Observation of ground motion in the LHC at the triplet


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Outline

1. Idea
   a) Measurement of IT eigenfrequencies
   b) Change of beta during squeeze

2. DOROS BPMS and ADT

3. Measurements and results

4. Summary
Idea

• closed orbit distortion is proportional to maximum beta function in IT

\[ x_{co}(s) = \frac{\sqrt{\beta(s)}}{2 \sin \pi \nu} \int_s^{s+C} d\bar{s} \Delta x(\bar{s}) kl \sqrt{\beta(\bar{s})} \cos(\pi \nu + \psi(s) - \psi(\bar{s})) \]

due to ground motion

• beta function increases mainly in the IT during the squeeze
  ⇒ change in amplitude of the orbit spectrum can be almost certainly related to a movement of the IT
  ⇒ record beam spectrum during the squeeze with the ADT and the DOROS BPMs

• amplification of the ground motion by up to factor 100 by the mechanical structure of the IT = IT eigen-frequencies (see M. Guinchard, 16\textsuperscript{th} HL-LHC PLC, Vibration analysis TT41 TAG41, \textit{indico})
  ⇒ are the IT eigen-frequencies visible in the beam spectrum?
Measurements of IT eigen-frequencies

M. Guinchard, 16th HL-LHC PLC, Vibration analysis TT41 TAG41, indico

Coupling from first horizontal mode around 10Hz

First vertical mode around 23 Hz

First horizontal mode around 10 Hz

$\Rightarrow$ amplification of up to factor 100 by IT, amplitude seen by the beam scales with $1/f$
Change of beta during squeeze

\[ x_{co}(s) = \frac{\sqrt{\beta(s)}}{2 \sin \pi \nu} \int_{s}^{s+C} \Delta x(s) kl \sqrt{\beta(s)} \cos (\pi \nu + \psi(s) - \psi(s)) \]

⇒ amplitude of beam spectrum scales with \( \sqrt{\beta_{IT}} \cdot (kl)_{IT} \)

Changes during the squeeze

<table>
<thead>
<tr>
<th>optics</th>
<th>( \beta^* ) [cm]</th>
<th>kl [1/m]</th>
<th>max(( \beta_{IT} )) [m]</th>
<th>sqrt(( \beta_{IT} )) \cdot (kl)_{IT} (optics/injection)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>min</td>
<td>max</td>
<td>min</td>
</tr>
<tr>
<td>injection (6.5 TeV)</td>
<td>1100</td>
<td>0.047</td>
<td>0.055</td>
<td>242</td>
</tr>
<tr>
<td>collision (6.5 TeV)</td>
<td>80</td>
<td>0.048</td>
<td>0.056</td>
<td>3028</td>
</tr>
<tr>
<td>collision (6.5 TeV)</td>
<td>40</td>
<td>0.048</td>
<td>0.056</td>
<td>6053</td>
</tr>
</tbody>
</table>
DOROS BPMs and ADT

DOROS BPMs:
• installed in IR1 and IR5 in front of Q1 (not all frontends available during the different measurement)
• orbit for spectra calculation is scaled by $1/\sqrt{\beta_{BPM}}$ in order to obtain only the amplification during the squeeze due to the misalignment of the IT ($\sqrt{\beta_{IT}}(k_l)_{IT}$)
• no synchronized measurement of Beam 1 and Beam 2 possible (yet)
• commissioned for nominal bunches, noisy results eventually for pilot bunches

ADT:
• 2 pickups per beam and plane installed in IR4 at Q7L,Q7R,Q9L,Q9R
• orbit for spectra calculation is scaled by $1/\sqrt{\beta_{ADT}}$
• no change of beta-function in IR4 during squeeze
• no synchronized measurement of Beam 1 and Beam 2 possible
Measurements

1) Beta*-reach: IR aperture measurement at small beta (MD307), fill 4037, 23.07.2015 20:58 – 24.07.2015 01:09:
   • 12 pilot bunches per beam
   • ADT on and orbit feedback off
   • ADT used for loss maps

2) Beta* reach: optics commissioning (MD384), fill 4033, 22.07.2015 08:43 – 14:22:
   • 1 pilot bunch per beam
   • ADT off and orbit feedback off
   • excitation by AC dipole

3) physics fill 3974, 07.07.2015 21:04 – 08.07.2015 05:52:
   • 152 nominal bunches
   • ADT on and orbit feedback off

