LHC impedance model and single beam instabilities

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2nd review on LHC performance limitations
29-11-2016
Outline

• How good is the transverse impedance model?
• Could it explain some of the 2012 instabilities or do we need other mechanisms?
• Was it an issue to run with very small chromaticities (sometimes negative) during the first part of the year?
• Can we explain the instabilities observed in 2016 with few bunches for the high beta run?
• Can we explain the 2016 beam stability of bunches of ~ 1.9E11 p/b within ~ 1.5 μm?
• Do we have some margin?
• Remaining questions to be answered / studies to be performed?
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How good is the transverse impedance model?

- LHC transverse impedance dominated by collimators.
- Experience gained so far through:
  - Direct methods: Collimator impedance measurements from tune shift Vs gap movement.
  - Indirect methods: octupole threshold measurements during collimation MDs and dedicated MDs.
Collimator tune shift measurements: TCSG.D4L7.B1

\[ \Delta Q_{\text{one}} = 3.94361e^{-05} \pm 1.39894e^{-05} \]

- Measured $3.9e^{-5}$, predicted $3.2e^{-5}$ tune shift @ $Q' = 5$ - > factor 1.2
- See also ColUSM 76 for details.
Close agreement between theory and simulation!
TCP.C6*7 slightly under-estimated (factor ~1.8)
Collimator tune shift measurements: TCP*B2

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Collimator tune shift measurements: TCSG*B1

- Factor ~3.2 in H, ~2.6 in V w.r.t. the model.
- Huge intensity loss during measurement provoked by high amplitude kick -> may lead to overestimation of the tune shift.
Collimator tune shift measurements: TCSG*B2

- Factor ~2.6 in H, ~1.7 in V w.r.t. the model.
- Less intensity loss -> More reproducible measurement.
Octupole threshold measurements

• TCSG.*7 at 8.0 sigma (2015)

Extensive report in L.Carver et al. in proc. of IPAC16
Octupole threshold measurements

- **TCSG.*7 at 7.5 sigma (2016)**

  DELPHI threshold prediction
  \( J_{\text{ext}} > 0, \ N_b = 1\times11, \epsilon = 2, \text{ um} \)

- Reasonably close to prediction.

See also “Stability margins” in [LBOC Meeting No 57](#)
Octupole threshold measurements

- **TCSG.*7 at 6.5 sigma (2016)**
  
  - Factor ~1.4 discrepancy w.r.t. prediction.

See for details: [LBOC Meeting No 63](#)
Octupole threshold measurements

• **TCSG.** 7 at **6.0 sigma** (2016)

  - Factor ~1.3 discrepancy w.r.t. prediction.

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Summary of octupole thresholds measurements

LHC 40cm squeezed optics, 100 turns damper, and 1.2e11 bunch in 2um emittance.
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Measurements scaled to 1.2e11 in 2um emittance if needed.

(*) Scaled to H plane from V plane considering the factor ~1.2 from impedance.

(**) Scaled to 40cm squeeze with the factor ~1.1 from impedance.
Summary of octupole thresholds measurements

LHC 40cm squeezed optics, 100 turns damper, and 1.2e11 bunch in 2um emittance.

Fill 4855, ~270 A (*)
Fill 4855 ~253 A
Fill 4804, 88 A (**)  
Discrepancy 7.5 -> 6.5 sigma to be understood

Several fills during 2015, 120 A (**)

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We compare the impedance model results for single beam octupole threshold against the instabilities observed in 2012 referring to:

1) N. Mounet, 2012 [CERN-ATS-Note-2012-073](https://cern.ch)
2) N. Mounet, 2014 [Evian’s paper](https://cern.ch)
3) G. Arduini, 2012 [LMC (15/08/2012)](https://cern.ch)
Could it explain some of the 2012 instabilities or do we need other mechanisms?

- **Case: LOF > 0**
- Both beams are considered together.
- Agreement for two cases in high Q’ region > 10 units.
- Instabilities occurred also at high octupole current with damper on -> Not explained by impedance only (Coupling? Q’’?)
Could it explain some of the 2012 instabilities or do we need other mechanisms?

- **Case: LOF < 0**
- One FT instability compatible with the impedance model in Y plane.
- Some instabilities occurred at high current with both damper on and off -> Not explained by impedance only (Coupling? ADT trip? Q’’?)
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DELPHI prediction are inaccurate for $Q' < 2$.

- Can be partially improved with appropriate damper transfer function.
- **Rise time vs chromaticity at injection** studies can give more info on this issue.
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- Low intensity run: few bunches with Nb~0.8e11 in 1um.
- Very close settings with TCP -> 2 sigma, for background cleaning improvement
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Example: B1H Fill 5146

Example: B1H Fill 5284
Can we explain the instabilities observed in 2016 with few bunches for the high beta run?

