STUDIES OF THE GROUND MOTION INDUCED VIBRATIONS IN FCC-EE Z MODE

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FCC Week 2022

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Summary

- Context of vibrations studies
    - Criticality of vibrations
    - Dynamic misalignments
    - Links to mechanical design

- Vibrations studies in the MDI region of FCC-ee
    - Methodology
    - Study cases

- Frequential studies: Effect of plane ground waves on the closed orbit

- Conclusions and Perspectives

Criticality of vibrations effects

LHC

FCC-ee

CLIC

Aim: Define vibrations tolerances of the machine

+

- Circular collider:

- High repetition rate of the beams
- Optics symmetry of e^+ and e^- beams

- Coherence around the IPs
- Beam control: orbit correction, post-IP BPM control

-

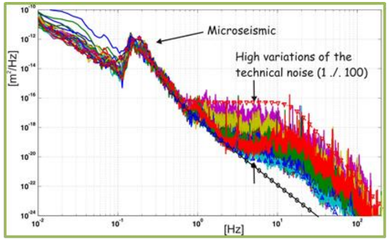
- Mechanical effects, resonance modes:

Cryostats in cantilever mode, supports and magnets, positioning system,…

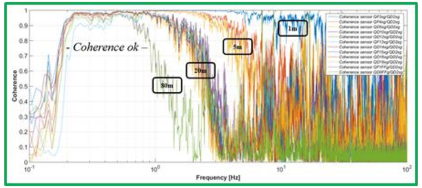
- Nanobeam in the vertical axis
- Weak coherence along the ring, relative to distance and frequency
- 2 different beam pipes
- BPM resolution

Specifically at the Interaction Point:
Small beta* values, meaning strong FFS quadrupoles → very sensitive to vibrations

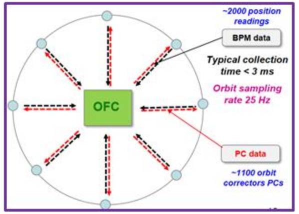
FCC-ee vibrations studies



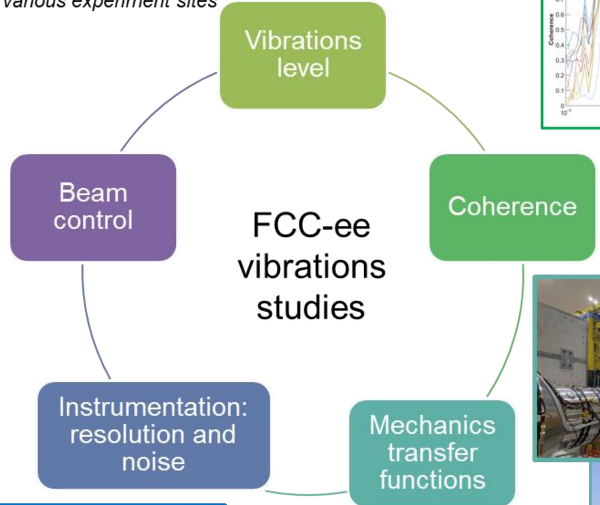
PSD displacement of various experiment sites



ATF2 coherence



LHC Feedback controller design



Vibrations level

Coherence

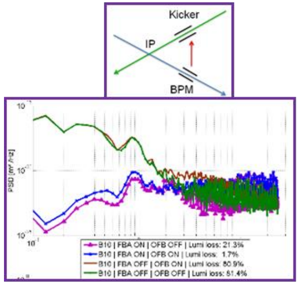
Mechanics transfer functions

Instrumentation: resolution and noise

Beam control

FCC-ee vibrations studies

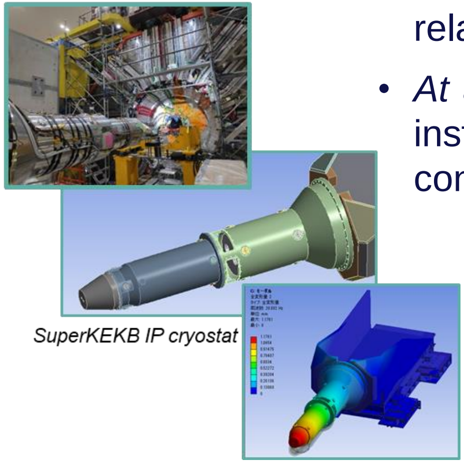
- *From now on*, focus on **vibrations** and **mechanics** related parameters
- *At a longer term*, integration of instrumentation and feedback control