4) physics fill 3986, 11.07.2015 20:12 – 22:30: (only ADT data)
   • 296 nominal bunches
   • ADT on and orbit feedback off
Comparison of averaged spectra, MD307

visible at 11 m and 40 cm (6.5 TeV):
- line at 4.5 Hz v-plane???
- 50 Hz line
- 2Qs just below 50 Hz line

only at 40 cm (6.5 TeV):
- “bump” around 12 Hz in h-plane
- “bump” around 20 Hz in v-plane

⇒ match first horizontal and vertical IT eigen-frequency
Comparison of averaged spectra, MD384

At 11 m (6.5 TeV):
- line at 4.5 Hz v-plane
- 50 Hz line
- 2Qs just below 50 Hz line
- “bump” around 12 Hz in h-plane

At 40 cm (6.5 TeV):
- “bump” around 12 Hz in h-plane
- “bump” around 20 Hz in v-plane
- Match first horizontal and vertical IT eigen-frequency

Data averaged over 10 samples, FFT with 131072 turns

(no DOROS data available for 11m)
3.5 TeV, 8 MV → $f_s = 22.9$ Hz

compatible with $Q_s$ and $2Q_s$, $f_s = 22.9$ Hz

$B2V, \beta^* = 2.0$ m

2010 data
17 May 2010
damper off
low bunch intensity
FFT of 4 bunches
(65536 turns)

3.5 TeV, 8 MV → $f_s = 22.9$ Hz

W. Hofle, D. Valuch @LBOC 21.08.2012
Scaling with $\beta^*$ (ADT), MD384

- same frequencies visible for 80 cm, 50 cm and 40 cm
- no obvious scaling of FFT amplitude with $\beta^*$, might lie in the noise of the measurement?

![Graph showing scaling with $\beta^*$](image)
Comparison of averaged spectra, 07/07/15

- only very short time at 11 m
  - orbit could be disturbed as just after the ramp, instability?
  - two “bumps” around 20Hz and 40 Hz?
  - 50 Hz line
  - 2Qs just below 50 Hz line
  - “bump” around 12 Hz in h-plane

at 40 cm (6.5 TeV):
- “bump” around 12 Hz in h-plane
- “bump” around 20 Hz in v-plane
⇒ match first horizontal and vertical IT eigen-frequency
Averaged Spectra ADT, 11/07/15

at 11 m and 80 cm (6.5 TeV):
- peak at 4.5 Hz v-plane??
- 50 Hz line
- Qs+2Qs just below 50 Hz line
- “bump” around 12 Hz

at 40 cm (6.5 TeV):
- “bump” around 12 Hz in h-plane
- “bump” around 20 Hz in v-plane
⇒ match first horizontal and vertical IT eigen-frequency

(no DOROS data available for 11m)
Summary

1. similar spectra obtained with ADT and DOROS BPMs at high \( \beta^* \) (11m) and even better agreement at low \( \beta^* \) (40 cm)
2. “20 Hz bump” visible in the vertical plane at low \( \beta^* \) (40, 50, 80 cm) while it is not visible at high \( \beta^* \) (11m)
   \[ \Rightarrow \text{first vertical IT eigen-frequency} \]
3. DOROS: “10 Hz bump” visible in the horizontal plane at low \( \beta^* \) (40, 80 cm), but not visible at high \( \beta^* \) (11m)
   ADT: “10 Hz bump” visible at high and low \( \beta^* \)
   \[ \Rightarrow \text{first horizontal IT eigen-frequency?} \]
4. 4.5 Hz peak?
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MD307, 12 pilot bunches

DOROS: horizontal – IR5, left, Beam 1

\[ \beta_{\text{IR5}} = 1100.0 \text{ cm, 2015-07-23 23:09:09} \]

Units on y-axis are \( \mu \sqrt{\text{m}} \)
MD307, 12 pilot bunches

ADT: horizontal – Q7, right, Beam 2

\[ \beta_{IP1} = 1100.00 \text{ cm, 2015-07-23 23:15:47} \]

![Graph 1](image1)

- Q7R b2h, scale=0.07

![Graph 2](image2)

- Q7R b2h, scale=0.07
MD307, 12 pilot bunches

DOROS: vertical – IR5, right, Beam 2

$\beta_{IR5} = 1100.0 \text{ cm, 2015-07-23 23:08:58}$

units on y-axis are $\mu \times \sqrt{\text{m}}$
MD307, 12 pilot bunches

**ADT: vertical – Q7, right, Beam 1**

\[ \beta_{\text{IP1}} = 1099.00 \text{ cm, 2015-07-23 23:31:02} \]

- Upper graph: horizontal displacement vs. number of turns
- Lower graph: amplitude vs. frequency (log-log scale)

- Line: Q7R b1v, scale=0.09