Collimation materials and designs: impedance motivation

N. Biancacci, E. Métral, B. Salvant

Measurements and simulations
by D. Amorim, N. Biancacci and G. Mazzacano

Internal workshop on collimation design and materials
May 2\textsuperscript{nd} 2017
Many talks on the subject recently
A lot of information was already presented at the HL-TCC by Nicolo.
Agenda

• Motivation for coating

• Lab measurements and possible improvements

• MD plan

• Long fingers

• Conclusion
Motivation

- The HL-LHC transverse impedance is largely dominated by collimators
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- The large collimator transverse impedance contribution is mainly due to the
  - Small gap of the collimators
  - High resistivity of the jaw material
- Therefore 2 methods to minimize this contribution
  - Increase the collimator gap (not really the baseline for collimation team)
  - Reduce the resistivity of the jaws: CFC $\rightarrow$ MoGr coated with 5 $\mu$m Mo
- Current HL-LHC baseline: replace the TCSGs in IR7 by low impedance collimators.
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  • Reduce the resistivity of the jaws: CFC → MoGr coated with 5 µm Mo
• Current HL-LHC baseline: replace the TCSGs in IR7 by low impedance collimators.

What can we gain:

• larger operational stability margin :
  • For standard 2-sigma retracted settings and possibility to operate with tighter settings.
  • In particular to help with destabilizing effect when cutting transverse tails.
Motivation

- The HL-LHC transverse impedance is largely dominated by the collimators contribution.
- The collimator transverse impedance is mainly due to the small gap of the collimators and the high resistivity of the jaw material.
- Impedance reduction technique: replacing the present CFC jaw collimators with "low impedance collimators" whose jaw material is MoGr bulk coated by 5um of Mo.
- HL-LHC baseline: replace the TCSGs in IR7 by low impedance collimators as they exhibit the largest impedance contribution among the present collimators.
- The impedance reduction would lead to a gain in octupole stability threshold, which allows larger safety margins in standard 2-sigma retracted settings and possibility to operate with tighter settings.
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- The HL-LHC transverse impedance is largely dominated by the collimators contribution.
- The collimator transverse impedance is mainly due to the small gap of the collimators and high resistivity of the jaw material.
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- The impedance reduction would lead to a gain in octupole stability threshold, which allows:
  - larger safety margins in standard 2-sigma retracted settings and possibility to operate with tighter settings.
  - "Immunity" from tail-related effects.

Predicted impact of cutting the transverse tails:
- Larger operational stability margin to help with destabilizing effect when cutting transverse tails.

Courtesy of N. Biancacci
Impact of collimator impedance in HL-LHC

- HL-LHC is more critical due to higher intensity
- With present CFC collimators, need according to simulations \( \sim 350 \text{A} \) octupole current
  - Perfect case – need margin for model errors (up to 50%)
  - Need to keep margin to counteract additional instability mechanisms (e.g. electron cloud)
- With tighter CFC collimators, would need 500 A
  - Not baseline, but could be considered for improved \( \beta^* \)-reach
- Solution: low-impedance secondary collimators
  - Gain close to 200 A in octupole current (TCP still in CFC in simulations)
  - Collimators will anyway have to be replaced due to aging and radiation damage

Simulations by N. Biancacci
HL-LHC v1.2, \( \beta^* = 48 \text{ cm}, Q' = 10, \text{LOF} < 0 \)

→ Large gain of stability margin for HL-LHC with the Mo coating
Agenda

• Motivation for coating

• Lab measurements and “possible improvements”
  • What measurements were performed?
  • Other measurements that could be done following the surprising results?

• MD plan

• Long fingers
Bench measurements on:
Single block of collimator jaw

- A single CFC block was produced with Cu and Mo stripes.
- The RF loop method was applied in order to deduce change in transverse impedance.

Measurements performed by G. Mazzacano and N. Biancacci
Bench measurements on: Single block of collimator jaw

- Overview of block material measurements between 2015/2016.

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- Generally in agreement with expectations.
- Mo coating always between 30 to 150 nOhm.m
- MoGr, CFC or C are always above or well above 1 µOhm.m (MoGr at ~1 and CFC at 5)
Lab measurements performed

• Transverse RF measurements on small blocks
  • Were performed and consistent with expectations

• RF measurements on collimator assembly
  • Were performed in a rush due to several issues (vacuum, blocked fingers)
  • Only for “quality control” to check for modes
  • Only longitudinal impedance (not transverse)
Bench measurements on full collimator assembly
Bench measurements on full collimator assembly: resonant modes

- Measured by the impedance team to validate the TCSPM for installation from the global LHC impedance point of view (only 2 days reserved due to previous delays, completed in 1 day). With more time, more accurate measurements of the transverse impedance could have been completed.
- Measured few resonant modes -> small shunt impedance, not expected to be harmful for stability.
Bench measurements on full collimator assembly:

- Bonus measurement: effect of the stripes from longitudinal impedance Vs X position
- Good relative agreement for TiN/Mo (Delta of ~0.1 Ohm)
- Unexpected lower impedance for MoGr stripe.
- Drop on Glid Copper (GC)
- Considerably larger longitudinal impedance than predicted.

This bonus measurement obtained in a rush is not consistent with expectations.
Simulating the longitudinal impedance

Checks made with CST simulations with Ti-MoGr-Mo as bulk:
- Negligible effect of the transition tapers.
- Negligible effect of change in $Z_c$ when moving the wire.
- Little effect w.r.t. wire (beam) offset.
- Reasonable agreement with IW2D.

Maybe bad contact resistances could explain part of the discrepancy with measurements.

