Longitudinal instability thresholds on the SPS flat top
LIU-SPS Beam Dynamics Working Group

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Outline

Motivations

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- The HL-LHC goals achieved with tight margins by impedance reduction of vacuum flanges .
- Is there any other way to obtain the desired stability threshold ?

Impedance model

Impedance model

Current configuration

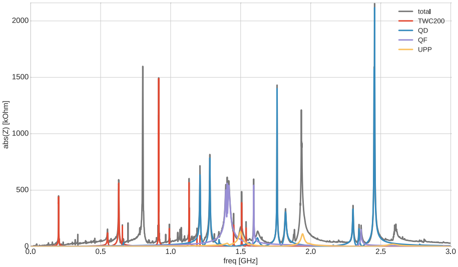
- TWC200
  - 2×4 sections + 2×5 sections.
  - 20dB reduction on main harmonic to modelize feedback.
  - 7 MV assumed, independent of beam current.
- - BPM - QD and BPM - QF.
  - QD type flanges.
- - QF type flanges.
- - 42 remaining unshielded pumping ports.

Future configuration

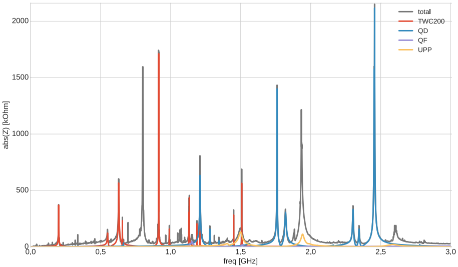
- TWC200
  - 4×3 sections + 2×4 sections.
  - 20dB reduction on main harmonic to modelize feedback.
  - 10 MV assumed, independent of beam current.
- \+ 3 sections
  - Main harmonic estimated using G. Dôme (CERN-SPS/ARF/ 77-11,1977).
  - HOMs reduced by 40% by comparing 4 and 5 sections.
- - 0 impedance for the BPM - QF.
- - QF reduced by a factor 20 assumed (J.Varela).
- - 25 remaining unshielded pumping ports.

Impedance model

- Current configuration



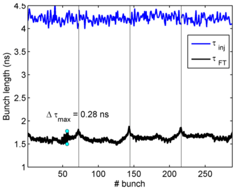
- Future configuration

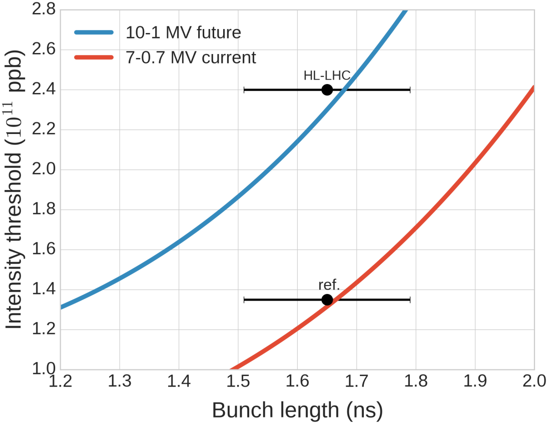


Instability thresholds at 450GeV for 72 bunches

Instability thresholds at 450 GeV for 72 b, 2 RF

- Comparaison now and after upgrade.
- TWC800 at 10%.
- HL-LHC intensity goal included.
- Reference measurement.





Instability threshold - Current situation

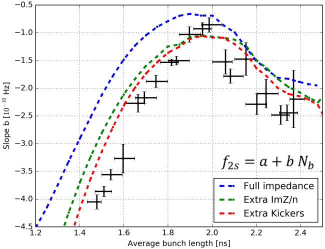
Instability threshold - Current situation - FT, 72 b, 2 RF

- Simulations based on the latest impedance model agree with measurements taking into account possible sources of errors.
  - The step in intensity used in simulations adds a $\pm 7\%$ error in threshold.
  - The voltage seen by the beam decreases with intensity due to beam loading. Not taken into account in simulations.
  - Bunch length variation in measurements due to beam loading and controlled emittance blow-up during ramp.
  - Measurements done with feedback, feed-forward and longitudinal damper on the TWC200.
  - In simulations TW800 kept at 10% in bunch shortening mode.
- Another source of impedance? $\rightarrow$ synchrotron frequency shift measurements.

