Simulation and observation of driven beam oscillations with space charge in the CERN PSB

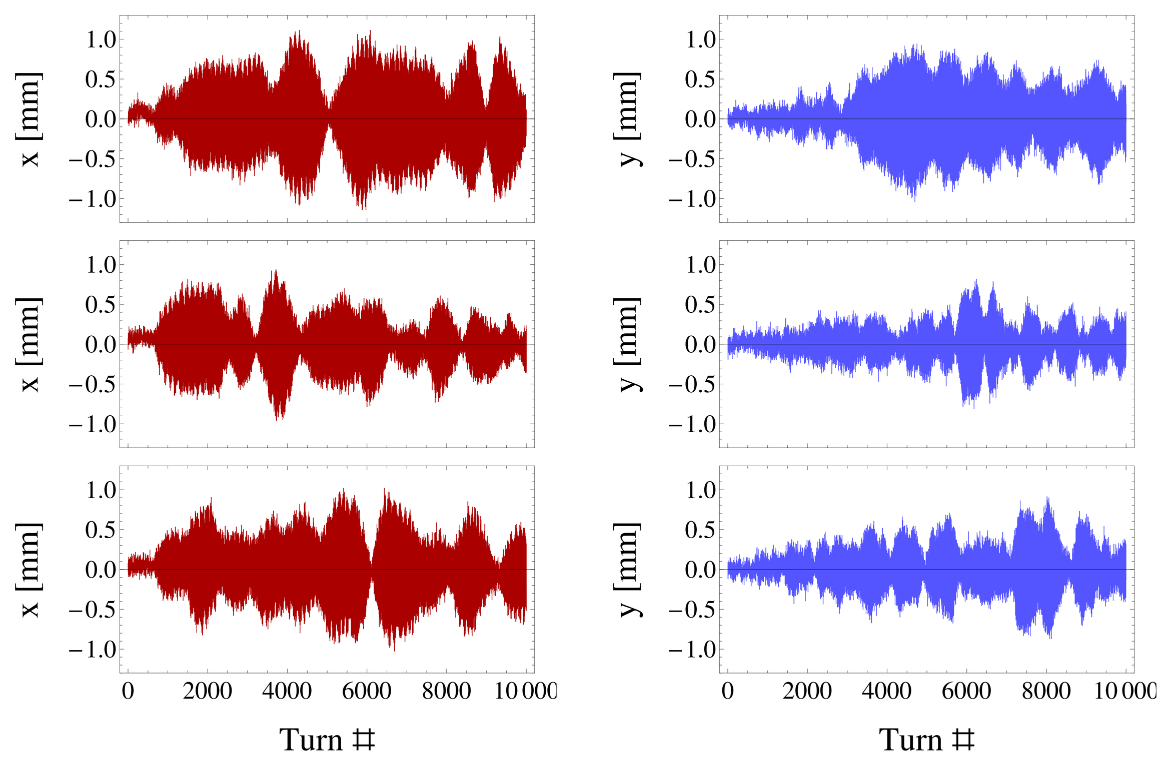
M. McAteer, J. Belleman, E. Benedetto, C. Carli, A. Findlay, B. Mikulec, R. Tomás
CERN, Geneva, Switzerland

1. Introduction

Before the first Long Shutdown (LS1) trial measurements were done in preparation for nonlinear optics measurements, using high-intensity beam and a prototype systems for both trajectory measurement and for beam excitation. The coherent betatron oscillations produced by AC dipole excitation were too small and irregular to allow for precise determination of the higher-order frequency components of the beam motion. In order to understand and correct the cause of this poor beam response, we examine the effects of space charge (SC) forces and tune ripple on driven beam oscillations.
Due to a hardware limitation, we expect that trajectory measurements will initially have to be made with high beam intensity in order to have good position resolution. The PTC-Orbit simulations will also be useful for understanding any effects of space charge on higher-order frequency components of the beam spectrum for nonlinear optics calculations.

