DEPENDENCE OF BEAM INSTABILITIES CAUSED BY ELECTRON CLOUDS AT CESRTA DUE TO VARIATIONS IN CHROMATICITY, BUNCH CURRENT AND TRAIN LENGTH *

M. G. Billing, G. Dugan, M. Forster, D. L. Kreinick, R. E. Meller, M. A. Palmer, G. Ramirez, M. Rendina, N. Rider, J. Sikora, K. G. Sonnad,
H. Williams, CLASSE Cornell University, Ithaca NY, USA
J. Y. Chu, CMU, Pittsburgh, Pennsylvania, USA
R. Holtzapple, M. Randazzo, CalPoly, San Luis Obispo, California, USA
J. W. Flanagan, KEK, Ibaraki, Japan

Abstract

Electron cloud-induced beam dynamics is being studied at CESRTA under various conditions. These measurements detect the coherent self-excited spectrum for each bunch within a train and bunch-by-bunch beam size. In the position spectrum coherent betatron dipole and head-tail motion is detectable for each individual bunch within the train with a sensitivity for the motion of 1.1 (2) microns-rms in the vertical (horizontal) direction for a 1 mA bunch current. 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 observations and results from studies of the instability growth vs. changes in chromaticity, the current per bunch and the length of the train.

SOME GENERAL PARAMETERS

We have developed the capability of making automated measurements of frequency spectra of individual bunches to look for signals of single-bunch instabilities. During such measurements, for each bunch in a train several frequency spectra are acquired, covering a range which spans the lowest betatron sidebands. Machine conditions, such as bunch current, magnet settings, feedback system parameters, etc. are automatically recorded and stored before and after each single-bunch spectrum is taken.

All experiments discussed in this paper were done at 2.085 GeV in a low emittance lattice. The machine parameters for these experiments are shown in Table 1. Trains having bunches ranging from 30 to 45, with a bunch spacing of 14 ns, and bunch currents in the range of $0.5-1.25$ mA ($0.8-2.0\times10^{10}$ particles) per bunch were studied. While measurements were carried out with electrons as well as positrons, this paper specifically discusses results obtained with positrons. As indicated in Ref [1], several systematic checks were undertaken to rule out distortion of the data due to instrumentation effects. The longitudinal feedback was off for these measurements. The 14ns digital vertical and horizontal feedback were turned down to 20% of full gain. Some experiments explored the effect of turning the vertical feedback entirely off.

To measure a bunch-by-bunch power spectrum, the machine is loaded with a bunch train with a uniform current per bunch, and software is run to automatically collect frequency spectra from a button BPM gated on the first bunch. The data acquisition takes about one minute, and the gate is then moved to the second bunch, and so on through the train. For bunch spacings greater than about 6 ns, the gate width is smaller than the bunch spacing, so only the motion of the gated bunch is observed. The frequency spectra are 10 s averages, acquired for 4 measurements, each with a 40 kHz span, covering the range from 170 to 330 kHz.

* Work supported by US DOE grant DE-FC02-08ER41538, NSF grant PHY-0734867 and PHY-1002467.

Table 1: Nominal Machine Parameters at 2 GeV. The Emittances and Tunes are Those of a Single Bunch in the Machine.

Parameter	Unit	Value
Energy	2.085	GeV
Lattice	2085mev_20090516	
Horizontal emittance	2.6	nm
Vertical emittance	~ 20	pm
Bunch length	10.8	mm
Horizontal tune	14.55	
Vertical tune	9.58	
Synchrotron tune	0.065	
Momentum compaction	6.8×10^{-3}	
Revolution frequency	390.13	KHz

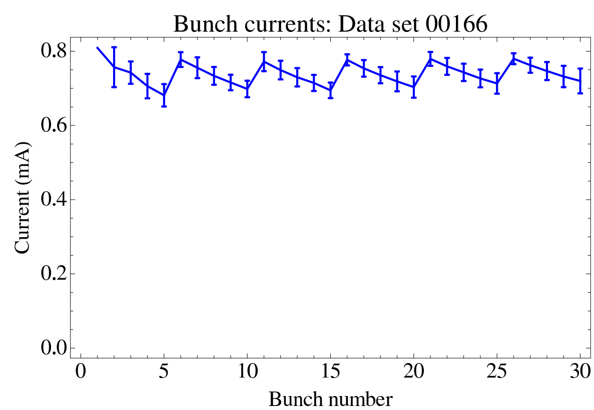

Figure 1: bunch by bunch currents at the instant of measurement of spectra.