CLIC post IP BPM feedback

LHC Beam Position Monitor

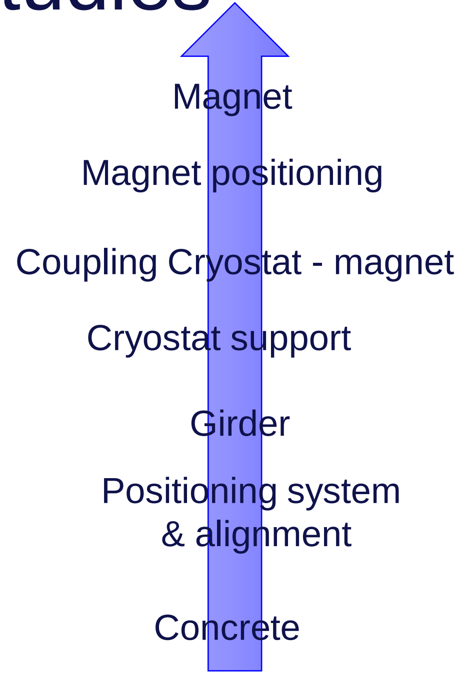
Vibration sensor



SuperKEKB IP cryostat

Vibrations studies

All defined by mechanical transfer functions
+
Ground coherence



Magnet

Magnet positioning

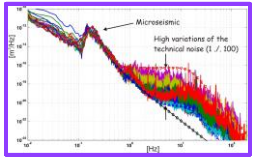
Coupling Cryostat - magnet

Cryostat support

Girder

Positioning system & alignment

Concrete



Ground Motion excitation

Aims: link beam optics and mechanical design

1. Integration of **dynamic effects** of each IP side: **vibrations** localized in the **MDI** region
2. Impact of **plane ground waves** on the closed orbit to evaluate global coherence: vertical **displacements** assigned to **all quadrupoles**

VIBRATIONS STUDIES IN THE MDI REGION OF FCC-EE

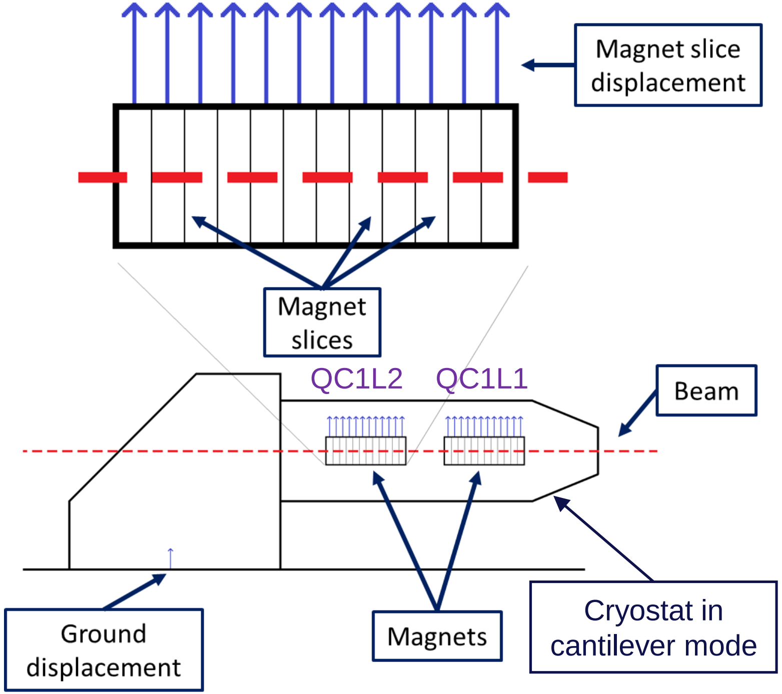
Objectives

Quantify the impact of vibrating MDI quadrupoles on beam characteristics

Aims:

- Vibrations study in the MDI region to define vibrations tolerances
    - **Vertical dynamical** displacements
    - Complementary study to the performed misalignments study
    - Impact on beam characteristics (emittance, size)
- Integration of dynamics beam optics with the mechanical design

