ALIGNMENT AND TOLERANCES

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Definition of the errors and correction scheme

Evaluation of the results

Dependency of various observables on the errors

Conclusions and perspectives
ERRORS DESCRIPTION

- FCC will be subject to various errors that will perturb its normal activity ⇒ important to study and to correct them

- Two types of errors contributing to beam misalignment are studied: **position error** and **field error** (both static)

- Position error is defined for all ‘MQ’ quadrupoles, in arc and in dispersion suppression (DIS) regions:
  - \( 0 < \sigma_{\delta x} < 0.5 \text{ mm} \)
  - \( 0 < \sigma_{\delta y} < 0.5 \text{ mm} \)

- Field error (random \( b1 \)) is defined for all ‘MB’ dipoles (in arcs and DIS) and ‘MBS’ dipoles (in DIS), in relative units:
  - \( 0 < \sigma_{\delta B/B} < 0.5 \% \)

- All errors are Gaussian distributed, truncated at 3-\( \sigma \) values

- No errors are applied in the straight (insertion) regions

- The error generator seed is user defined, and different for each of the 500 runs
The complete FCC ring lattice is used, at collision energy (50 TeV)

All quadrupoles of the arc and DIS sections have a BPM and a corrector (L = 0.647 m) next to them, with the same polarity (BPMs are used on the corresponding plane only).

**Exception:** the first quadrupole of the DIS before each arc section (no BPM), and the last quadrupole of the DIS after each arc section (no corrector).

- Same number of BPMs (parameters) and correctors (variables)
- Optimization using the CORRECT command of MADX (SVD mode)
- The errors are evaluated only for the arcs
- IR orbit correction done in parallel → talk of A. Seryi (next session)
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- IR orbit correction done in parallel → talk of A. Seryi (next session)
For each run, calculation of the RMS and maximum values for the corrector strengths and the following observables over all elements of the arcs:

- residual orbit
- residual angle
- beta-beating $\Delta \beta / \beta_{\text{ref}}$
- parasitic dispersion or dispersion beating $\Delta D / \sqrt{\beta_{\text{ref}}}$

→ see LHC Project Report 501 for more details

From the distribution of the maximum values the 90-percentile (value for which 90% of the distribution is included) is calculated over all runs.

The dependency on each main error contribution is studied with:

- Quadrupole alignment error. The RMS error is assumed identical in both planes (x and y).
- Dipole field errors. The relative RMS error is assumed to be identical for the two types of magnets (MB and MBS).

When one error contribution is varied, the other contribution is fixed with the reference values of **0.35 mm** for the quadrupole misalignment and **0.1%** for the dipole field errors, resp.
Case 0.35 mm, 0.1 %

Vertical residual orbit for each element in one run

Mean value of the vertical residual orbit for each element over the 500 runs

Histogram =>

Distribution of the maximum value of horizontal beat-beating

* 500 runs =>

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Horizontal correctors always stronger

Strong dependency in x plane

Constant in y plane

Integrated corrector strengths @ 0.35 mm, 0.1 % (90-percentile):

\[ B_x \times L = 3.6 \text{ Tm} \]
\[ B_y \times L = 2.9 \text{ Tm} \]

Compatible with the Nb-Ti technology (4 Tm) → talk of E. Todesco (Thursday)
CORRECTOR STRENGTHS

Evolution of corrector 90% strengths with quadrupoles misalignment:
- Horizontal correctors
- Vertical correctors
- Bin size 0.2 Tm

\[ \sigma_{\delta B/B} = 0.1 \% \]

Evolution of corrector 90% strengths with dipole field errors:
- H Kickers
- V Kickers

\[ \sigma_{x,y} = 0.35 \text{ mm} \]

Histogram of the maximum value of the integrated correctors strengths:
- Horizontal correctors
- Vertical correctors
- Bin size 0.2 Tm

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Linear trend in both planes

x always superior to y

Residual orbit @ 0.35 mm, 0.1 % (90-percentile)

X = 0.53 mm
Y = 0.41 mm
**Residual Angle**

**Evolution of 90% Orbit with Quadrupoles Misalignment**

- Linear trend in both planes
- \( x \) always superior to \( y \)
- Residual angle @ 0.35 mm, 0.1 \% 
  
  \[ X' = 14 \ \mu\text{rad} \]
  \[ Y' = 5 \ \mu\text{rad} \]
  
  Should not influence beam screen design

\[ \sigma_{\delta B/B} = 0.1 \% \]

**Evolution of 90% Orbit with Dipole Field Errors**

- Strong dependency in \( x \) plane
- Constant in \( y \) plane

\[ \sigma_{x,y} = 0.35 \text{ mm} \]
Strong beta-beating in y plane, even without quadrupole errors
=> sextupole contributions

\[ \sigma_{\delta B/B} = 0.1\% \]

\[ \sigma_{x,y} = 0.35\text{ mm} \]

\[ \Delta \beta_y/\beta_y > 10\% \text{ for } \sigma_{\delta B/B} = 0.5\% \]

Beta-beating @ 0.35 mm, 0.1 % (90-percentile)
\[ \Delta \beta_x/\beta_x = 1.2\% \]
\[ \Delta \beta_y/\beta_y = 7.0\% \]
Constant in x plane, strong
Small dependency in y plane

Strong dependency in x plane
Constant in y plane

Dispersion beating @ 0.35 mm, 0.1 % (90-percentile)
\[ \frac{\Delta D_x}{\sqrt{\beta_x}} = 6.9 \times 10^{-2} \text{ m}^{1/2} \]
\[ \frac{\Delta D_y}{\sqrt{\beta_y}} = 5.7 \times 10^{-3} \text{ m}^{1/2} \]
Conclusions and Perspectives

- Corrections of the closed orbit have been performed for all arcs of the FCC ring with various sets of errors.

- For a configuration with 0.35 mm quadrupoles alignment errors and dipole relative field errors of 0.1% the correctors have an integrated strength up to +/- 3.6 Tm @ 90-percentile level.

- The case of quadrupole errors above 0.4 mm or dipole errors of 0.5% would require a new technology.

- To be done:
  - Include additional error contributions (BPM read error, roll angle plus field error in the dipoles).
  - Test more errors combinations (different x and y for quadrupoles).
  - Test ‘clustering’ of errors (as the alignment of a group of magnets is done in real world).
  - Use a different correction scheme (remove 1/n correctors/BPMs, integrate IR region?).
  - Comparison with LHC scheme.