HIFAN 1791

SPS ECLOUD INSTABILITIES - ANALYSIS OF MACHINE STUDIES AND IMPLICATIONS FOR ECLOUD FEEDBACK

by
J.D. Fox, A. Bullitt, T. Mastorides, G. Ndabashimiye, C. Rivetta, O. Turgut, D. Van Winkle
Stanford Linear Accelerator Center, Stanford, CA, USA
J. Byrd, M. Furman, J-L. Vay, Lawrence Berkeley Laboratory, Berkeley, CA, USA
W. Hofle, G. Rumolo, CERN, Geneva, Switzerland
R. De Maria, Brookhaven National Laboratory, Upton, NY, USA

Accelerator Fusion Research Division (AFRD)
Accelerator and Fusion Research Division
Ernest Orlando Lawrence Berkeley National Laboratory
Berkeley, California 94720

and

US LHC Accelerator Research Program (LARP)

May 2010

This work was supported by the Director, Office of Science, Office of Fusion Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231 and the work was supported by the U.S. Department of Energy under contract # DE-AC02-76F00515 and the US LHC Accelerator Research Program (LARP).

HIFAN 1791

SPS ECLOUD INSTABILITIES - ANALYSIS OF MACHINE STUDIES AND IMPLICATIONS FOR ECLOUD FEEDBACK*

J.D. Fox, A. Bullitt, T. Mastorides, G. Ndabashimiye, C. Rivetta, O. Turgut, D. Van Winkle
Stanford Linear Accelerator Center, Stanford, CA, USA
J. Byrd, M. Furman, J-L. Vay, Lawrence Berkeley Laboratory, Berkeley, CA, USA
W. Hofle, G. Rumolo, CERN, Geneva, Switzerland
R. De Maria, Brookhaven National Laboratory, Upton, NY, USA

Abstract

The SPS at high intensities exhibits transverse single-bunch instabilities with signatures consistent with an Ecloud driven instability.[1] We present recent MD data from the SPS, details of the instrument technique and spectral analysis methods which help reveal complex vertical motion that develops within a subset of the injected bunch trains. The beam motion is detected via wideband exponential taper striplines and delta-sigma hybrids. The raw sum and difference data is sampled at 50 GHz with 1.8 GHz bandwidth. Sliding window FFT techniques and RMS motion techniques show the development of large vertical tune shifts on portions of the bunch of nearly 0.025 from the base tune of 0.185. Results are presented via spectrograms and bunch slice trajectories to illustrate development of the unstable beam and time scale of development along the injected bunch train. The study shows that the growing unstable motion occupies a very broad frequency band of 1.2 GHz. These measurements are compared to numerical simulation results, and the system parameter implications for an Ecloud feedback system are outlined.

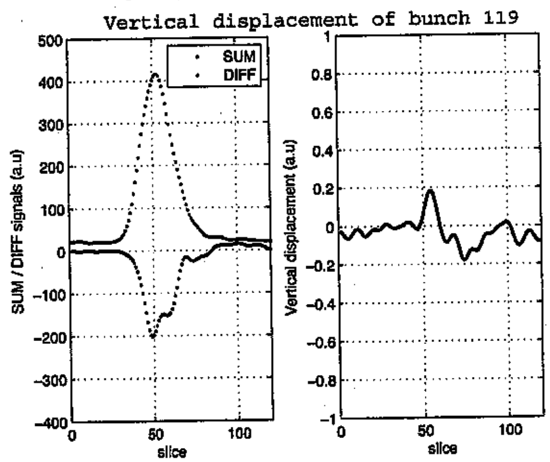

Figure 1: Sum and DeltaY signals from SPS receiver (after equalization). Bunch 119, turn 100 after injection, 26 GeV. The vertical offset is removed in the rightmost plot. Bunch 119 is becoming unstable, as seen in the high-frequency structure. Each slice (sample) is 20 ps.

EXPERIMENTAL INSTRUMENTATION AND MACHINE CONDITIONS

For these studies the SPS was run with 1E11 P/bunch, and two 72 bunch stacks were sequentially injected into the SPS. This data was taken with vacuum and scrubbing conditions such that the second 72 bunch stack would exhibit Ecloud-like instabilities roughly 100 turns after injection. This data was taken during a single MD in June, 2009 at the injection energy of 26 GeV.

