Transverse Damping Requirements

Elias Métral for the instability team (and BE-ABP-HSC section)
Contents
Contents

- Introduction
Contents

- Introduction
- Predicted beam stability without e-cloud
Contents

- Introduction
- Predicted beam stability without e-cloud
- Highest bunch brightness reached so far
Contents

- Introduction
- Predicted beam stability without e-cloud
- Highest bunch brightness reached so far
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Contents

- Introduction
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- E-cloud induced instabilities
- Conclusion
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- E-cloud is the main worry
  - What is the role of e-cloud in the instabilities observed since 2015?
  - Can simulations explain the observations?
  - What will happen for HL-LHC?
Predicted beam stability without e-cloud
Predicted beam stability without e-cloud

- Nominal collimator settings for HL-LHC parameters and machine components for the present baseline: 2 CC/beam/IP side and low-impedance collimators in LSS7. Assumed here DQW cavities and machine at the end of the pre-squeeze => Further work has been done to reduce the impedance of a remaining HOM at 920 MHz by a factor ~ 20 (new table from 21-10-2016 used)
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-Beam is stable for a current in the Landau octupoles (LOF) < ~ 300 A, what ever the sign and even if the transverse tails would be cut down to ~ 3 σ
LOF < 0

Courtesy of N. Biancacci
LOF < 0

LOF > 0

Courtesy of N. Biancacci
Highest bunch brightness reached so far
Highest bunch brightness reached so far

- The HL-LHC bunch brightness has already been reached! =>
  In 2016 at 6.5 TeV, bunches of ~ 1.4 times higher brightness than for HL-LHC were brought into collision with very good lifetime (burn-off dominated)
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [TeV]</td>
<td>7</td>
</tr>
<tr>
<td>Bunch population [$10^{11}$]</td>
<td>1.15</td>
</tr>
<tr>
<td>Transv. emittance [μm]</td>
<td>3.75</td>
</tr>
<tr>
<td>Brightness [$10^{11} / \mu$m]</td>
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<td>2.2</td>
</tr>
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</tr>
<tr>
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</tr>
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<td>7</td>
<td>7</td>
<td>6.5</td>
</tr>
<tr>
<td>Bunch population ([10^{11}])</td>
<td>1.15</td>
<td>2.2</td>
<td>1.9</td>
</tr>
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Factor 4.1!
Highest bunch brightness reached so far

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<th>HL-LHC</th>
<th>LHC 2016</th>
<th>Delta [%]</th>
</tr>
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<tbody>
<tr>
<td>Energy [TeV]</td>
<td>7</td>
<td>7</td>
<td>6.5</td>
<td>- 7</td>
</tr>
<tr>
<td>Bunch population (10^{11})</td>
<td>1.15</td>
<td>2.2</td>
<td>1.9</td>
<td>- 14</td>
</tr>
<tr>
<td>Transv. emittance [μm]</td>
<td>3.75</td>
<td>2.5</td>
<td>1.5</td>
<td>- 40</td>
</tr>
<tr>
<td>Brightness ([10^{11} / \mu m])</td>
<td>0.31</td>
<td>0.88</td>
<td>1.27</td>
<td>+ 44</td>
</tr>
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Factor 4.1!
- Lifetime at the beginning of the study (highest beam-beam tune shift, without extra noise) is burn-off dominated.
News on destabilising effect of linear coupling
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- The worry from 2012 (i.e. without e-cloud) has been partly dissipated with the discovery of the effect of linear coupling: see talk at the last HiLumi meeting. Since then, 2 additional info going in the same direction
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  - Instability in physics with 600 bunches disappeared after coupling correction => A coupling (closest tune approach) of ~ 0.005 is bad!
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  - A measurement from 2012 revealed an important coupling in October (~ 0.01)
Sunday 25/09/16, Fill #5332: Instability with 600 bunches
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- LOF were at 470 A, Q’ ~ 15 units and nominal damper
Sunday 25/09/16, Fill #5332: Instability with 600 bunches

- LOF were at 470 A, Q' ~ 15 units and nominal damper
Chart between 2016-09-25 15:47:00.000 and 2016-09-25 15:55:00.000 (LOCAL_TIME) Timescaled with REPEAT every 1 SECOND

- HX:BETASTAR_IP1
- LHC.BQBBQ.CONTINUOUS_HS.B1:EIGEN_AMPL_1
- LHC.BQBBQ.CONTINUOUS_HS.B1:EIGEN_AMPL_2

Locality Enhancing Experiment (HiLumi)

E. Métral, Paris, 15/11/2016
Timeseries Chart between 2016-09-25 15:47:00.000 and 2016-09-25 15:55:00.000 (LOCAL_TIME)

- Bump in |C^-|
- β^*
- B1H BBQ activity
- B1V BBQ activity
Timeseries Chart between 2016-09-25 15:47:00.000 and 2016-09-25 15:55:00.000 (LOCAL TIME) Timescaled with REPEAT every 1 SECOND

- $Q_x$ _FB_Trim
- $Q_y$ _FB_Trim
- $\beta^*$
- B1H BBQ activity
- B1V BBQ activity

Bump in $|\mathcal{C}|$
Similar picture as during our dedicated study on linear coupling.
BBQ coupling B2