2. Trajectory measurements

- Beam response to AC dipole was irregular and much too small for precise measurement of higher-order frequency components
- Possible causes investigated: insufficient kick strength, space charge effects, effects of tune ripple
- Kick strength $\approx 1\mu rad$ [1], $\beta_x = 5.7m$ and $\beta_y = 4.1m$ at AC dipole

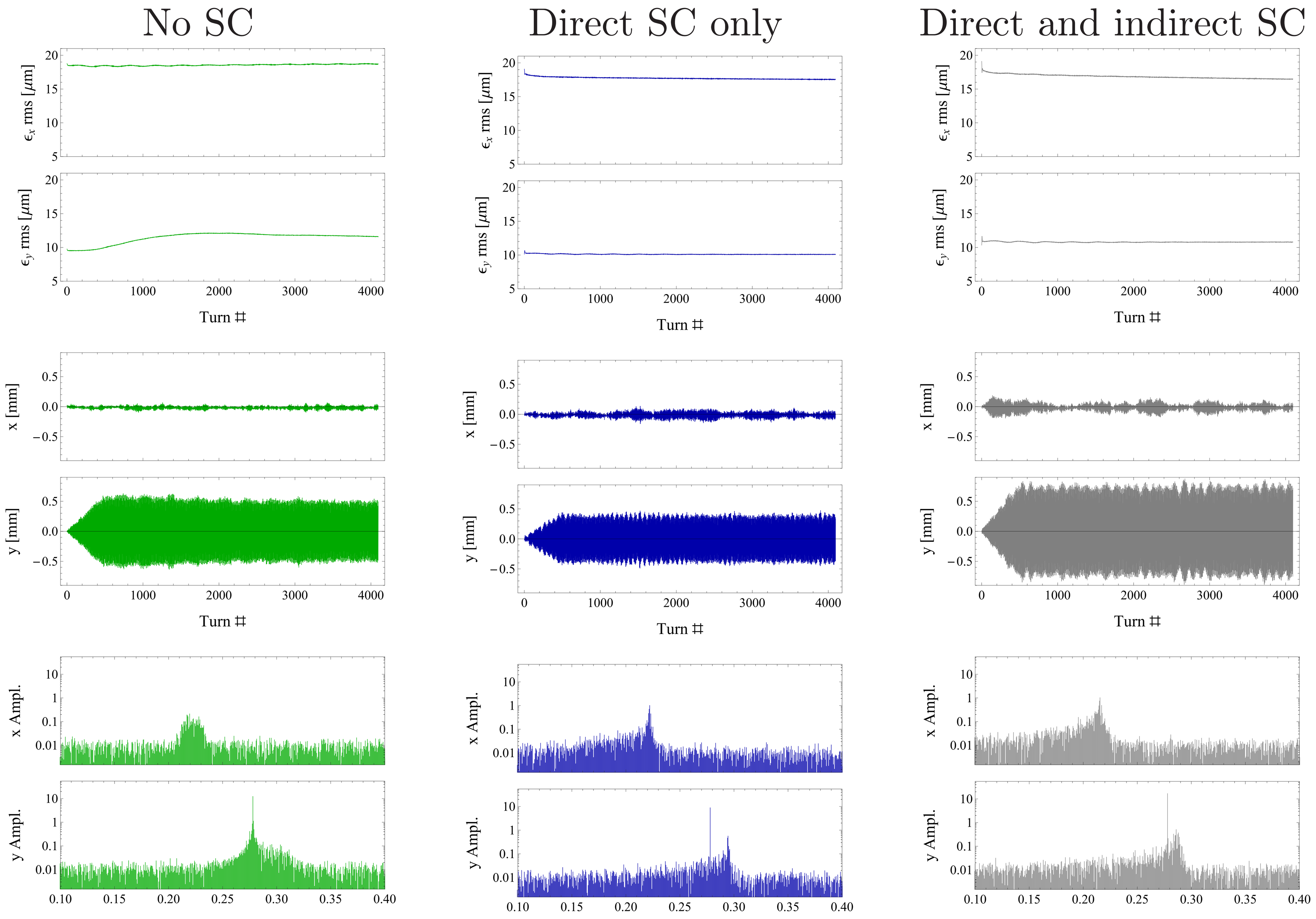


Measured trajectories while driving with AC dipole in both planes, for three beam pulses.

