Single-beam instabilities update

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O. Frasciello & M. Zobov (INFN) for the geometric impedance of collimators

Summary of single-beam instabilities observed.

Recent refinement of the LHC impedance model.

New comparison between measured and computed single-bunch tune shifts for collimators.

Update of stability limits for several collimator scenarii if 2012 strategy maintained.

Some parameter space exploration.

Other ongoing efforts.
"Stability parameter" $\mu$ Oct * emittance / intensity, vs $Q'$ (the higher the worse for stability). Note: damper gain effect neglected & no blow-up.

→ no clear difference flat top / squeeze but big difference neg. / pos. oct.
Refining the LHC impedance model

- **Updates / additions to the LHC model:**
  - geometric impedance of collimators re-evaluated from Stupakov formula (pessimistic, maybe by factor 2), geometric wake function directly from GdFidl computations (M. Zobov & O. Frasciello - INFN),
  - refine resistive-wall impedance of beam screens and warm vacuum pipe, including NEG for the latter, effect of weld for the former (C. Zannini),
  - pumping holes impedance re-evaluated thanks to S. Kurennoy formula & A. Mostacci,
  - details of the triplet region (tapers – Yokoya formula, BPMs from B. Salvant),
  - Broad-band and high order modes of RF cavities (E. Haebel et al, CERN sl-98-008), CMS (R. Wanzenberg, LHC Project Note 418), ALICE and LHCb experimental chambers (B. Salvant).
  - Cutoff frequency of all broad-band resonators ”artificially” put to a very high value (50 Ghz), to avoid ”dip” in the wake at ~5cm.
Collimator impedance: old model (RW only)

- **Collimator tune shift measurements** (compared with resistive-wall impedance model + HEADTAIL)

![Bar chart showing discrepancy factor with model is ~2 for the tune shifts at low chromaticity.]

Discrepancy factor with model is ~2 for the tune shifts at low chromaticity.

IPAC'13, TUPWA047
Collimator impedance: new model (RW + geom)

- Collimator tune shift measurements (compared with RW + geometric – from Stupakov – impedance model, & DELPHI)

Discrepancy factor with new model + Vlasov solver is smaller: ~ 1.5!
Part of the improvement is due to a systematic difference between DELPHI and HEADTAIL.

Still, DELPHI might be more right in this case... (something similar seen between HEADTAIL & Laclare – PhD thesis 5305) → convergence of HEADTAIL has to be checked carefully for tuneshifts.

Another potential source of overestimation of tune sfhits: Stupakov formula, more pessimistic than GdFidl (see M. Zobov & O. Frasciello)
Tune shifts increase due to the geometrical impedance only:

→ effect of geometric impedance: at most 15-20%.
Estimate of single-beam stability limits after LS1

- **Strategy:**

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

    → beam assumed to be at the threshold of instability at 4TeV with
      \[ I_{oct} = 510 \text{ A or } -250 \text{ A in the octupoles}, \quad Q' = 15 +/− 1, \]
      \[ \epsilon = 2.5 \text{ mm.mrad norm. emittances}, \quad N_b = 1.5 \times 10^{11} \text{ p+/bunch}. \]

  - For any intensity, compare imaginary tune shift $\Im(\Delta Q_{coh})$ (from DELPHI) of most critical mode for post-LS1 with the one of 50ns beam in 2012 in the conditions above, and to get emittance at threshold, assume:

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

  - 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.
Estimate of single-beam stability limits for post LS1 LHC: damper 50 turns, **pos. oct.**

- Intensity limit vs emittance for single-bunch / 50ns / 25ns, with positive oct. polarity:

![Graph showing intensity limit vs emittance](image)

- All scenarios unstable except for 25ns beam (non BCMS) with relaxed collimator settings...

From R. Bruce
Estimate of single-beam stability limits for post-LS1 LHC: damper 50 turns, neg. oct.

- Intensity limit vs emittance for single-bunch / 50ns / 25ns, negative oct. polarity:

→ much better than with positive polarity,
→ most scenarios stable with relaxed settings (except BCMS 50ns),
→ classical 25ns stable in any case.
Estimate of single-beam stability limits for post-LS1 LHC: 50ns, no damper, neg. oct.

- Intensity limit vs emittance for negative oct. polarity:

→ all scenarios unstable if 2012 instabilities were mainly coupled-bunch.
→ all other cases without damper (25ns or positive oct.) are even worse.
Parameter space exploration: can we do better?

- Single-bunch / 50ns / 25 ns, with damper 50 turns: growth rates vs. $Q'$ for several scenarii (no Landau damping, 1.7e11 p+/bunch, hor. plane)

$\rightarrow$ large stability region at negative chromaticities, (-11<$Q'$<-5) for any settings (also in y),
$\rightarrow$ larger than at 4TeV,
$\rightarrow$ also tiny stability region for $Q'$~1.
Parameter space exploration: can we do better?

- Single-bunch with damper: "robustness" of negative $Q'$ stability region, w.r.t. longitudinal non-linearities (non-linear bucket & quadrupolar impedance) ($1.5 \times 10^{11}$ p+, "mm kept" coll. settings).

\[ \text{Graph: } \text{Growth rate in [s}^{-1}\text{] vs. } Q'_x \]\n
$\downarrow$ still large stability region at negative chromaticities, (-15 < $Q'$ < -5).
Parameter space exploration: can we do better?

- Single-bunch with damper: "robustness" of negative $Q'$ stability region, w.r.t. intensity: test with $3\times10^{11}$ p+/bunch ("mm kept" coll. settings)

$\rightarrow$ stability region not anymore here!
$\rightarrow$ still 2 "instability minima" remain, close to $Q'\sim -12$ and to $Q'\sim 1$. 
→ for a larger stability region at negative chromaticities, there seems to exist an optimum damper gain (reducing it could be beneficial...),
→ BUT this is with an ideal bunch-by-bunch damper ...
Other ongoing efforts

- Analysis & systematic comparison with HEADTAIL of single-bunch instabilities observed (2011-2012), by D. Astapovych (first talk in December 2013).

- Attempt to reduce, if possible, collimator impedance, thanks to:
  - Retraction of well chosen collimators (with R. Bruce & collimation team).
  - Further optimization of IR7 beta functions (with optics team).
Backup slide
Parameter space exploration: can we do better?

- **Effect of damper gain**: growth rates vs $Q'$ stability region ("mm kept" coll. settings, single-bunch, $3e11$ p+/bunch, single-bunch, hor.)