Destabilising effect of the resistive transverse damper (single bunch, $Q' = 0$)

E. Métral, D. Amorim, N. Biancacci, X. Buffat and K. Li

- Past observations made in simulations
- New observations
- What is the mechanism?
Some of the past observations in simulations

- **PyHEADTAIL simulations for LHC / HL-LHC (K. Li)**

Figure 6: TMCI (left) and its mitigation using a transverse damper (right). In addition, it is clearly visible how, instead, a head-tail mode -1 is excited.
Some of the past observations in simulations

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- **Benchmark of BimBim, COMBI and HEADTAIL (respectively lines, crosses and dots) for 2012 LHC (X. Buffat)**

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![Graphs showing TMCI and its mitigation using a transverse damper](image)

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- **DELPHI for LHC (N. Biancacci)**
New observation / analysis with model discussed last time:
CASE WITH $fr \times taub = 0.8$

With transverse damper (resistive, 50 turns) in red

Could be a factor 2 larger => Under checks with DELPHI and pyHEADTAIL
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CASE WITH \( f_r \times \tau_{ab} = 0.8 \)

With transverse damper (resistive, 50 turns) in red

Could be a factor 2 larger => Under checks with DELPHI and pyHEADTAIL
Where does this instability come from with the damper?

- Mode 0 (1\textsuperscript{st} radial mode) only
  => Stable

New observation / analysis with model discussed last time:
CASE WITH $fr \times \tau_a = 0.8$
New observation / analysis with model discussed last time: CASE WITH \( fr \times taub = 0.8 \)

Where does this instability come from with the damper?

- Mode \(-1\) (1\textsuperscript{st} radial mode) only
  
  \Rightarrow \text{Stable}
New observation / analysis with model discussed last time: CASE WITH fr × taub = 0.8

Where does this instability come from with the damper?

- Instability appears when both modes -1 and 0 (with only 1st radial mode) are considered.
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Where does this instability come from with the damper?

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- => This is the interaction between modes -1 and 0 through the damper which creates the instability.
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- The "coupling" between the 2 modes pushes apart the instability growth rates and as the lowest one is 0, it becomes negative.
New observation / analysis with model discussed last time: 
CASE WITH $\text{fr} \times \text{taub} = 0.8$

Where does this instability come from with the damper?

- If one looks at the matrix to be diagonalized, it can be approximated by (with $x = -jZ\varepsilon$)

$$
\begin{pmatrix}
1 & 0.23 j x \\
0.55 j x & 0.92 x + 0.48 j
\end{pmatrix}
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Introduced by the transverse (+ resistive) damper.
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\[
\begin{pmatrix}
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0.55 j x & 0.92 x + 0.48 j
\end{pmatrix}
\]

- N.B.: Would be $+0.48$ for a + reactive damper

New observation / analysis with model discussed last time: CASE WITH fr $\times$ tau b = 0.8
New observation / analysis with model discussed last time: CASE WITH $fr \times taub = 0.8$

Where does this instability come from with the damper?

$$x = -j Z \epsilon$$

$$\text{Im} \left( \frac{\omega - \omega_y}{\omega_s} \right) + 0.48j$$
New observation / analysis with model discussed last time: CASE WITH $fr \times taub = 0.8$

Where does this instability come from with the damper?

$$x = - j Z \epsilon$$

$$\text{Im} \left( \frac{\omega - \omega_y}{\omega_s} \right) + \frac{0.48}{2} j$$
New observation / analysis with model discussed last time: CASE WITH $fr \times \tau_{ub} = 0.8$

Where does this instability come from with the damper?

$$x = - j Z \epsilon$$

$$+ \frac{0.48}{4} j$$
New observation / analysis with model discussed last time: CASE WITH $fr \times taub = 0.8$

Where does this instability come from with the damper?

\[ x = -j Z \epsilon \]

\[ + \frac{0.48}{10} j \]
New observation / analysis with model discussed last time: CASE WITH $fr \times taub = 0.8$

Where does this instability come from with the damper?

\[ x = -j Z \epsilon \]

\[ + \frac{0.48}{100} j \]

i.e. almost no damper
New observation / analysis with model discussed last time: CASE WITH $fr \times taub = 0.8$

Where does this instability come from with the damper?

\[ x = -jZ\epsilon \]

\[ \text{Im} \left( \omega - \omega_y \right) / \omega_s \]

i.e. using a REACTIVE damper
New observation / analysis with model discussed last time:
CASE WITH $fr \times taub = 0.8$

Where does this instability come from with the damper?

i.e. using a REACTIVE damper 2 times stronger
Conclusion

- The destabilising effect of the resistive transverse damper for $Q' = 0$ (single bunch) comes from the interaction between modes 0 and -1 through the damper.
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- The reactive damper is more efficient than the resistive one for this particular case (as found / discussed also in the past => See e.g. A. Burov: Efficiency of feedbacks for suppression of transverse instabilities of bunched beams, PRAB 2016). However, for $Q'$ not close to 0, the situation is different.
Conclusion

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- As the destabilising effect comes from the interaction between modes 0 and -1 it raises the question of the Landau damping: the dispersion integral we consider (most of the time) assumes independent modes. Can this explain the LHC instabilities with $Q' \sim 0$? => To be studied in detail.
Reminder:
Overview of 2015 single-bunch meas. vs. Q’ close to 0

Figure 4: Overview of single bunch measurements of instability threshold performed in 2015, plotted alongside DEL-PHI predictions for different damping times with an additional curve for the case where there is no damper.