Update on transverse stability studies for the 200MHz cavity HOMs

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Thanks to N. Biancacci, K. Li, E. Métinal, B. Salvant

LIU-SPS beam dynamic WG meeting

06/04/2017
Outline

• Introduction

• Impedance model used and stability simulations parameters

• Simulations results and remarks

• Conclusion and next steps
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Introduction

• Need to reduce the 620MHz longitudinal HOM
• Doing so might modify the 940MHz transverse HOM
• We want to assess the transverse stability margin supposing this mode grows when optimizing the 620MHz HOM

• Method: transverse stability simulations with DELPHI, crosschecked with Sacherer formula

• Follow up of the presentation on the 2/03/2017 meeting
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Impedance model used

• Existing SPS impedance model, the 200MHz cavities are replaced by a single HOM

• Resonator parameters
  • $f_{\text{res}} = 938.493 \text{ MHz}$
  • Resonance frequency chosen to fall on top of a coupled bunch mode line (worst case scenario)
  • Quality factor: 1000/10000/60000
  • Scan in shunt impedance: $10 \leq R_s \leq 10^8 \text{ M}\Omega/m$
Impedance model used

- Existing SPS impedance model stops at 1.9GHz

- Extended the base model up to 10 GHz to properly cover the higher azimuthal modes

- Checked that the resonator impedance is properly sampled, especially for higher quality factors

- Checked that the addition of the resonator to the base model doesn’t create discontinuities

- Ongoing work to include the transverse HOMs in the SPS impedance model
  - Simulations of the modes
  - Machine measurements (M. Beck)
Impedance model used

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\[ R_s = 10 \text{M}\Omega/m \]
\[ f_{res} = 938.493 \text{MHz} \]
\[ Q=60000 \]
Stability simulations parameters

• Growth rates obtained with DELPHI
  • Vertical plane
  • 4620 bunches (5ns spacing)
  • Single bunch intensity $10^{11} \text{ppb}$
    • For fixed target experiment, single bunch intensity is $\sim 10^{10} \text{ppb}$ but the results scale linearly with intensity
  • Zero chromaticity, no damper (conservative parameters)

• Crosscheck with Sacherer formula:
  • Approximate calculation of rise time and frequency shift:
    • $\Delta \omega_m = j \frac{1}{|m|+1} \cdot \frac{e^2 \beta N_b}{4\pi m_0 \gamma Q_{y0} \tau_b} (Z_{\text{eff}})_m$
    • With the effective impedance $(Z_{\text{eff}})_m = \frac{\Sigma_p Z(\omega_p) h_m(\omega_p)}{\Sigma_p h(\omega_p)}$
    • $h_m$ is the power spectrum
  • The growth rate $GR$ (in s$^{-1}$) is proportional to the real part of the transverse impedance
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DELPHI stability simulations results

Most unstable CB mode growth rate (DELPHI)

\[ N_b = 1 \cdot 10^{11} \text{ppb}, \ Q_p=0, \ \text{no damper} \]

![Graph showing growth rate vs resonator shunt impedance](image)

- For \( f_{res} \) on top of a coupled bunch mode line, the effect of the resonator starts to be seen at \( 10 \ G\Omega/m \leq R_s \)
Sacherer formula results

- With Sacherer formula for the same impedance model, the effect of the resonator is seen at $1 \text{ GΩ/m} \leq R_s$.
Sacherer formula results

- Sinusoidal modes are used for Sacherer formula
- The HOM will mostly drive azimuthal modes number 4 and 5
Results of simulations

• The HOM falls on top of the \( n_x=1451 \) coupled bunch mode. Both DELPHI and Sacherer formula find this mode as the most unstable

• DELPHI simulations show a higher shunt impedance threshold for \( Q=60000 \) (factor 5 compared to the lower quality factor cases)
  • This could come from the fact that the HOM is not exactly on top of a CB mode line or that at lower quality factor, multiple CB lines are overlapped by the HOM

• For all quality factors studied, Sacherer formula gives a lower shunt impedance threshold compared to DELPHI
  • Sacherer formula might overestimate the growth rates caused by azimuthal modes higher than 0 as showed by N. Biancacci (DELPHI studies on HOM driven growth rates and CB spectrum for crab cavities)

• Once scaled with intensity (single bunch intensity of \( 10^{10} \text{ppb} \)), the growth rate values for the baseline impedance are:
  • 1300 s\(^{-1}\) (33 turns) for DELPHI results
  • 2200 s\(^{-1}\) (19 turns) for Sacherer formula results

• This factor 2 on the baseline growth rates could also be explained by the overestimation of the higher azimuthal modes by Sacherer formula
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Conclusion

• New studies performed for a more critical case: HOM resonance frequency falling on top of a coupled bunch mode line

• For $f_{res} = 938.493 \text{ MHz}$, $Q=1000/10000/60000$ no impact on the baseline until $1 \text{ G} \Omega/m \leq R_s$ (Sacherer formula) or $10 \text{ G} \Omega/m \leq R_s$

Next steps

• Add the transverse damper and chromaticity to reproduce existing observations

• Perform the simulations for the Q26 optics (used for fixed targets)

• Study the sensitivity to the HOM resonance frequency
  • Have the HOM falling either on top or between two coupled bunch mode lines

• Add to the model the other transverse HOMs identified: one at 460MHz with $Q \approx 70000$ (P. Kramer). Estimated shunt impedance needed to reduce the number of variables

• Better understand the differences between DELPHI results and Sacherer formula, as the last method can give a quick results
  • Study Sacherer with Gaussian modes
References

• 1) E. Shaposhnikova, *Resonant impedances in the SPS*, SL-Note 96-49 RF
• 2) N. Biancacci, *Impact of transverse HOM on beam stability in the HL-LHC*, 10/12/2014
• 3) N. Biancacci, *DELPHI studies on HOM driven growth rates and CB spectrum for crab cavities*, 25/03/2015
• 4) R.J. Lauckner and T.P.R Linnecar, *The transverse coupled bunch mode instability at 940MHz in the SPS*, 03/09/1980
• 5) K.Y.Ng, *Coupling Impedances and Beam Instabilities in Accelerator Rings*, 2015
• 6) C.Zannini, *Electromagnetic Simulation of CERN accelerator Components and Experimental Applications*, 2013
Comparison of DELPHI and Sacherer growth rates

DELPHI modes

**N.Biancacci**

- Study of the instability growth rate driven by a transverse HOM with $R_s = 1.6 \, M\Omega/m$ per crab cavity, $Q = 1000$ and variable frequency. This means a total $R_s$ of $\approx 1.3 G\Omega/m$ for 16 cavities at $\beta_y = 3600$ m.

- Comparison with Sacherer sinusoidal modes with and without damper and $Q' = 0$.

![Graphs showing growth rates of different modes](image)

→ The damper can damp the mode 0 but not the mode 1.
→ It could be confirmed with HEADTAIL simulations.
CB mode lines and impedance

\[ R_s = 10 \, G\Omega/m \]

\[ f_{\text{res}} = 938.493 \, MHz \]

\[ Q = 10000 \]

\[ n_x = 1451 \]
CB mode lines and impedance

\[ R_s = 10 \text{G}\Omega/m \]
\[ f_{res} = 938.493 \text{ MHz} \]
\[ Q=60000 \]
\[ \text{nx}=1451 \]