Copyright © 2012 by IEEE – cc Creative Commons Attribution 3.0 (CC BY 3.0) — cc Creative Commons Attribution 3.0 (CC BY 3.0)

ISBN 978-3-95450-115-1

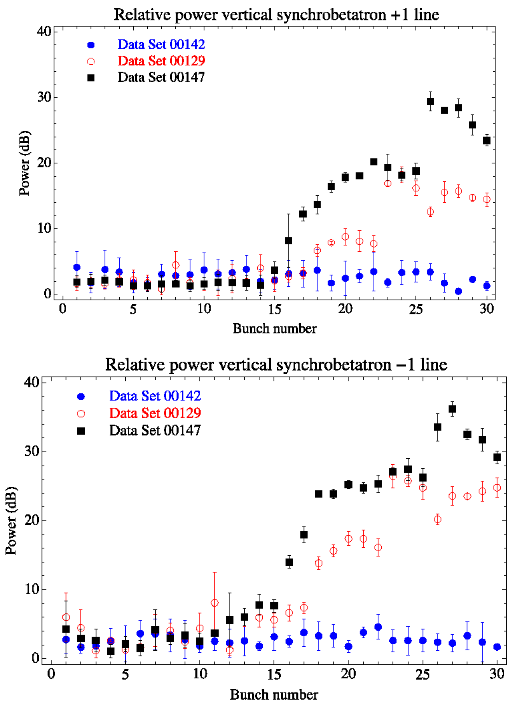

Figure 2: Data sets 142, 129 and 147: vertical head-tail lines compared. All sets have the same nominal bunch current (about 0.75 mA) but different chromaticities, as follows: 142: (H,V) = (1.34, 1.99); 129: (H,V) = (1.07, 1.78); 147: (H,V) = (1.33, 1.16) .

GENERAL OBSERVATIONS

The basic observation is that, for many of the bunches along the train and under a variety of conditions, the frequency spectra exhibit the vertical $m = \pm 1$ synchrobetatron (head-tail) lines, separated from the vertical betatron line by the synchrotron frequency. The amplitude of these lines typically (but not always) grows along the train. Under some conditions, the first bunch in the train also exhibits a synchrobetatron line ($m = -1$ only). Similar features related to head-tail lines have been obtained in from simulation of single bunch dynamics [3]. Electron induced Head-tail lines were previously observed at KEK [2].

Since the beam has a relatively short lifetime, it is necessary to periodically pause the measurements and “top off” the bunch train. Typically, this is done after data acquisition is completed for a group of 5 bunches. As a result, we see a discontinuity in the heights of the head-tails lines after every five bunches. Figure 1 shows the bunch current at the instant of measurement and the periodic decay in current along sets of 5 bunches. The plots of head-tail lines shown in the rest of this section are all relative to the the local noise floor.

Chromaticity Dependence

The chromaticity dependence of the head-tail lines is illustrated in Fig. 2. For all data sets the nominal bunch current was abut 0.74 mA. We see that for data set 142, with a higher value of the vertical chromaticity than data set 147, there are no head-tail lines observed. For data set 129, with lower values of both chromaticities than data set 142, but a higher value of the vertical chromaticity than data set 147, head- tail-lines are observed, but their onset is a few bunches later in the train. Also, the excitation levels are lower than for data set 147, which has the lowest vertical chromaticity. It may be noted chromaticity in this paper is defined as $Q' = \frac{dQ}{d\delta}$ where Q is the betatron tune and δ the relative energy offset.

