TCSPM Beam Tests at the LHC and Ideas for IR7 Low-Impedance Upgrade for LS2

A. Mereghetti, on behalf of the LHC Collimation Team

Many thanks to all teams involved in the work, especially to the LHC impedance team.
Outlook

- Introduction
- TCSPM Measurements at the LHC
- Ideas for IR7 Low-Impedance Upgrade for LS2
- Conclusions
• Introduction
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• Ideas for IR7 Low-Impedance Upgrade for LS2
• Conclusions
Introduction

- IR7 collimators account for a significant fraction of the LHC impedance budget, which has impact on beam stability;
  - IR7 is the location in the LHC with the largest fraction of LHC collimators;
  - The vast majority with jaws in graphite: TCPs and TCSGs;
  - Contribution of IR7 carbon collimators to LHC impedance budget enhanced by small gaps and large number of collimators in the same family;

- With respect to Nominal LHC parameters, HL-LHC foresees to double the bunch population and to reduce the normalized emittance;
  - Increased impact of collimators on impedance;
  - Increased load on collimators for the same beam lifetime!

- Extensive R&D program allowed to converge on:
  - MoGr as jaw material – to enhance robustness and improve impedance;
  - Mo as coating material of TCSGs – to further improve the picture in terms of impedance;

- Baseline upgrade of the LHC collimation system in view of HL-LHC:
  - Consolidation of present system (post-LS2 era):
    - Exchange 2 TCPs (H+V) with TCPMs (60cm, MoGr);
    - Exchange of 4 TCSGs with TCSPMs (1m, MoGr, Mo-coated);
  - Full HL-LHC upgrade (post-LS3 era):
    - Exchange the remaining 7 TCSGs with TCSPMs (1m, MoGr, Mo-coated);

Necessity to validate design with beam!

Actual slots not finalized yet!
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TCSPM Prototype

- The finalization of the TCSPM design required to verify with beam the beneficial effects of the material choice;
- During YETS 2016, a prototype of TCSPM was installed (LHC-TC-EC-0006) in slot D4R7.B2 for tests with beam:
  - Vertical secondary collimator;
  - Position characterized by the smallest beam $\sigma$ among the secondary collimators $\rightarrow$ ideal for impedance measurements;
  - In that same slot a regular TCSG is already present;
  - Three coating layers, to quantify beneficial effects onto impedance with respect to traditional TCSGs;
- During 2017, extensive MD campaign of tune-shift measurements in order to benchmark expectations (impedance model);
MD2193 (TCSPM): Single Stripe Impedance

- **Aim:** measure the **impedance** contribution from each TCSPM stripe and compare results against the TCSG nearby;
- **Impedance:**
  - Real part $\rightarrow$ instability threshold (octupole currents);
  - Imaginary part $\rightarrow$ tune-shift;
- **Depending on the collimator material and gap a different tune-shift is induced:**
  - Measurements carried out **cycling the collimator gap** and monitoring the tune signal;
  - Tune measured kicking the whole bunch and monitoring the damped oscillations;

**Measurements with the highest sensitivity**

![Graph showing TCSPM stripe position and Tune $Q_y$.](image)

<table>
<thead>
<tr>
<th>TCSPM stripe position</th>
<th>Mo</th>
<th>MoGr</th>
<th>TiN</th>
</tr>
</thead>
</table>

**Courtesy of D. Amorim**
MD2193 (TCSPM): Single Stripe Impedance (II)

Good agreement between measurements and expectations (ImpedanceWake2D, resistive wall + geometrical impedances);

Though measurements with Mo constantly x2 expectations
MD2191 (TCSPM): Impedance with HL-LHC-type Bunches

Same measurements as before, repeated with an HL-LHC-type bunch (~$1.9 \times 10^{11}$);

...measurements with Mo still constantly x2 expectations

...roughness of coating (5 µm) translates into a non-uniform / different thickness of Mo, with effects on impedance → ongoing studies (G. Mazzacano, ABP-HSC)

17th – 18th Sep 2017
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Consolidation of the LHC Collimation System in IR7 – post-LS2 Era

