Collective Effects in MAX IV

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Outline

- Impedance measurements in MAX IV 3 GeV ring
  - Bunch lengthening
  - Detuning with bunch current
  - Transverse mode-coupling instability
  - Effect of amplitude dependent tune shift
- Evaluation of beam transients
  - Matrix method
MAX IV Laboratory

- Light source facility, currently under commissioning in Lund, Sweden [1]
- 3 GeV ring based on multibend achromat lattice

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Horizontal emittance (pm)</td>
<td>300 (200 with IDs)</td>
</tr>
<tr>
<td>Design current (mA)</td>
<td>500</td>
</tr>
<tr>
<td>Vacuum chamber radius (mm)</td>
<td>11</td>
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<tr>
<td>Natural bunch length (ps)</td>
<td>40</td>
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Bunch Lengthening

- Bunch lengthening measured as a function of current using sampling oscilloscope
- Zotter curve fitted to results
- Effective normalised impedance:
  \[
  \left( \frac{Z}{n} \right)_{\text{eff}} = 0.98 \, \Omega
  \]
- 0.1 \, \Omega predicted
- Have to measure IBS

Single-bunch detuning

- Linear fit of tune shift against current divided by bunch length
- Fit to experimental data much better
- Measured effective impedance larger:
  \[ Z_{eff}^{\perp} = 470 \pm 2 \text{ k}\Omega \text{ m}^{-1} \]
- 150 k\Omega m\textsuperscript{-1} predicted

Transverse sawtooth instability

- Low chromaticity
- Threshold current around merging of mode frequencies
- Threshold dependent on synchrotron tune
- Easily controlled using bunch-by-bunch feedback
Amplitude-dependent tune shift

- ADTS suggested as a reason for weakness of instability
- Besnier dispersion integral
- Growth time dependent of tune spread within bunch
- Growth time falls of faster with negative ADTS

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Amplitude-dependent tune shift

● Negative ADTS acts against detuning due to current
Amplitude-dependent tune shift

- Results reproduced in macroparticle tracking (mbtrack)

- Saturation emittance inversely proportional to tune-shift

- Smaller saturation emittance with negative tune shift
Amplitude-dependent tune shift

- Introduction of radiation damping leads to sawtooth instability in simulation
- Beam size reduction according to radiation damping time
- Decoherence of bunch centroid motion much faster
Beam transients

- Plans to have different timing modes in the 1.5 GeV ring under evaluation (T. Olsson)

- Considerations regarding transients:
  - Double RF system
  - Bunch-by-bunch feedback
  - Collective effects

Matrix method

- Determine time offsets for which energy gain per turn is zero for all bunches
- First order Taylor expansion:

\[
\begin{bmatrix}
V'_w(\tau) - V'_rf(\tau)
\end{bmatrix} \delta \tau = V_{rf}(\tau) - U_0 - V_w(\tau)
\]

- Both $V_w$ and $V'_w$ are evaluated to infinite turns analytically using phasor representation
- Invert matrix to find correction to time offset $\delta \tau$
- Recalculate potentials for new transients and form factors

- Beam-loading potential
- RF potential (diagonal)
- Energy lost to radiation
Results

- MAX IV 3 GeV Ring
- 500 mA beam current, 3/4 fill
- Ideal main cavity
- Passive harmonic cavity providing flat potential with uniform fill

Single-particle tracking

Matrix method
Bunch length

- Calculate synchrotron tune from total voltage gradient seen by the bunch
- Effective for small transients but for large ones, should calculate more accurate form factor from full potential
Conclusion

- Impedance of the MAX IV 3 GeV ring has been measured
- Larger than predicted geometric impedance should not have an adverse effect on operation
- HOMs in main and Landau cavities biggest challenge in terms of collective effects (see Pedro’s talk)
- Matrix method to evaluate transients due to beam-loading
- To be compared with single-particle tracking, macro-particle tracking, experiment (T. Olsson)