Electron-cloud instability in the CLIC damping ring for positrons

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Introduction

- Electron cloud can lead to coherent beam instability (see talk of G. Rumolo)
  - Coupled bunch instability $\rightarrow$ feedback
  - Single bunch instability $\rightarrow$ emittance growth faster than radiation damping, feedback difficult due to bandwidth (see talk of K. Li)

- Single bunch electron cloud instability depends on
  - electron density
  - optics (beta functions)
  - synchrotron tune
  - chromaticity
  - transverse emittance
  - bunch length

- Here: study of single bunch instability for superconducting wigglers

… needs to be studied in detail
CLIC damping rings

See talk of F. Antoniou

C = 427.5 m, \( L_{\text{wigglers}} = 104 \text{ m} \)

Wigglers occupy \( \frac{1}{4} \) of the total ring...

\[
Q_x = 48.38 \\
Q_y = 10.39
\]

2 options: 0.5 ns or 1 ns bunch spacing

<table>
<thead>
<tr>
<th>Description</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>( E_0 ) [GeV]</td>
<td>2.86</td>
</tr>
<tr>
<td>Normalized transverse equilibrium emittances</td>
<td>( \varepsilon_{n,x,y} ) [nm]</td>
<td>500, 5</td>
</tr>
<tr>
<td>Average beta and dispersion functions (Wigglers)</td>
<td>( b_{x,y}, D_x ) [m]</td>
<td>4.2, 9.8, 2.6 \times 10^{-5}</td>
</tr>
<tr>
<td>Bunch length (rms)</td>
<td>( \sigma_z ) [mm]</td>
<td>1.6</td>
</tr>
<tr>
<td>Synchrotron tune</td>
<td>( Q_s )</td>
<td>6.5 \times 10^{-3}</td>
</tr>
</tbody>
</table>
Electron cloud simulations

Multi-bunch beam

E-cloud build up

Primary and secondary electron production, chamber properties

Equations of motion of the beam particles

Noise
Electron cloud simulations: splitting the problem

The build up problem

The instability problem

Multi-bunch beam
One turn

Primary and secondary electron production, chamber properties

used here: HEADTAIL code

Equations of motion of the beam particles

Single bunch
Several turns

Noise

E-cloud build up

x

y

Equations of motion of the beam particles

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The HEADTAIL code: simulation principle
The HEADTAIL code: simulation principle
The effect of the electron cloud on the beam becomes visible only after many turns.

The electron cloud is refreshed at every interaction point.

Slicing is renewed at every turn.
Instability threshold for e-cloud in wigglers

- Simulations with uniform electron density
- Electrons in magnetic dipole field (no horizontal motion in HEADTAIL)
  - No (single bunch) instability in horizontal plane
Instability threshold for e-cloud in wigglers

- Simulations with uniform electron density
- Electrons in magnetic dipole field (→ no horizontal motion in HEADTAIL)
  - No (single bunch) instability in horizontal plane
  - Strong growth of vertical emittance ($\varepsilon_{n,y}$) above threshold

- Fast growth compared to vertical damping time (2 ms)
- Local electron densities of $1.2 \times 10^{13}$ m$^{-3}$ in wigglers (25% of circumference) drive beam unstable
Dependence on bunch intensity

- Simulations with uniform electron distributions
- Weak dependence of instability threshold on bunch intensity
  - Studied in view of future optimization of CLIC parameters

![Threshold electron density in wigglers](image)

- Similar threshold electron density for the studied range of positron bunch intensities …

Nominal CLIC intensity
Using electron distributions from PyECLOUD

- PyECLOUD simulation for generation of macroparticle distribution
  - 1 ns bunch spacing

=max. central density

\[ \text{SEY} = 1.5 \]

See talk of G. Iadarola

⇒ Using distribution (just before bunch passage) with maximum central density = most critical for instability
Using electron distributions from PyECLoud

- PyECLoud simulation for generation of macroparticle distribution
  - 1 ns bunch spacing
  - Generation of uniform spatial distribution with variable charges/weights

Histogram

SEY = 1.5 (bunch 350)

Electron distribution

beam (±3σ)

Number of electrons / macroparticle

CERN

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Using electron distributions from PyECloud

- PyECloud simulation for generation of macroparticle distribution
  - 1 ns bunch spacing
  - Generation of uniform spatial distribution with variable charges/weights

- HEADTAIL simulations with distributions from PyECloud
  - Bunch passages with maximum central density along the train

⇒ Beam unstable as soon as electron build-up saturated
Mitigation with chromaticity?

- Increasing vertical chromaticity is one of the measures against e-cloud instability

- Simulation for uniform e-cloud distribution
  - \( \rho_e = 4 \times 10^{13} / \text{m}^3 \) (equivalent to \( \rho_e = 1.6 \times 10^{14} / \text{m}^3 \) in the wigglers)

\[ \Rightarrow \] Even very high chromaticity not sufficient for beam stability (+ incoherent effects)
Summary and conclusions

- Electron cloud instability simulations with HEADTAIL
  - Decoupled from build-up simulations (computing power)
  - Semi-self consistent by using electron distribution from build-up code
  - Only single bunch instability

- Simulations for wigglers with uniform $e^-$ distribution
  - Threshold density in wigglers $\approx 1.2 \times 10^{13} / m^3$
  - Emittance growth rate fast compared to damping times
  - Little dependence on bunch intensity
  - Mitigation by chromaticity not sufficient

- Simulations for wigglers using distribution from PyECLOUD
  - Beam is unstable for all SEY values above build-up threshold (i.e. SEY > 1.4)
  - Need to suppress e-cloud build-up!