Close TCP.D6[L/R]7 → Visible impact on expected tune shift (w/o damper)
Can we explain the instabilities observed in 2016 with few bunches for the high beta run?

- Instability induced by very close TCP collimators.
- Reasonable good agreement with models.

More details in D.Amorim 26-09-2016 HSC talk
Can we explain the instabilities observed in 2016 with few bunches for the high beta run?

- Few instabilities occurred also with RP deeply in (2.5sigma).
- Updated the impedance database with available models.
Can we explain the instabilities observed in 2016 with few bunches for the high beta run?

- With a current of 470 A we would predict stability $\rightarrow \sim \text{factor 2 discrepancy}$!
- Possible explanations:
  - Different **emittance value** from BSRT (lower) and wirescanner (larger emittance) $\rightarrow$ Almost a factor 2 difference.
  - **Rough impedance model of RP**.

\[
\text{Octupole current threshold [A]} \\
\begin{array}{cc}
\text{LHC ft High beta, gaussian} \\
\text{LHC ft High beta, parabolic}
\end{array}
\]
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Can we explain the 2016 beam stability of bunches of \( \sim 1.9\times10^{11} \) p/b within \( \sim 1.5 \) μm?

- Predicted ~320 A, but unstable at 470 A. The factor 1.4 is not yet understood.
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- **Present model** with CFC collimators at 7.5s, $Q' = 10$ with 100 turns damper
  - $Nb \; 1.2e11$ in 2um -> **120 A predicted, 450 A margin**
  - $Nb \; 2.2e11$ in 2um -> **240 A predicted, 330 A margin**

- Accounting for a **factor 1.5 from the High Brightness MD**
  - $Nb \; 1.2e11$ in 2um -> **180 A predicted, 380 A margin**
  - $Nb \; 2.2e11$ in 2um -> **360 A predicted, 210 A margin**

- Accounting for a **factor 1.5 from the High Brightness MD, and 1.3 for 6.5s collimator settings in IP7:**
  - $Nb \; 1.2e11$ in 2um -> **230 A predicted, 336 A margin**
  - $Nb \; 2.2e11$ in 2um -> **460 A predicted, 110 A margin**
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- **Collimator impedance:**
  - Address collimator discrepancy between model and measurements with **tune shift scan with gradual decreasing collimator gap** (8 -> 6 sigma).
  - Repeat the **TCSGs at 6.5 sigma** to improve measurement quality.
  - **RP impedance** with tune shift measurement versus gap.
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- **Total impedance budget:**
  - Measurement of **tune shift versus intensity** (with new ADT system)
  - Continuation of **bunch by bunch tune shift** measurements.
  - **TMCI measurements** with pushed collimator settings (5e11 at nominal): could give further information also on stability of high brightness bunches.
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• **General questions:**
  • Studies of **instability developing on scraped bunches**.
  • **Effect of new elements to be included in the model:** Injection kickers,
    geometrical impedance of RP, new experimental beam pipes.
  • Address the **2-beam impedance impact**.
Thanks for your attention!
Can we explain the instabilities observed in 2016 with few bunches for the high beta run?
Can we explain the 2016 beam stability of bunches of $\sim 1.9E11$ p/b within $\sim 1.5 \mu$m?

- Fills 5367, 5368 with few bunches of high brightness ($\sim 1.9e11$ in $1.5\mu$m)
- Instability on higher intensity ones

NB: Only return signal when in saturation!
Can we explain the 2016 beam stability of bunches of \(~1.9 \times 10^{11}\) p/b within \(~1.5\ \mu\text{m}\)?
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Remaining questions to be answered:
Instabilities after preceding beam losses

- The instability starts when going in with the secondaries to **6.5 sigma** after having set the D4L7 already at 6 sigma.
- **No instability** observed only with primaries at 4.5 sigma.
- Octupoles at 470A.
• **Stability threshold at ~ 200 A** (factor 2 discrepancy to be understood).
Possible explanation

• The beams underwent already emittance growth/ intensity loss from injection.
• B1 suffered more than B2.
• The abort-gap cleaning is acting at 1Hz on the beam, heavily seen in V plane (same of instability) for 10’.
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Our models are normally appropriate for clean bunches: need to develop approaches also for this kind of events.
Can we explain the instabilities observed in 2016 with few bunches for the high beta run?

Possible explanations:
• Emittance from BSRT lower than wirescanner: 0.5 um gives a factor 2 in octupole threshold.
• Impedance model may be underestimating the geometrical part.
Can we explain the 2016 beam stability of bunches of \( \sim 1.9 \times 10^{11} \) p/b within \( \sim 1.5 \mu \text{m} \)?

- Emittance from BSRT looks smaller (\( \sim 1.2 \mu \text{m} \)) but cannot completely explain the instability.