3. PTC-Orbit simulations with AC dipole

- Tracking simulations were done to determine the effects of strong SC on beam response to AC dipole [2, 3]
- SC effects reduced oscillation amplitude by $\sim 25\%$ and also reduced emittance growth caused by chromatic tune spread
- With SC, natural tune remains visible in spectrum

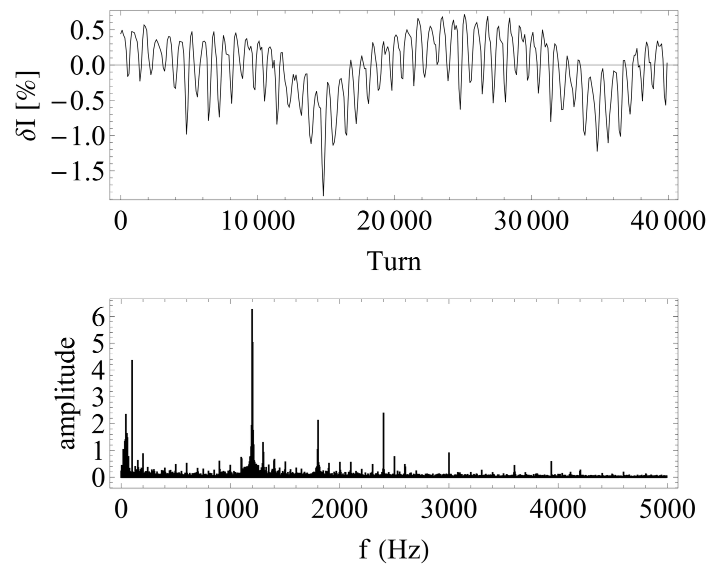
No SC | Direct SC only | Direct and indirect SC



RMS emittance evolution , beam trajectories, and beam trajectory spectra from PTC-Orbit simulations with AC dipole excitation in vertical plane only. Three cases are shown: without SC effects, with direct SC only, and with both direct and indirect SC.