BBQ coupling B1

=> B1

INSTABILITY

(600b)

40 cm reached at 15:49:53
Linear coupling was then corrected

40 cm reached at 15:49:53

40 cm reached at 09:17:09

40 cm reached at 16:26:21

Linear coupling was then corrected

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Linear coupling was then corrected

40 cm reached at 09:17:09

40 cm reached at 16:26:21
Warning for BBQ coupling
=> Measurement from OMC team with AC dipole + pilot:

تانوي ~ 0.005 before correction

< 0.001 after correction

Linear coupling was then corrected
Could linear coupling have played an important role in the 2011-2012 End Of Squeeze Instability?
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- Info from RogelioT: In 2012, very few linear coupling measurements took place at 60 cm
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Model selected: 0.6m_b1_fullresponse_2012_10_12  LHCB1 Memory used: 428 Mb / 91

| C | ≈ 0.01 (before correction) | 

Courtesy of R. Tomas
Could linear coupling have played an important role in the 2011-2012 End Of Squeeze Instability?

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  - Commissioning in March => $|C| \leq 0.002$: OK
  - Measurement during an MD on 12/10/2012: Huge coupling ($\sim 0.01$)! => Was corrected for the MD but was not put in the nominal cycle after the measurement…

$|C| \approx 0.01$ (before correction)

There was no request from our side at that time!
Is leveling by transverse offset a viable option?
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- The stability of the beams is reduced when colliding with an offset, BUT the model predicts sufficient margins with current machine and beam parameters.
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![Graph showing damping time and chroma](image-url)
Is leveling by transverse offset a viable option?

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Courtesy of X. Buffat
Is leveling by transverse offset a viable option?

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- A strong instability was observed when the damper was off (as predicted)

- Some instabilities observed in ADJUST in the vertical plane of B1 during physics fill and some studies remain to be understood…
E-cloud induced instabilities
E-cloud induced instabilities

**INJECTION**: In 2016, moving to BCMS beam (with smaller transverse emittances), the beam became unstable at injection $=>$ Could be stabilised by increasing the current in the Landau octupoles: LOF increased from 20 A (knob = -1.5) to 40 A (knob = -3)
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Fill #5217, 18/08/16 => Similar results for H and V

![Graph showing horizontal emittance over 25 ns slots with different octupole gains and settings.](image-url)
E-cloud induced instabilities

- Can this be explained by simulations?
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Octupole knob value to suppress emittance growth below 10% in 1000 turns.

\[ \rho_e = 16 \times 10^{11} \text{ m}^{-3} \]

Courtesy of K. Li
E-cloud induced instabilities

- Can this be explained by simulations?

![Diagram showing Octupole knob value to suppress emittance growth below 10% in 1000 turns.](Image)

- $\rho_e = 16 \times 10^{11} \text{ m}^{-3}$

** Courtesy of K. Li **
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1.50 µm

Courtesy of K. Li
E-cloud induced instabilities

- Summary
E-cloud induced instabilities

Summary

• E-cloud (from dipoles only) could explain the observations in V-plane
E-cloud induced instabilities

Summary

• E-cloud (from dipoles only) could explain the observations in V-plane
• However, the H-plane should be stable => Simulations ongoing adding e-cloud in quadrupoles, etc.
E-cloud induced instabilities

- **STABLE BEAM**: In 2016, signs of e-cloud induced instability in stable beam with batches of 72 bunches for $Q' \sim 15$
E-cloud induced instabilities

◆ **STABLE BEAM**: In 2016, signs of e-cloud induced instability in stable beam with batches of 72 bunches for Q’ ~ 15
  - Only vertical (B1&B2)
  - At the end of trains of 72 bunches
  - Emittance BU by a factor ~ 2
  - No beam loss
E-cloud induced instabilities

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"Pop corn" instability
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"Pop corn" instability

=> Was cured by increasing the vertical chromaticity (+7) in stable beam (to $\sim 22$)
E-cloud induced instabilities

- Possible mechanism?
E-cloud induced instabilities

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E-cloud induced instabilities

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  - Huge simulation work which seems to confirm the predicted effect

Courtesy of G. Iadarola and A. Romano
E-cloud induced instabilities

- Possible mechanism?

- Huge simulation work which seems to confirm the predicted effect
- If confirmed, should not be a problem for HL-LHC

Courtesy of G. Iadarola and A. Romano
Conclusion
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◆ Impedance induced instabilities
Conclusion

- Impedance induced instabilities
  - ~ As predicted (or even better)
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  - ~ As predicted (or even better)
  - A sufficient margin should exist

- 2 mechanisms are critical for beam stability (from both simulations and measurements)
  - Linear coupling between the transverse planes => OK when corrected (at the ~ 0.001 level)
  - E-cloud => From injection till stable beam!
Conclusion

In case of issues with transverse instabilities in the future, other remedies exist and are being studied
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❖ In case of issues with transverse instabilities in the future, other remedies exist and are being studied

- Q”
Conclusion

- In case of issues with transverse instabilities in the future, other remedies exist and are being studied
  - Q’”
  - RFQ
Conclusion

- In case of issues with transverse instabilities in the future, other remedies exist and are being studied:
  - Q"
  - RFQ
  - Wide-band feedback system
Thank you for your attention!