These studies focussed on the second stack bunches which developed unstable vertical motion. The goal is to use this quantitative information, in conjunction with numeric simulation codes[2] [3], to estimate necessary specifications of a wideband front-end and feedback processing channel [4] intended to control both Ecloud and an anticipated single bunch TMC instability [5] [6].

This set of measurements is taken through exponentially-tapered stripline pickups [7] and a delta-sigma hybrid receiver. The receiver system uses Bessel bandpass filters in both sum and difference (delta y) paths to roll off the response above 1.8 GHz. The response of the pickups, and the dispersive effects from the long instrument cables, have been equalized via post-processing [7]. Additionally, the data from the sum and delta y channels has been post-processed to remove longitudinal motion, via a method which re-aligns the centroid of each bunch signal to a nominal time position in each turn. The analysis of the MD data is too extensive to detail in a short conference paper, only a few selected results are shown. More extensive discussion, and animated videos of the beam motion, are presented in [8] and [9].

* Work supported by the U.S. Department of Energy under contract # DE-AC02-76SF00515 and the US LHC Accelerator Research Program (LARP).

BUNCH STRUCTURE AND TUNE SHIFTS DUE TO ECLOUD EFFECTS

Figure 1 presents processed (equalized and time-aligned) receiver signals from bunch 119 on turn 100 post injection. The rightmost section shows the deviation of the vertical signal from a mean offset (the orbit offset and electronic offsets are removed, so that the deviation from the average position is shown). The signal from bunch 119 shows the beginning of a high-frequency structure.

Individual slice frequencies (tunes) are computed via an FFT of slice vs. turn vectors. Figures 2 and 3 study

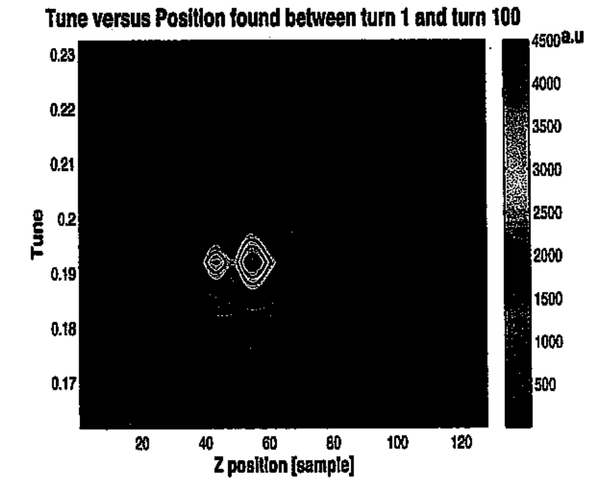

Figure 2: Tune vs. Z position, bunch 119, averaged over turns 1–100 after injection. 20 ps/sample, Positive Z is towards the tail of the bunch (later time).

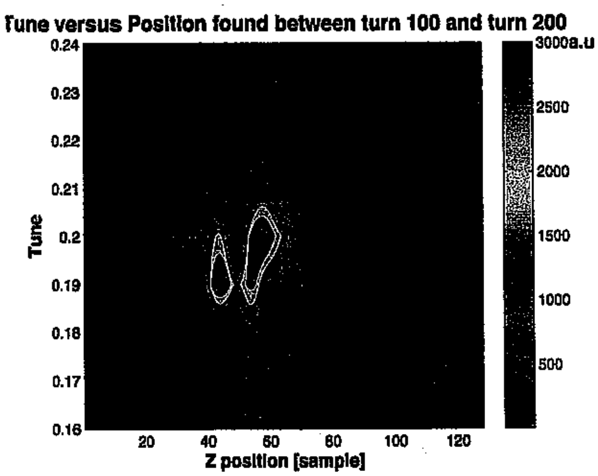

Figure 3: Tune vs. Z position, bunch 119, averaged over turns 100–200 after injection.

bunch 119 and compare the tune vs. slice position for 0–100 and 100–200 turns after injection. At injection both head and tail of the bunch oscillate at the same nominal tune near 0.19. However, by turns 200 and 300, the tail of the bunch clearly shifts in oscillation frequency in a band up to near 0.21. We attribute this tune shift to the presence of the electron cloud.