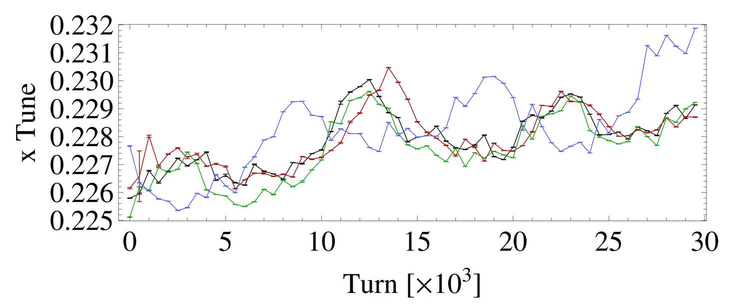
4. Effects of tune ripple

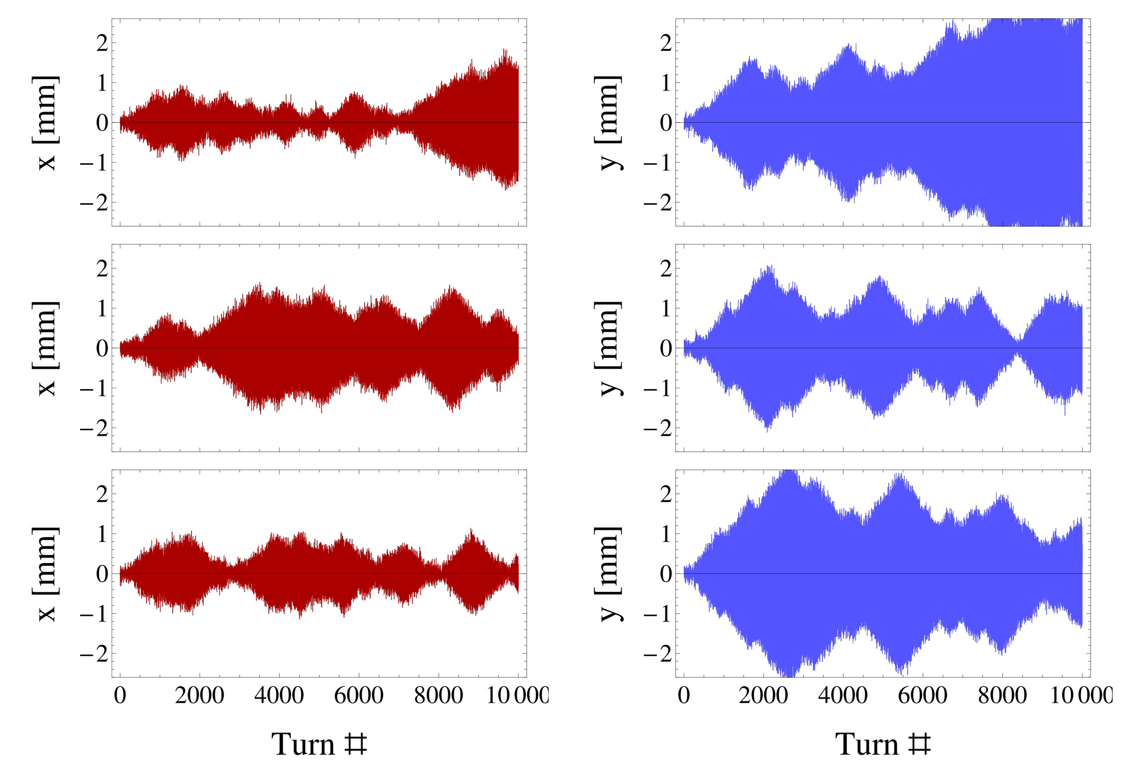
- Power supply for focusing quadrupoles (all powered in series) was found to have $\sim 1.5\%$ fluctuation, corresponding to $\sim 0.005\%$ tune ripple with period of a few hundred turns
- Given small kick amplitude, we expect to need $q_{AC} \approx 0.001$ for significant beam response, so tune ripple can prevent oscillation amplitude growth



Variation in measured focusing quadrupole magnet current (top) and frequency spectrum of current (bottom).

Measured tune ripple on five pulses, calculated in 500-turn increments.





Simple tracking simulation including measured quad ripple, showing small and irregular beam response.

5. Conclusions

Simulations with PTC-orbit show that space charge reduces the amplitude of the response by about 25%, but otherwise does not alter the typical beam envelope response. The SC incoherent tune spread suppresses the emittance growth that would otherwise be caused by the chromatic tune spread, which may be beneficial given that chromaticity cannot be corrected in both planes simultaneously in the PSB. The natural coherent tune is visible in the frequency spectrum of the driven beam along with the driving tune in these simulations, and further studies is needed to understand all effects of SC on higher-order resonance lines.
The betatron tune ripple has a larger impact on beam response to the AC dipole. The driving kick used during these tests was only about 1 μrad, and it would require a small AC dipole tune difference $\delta q_{AC} \approx 0.001$ to produce a significant beam amplitude response with that small angular kick. The tune ripple is about 0.005 with a period of a few hundred turns, preventing development of large beam oscillations. The power supply ripple and faulty amplifiers in the damper kickers were repaired during LS1 so we expect to have larger beam response in future measurements, allowing for a precise determination of higher-order frequency components in the beam spectra.

References

[1] C. Carter et al., "The Transverse Feedback System for the CERN PS Booster" Particle Accelerator Conference 1981, Washington.
[2] A.Shishlo, J.Holmes, E. Forest, A.Molodozhentsev. Synopsis of the PTC and ORBIT integration. KEK Internal Report (A), 2007-4, Nov. 2007.
[3] V. Forte et al., "Investigations on CERN PSB Beam Dynamics with Strong Direct Space Charge Effects Using the PTC-ORBIT Code" WEPEA052, IPAC'13, Shanghai, China.

Acknowledgments

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289485.