Update on stability limits and collimator impedance upgrade needs

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This is an ongoing work.

Impedance models (in particular HL-LHC) not yet finalized

> see later in HL-LHC annual meeting (11-15 Nov.).

Stability limits given are very preliminary (will evolve with our understanding of 2012 instability observations).
Update on stability limits and collimator impedance upgrade needs

- First LHC & HL-LHC impedance models
- Growth rates comparison
- HL-LHC stability limits for various scenarii
- Preliminary conclusions and future work
First LHC & HL-LHC impedance models

- LHC model in its current state contains:
  - resistive-wall impedance of collimators (2012 settings),
  - resistive-wall impedance of beam screens and warm vacuum pipe,
  - broad-band estimates from design report.

  All are weighted by local beta functions (0.6m squeeze in IP1 & 5).

- HL-LHC model (first version) is very similar:
  - resistive-wall impedance of collimators (HL-LHC settings from R. Bruce), with same materials as 2012 or with all TCSG (IR3&7) in molybdenum,
  - the rest as above.

  Again, all weighted by local beta functions (0.1m squeeze in IP1 & 5, from S. Fartoukh, June 2013 → pessimistic for impedance, but might be optimistic for $\beta$ functions in octupoles).
Comparison on vertical dipolar impedance:
First LHC & HL-LHC impedance models

Ratio of vertical dipolar impedances HL-LHC / LHC:

→ HL-LHC quite similar to LHC 2012, at high freq.

→ we gain a lot with Mo TCSG at high freq., but at low freq. the real impedance is slightly worse.
LHC / HL-LHC impedance comparison: growth rates at fixed intensity, with damper

- Growth rate (50ns) vs $Q'$ with 50 turns damper, for LHC (typical 2012 settings, 4TeV) and HL-LHC (7TeV), both with $1.7 \times 10^{11}$ p+/bunch (no Landau damping):

  → the gain for HL-LHC is due to the higher energy (7TeV),
  → with Mo the situation is much better.
LHC / HL-LHC impedance comparison: growth rates at fixed intensity, **without damper**

- **Growth rate** (50ns) vs $Q'$ without damper, for LHC (typical 2012 settings, 4TeV) and HL-LHC (7TeV), both with $1.7 \times 10^{11}$ $p+/bunch$ **(no Landau damping):**

\[
-\text{Im}(Q - Q_0)
\]

\[
\begin{align*}
\text{DELPHI, 2012} \\
\text{DELPHI, HL-LHC} \\
\text{DELPHI, HL-LHC with Mo TCSG}
\end{align*}
\]

→ at low chromaticity, Mo does not help when damper is off, and HL-LHC can be worse than LHC despite higher energy, → at $Q' \sim 15$, all growth rates quite similar.
Estimate of single-beam stability limits
for HL-LHC

Strategy:

➢ Based on 2012 observations to define the stability limit, with pessimistic assumptions:

→ 50ns beam assumed to be at the threshold of instability at 4TeV with

\[ I_{oct} = 510 \text{ A} \text{ or } -250 \text{ A} \text{ in the octupoles}, \quad Q' = 15 \pm 1, \]

\[ \varepsilon = 2.5 \text{ mm.mrad} \text{ norm. emittances}, \quad N_b = 1.5 \times 10^{11} \text{ p+/bunch}. \]

➢ For any intensity, compare imaginary tune shift \( \Im(\Delta Q_{coh}) \) (from DELPHI) of most critical mode for 25ns beam in HL-LHC with the one of 50ns beam in 2012 in the conditions above, and to get emittance at threshold assume:

\[ \frac{I_{oct} \cdot \varepsilon}{E^2 \cdot \Im(\Delta Q_{coh})} = \text{constant} \]

Note: additional (favourable) factor 3 on \( I_{oct} \) for HL-LHC due to higher \( \beta \) in many octupoles (10cm \( \beta^* \) optics).

➢ Since remains unclear the part due to coupled-bunch modes in the instabilities observed in 2012, we compute here stability limits for 2 scenarios:

with damper at 50 turns & without damper.
Preliminary estimate of single-beam stability limits for HL-LHC: 25ns, damper 50 turns

- Intensity limit vs emittance for HL-LHC with or w/o Mo TCSG, positive oct. polarity:

  \[ \Delta Q \propto N_b \]

From R. de Maria, 24/10/2013

\[ \rightarrow \text{all scenarios stable if 2012 instabilities were single-bunch,} \]
\[ \rightarrow \text{much more margin with metallic coll.,} \]
\[ \rightarrow \text{it depends also on } \beta^* \text{ and ATS optics (higher } \beta \text{ in octupoles)} \]
Preliminary estimate of single-beam stability limits for HL-LHC: 25ns, no damper

- Intensity limit vs emittance for HL-LHC with or w/o Mo TCSG, positive oct. polarity:

→ all scenarios unstable if 2012 instabilities were mainly coupled-bunch, → worse with metallic collimators.
Preliminary estimate of single-beam stability limits for HL-LHC: 25ns, no damper

- Intensity limit vs emittance for HL-LHC with or w/o Mo TCSG, negative oct. polarity:

  - Much better than with positive polarity,
  - All scenarios except US2 become (marginally) stable even if 2012 instabilities were mainly coupled-bunch,
  - All scenarios unstable with metallic collimators.
Preliminary conclusions and future work

- At high frequency, HL-LHC impedance close to LHC 2012 one for this first model. At low frequency, up to factor 3 higher for HL-LHC ($\beta$ functions higher for beam screens & vacuum pipe).

- Single-beam stability limits for 25ns beam for 10 cm $\beta^*$ ATS optics (depends on optics through $\beta$ in octupoles):
  - All scenarios stable with 50 turns damper if 2012 instabilities were purely single-bunch. Situation much better (much more margin) with metallic collimators.
  - All scenarios unstable if coupled-bunch modes were the main source of 2012 instabilities and if positive polarity in the octupoles is kept. With negative polarity, only US2 remains unstable. Metallic collimators always make the situation worse.
Future work

- Add many other elements in the models (most of them already computed):
  - More accurate geometric collimator impedance (M. Zobov & O. Frasciello),
  - Better described triplet region (see talk in July 2013),
  - Pumping holes and weld in the arcs, NEG coating of warm pipe,
  - MKI kickers and others.

- Analysis of previous instability observations:
  - Current work by D. Astapovytch to compare all single-bunch instabilities observations with model.
  - Comparison single-bunch / multibunch instabilities.