$\Delta \sim 0.15 \, \Omega$
$\Delta \sim 0.2 \, \Omega$
$\Delta \sim 0.4 \, \Omega$

$\rightarrow$ Longitudinal simulations are consistent with expectations from conductivity difference.
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→ measurements are off compared to expectations by a large amount for all materials
Other measurements that could be performed?

• DC conductivity measurements on similar blocks (requested)

• RF bench measurements on similar blocks (requested)

• RF measurements (transverse this time) on another collimator assembly with similar blocks

• Everything we can learn on the TCSPM that was installed when it is taken out of the machine (electrical, RF and chemical analysis)

→ in case MDs confirm the surprising results on the full assembly and not the single block results.
Possible improvements

Allow:
- More time for collimator assembly measurements
- Some time to check the data and measure again in case of surprise.
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• Long fingers
MD request

Impedance

TCSPM

- New low impedance prototype collimator (TCSPM) installed.
- Has three stripes of different coatings which have different impedances.
- Would like to measure tune shifts of each stripe (need to kick with ADT/MKQA for tune measurements).
- **Can the TCSPM be moved along the 5th axis (to move from one stripe to another) while there is beam in the machine?**
- If not could use orbit bumps.
- To increase sensitivity, highest possible stable intensity could be considered.
- Single bunch at flat top needed, ~8-12 hours (probably).

Right image taken from:

Lee Carver, LHC MD day, 31 March 2017
Measurements plans for 2017

• Collimator impedance can be inferred by tune shift measurements. Example: $\beta_y = 70m$, flat top, 1.15e11ppb bunch intensity.

• We could measure the three materials moving at 4sigma (~0.75mm half gap) to be enough above measurement resolution.

• Higher intensity can enhance the effect (reached 1.9e11 in 1.5um).

• Moving at injection does not help: tune shift reduces as $\sqrt{\text{energy ratio}}$, i.e. ~1/4

• More refined estimations going on, also on stability if tail cut occur (S.Antipov)

• Alternative measurement techniques being explored: growth rate vs gap, stable phase shift

Settings at 6.5TeV (as for D4R7). $\beta_y = 69m$
7.5 sigma* <-> ~1.4mm
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TiN coating
Mo coating
MoGr bulk

Reached on D4L7
To be reached for TCSPM
~7.5 sigma
B.Salvant

~4 sigma
MD plan: checklist

• Was the commissioning of movement successful?

• Need to make sure that we are on the right stripe (both position and angle) → collimation team

• With tune shift measurements with gap:
  • Priority #1: check the hierarchy of materials
  • Priority #2: quantify the effective impedance
  • Priority #3: quantify the error

• If higher (full) intensity is allowed, check also all parameters, in particular temperatures and vacuum to spot potential issues with geometrical design.
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Strategy for mode mitigation from RF fingers task force

• Ferrite vs fingers:
  → several issues with ferrites in LHC
  → it is safer to avoid the mode at the source than to damp it
  → shielding with fingers is preferred when possible

• Recommendation for long fingers:
  • use funnelling
  • Here funnelling stops at very large collimator gaps
  • Risk? In conjunction with beam induced heating if bad contact?
    → EN-MME has the expertise
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• Summary
Summary and next steps

• Low impedance collimators with coating brings significant stability margin for HL-LHC

• The only bench measurements on full assembly are contradicting simulations and bench measurements on individual blocks.
  → important to follow up with further checks on similar blocks
  → important to get crosscheck with MD with TCSPM

• Are experts considering that the unfunnelled long fingers facing the beam are safe?
Thank you for your attention!
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Single block of collimator jaw

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Inferred resistivity for Cu stripe = (43 +/- 10) nOhm.m
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Inferred resistivity for Mo stripe: $(139+/- 38 \text{ nOhm.m})$

Very different behaviors w.r.t. wire position -> stripes can be distinguished.
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- Generally in agreement with expectations.
- Mo and TiN tends to have different behavior from case to case (impact of the measurement setup? Production process?)
- Would be useful to measure a 3-stripe block as for the TCSPM (MoGr bulk).
Outline

• Proof-of-principle of 3-stripes low impedance collimator

• Bench measurements on:
  • Single block of collimator jaw
  • Full collimator assembly

• Beam measurements results in 2016
• Beam measurements plans for 2017
• Conclusions and outlook
Beam measurements results in 2016

- Measured $3.9 \times 10^{-5}$, predicted $3.2 \times 10^{-5}$ tune shift with $\sim 1 \times 10^{-5}$ accuracy!
- See also D.Valuch et al. ColUSM #75.
Close agreement between theory and simulation!

TCP.C6*7 slightly under-estimated (factor \~1.8)

See also CWG #210
Beam measurements results in 2016

TCP in B2

- Close agreement between theory and simulation!
- TCP.C6*7 slightly under-estimated (factor \(~1.2\))
- See also [CWG #210](#)
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7.5 sigma* <-> ~1.4mm
*1sigma w.r.t en=3.5um
The “standard” procedure of single collimator tune shift measurement may be applied.

**TCSPM case:**
1. Set the beam orbit below a stripe
2. Perform series of gap open/close
3. Measure corresponding tune variation.
4. Move orbit (or collimator axis) and repeat.

Additional remarks:
- ADT excitation can be used.
- Damper, octupole and chromaticity settings are reduced.
- Kick strength is kept low to avoid losses and orbit intensity related drifts.
- At least 8h-12h (2 MD slots) time would be required to set up the measurements with additional complication of the orbit or 5th axis movement.
- To prevent instability due to tail cut we might need to open other collimators to lower the total machine impedance.