Transverse stability margins from non-conformities and/or beam damage

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Transverse stability margins (from impedance)

Motivation:

- Up to now, the impedance of the HL-LHC machine is assumed “ideal”, i.e. without any imperfections.

- The usual “factor of 2” currently applied to instability predictions (made with the DELPHI Vlasov solver) is **NOT a margin** but part of the full model itself – it represents the discrepancy currently observed between the Vlasov model and measurements.

⇒ What is the sensitivity of the stability situation to impedance imperfections or non-conformities?
Transverse stability margins – non-conformities

- How to study this:
  - The most critical part of the impedance is due to the resistivity of a few collimator materials, in a handful of collimators.
  - Most of the remaining impedance is geometric, and comes from a collection of geometric features distributed around the ring (e.g. pumping holes & tapers), rather than single objects.

  → we chose to study the impact of unforeseen changes of collimator materials resistivity, rather than that of geometric non-conformities which would typically be less dramatic if a single object is affected.

  → such resistivity modifications could actually occur because of irradiation or beam damage.

**DISCLAIMER**: this is a very VERY preliminary study.
In case of asynchronous beam dump, a 1mm-wide groove can appear in the 5μm-thick Cu-coating on the TCDQ jaws, possibly on the two first blocks (A. Lechner, C. Bracco) – precise FLUKA studies are ongoing.

Computations by B. Salvant in 2016 on the TDI with a 2mm-wide groove (~same half-gap of 4mm as TCDQ, but 2 symmetric jaws with Cu-coated graphite instead of a single jaw of Cu-coated CFC), gave a 13 times higher transverse impedance.

For the TCDQ, CFC is behind Cu ($\rho_{CFC} = 3\rho_{graphite}$), so in a first approximation the factor has to be rescaled by $1/\sqrt{3}$ ⇒ **7.5 times higher impedance**.
Second scenario: Mo coating resistivity

- According to the current specification (EMDS n° 2016583), Mo coating should have a smaller resistivity than 100 nΩm.

- In current measurements (and model): ~half this value: $\rho_{Mo} \approx 54 \, n\Omega$.  

- But what if we really have $\rho_{Mo} = 100 \, n\Omega m$?

- This is also an interesting scenario to study in case of degradation of the resistivity through irradiation along the run (see next slides).

S. Antipov et al,  
WP2 #161, 29/10/2019
Third scenario: fall back to CFC collimator

- We can imagine that we have to put back an old CFC collimator instead of an upgraded (Mo-coated Mo-graphite) one.

⇒ Let’s imagine we are not lucky and this happens for the worst (upgraded) TCSG collimator, namely the TCSG.D4L7 (here for B1).
More scenarios: effect of irradiation

- Resistivity of collimator might be affected by irradiation:

  C. Accettura, ColUSM #119, 13/09/2019

  See also summary talk by N. Biancacci, WP2 #173, 21/04/2020

Conclusion

- DPA and gas production quantities (H, He appm) were calculated using FLUKA for collimator materials to estimate radiation damage in collimator materials for HL era (1E17 protons lost in IR7).
- Assumption of perfectly aligned geometries and homogeneous materials
- Cross-check with radiation damage effects in BLIP capsule samples:
  - CFC, MoGR: 0.06 DPA, ~100 H, He appm, ~1500-2000 appm/DPA
  - Mo coating: 0.55 DPA, ~200-350 H, He appm, ~500 appm/DPA
- Calculations performed for current HL simulation baseline for IR7 and compared to previous simulation results:
  - Primary collimators: < 0.2 DPA, peak 50 H appm, up to 150 He appm locally due to focused impacts of primary beam particles, range of several 100 up to several 1000 appm/DPA over collimator length
  - Secondary collimators:
    - CFC, MoGR bulk material: ~1E-4 DPA, ~0.1 appm, range of several 100 up to several 1000 appm/DPA over collimator length
    - Mo coating: ~1E-3 DPA, < 2 appm, range of several 100 up to ~1500 appm/DPA over collimator length
    - Limited reduction of DPA in coating when comparing TCSPM.A6 and TCSPM.B5, 80% reduction in He appm