A WARP numeric simulation of this bunch (similar charge density, 26 GeV) is shown in figure 4. Processed similarly, for the turns 100–200 after injection, the simulation shows the shifted tune as two distinct frequency and time-resolved sections of the beam. In this simulation the secondary emission was set tentatively at 1.2, and bunch 36 is shown as the tune shift is similar to the measured data. A parametric study for adjusting the SEY value to match the simulation with the measured tune shift on bunch 119 will be conducted in the near future.

These figures are snapshots in time, and the trajectories of the systems are quite complicated. The MD data shows a very interesting and complex relaxation oscillation, where the bunch motion grows, exhibits large tune shifts on the tail of the beam, decoheres, then grows again in time scales of a few hundred turns. We have prepared several videos of the measured data which show this effect [9].

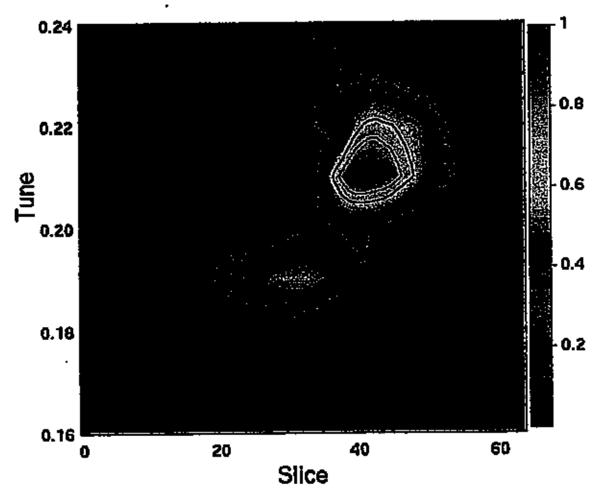

Figure 4: WARP simulation, Tune vs. Z position, averaged over turns 100–200 after injection. 94.4 ps/sample, positive Z is towards the tail of the bunch (later in time).

MODAL DECOMPOSITION AND ESTIMATES OF REQUIRED FEEDBACK BANDWIDTH

To understand the phase relationship between the oscillating slices (estimate the bandwidth required in the processing), we take the vector of transverse vertical slice offset on each turn, and calculate an FFT of each turn in secession. Figure 5 shows this spectrogram of the unstable bunch 119. In general, consistent with an earlier study[4], the unstable motion fills a band up to about 1.2 GHz. The WARP numeric simulation shows similar bandwidth of the unstable bunch motion, and also has qualitative similarity in the structure.

OBSERVATIONS

The most significant observation is the clear development of a tune shift on the tail portion of the bunch as the unstable motion develops. This is significant in the design of the feedback controller, as it must have adequate damping for both the nominal and the shifted tunes.The second observation is that the unstable motion clearly occupies at least 1 GHz of frequency bandwidth. Many more studies are needed to quantify the system at higher energies and validate a theoretical prediction that the Ecloud threshold should decrease with energy, as well as cause excitation of

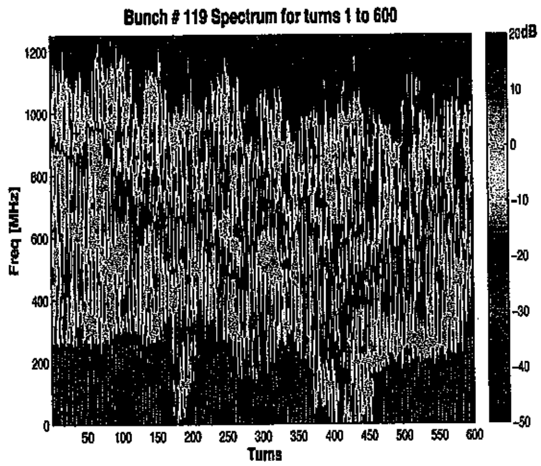

Figure 5: Spectrogram of bunch 119 vertical signal for the transients in Figures 1–3. The unstable bunch shows frequency content up to roughly 1.2 GHz, with most power in the band up to 600 MHz. The complex time structure is related to the 100–200 turn relaxation oscillation.

the bunch structure at higher modal frequencies [10]. Another concern is seen in the video1 transient [9], in which the horizontal tune is seen in the vertical receiver channel as a result of the horizontal SPS injection. The time scales of injection transient and the growth of the vertical Ecloud instability are comparable. Unless the receiver has adequate rejection of the horizontal motion, and the feedback channel has enough frequency selectivity to isolate the horizontal and vertical tune signals, it is likely the power amplifier stage will be saturated by the horizontal injection transient, blinding the system to growing vertical Ecloud motion.

