Incoherent Vertical Emittance Growth from Electron Cloud at CesRTA

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• An increase in vertical beam size due to electron cloud has been seen in many e+ rings:
  – PEPII, KEKB, DAPHNE, CESR
• Electron cloud (EC) can be a limiting factor and has been studied at CESRTA (the Cornell Electron-Positron Storage Ring Test Accelerator) since 2008
  – Including efforts to inform ILC damping ring design
• Emittance growth from EC not well understood

⇒ We have developed an incoherent model which predicts emittance growth from electron cloud
• This talk will compare simulations to data for tune shifts and equilibrium beam size
• Buildup of electrons hitting the vacuum chamber wall and generating secondary electrons
• Main source: photoelectrons from synchrotron radiation
  – Also beam-gas ionization or stray protons hitting the wall
• Bunches accelerate the electrons as they pass
• Positron bunches pull the cloud towards it (“pinch effect”)
• EC builds up along a train of bunches
• Beam:
  – 2.1 GeV positrons or electrons
    ★ Horizontal emittance: 3.2 nm, fractional energy spread: $8 \times 10^{-4}$, bunch length: 9 mm
  – 30 bunch train, 0.4 mA/b and 0.7 mA/b, 14 ns spacing
    ★ (0.64$ \times 10^{10}$ and 1.12$ \times 10^{10}$ bunch populations)
  – 1 witness bunch, 0.25 to 1.0 mA, bunch positions 31 to 60
    ★ Witness bunch position probes cloud as it decays
    ★ Witness bunch current controls strength of pinch effect

• Measure:
  – Betatron tunes: from FFTs of bunch centroids from multiple BPMs
    ★ Bunch-by-bunch, turn-by-turn
  – Vertical bunch size: from X-ray beam size monitor
    ★ Bunch-by-bunch, turn-by-turn
  – Horizontal bunch size: from visible light gated camera
    ★ Bunch-by-bunch, single-shot

• Bunch-by-bunch feedback on to minimize centroid motion
  – Disabled for a single bunch when measuring its tune
• Start with EC buildup simulations with ECLOUD in both dipole and field-free regions
• Use element-type ring-averaged beam sizes
  – Dipole: 730 x 20 um
  – Drift: 830 x 20 um
    ★ The large horizontal size is dominated by dispersion
• Obtain electric field maps from the EC for 11 time slices during a single bunch passage, in ±5σ of the transverse beam size
  – Δt = 20 ps
• Only ~0.1% of electrons are within this beam region
  – Necessary to average over many ECLOUD simulations
• Use the time-sliced electric fields in EC elements at the dipole and drifts
• Track particles in bunch through the full lattice (using Bmad) for multiple damping times, with radiation excitation and damping
• This model does not take into account effects on the cloud due to changes in the beam ("weak-strong" model)
  – **Weak**: positron beam; **Strong**: electron cloud
  – Justification: EC simulations are rather insensitive to vertical beam size
• Strong-strong simulations are too computationally intensive to track for enough turns
  – Damping times at CesrTA are ~20,000 turns
• Feedback is disabled for a single bunch when measuring its betatron tunes
• Don’t use external source to enhance oscillation which can cause the bunch to explore different regions of the cloud
• Rely on the self-excitation of the bunch centroid
  – Avg. RMS motion in the BPMs:
    ★ x: ~40 um
    ★ y: ~20 um
• Tunes from simulation calculated from 1-turn transfer matrix or FFTs (good agreement)
• Dipoles (62% of ring) dominate the horizontal tune shift compared to drifts (23%) which contribute to vertical tune shift

(Revolution frequency: 390 kHz)
- No bunch size growth seen for electron beam
- Growth for 0.7 mA/b positron beam, but not at 0.4 mA/b
  - 0.4 mA/b is just under the threshold for vertical bunch size growth
- Bunch sizes from simulation averaged over last 10k turns (of 60k)
- See growth in 0.7 mA/b simulations though there are discrepancies
  - Under investigation
• More emittance growth with:
  – shorter distances from train (more cloud)
  – higher bunch current (more pinch)
• Simulations show similar behavior
We have measured tune shifts and bunch sizes along 0.7 and 0.4 mA/b trains of positrons and electrons with witness bunches at various currents and distances from the train.

Tune shifts and bunch size growth were seen in the 0.7 mA/b positron trains but not in trains of electrons.

Our weak-strong incoherent model predicts:
- tune shifts in good agreement to data
- emittance growth which scales with cloud density and witness bunch current (as seen in data)

Future work:
- Reconcile data/simulation discrepancies
- Revisit emittance growth predictions in ILC damping ring
- Use model to understand underlying factors driving emittance growth
  - Develop new approaches to mitigating emittance growth from EC