Missing impedance

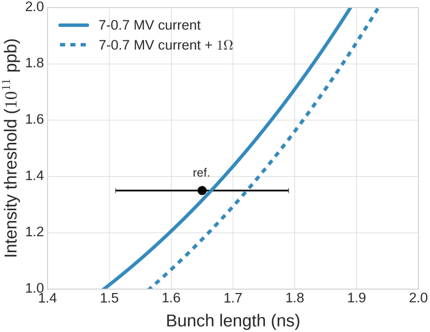
Missing impedance

- Simulations/measurements disagreement in synchrotron frequency.
  - Transfer function of measurement system lengthen the profile (up to 100 ps possible for short bunches).
  - Some inductive impedance seems to be missing.
  - Tough measurement due to control of the BL, need to be cross-checked.
- Adding 1 Ω pure inductive impedance improves agreement with measurements.
- Multiplying the kickers by 1.5 improves agreement too.



Missing impedance

- Simulations with 72 b at FT, 2 RF.
- The frequency dependence of the missing impedance is unknown.
- Adding 1 Ω lowers the stability threshold by 10% at 1.65 ns.
- Pessimistic result compared to the actual measurement.
- Missing impedance could come from loop in insulated VF (measurements needed).

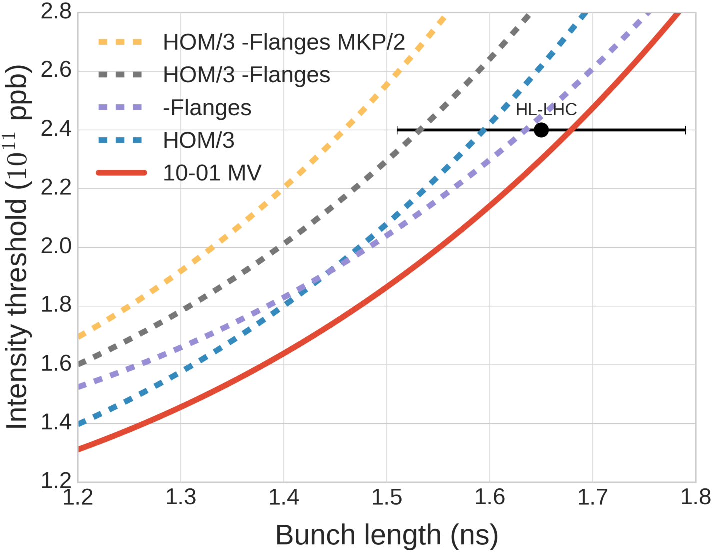


Instability thresholds - future situation

Instability thresholds - future situation - FT, 72 b, 2 RF

- To achieve **safely** the HL-LHC goals, impedance reduction of vacuum flanges is probably not sufficient. How can we gain some margins?
  - Reduce the 630 MHz HOM in TWC200. Difficult to have more than a factor 2 for the moment.
  - Act on the kickers (MKP, factor 2).
  - Act on all flanges?
  - The TWC800 stabilizes the beam, we can try to optimize its parameters.

Instability thresholds - future situation - FT, 72 b, 2 RF



How to reach HL-LHC goals ?

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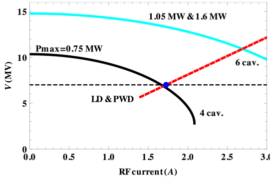
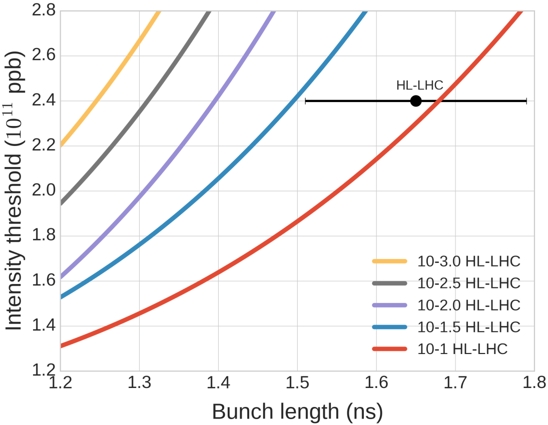
- Fourth harmonic cavity needed to stabilize the high intensity LHC beam.
- Used in bunch shortening mode.
- Ratio between TWC200 and TWC800 voltage set to 10% in operation.
- A second TWC800 is now operational, more voltage available (also function of beam current, up to 3 MV).
- We explored larger values of this ratio in simulations.

How to reach HL-LHC goal ?

- What happen through ramp?
- Voltage available changes with beam current.
- 10MV at $\sim 2.2 \times 10^{11}$ ppb.