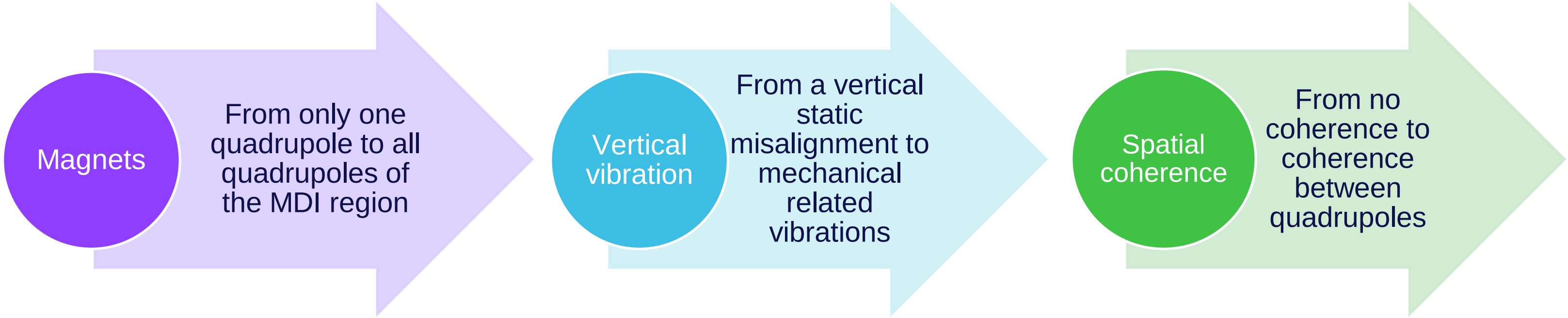
(see S. Grabon's talk, Thursday 2nd June 2022, 12h)



Methodology (1)

Modus operandi:

Gradual complexification of the simulations:



Magnets

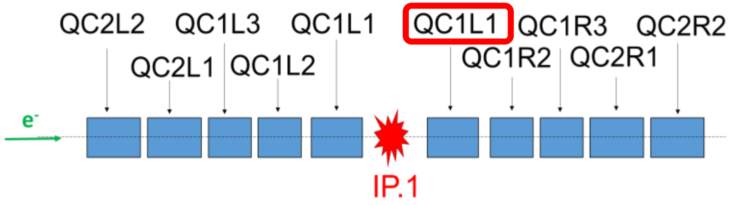
From only one quadrupole to all quadrupoles of the MDI region

Vertical vibration

From a vertical static misalignment to mechanical related vibrations

Spatial coherence

From no coherence to coherence between quadrupoles

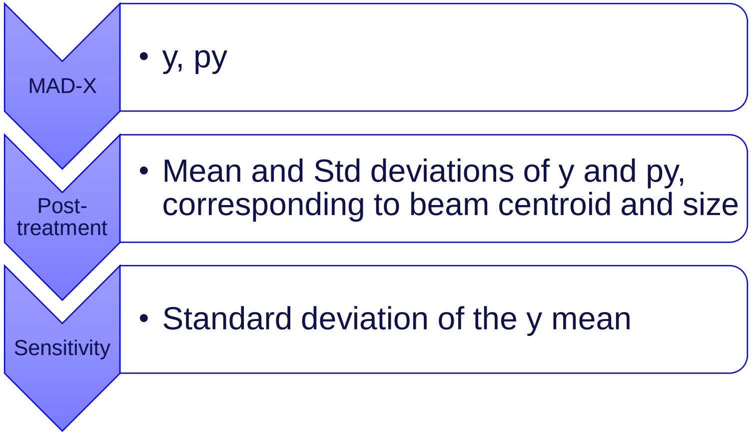


Methodology (2)

Tools:

- Latest layout used (PA31-1.0)*, ~91 km long
- Z lattice considered, as smallest beam spot sizes at IP
- Optics simulation with MAD-X:
  Dynamical study → Tracking module used, number of accelerator turn dependent
- **No optics correction** considered, to highlight vibrations impact on beam characteristics

Observables:

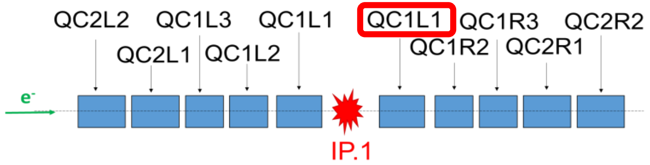


- y, py

- Mean and Std deviations of y and py, corresponding to beam centroid and size

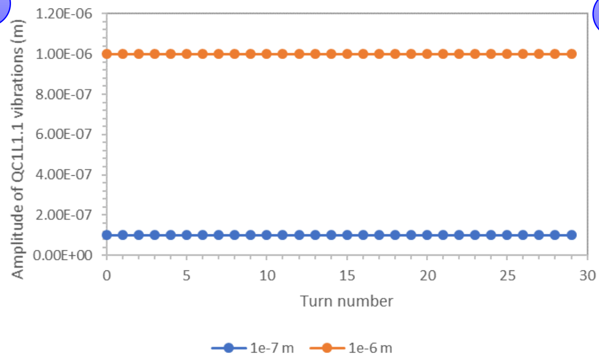
- Standard deviation of the y mean

First study cases (1)



