Collimation Aspects for Crab Cavities?

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Thanks to Daniel Wollmann for presenting this talk on my behalf (criticism and complaints please to my address…)

Crab Cavities and LHC Collimation

- Very complete study by Yi-Peng Sun *et al*
- Addresses many issues with a lot of detailed simulations and interesting insights, answering many of the previous questions.
- Details see this paper:

Beam Dynamics Aspects of Crab Cavities in the Large Hadron Collider

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Global Crab Cavity Program on One Slide

- Main machine changes:
  - One 800 MHz crab cavity installed in IR4, optimized for IP5.
  - Crab cavity detuned during injection, ramp & squeeze.
  - Ramped up after squeeze for ≥ 10 turns to ≈ 2.3 MV.
  - Compensation for limited voltage with (*one for β^*=0.55m, both for β^*=0.25m*):
    - Option 1: Decrease fractional horizontal tune to 0.05.
    - Option 2: Increase beta at IR4 crab location to 3 km.
  - Compensation for 0.5-1.0 σ decrease in aperture with either:
    - Option 1: Correct orbit to smaller maximum excursion (smaller margin).
    - Option 2: No squeeze in IR1, IR2, IR8.
  - Collimate head and tail of beam at 0.5-1.0 σ below the canonical 6 σ.
  - Slightly smaller tolerances for dynamic changes in orbit and beta beat (respect of collimation hierarchy).
  - Predicted 1-2 σ loss in dynamic aperture.
- Increase in luminosity to be measured in IP5 (decrease in IP1):
  - **4% (β^*=0.55m) or 14% (β^*=0.25m)**

Collimation-Related Issues I

- **Feasibility to collimate at lower gaps.** OK at 3.5 TeV!
  - Reduce collimation in steps from 6 σ to 5 σ for different intensities.
  - Verify that beam lifetime, impedance, stability, background, etc remain acceptable for lower collimation gaps.
- **Feasibility to work with reduced orbit margin.** OK at 3.5 TeV!
  - Correct orbit to smaller excursion such that more aperture is available.
  - Check stability with smaller horizontal tune.
- **Feasibility to work with reduced dynamic aperture.** OK at 3.5 TeV?
  - Measure dynamic aperture with increased IR4 beta and lower fractional tune.
  - Assess room in dynamic aperture, e.g. by reducing the achieved dynamic aperture by 2 σ.
- **Feasibility of slightly reduced operational margins.**
  - Understand operational margins and assess if critical at the 0.1 σ level.

Nominal margins not reached at 3.5 TeV! Critical…

Collimation-Related Issues II

- **Feasibility of non-closed crabbing** (single bunch, low I)
  - Ramp up cavity voltage to 2.3 MV, low tune or high IR4 beta.
  - Verify that collimation and protection hierarchy is maintained.
  - Verify acceptable beam lifetime and background.

To be assessed with beam tests…

Disclaimer: Collimation Hierarchy

- Up to 1 σ changes of horizontal orbit along a bunch would normally be incompatible with collimation hierarchy.
- This was the reason for the strong concerns put up from our side.
- Latest results show that the retraction is not much reduced by this x-z correlation.
- This is due to a cancellation between the crab induced x-z correlation and the dispersion offset of off-energy particles at the collimators (particles with z offset have also energy offset).
- This is very good news for crab cavities but **needs to be confirmed in detailed measurements** (effect of phase, optics, … errors?).
- Normalized distance between collimator families should be measured versus crab cavity voltage.

What About Low Emittance?

- It is proposed to use a low emittance beam to enhance the luminosity gain at top energy.
- We must note:
  - This idea relies on gaining normalized aperture with smaller beam size.
  - The gain in aperture is then used to increase the crossing angle, reducing the luminosity.
  - The increased crossing angle is then compensated with the crab cavities, resulting in larger luminosity gain to be observed (25%).
  - Requires that collimators sit at same normalized settings, meaning factor 2 smaller real gaps with low emittance (factor 1.4 with triplet upgrade).
- As for the TOTEM beam, this low emittance option cannot be guaranteed from the collimation side.
- The low emittance option imposes much tighter collimation and machine stability tolerances and is very difficult.
- Clear NO to rely on this option (should still try it).

What About Momentum Cleaning with Crab Cavities? (S. Fartoukh et al., LHC-CC09)

- This idea relies on using crab cavities to convert energy offsets into horizontal offsets such that particles are cleaned in the betatron cleaning system. Nice concept in principle.
- However, the LHC momentum cleaning system is most needed at the start of the energy ramp, to intercept un-captured beam as specified by the RF group.
- I assume that nobody proposes using crab cavities in the LHC at injection!? This would not work.
- Clear message: Crab cavities cannot replace the momentum cleaning system of the LHC.
- Possible benefit at top energy for such a system: Allows smaller β^* with triplet upgrade if limited by off-momentum β beat...
- Remember: Off-momentum β beat in one half of the ring.
- New solution for correction of off-momentum β beat as proposed by S. Fartoukh may solve that.

Conclusion

- The global crab cavity test in the LHC imposes major machine changes (high beta IR4, low Q_x, collimation at 5σ for head/tail, …).
- Should stick to the less demanding baseline scenario even if luminosity gain is smaller (no small ε, no "crab collimation").
- **No a priori show-stopper visible anymore** after quite impressive work progress over the last years. See paper by Yipeng Sun et al.
- Clear risks are still visible but also good potential:
  - 3.5 TeV experience looks encouraging for collimation depth, orbit and dynamic aperture.
  - Impact on tolerance budget most critical: did not reach nominal tolerances in 2010 – still far away.
  - Impact on collimation hierarchy theoretical OK but subtle cancellation effects must be verified in crab cavity tests with beam.

Backup

The Global Crab Cavity in IR4

- Explained before in detail…
- Meant as a demonstration experiment. Goals:
  - **Show that crab cavities do not disturb the beam.**
  - **Show that the predicted gain is really achieved.**
- Some price to be paid:
  - Not closed solution, so beam changed all around the ring.
  - Have to address issues that would be no problem for a closed solution, e.g. collimation and MP.
  - Additional issues can cause problems…