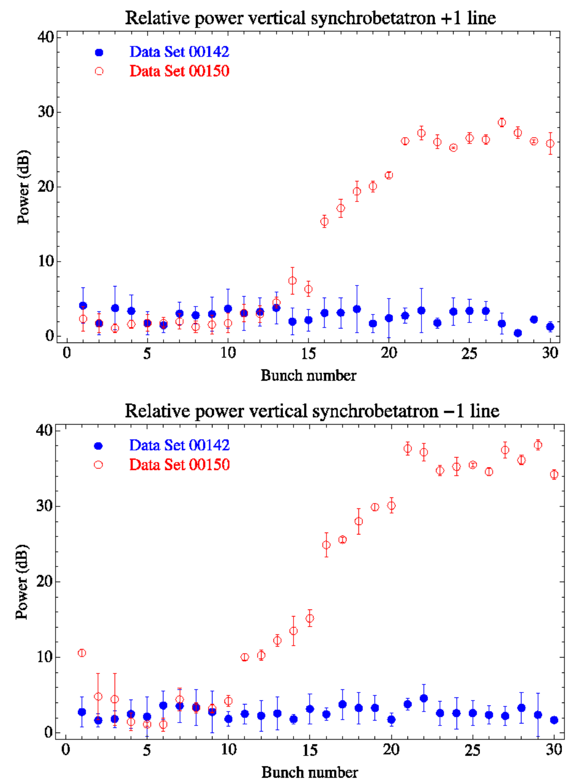

Figure 3: Data sets 142 and 150: vertical head-tail lines compared. Both sets have the same chromaticity [(H,V) = (1.34, 1.99)] but different bunch currents as follows: 142: 0.74 mA; 150: 0.95 mA.

Current Dependence

The current dependence of the head-tail lines is illustrated in Fig. 3 and Fig. 4. In Fig. 3, both data sets have the same chromaticity, but the data set with the lower bunch current (data set 142) shows no head-tail lines, while the higher current data set (data set 150) shows head-tail lines starting to emerge around bunch 12. Similarly, in Fig. 4, both data sets have the same (lower) chromaticity, but the data set with the lower bunch current (data set 178) shows no head-tail lines, while the higher current data set (data set 147) shows head-tail lines starting to emerge around bunch 13.

Copyright © 2012 by IEEE – cc Creative Commons Attribution 3.0 (CC BY 3.0) — cc Creative Commons Attribution 3.0 (CC BY 3.0)

ISBN 978-3-95450-115-1

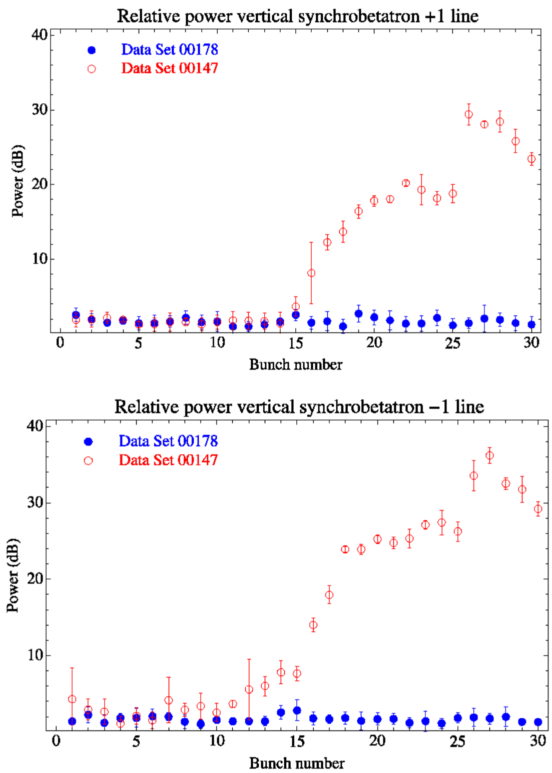

Figure 4: Data sets 147 and 178: vertical head-tail lines compared. Both sets have the same chromaticity [(H,V) = (1.33, 1.16)] but different bunch currents as follows: 147: 0.74 mA; 178: 0.5 mA.