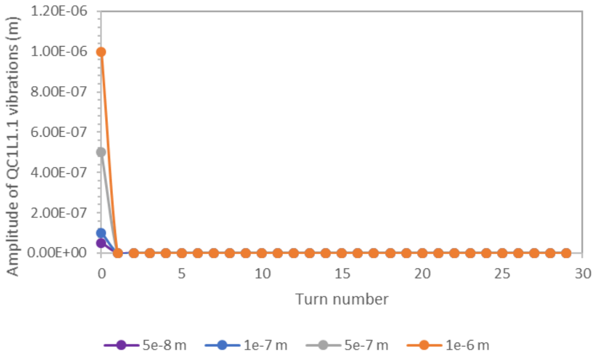
- Only one quadrupole, QC1L1.1, is concerned by vertical displacements/vibrations
- Bunch of 200 electrons
- 30 turns, i.e. 0.01 s *(not much, only to assess the behaviour of the machine…)*
- Three cases, from static to sinusoid displacement:

①



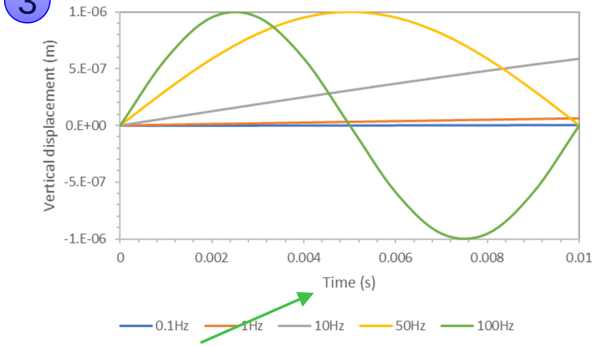
Static vertical displacement

②



“Bump” like vertical displacement

③



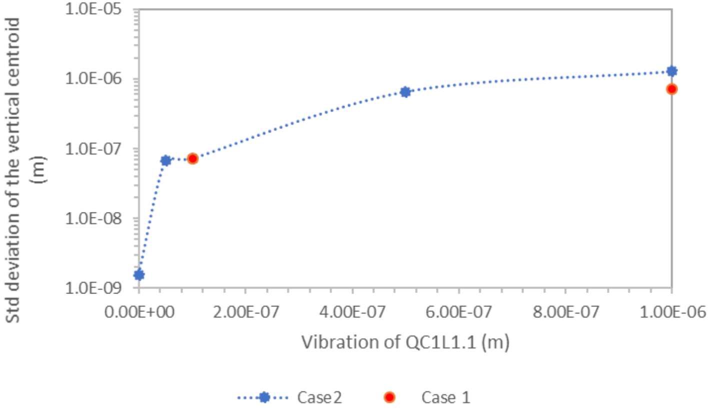
Change of axis scale

Sinusoidal vertical displacement (different frequencies)

First study cases: sensitivity (2)

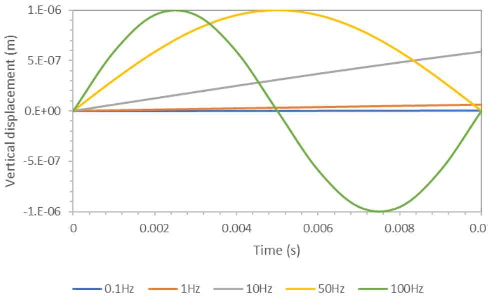
- Variation of the standard deviation of the beam centroid, relative to very local displacement, for **30 turns**
- No major differences between the two static cases
- For static cases, the results would tend to indicate a maximum value of sensitivity, but further studies have to confirm.