A. Waets et al, ColUSM #123, 31/01/2020
More scenarios: effect of irradiation

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**Conclusion**

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- Assumption of perfectly aligned geometries and homogeneous materials
- Cross-check with radiation damage effects in BLIP capsule samples:
  - CFC, MoGR: 0.06 DPA, ~100 H, He appm, ~1000-2000 appm/DPA
  - Mo coating: 0.56 DPA, ~200-350 H, He appm, ~500 appm/DPA
- Calculations performed for current HL simulation baseline for IR7 and compared to previous simulation results:
  - **Primary collimators**: < 0.2 DPA, peak 50 H appm, up to 150 He appm locally due to focused impacts of primary beam particles, range of several 100 up to several 1000 appm/DPA over collimator length
  - **Secondary collimators**:
    - CFC, MoGR bulk material: ~1E-4 DPA, ~0.1 appm, range of several 100 up to several 1000 appm/DPA over collimator length
    - Mo coating: ~1E-3 DPA, < 2 appm, range of several 100 up to ~1500 appm/DPA over collimator length
    - Limited reduction of DPA in coating when comparing TCSPMA6 and TCSPMB5, 80% reduction in He appm

**A. Waets** et al, ColUSM #123, 31/01/2020
More scenarios: effects of irradiation

- **“Small” irradiation**: are affected
  - Mo-Graphite in primaries: $\rho_{MoGr} = 1.7 \mu\Omega m$ (instead of $1 \mu\Omega m$)
  - Mo coating in secondaries: $\rho_{Mo} = 108 \text{ n}\Omega m$ (instead of $54 \text{ n}\Omega m$)

- **“Strong” irradiation**: are affected
  - Mo-Graphite in primaries: $\rho_{MoGr} = 5 \mu\Omega m$ (factor 5 higher)
  - CFC in primaries: $\rho_{CFC} = 15 \mu\Omega m$ (factor 3 higher)
  - Mo coating in secondaries: $\rho_{Mo} = 167 \text{ n}\Omega m$ (factor ~3 higher)
  - Mo-Graphite in secondaries: $\rho_{MoGr} = 1.7 \mu\Omega m$ (instead of $1 \mu\Omega m$)

**DISCLAIMER**: these are very simplified, preliminary scenarios in which one assumes the **whole jaw material** is affected **homogeneously** and in the same way in all collimators

$\Rightarrow$ in reality the **DPA** will be distributed **inhomogeneously** (longitudinal / transverse), and the overall effect probably **smaller**.
Impact on transverse impedance

- Impedance vs. frequency (zoomed around the main freq. of interest):

  ➢ Clear impact on impedance of the most pessimistic scenarios: **strong irradiation** and fall back to CFC for TCSG in D4.
  ➢ Much less impact for the others scenarios.
Impact on single-beam stability

- Relative difference in **octupole threshold** (with positive polarity) with HL-LHC parameters:
  - 25 ns beam
  - $N_b = 2.3 \times 10^{11}$ p+/b
  - $\varepsilon = 2.1 \mu$m
  - ADT gain: 100 turns
  - bunch length (4xRMS) = 1.2 ns
  - Distribution cut at $3.2\sigma$

$\Rightarrow$ No more than 20% impact on octupole current.
$\Rightarrow$ TCDQ grazing has a negligible impact.
$\Rightarrow$ Mo resistivity at spec. or small irradiation have an impact at the level of a few percents.
Other examples of non-conformity - HOM

- Unforeseen high order mode(s) in e.g. a cavity or collimator, whatever the reason, is a potential source of impedance, hence instability.

- Analysis (in the case of crab cavities) by N. Biancacci: limit in terms of shunt impedance, vs. frequency of the mode, to get a given, additional amount of octupole current needed to stabilize the beam:

![Graph showing single-bunch and multibunch scenarios](attachment:graph.png)

*N. Biancacci* et al., WP2 #56, 02/10/2015
Unforeseen collimator misalignment, is a potential source of increased impedance, hence instabilities ➞ to be further investigated by simulations, and an MD during Run 3.

Even a 100 μm orbit offset might increase impedance by 10-20%

S. Antipov et al, WP2 #161, 29/10/2019
Conclusions

- A number of non-conformity scenarios, in terms of materials resistivity, were preliminary investigated.

- Several are found to be marginally affecting the stability situation:
  - TCDQ grazing due to asynchronous dump,
  - a small irradiation of Mo coating and Mo-graphite of primaries,
  - Mo-coating at twice the currently measured resistivity (as in spec.).

- More pessimistic scenarios are instead affecting stability (in terms of oct. currents) by up to ~15-20%:
  - fall back to an non-upgraded CFC collimator (TCSG.D4),
  - a strong irradiation in primaries and also secondaries.

- Other examples of non-conformities:
  - high order modes (studied by N. Biancacci et al, for crab cavities),
  - collimator misalignments (to be further studied).