a single bunch within the train at the same time that the dipole transverse feedback is disabled for that bunch. The CBPM system is timed to read out a number of beam position monitors (BPMs) for a few thousand turns for all bunches. The data acquisition is synchronized with the triggering of the ferrite magnet's pulse for the pinged method, while for the single bunch method, the number of turns of data is sufficient that the bunch will be resonantly excited at least once. A single data acquisition of the CBPM system captures all of the pinged data, but separate individual acquisitions are needed as the single bunch excitation is stepped from one bunch to the next. The turn-by-turn bunch positions are analyzed offline with a model independent analysis technique[4] to combine the data from all the BPMs and then employing a Fast Fourier transform (FFT) of the temporal response vectors to yield the betatron tunes. To measure the tune shift at higher EC densities, the transverse dipole feedback is on and the chromaticities are moderately high to achieve the desired bunch currents.

The stability of the bunches within the train are studied with two very different methods. The first of these, labeled instability measurements, are performed bunch-by-bunch using a BPM detector connected to one of CESR's original relay-based BPM system processors. The signal, taken from one button that is sensitive to both horizontal(H) and vertical(V) motion, is gated to select a particular bunch within the train. The gated signal is transmitted as a video signal on a wideband coaxial cable to a spectrum analyzer in the control room. The spectrum analyzer performs a ±20 kHz FFT on frequency slices of the signal and these spectra are averaged for 10 seconds. The analyzer's center frequency is then stepped to cover the entire desired betatron frequency range and this is repeated bunch-by-bunch. During these measurements additional turn-by-turn data is taken using the bunch-by-bunch x-ray vertical beam size monitor (xBSM)[5] to detect beam size growth along the train. This method observes the displacement and size of the bunches as the

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motion becomes unstable down the length of the train. In order to enhance the effect of head-tail instabilities, the transverse dipole feedback is routinely turned off and the chromaticities are set near zero.

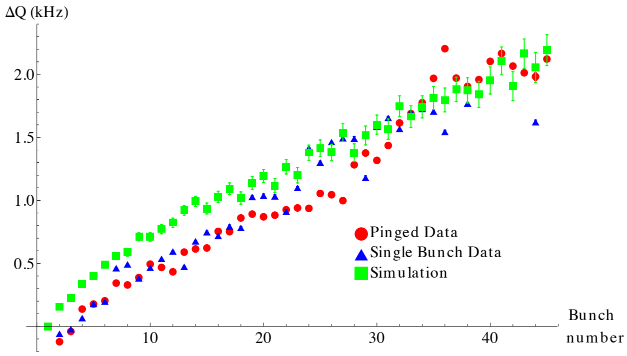

Figure 1: Vertical tune shift due to the electron cloud for all 45 positron bunches in a train at 4.0 GeV. The horizontal axis is the bunch number and the vertical axis is the tune shift with respect to the first bunch. The red dots are from pinged excitation, the blue triangles are single-bunch excitation data and the green squares are from a CESRTA electron cloud simulation[6].

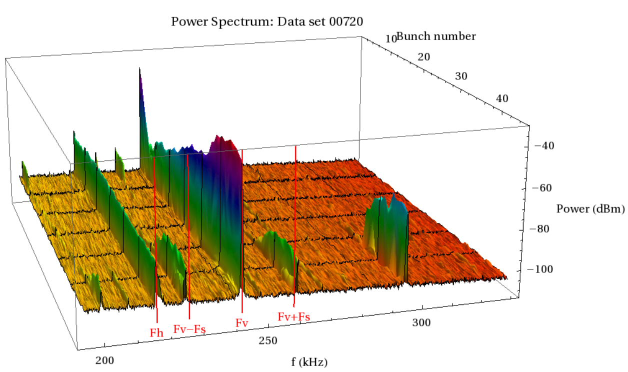

Figure 2: Self-excited beam position spectra for all 45 positron bunches in a train at 4.0 GeV. The horizontal axis is the frequency, the vertical axis is the spectral power and the third axis is the bunch number. (Bunch 45 is in the foreground.) Red lines locate the m = ±1 vertical head-tail lines, and the horizontal and vertical tunes.

The second type of stability observation, called drive-damp measurements, uses the same BPM hardware configuration as the instability measurements described above. However, in this case a single bunch within the train is excited by a vertical stripline kicker driven by a 1.5 ms-long modulated signal coming from the tracking generator output of the spectrum analyzer, while it operates as a CW tune receiver. The spectrum analyzer measures the temporal response of the amplitude of motion of the bunch following the 1.5 ms-long excitation. Similar to the instability measurements, the drive-damp measurements are undertaken at lower currents per bunch with low chromaticities and feedback switched off for the bunch being studied.

OBSERVATIONS

Data were acquired during the June 2011 CESRTA experimental run. A relatively small sample of all of the measurements taken during this run are reported below. All of results described here were using single trains with positron bunches spaced by 14 nsec.

Tune Shift Measurements

Observations of vertical tune shift were made at 4 GeV using a train of 45 bunches with1 mA per bunch. Figure 1 shows the tune shifts measured by both pinged and single-bunch-excitation methods. Notice that there is reasonably good agreement between the two methods. The plot also shows the vertical tune shift increases as the EC grows along the train in good agreement with the simulation.

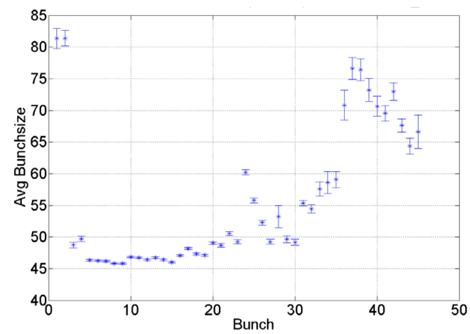

Figure 3: Vertical beam size measurements for a 45-bunch positron train at 4.0 GeV. The horizontal axis is bunch number and the vertical axis is the average vertical beam size. Large error bars indicate that the bunch shape is varying from one turn to the next.