We are encouraged by the agreement between the simulation models and the MD data, and this has led to simulation efforts adding an idealized feedback model to the numeric simulation [11] [12]. We also have begun to use these methods to estimate the control of the TMC instability. We continue to develop linear models from the MD and numeric simulations for use in developing feedback controllers, particularly in the estimation of the limits of the controller and the extraction of growth rates and oscillation frequencies. A very interesting, and unresolved question is the necessary bandwidth in the feedback channel to control this effect (e.g. would a channel with 500 MHz bandwidth be useful, or is a full 1 or 1.5 GHz control bandwidth needed over the full range of energy and current?)

SUMMARY

Much additional analysis and system modeling work is yet to be completed. We anticipate more MD efforts understanding the dynamics at higher energies. We continue a hardware effort to build up a 4 GS/sec. back end modulator and power stage to allow measurement of beam transfer functions from time-domain excitations. A vital effort is also in process to understand what useful kicker options can be implemented for transverse bandwidths up to 1 GHz in our beam testing. This technique would be a very useful diagnostic, as it could be made for stable beam below the instability threshold, where the presence of an electron cloud would be seen in the tune shift and damping. These measurements also help validate the numeric simulation codes across a wide range of energy and electron cloud parameters.

ACKNOWLEDGEMENTS

The authors would like to thank the CERN operations teams for providing and setting-up the beams necessary for this study and Urs Wehrle for his help with the experimental set-up indispensible for these studies. We thank the SLAC ARD, CERN AB RF departments and the US LHC Accelerator Research program (LARP) for support.

REFERENCES

[1] G. Rumolo *et al.*, "Experimental Study of the Electron Cloud Instability in the CERN-SPS," EPAC 08, Genoa, Italy, pp TUPP065 June 2008

[2] G. Arduini *et al.* 31st Advanced ICFA Beam Dynamics Workshop, Napa, CA, USA, CERN-2005-001,

[3] Jean-Luc Vay *et al.*, "Update on Electron-Cloud Simulations Using the Package WARP-POSINST," PAC09 FR5RFP078

[4] J.D.Fox *et al.*, "Feedback Techniques and Ecloud Instabilities—Design Estimates," SLAC-PUB-13634; Presented at Particle Accelerator Conference (PAC 09), Vancouver, BC, Canada, 4–8 May 2009

[5] B. Salvant *et al.*, Proceedings Beam07, p. 113–118, CERN-2008-005, and B. Salvant *et al.* EPAC 08, Genoa, p. 1694–1697

[6] E. Shaposhnikova, "Intensity upgrade plans for CERN-LHC INJECTORS", 42nd ICFA Advanced Beam Dynamics Workshop Nashville, Tenn., USA, 2008, CERN-AB-2008-065

[7] Riccardo De Maria *et al.*,"Performance of Exponential Coupler in the SPS with LHC Type Beam for Transverse Broadband Instability Analysis". 2009 DIPAC MOPD17

[8] J.D. Fox, "Feedback Control of Ecloud Instabilities", LARP CM13 meeting, http://larpdocs.fnal.gov/LARP-public/DocDB/DisplayMeeting?conferenceid=69

[9] `http://www.slac.stanford.edu/~dandvan/e-clouds/aug_09` and in alternate format at `http://www.slac.stanford.edu/~rivetta/e-clouds/movies_Aug09`

[10] G. Rumolo *et al.*, "Dependence of the electron-cloud instability on the beam energy," Phys. Rev. Lett. f 100, 144801 (2008).

[11] J.R.Thompson, J.M.Byrd, W.Hofle and G.Rumolo, "HEADTAIL feedback module: Implementation and results," CERN-AB-2008-070

[12] Jean-Luc Vay *et al.*, "Simulation of E-Cloud Driven Instability and its Attenuation using a Simulated Feedback System in the CERN SPS", IPAC10 WEOBRA02