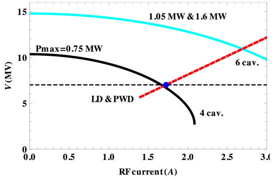


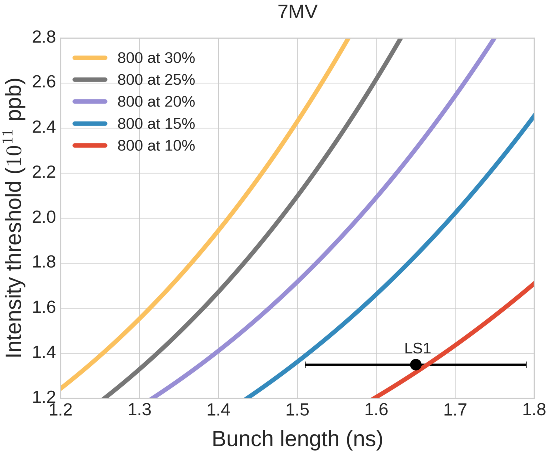


How to reach HL-LHC goals ?

- Increased ratio allows to reach easily LIU requirement.
- Huge margins to play with.
- Uncertainties in low level RF must be taken into account (phase shift from beam loading compensation).
- Ramp has to be simulated. Need speed up in simulation time, ongoing work (K. Iliakis).
- To compare with measurement, simulations with present model performed.

- Ramp still need investigations.
- Voltage available changes with beam current.
- 7MV at $\sim 1.4 \times 10^{11}$ ppb.

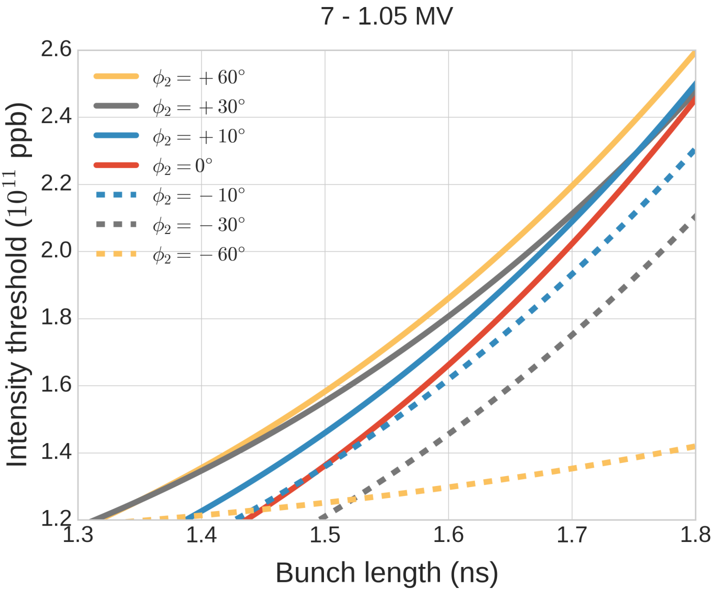




800 MHz - current situation

- The increase in stability threshold important in this case too.
- 25% gain at 1.65ns for TWC800 at 15%.
- Difficult to reproduce in operation, 7MV not available for more than 1.4×10^{11} ppb.
- MDs can be done to investigate for short bunches only.
- The uncertainties on the TWC800 phase introduces new question.
  - Synchrotron frequency distribution modified, new instabilities (possible loss of Landau damping).
- Simulations done to have an idea of changes with phase shift ϕ_2 ($V_{800}(t) = V_2 \sin(4\omega_{RF} t + \phi_2)$).

800MHz - current situation



800 MHz - current situation

- Non monotonic dependence on phase shift due to intensity effects.
- $\phi_2 = \pm 30^\circ$ w.r.t. the TWC800 moves instability threshold by ± 15 % at 1.65 ns.
- For very large values ($\pm 120^\circ$), beam unstable in this range of BL and intensity.
- Positive phase shift should be kept in operation to increase stability.
- MDs should be done to assess real phase in multibunch batches.
- Simulations required to explore behavior during ramp. Need speed up in simulation time, ongoing work (K. Iliakis)

Conclusion

Conclusion

- Simulations in current situation close to measurements. But a source of impedance is missing.
  - $+1\,\Omega$ of pure inductive impedance gives too pessimistic instability threshold for 72b at FT.
  - A source could be loop in insulated VF.
- We use now a model of impedance reduction after LS2 based on shielding from J. Varela assuming a factor 20 in the QF type flanges.
- Due to uncertainties in measurements and simulations, safety margins are needed to reach the HL-LHC parameters.
  - Increase in voltage of TWC800 gives large margin at 450 GeV.
  - Uncertainties in low level RF can change this threshold but we observe that $-60^\circ < \phi_2 < +60^\circ$, the gain is still important.
  - What happen through the ramp?