Observation of Instabilities

Unstable motion due to EC was studied with 45 bunch trains of 0.5 mA per bunch at 4 GeV. In these conditions both transverse betatron dipole feedback systems were set to their lowest gains, the longitudinal dipole feedback system was off. Nominal chromaticities ($Q'=dQ/d\delta$, where Q and δ are the tune and fractional energy spread, respectively) are approximately 0.8(V) and 1.2(H). A surface plot of the frequency spectrum of the beam vs. the bunch number within the train is shown in Figure 2. The horizontal betatron spectral line near 220 kHz remains self-excited at the same level through the train. The amplitude of the vertical betatron line near 238 kHz is large for the first few bunches, dropping to a minimum around bunch 4 and then growing slowly until it makes a step upwards around bunch 31. The vertical head-tail lines around 222 and 254 kHz also exhibit a signal for the first two bunches and then again beginning around bunch 30. The average vertical beam size, bunch-by-bunch along the train, is shown in Figure 3. This indicates a larger vertical size for the first two bunches and then a growth at the end of the train, beginning around bunch 34. After the onset of the instability, motion becomes more complex making beam size measurements less accurate; although our focus is on bunches up to number 34. Our explanation for the increase in betatron dipole (D) and head-tail (H-T) motion and the vertical beam size around bunch 34 is due to the interaction with the growing EC along the train. Similar increases in size and motion for the first few bunches is due to a remnant EC having a long lifetime in some parts of the accelerator (e.g. quadrupoles), persisting until dislodged by lead bunches in train. This conjecture was tested by placing a precursor bunch a few hundred ns ahead of the train and observing no increase in the vertical beam size as well as no D nor H-T motion for the first bunches.

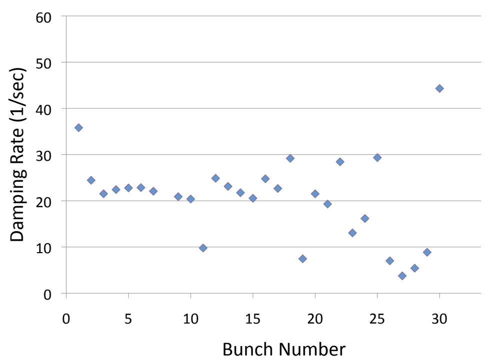

Figure 4: Damping rate of the vertical betatron dipole mode vs. the bunch number.

Drive-Damp Measurements

To study the development of the instability at 2 GeV we employed trains of 30 bunches with 0.35 mA per bunch. For these conditions chromaticities were -2.10(V) and 0.80(H). The longitudinal dipole feedback was off and the H and V dipole feedback was set to full gain, except for the bunch being measured, for which they were both off. The excitation of the vertical betatron dipole mode was described above; in order to couple to the head-tail modes with the dipole stripline kicker excitation, we also drove the beam with a large energy oscillation. The amplitudes for the D and H-T modes display exponential damping for the lead bunches in the train. Later bunches show more complicated temporal behaviors. One of the more common responses exhibited appears as the exponential decay of two modes with nearly the same frequency, i.e. a decay with interference beats. The latest bunches in the train can have temporal responses, which at first damp and then grow to amplitudes sometimes much larger than the initial amplitude. To parameterize the behavior of the earlier bunches within the train, the vertical amplitude y(t) is fit to two damped oscillators plus a noise level,

$$\text{Power in } y(t) = a_1^2 \exp(-2\alpha_1 t) + a_2^2 \exp(-2\alpha_2 t) + 2a_1 a_2 \exp\{-(\alpha_1+\alpha_2)t\}\cos\Delta\omega t + P_N$$

Figures 4 and 5 display the lower damping rate α_1 ($\alpha_1<\alpha_2$) for the D and H-T modes (upper H-T sideband) vs. bunch number for preliminary fits to the data. Both plots indicate that bunches later in the train become less stable, with bunches after bunch 20 developing a H-T instability and the damping rate for the D mode falling by bunch 25. This instability is in part evident by the decreasing damping rate. This is much clearer in the raw damping waveforms (not shown here.) After some initial damping, the H-T mode's amplitude begins to grow, delayed by 20 to 30 msec, reaching a peak around 40 to 50 msec. These results are consistent with earlier 2 GeV measurements.

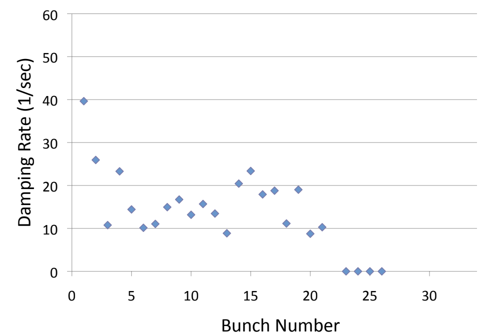

Figure 5: Damping rate of the vertical upper head-tail mode vs. the bunch number.

CONCLUSIONS

A few measurements from the CESRTA experimental run of June 2011 are presented here. Observations of the V tune shifts along the train at 4 GeV indicate that pinged and single bunch excitation data are in good agreement. At 4 GeV, instability measurements show the onset of unstable motion, occurring with an increase in D mode and H-T mode amplitudes for the bunches with approximately the same bunch number where the growth of the vertical beam size becomes evident. At 2 GeV drive-damp measurements indicate a destabilization of a head-tail mode and a reduction of the stability of the vertical dipole mode in later bunches in the train.

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