Nonlinear analysis and dynamic aperture

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Outline

➤ Introduction
  ● HE-LHC optics under design
  ● See Y. Nosochkov’s talk for HE-LHC optics design efforts

➤ Resonance driving term (RDT) and dynamic aperture (DA) calculation
  ● Only applied to injection optics w/o errors for HE-LHC for this moment
  ● Only lattice sextupoles taken as sources of non-linear effects

➤ Summary and outlook
1. Introduction

- **Alternatives for arc cells fitting to the geometry of LHC arcs**
  - **Motivation:** simply scaling (HL-)LHC hits the limits set by FCC technologies
  - **Rules:** Assume the same drifts between magnets as LHC; Fit to the arc length of LHC

<table>
<thead>
<tr>
<th></th>
<th>LHC-like</th>
<th>24x 60° HE-LHC</th>
<th>20x 90° HE-LHC</th>
<th>18x 60° HE-LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc cell phase advance [deg]</td>
<td>90/90</td>
<td>60/60</td>
<td>90/90</td>
<td>60/60</td>
</tr>
<tr>
<td>Arc cell length [m]</td>
<td>106.9584</td>
<td>102.5018</td>
<td>123.00</td>
<td>136.669</td>
</tr>
<tr>
<td>K1 [m⁻¹]</td>
<td>0.02697</td>
<td>0.0199</td>
<td>0.0234</td>
<td>0.01485</td>
</tr>
<tr>
<td>(\beta_{\text{max/min}}) [m]</td>
<td>181.3/31.54</td>
<td>176.6/59.48</td>
<td>208.68/36.24</td>
<td>235.74/79.22</td>
</tr>
<tr>
<td>(\eta_{\text{max/min}}) [m]</td>
<td>2.21/1.07</td>
<td>3.75/2.26</td>
<td>2.92/1.41</td>
<td>6.67/4.02</td>
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<tr>
<td>Dipole field [T]@13.5TeV</td>
<td>16.06</td>
<td>16.23</td>
<td>15.99</td>
<td>15.61</td>
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<tr>
<td>Filling factor</td>
<td>0.802</td>
<td>0.794</td>
<td>0.806</td>
<td>0.825</td>
</tr>
</tbody>
</table>
1. Introduction

Alternatives for arc cells

- **23x 90-deg arc cell**
- **20x 90-deg arc cell**
- **18x 60-deg arc cell**
- **24x 60-deg arc cell**
1. Introduction

➤ Integration with IRs (Start from IP1 for plots)

Injection lattice by Y.N. 24x 60-deg arcs

Modified HL-LHC injection lattice by T. Risselada 24x 60-deg arcs + IRs of SLHCV3.1a (by S. Fartoukh)

Injection lattice by Y.N. 18x 60-deg arcs

Injection lattice by Y.N. 20x 90-deg arcs

Basic IR

Realistic IR
1. Introduction

➤ Simulation tools

- PTC developed by E. Forest at KEK
  * MAD8/MAD-X lattices translated to PTC flat format via Bmad or AML/UAP
- SAD developed by K. Oide et al. at KEK
  * MAD8/MAD-X lattices translated to SAD via Bmad or SAD scripts

See webpage: http://svnweb.cern.ch/world/wsvn/madx/branches/madX-SAD/tools/translators/
1. Introduction

➤ Simulation conditions

• RDT calculation
  * PTC tracking w/o SR, w/o errors
  * Integrate RDTs along beam orbit

• DA calculation
  * SAD tracking w/o SR, w/o errors
  * Use standard FMA algorithm
  * Short-term DA by tracking 1024 turns (also see Y.N.’s talk)

• Normalized emittance $\gamma \varepsilon = 2.5 \ \mu m$; Beam energy $E = 450 \ \text{GeV}$

• Linear chromaticity set at $(Q_x', Q_y') = (3, 3)$ for all lattices under consideration
2. RDT and DA calculation

- Injection lattice with 24x 60-deg arcs (by Y.N.)
  - Use basic IRs
  - Working point (49.28, 47.31)
2. RDT and DA calculation

- Injection lattice with 18x 60-deg arcs (by Y.N.)
  - Use basic IRs
  - Working point (37.28, 39.31)
2. RDT and DA calculation

- Injection lattice with 20x 90-deg arcs (by Y.N.)
  - Use basic IRs
  - Working point (56.28, 57.31)
2. RDT and DA calculation

- **LHC injection lattice (Ver. V6.503)**
  - 23x ~90-deg arcs, same dipole for both arcs and DSs
  - Working point (64.28, 59.31)
2. RDT and DA calculation

- Modified HL-LHC injection lattice (SLHCV3.1a designed by S. Fartoukh)
  - Use 24x 60-deg arcs (developed by T. Risselada), same dipole for both arcs and DSs
  - Tune matched to (46.28, 45.31). No nonlinear optimization could be improved

![Graphs and diagrams related to RDT and DA calculation]
2. RDT and DA calculation

➤ Theory of resonance cancelation

● Cancellation condition (C.C.):
\[ N_c(n_x \mu_{xc} + n_y \mu_{yc}) = 2k\pi \ & (n_x \mu_{xc} + n_y \mu_{yc}) \neq 2k'\pi \]

\( N_c \): number of cell; \( \mu_{xc}, \mu_{yc} \): Phase advance per cell

● 60-deg cell:
  * C.C.: \( N_c = 6N \)
  * Lowest order resonances: \( n_x - n_y = 0 \) and \( n_x + n_y = 6 \)

● 90-deg cell:
  * C.C.: \( N_c = 4N \)
  * Lowest order resonances: \( n_x - n_y = 0 \) and \( n_x + n_y = 4 \)
3. Summary and outlook

➤ RDT and DA calculation for HE-LHC injection lattices w/o errors

● 60-deg arc cells show huge DAs mainly resulted from:
  * Large beta and dispersion functions, and weaker sextupoles
  * Well-suppressed 3rd and 4th RDTs

● 90-deg arc cells show relative smaller DAs mainly resulted from:
  * Stronger sextupoles
  * 4th RDTs not well-suppressed

➤ Outlook

● Impact of errors and relevant tolerances to be investigated
● Integration of 60-deg arc cells to collision lattices (in parallel to design efforts on insertions of HE-LHC) to be investigated
Thank you for your attention!