Studies of collective effects in the MAX IV 3 GeV ring

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Outline

● Introduction to MAX IV 3 GeV ring
● MAX IV project status
● Scope of the project
● Latest results of studies
  ➢ transverse single bunch
  ➢ transverse multi bunch
  ➢ resistive wall of low-gap ID chambers

● Thresholds overview

● Harmonic cavity and head-tail damping preliminary studies

● Outlook
MAX IV 3 GeV storage ring

| Energy | E₀ | 3.0 GeV |
| Current | I | 500 mA |
| Circumference | L | 528.0 m |
| Harmonic number | h | 176 |
| RMS bunch length w/o HC | σₜ | 40 ps |
| RMS bunch length at 500 mA | σₜ | 195 ps |
| Peak rf-voltage w/o IDs | Vₘ | 1.02 MV |
| rf-frequency | fₘ | 99.931 MHz |
| Energy loss per turn w/o IDs | Uₗ | 360 keV |
| Higher harmonic of HC | n | 3 |
| Quality factor of HC | Qₘ | 21600 |
| HC detuning | Δf | 48.1227 kHz |
| Total shunt impedance HC | Rₛ | 2.36441 MΩ |

- Multibend achromat lattice
- Ultra-low hor. emittance: 0.2 - 0.4 nm rad
- Round beam pipe, small radius: 11 mm
- High beam intensity: 500 mA
- Passive harmonic cavities:
  - relax the Touschek life-time and intra-beam scattering
  - fight collective beam instabilities
MAX IV project status

- Beam commissioning with the thermionic gun has started:
  - transport through first three linac sections up to first bunch compressor
  - energy 280 MeV

- Delivery of main components of the storage ring is on track

- 3 GeV ring:
  - ongoing installation of concrete girders, cabling and cooling infrastructure
  - Installation of magnets/chambers planned in October 2014

- Commissioning is planned on July/August 2015
Scope of studies

● Building the machine impedance model
  ➢ numerical calculations using GdfidL

● Determination of single- and multi-bunch instability thresholds given the impact of
  ➢ geometric impedance
  ➢ resistive wall impedance
  ➢ passive HC

● The effect of low gap insertion device (ID) chambers on the thresholds considering
  ➢ resistive wall impedance
  ➢ geometric impedance

● Study of harmonic cavity impact on the internal bunch motion
Particle tracking: *mbtrack*

6D macro-particle tracking code:

- Internal motion and micro-structures
- Quantum excitation and radiation damping
- Arbitrary filling pattern

Single-(Intra-) bunch effects:
- geometric ring impedance
- resistive wall impedance
- HC(passive or ideal potential)

Multi-(Inter-) bunch effects:
- resistive wall impedance(RW)
- HC(passive or ideal potential)
Transverse single-bunch

HC has no effect at zero chromaticity

- Instabilities are damped by bunch lengthening and tune spread
  - Lengthening from longitudinal impedance improves the situation
  - HC enhances the effect

- Same trend in horizontal plane but more relaxed

single bunch current: 2.84 mA @500mA current
Multi-bunch: resistive wall

For RW *mbtrack* uses the eff. radius $b_{\text{eff}}$

- With passive HC the threshold is at $\sim 40$ mA
  
  cavity tuning for optimal bunch lengthening is needed

- Further investigation with ideal cavity potential (cross check with passive HC)
  
  ➢ geometric impedance improves the threshold
  
  suggests the head-tail damping

- RW scales as $I \cdot b_{\text{eff}}^3$
  
  ➢ $I_{\text{th}}$ with 5 planned IDs ($\xi=1$): 380 mA
  
  ➢ $I_{\text{th}}$ with 5 planned IDs ($\xi=1.2$): >500 mA

  $\xi > \xi_{\text{design}}$ allows to achieve design current

  Optics design has been made to provide $\xi$ up to +4
Threshold currents (mA) in MAX IV 3 GeV ring considering different effects

<table>
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<tr>
<th>Plane</th>
<th>$\xi$</th>
<th>$Z_{geom}$</th>
<th>$Z_{geom}$ + RW</th>
<th>$Z_{geom}$ + RW$_{5IDS}$</th>
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<tr>
<td></td>
<td></td>
<td>HC off</td>
<td>HC on</td>
<td>HC off</td>
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<tr>
<td>Longitudinal</td>
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<td>620</td>
<td>970</td>
<td>-</td>
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<td>17100</td>
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<td>1.2</td>
<td>5040</td>
<td>21900</td>
<td>-</td>
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<tr>
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<td>710</td>
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<td>2200</td>
<td>10400</td>
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<td></td>
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<td>15100</td>
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<td>Vertical</td>
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<td>50</td>
</tr>
</tbody>
</table>

*in mA

Harmonic cavity is crucial for successful operation!
Geometric impedance of low gap ID chambers

Impedance processing:
- Numerically obtained using GdfidL (Thomas Günzel (ALBA), David Olsson (MAX IV laboratory))
- Fitted to as series of resonators (broad- or narrow-band) with additional purely resistive and inductive components

Impedance model of ID chambers:
- Longitudinal is obtained assuming all straight sections occupied
  - increase of inductive component
- Transverse in progress...

tracking with new impedance model is next step
Head-tail modes influenced by HC

m=1 mode is excited in initial distribution
no impedance effects

- Evolution w/o HC
  - $\xi = 0$: pure m=1 present
  - $\xi = 1.2$: m=1 with CM offset

- Evolution with HC
  - $\xi = 0$: HC induced amplitude dependent tune shift destroys coherent motion
Head-tail modes influenced by HC

- Tune shift smears out the coherence
- What is the effect of the chromaticity and HC together?
To be studied further...

\[ \xi = 0, \text{HC off} \]

\[ \xi = 0, \text{HC on} \]
Conclusion and Outlook

● MAX IV instability thresholds without ID chambers determined
  ➢ Single-bunch: at design chromaticity $\xi = 1$ well above the operation current
  ➢ Multi-bunch: instability sets in at low currents leading to the need of precise cavity tuning
  ➢ Provided optimal lengthening from HC and $\xi = 1$ threshold is above the operating current

● MAX IV instability thresholds with ID chambers RW effect
  ➢ RW from low-gap chambers requires slight increase of chromaticity to reach the design current

● Evaluation of low-gap ID chambers impedance launched
  ➢ tracking to follow

● Nature of instabilities and HC role is under thorough investigation
Thank you