Bunch Number Dependence

The bunch number dependence of the head-tail lines is illustrated in Fig. 5. Both data sets have the same chromaticity and bunch current, but data set 156 contains 45 bunches in the train. The vertical tunes of the first bunch were slightly different for the two runs: for run 142, it was about 227 kHz, while for run 156 the tune was about 221 kHz. No head-tail lines are observed in data set 142 out to the end of the train, bunch 30. But with 45 bunches, head-tail lines are observed starting around bunch 18, then growing to a peak around bunch 25, and falling off at the end of the train. The fact that the head-tail lines are seen with a 45 bunch train with the same bunch current as a 30 bunch train for which no lines are seen, is suggestive that there is a residual cloud density which lasts more than one turn and depends on the total current.

CONCLUSION

The onset of the head-tail lines depends strongly on the vertical chromaticity, the beam current and the number of bunches. Results clearly show that chromaticity help suppress the head-tail lines. For bunch numbers greater than about 15, where the head-tail lines appear above the background, the frequency difference between these head-tail lines and the vertical betatron line is equal to the synchrotron frequency (within the errors). The corresponding cloud densities have been calculated for using build up simulation codes, estimation of tune shifts and validating against measured tune shifts under identical conditions [4]. These studies show that the head-tail lines emerge at an initial beam-averaged cloud density around $8X10^{11}m^3$.

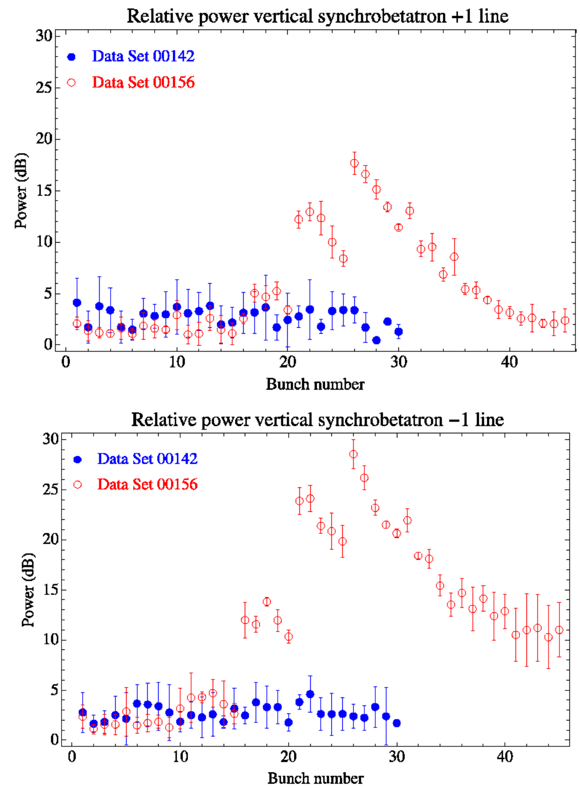

Figure 5: Data sets 142 and 156: vertical head-tail lines compared. Both sets have the same chromaticity [(H,V) = (1.34, 1.99)] and bunch current (0.74 mA), but different numbers of bunches, as shown in the figure. The increased amplitude in data set 156 at bunches 21 and 26 is an artifact due to refilling of the train at these bunch numbers.

REFERENCES

[1] M. G. Billing *et al* WEP194, Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA

[2] J. W. Flanagan, K. Ohmi, H. Fukuma, S. Hiramatsu, M. Tobiyama and E. Perevedentsev, Phys. Rev. Lett. 94, 054801 (2005)

[3] K. G. Sonnad *et al* MOPS088, Proceedings of IPAC2011, San Sebastin, Spain

[4] D.L.Kreinick *et al* WEP108 Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA

Copyright © 2012 by IEEE – cc Creative Commons Attribution 3.0 (CC BY 3.0) — cc Creative Commons Attribution 3.0 (CC BY 3.0)

ISBN 978-3-95450-115-1