① Case 1: static vertical displacement
② Case 2: « bump » like displacement



Towards "real" vibrations (i.e. time-dependent):

- Consideration in terms of time, not in number of turns anymore, as one period of a sinusoidal vibration corresponds to a certain amount of time, different for each frequency.
- Studies ongoing



Conclusions on vibrations in MDI

Method:

Tools are set up to simulate more and more realistically the vibrations in the MDI region:

- MAD-X Tracking module adapted to time-dependent vertical displacements of quadrupoles
- Automatization of data processing
- Crosscheck and validate the process with simple study cases *(not realistic yet…)*

Studies ongoing

Perspectives:

Complexify simulations while considering:

- Quadrupoles concerned by vibrations
- Vibrations defined relative to the mechanical design, and add of coherence
- Longer time of machine run, *i.e.* >> 30 turns ⇔ 0.01 s

In parallel:

Provide the same simulations with SuperKEKB cryostat vibrations to compare with real measurements of luminosity

M. Serluca *et al.*, Vibration and luminosity frequency analysis of the SuperKEKB collider, NIMA 1025 (2021) 166123

EFFECT OF PLANE GROUND WAVES ON THE CLOSED ORBIT OF FCC-EE

Simulations of plane ground waves (1)

Aims:

- Compute the response of FCC-ee to coherent plane ground waves
- Compare simulation results obtained to the ones of other machines (*e.g.* LEP, LHC)

Definitions:

- The plane ground wave is described by:
    - its amplitude: 1 μm
    - its oscillation frequency: from 0.1 to 100 Hz
    - its phase advance *(0 for now in the first works)*

- To refer to literature: Amplification factor: $\frac{closed\ orbit\ offset}{ground\ motion\ amplitude}$; Harmonic number $\mathrm{h} = \frac{C}{\lambda}$

J. Roßbach, Closed-orbit distortions of periodic FODO lattices due to plane ground waves, Particle Accelerators 23 (1988) 121-32
E. Keil, Effect of plane ground waves on the closed orbit in circular colliders, CERN SL/97-61 (1997)

Simulations of plane ground waves (2)

Procedure in MAD-X:

No tracking module used

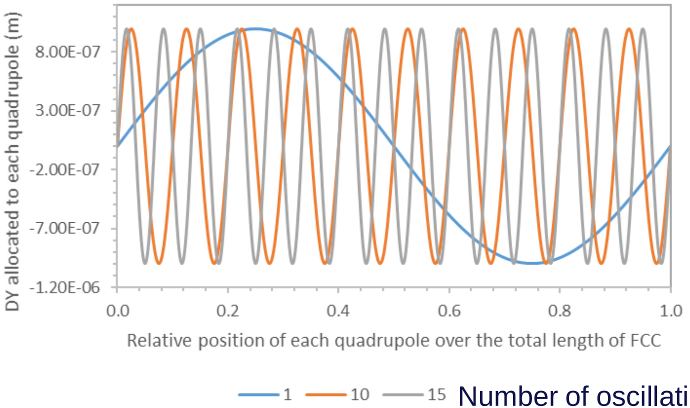
TWISS of the nominal sequence

Assigning vertical displacements of all quadrupoles relative to ground motion

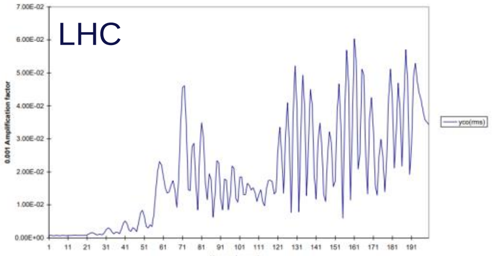
TWISS of the “misaligned”sequence

Extraction of the vertical closed orbit offset

Plot the amplification factor relative to frequency/harmonic number



Number of oscillations or periods relative to FCC total length



E. Keil

Conclusions and Perspectives

Two studies run in parallel:

- Impact of time-dependent vertical vibrations applied in the MDI region on beam characteristics
    - Cumulative perturbation of quadrupoles located in the MDI along time
- Effect of plane ground waves on the closed orbit of FCC-ee
    - No cumulative perturbation, vertical misalignments allocated to all quadrupoles along the ring

Both studies will require dedicated investigation to provide more realistic results.

At a longer term:

- Define vibrations relative to mechanics design
- Add local and global corrections

(see T. Charles talk, Tuesday 31st May, 2022, 9h50, and R. Garcia's talk, Wednesday 1st June, 2022, 14h)

- Consideration of both positron and electron beams

…

Many thanks to: M. Boscolo, T. Charles, M. Hofer, K. Oide, G. Roy, L. Van Riesen-Haupt, F. Zimmermann and the whole FCC-ee collaboration team

Thank you
for your attention!

Simulations of plane ground waves

- First results of MAD-X simulations
- Number of oscillations per unit FCC total length investigated: 1, 10, 15, 50, 100 (“periods”)

- Need to investigate the whole range of x-axis to observe maxima of amplification factors