- As part of the consolidation of the LHC collimation system in IR7, it is foreseen to exchange:
  - 2 TCPs (H/V) in graphite (60cm) with TCPMs in MoGr (60cm);
  - 4 TCSGs in graphite (1m) with TCSPMs in MoGr (1m), Mo-coated;
  - Slots of the 4 TCSGs not finalized yet;

4 possible configurations proposed:
1. Reduce impedance as much as possible;
2. Avoid first two skew collimators (most exposed to steady-state losses);
3. Avoid H and V secondary collimators, for protection reason;
4. Avoid H secondary collimators only (ABD);

Finalization of choice could take advantage of more detailed estimations of impact on impedance and load on coating;
Impedance Considerations

Mo coating on IR7 TCSGs: machine impedance and octupole threshold reduced by ~ 30% if all TCSGs are exchanged;
→ 50% of the expected impedance reduction can be achieved exchanging only 4 collimators → LS2.2 offers the largest decrease

![Graph showing impedance reduction]
Load on Coating Layer

- Load on coating layer “roughly” estimated with tracking studies performed with the Fluka-SixTrack coupling:
  - Endep scored in a regular USRBIN mesh of Fluka, but transport thresholds cut EM part (including δ-rays from ionisation) and kills all hadrons but protons >1TeV;
  - HLLHCv1p3 – 2 optics considered:
    - β*=15cm, no TCLD;
    - EoS, without MQWA.5[L,R]7 (courtesy of R.Bruce);

<table>
<thead>
<tr>
<th>IR</th>
<th>Coll Family</th>
<th>Settings@15cm [σ]</th>
<th>Settings@FT [σ]</th>
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<tbody>
<tr>
<td>IR7</td>
<td>TCP / TCSG / TCLA / TCLD</td>
<td>5.7 / 7.7 / 10.7 / out</td>
<td>5.7 / 7.7 / 10.7 / 14</td>
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<tr>
<td>IR3</td>
<td>TCP / TCSG / TCLA</td>
<td>15 / 18 / 20</td>
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<td>IR6</td>
<td>TCDQ / TCSP</td>
<td>8.5 / 8.5</td>
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<td>IR1/5</td>
<td>TCT / TCL</td>
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<td>37 / out</td>
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<tr>
<td>IR2</td>
<td>TCT</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>IR8</td>
<td>TCT</td>
<td>15</td>
<td>37</td>
</tr>
</tbody>
</table>
Endep in Coating Layer (II)

TCSPM Fluka model originally by E. Skordis; → Improved to take into account the coating layer

Scoring mesh: 5μm x 400μm x 5cm

Development of cascades interrupted; → Showering from upstream collimators NOT taken into account;

Pre-processing script for automatic generation of Fluka geometry for coupled simulations upgraded to fully exploit LB capabilities (including per-collimator scorings)
Endep in Coating Layer (III)

First three skew collimators most impacted in post-LS2 era!

V plane more affected than H plane!!
B1H Loss Maps – $\beta^*=15\text{cm} – \text{IR7}$
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Conclusions

• Installation of TCSPM prototype in slot D4R7 during YETS 2016:
  • Played a key role in verifying with beam predictions of effects on impedance from the IR7 collimator upgrade for HL-LHC;
  • Three coating stripes (Mo, MoGr and TiN): important to prove Mo coating as best option impedance-wise, though measurements do not show a performance as good as predicted;
  • Verifications on effects from thickness of coating layer on-going;

• Consolidation of IR7 collimation system:
  • Planned to exchange:
  • 2 TCP (H/V) collimators (60cm, carbon) with TCPMs (60cm, MoGr, un-coated);
  • 4 TCSG collimators (1m, carbon) with TCSPMs (1m, MoGr, Mo-coated) → slots not yet finalized;
Finalization of Choice of TCSPM Slots (for discussion)

- **Option #2:**
  - Impedance-wise, the best one in terms of benefits;
  - Does not spare H/V TCSs;
  - Lowest effects on peak endep in coating layer;
- **Option #4:**
  - Impedance-wise, one of the worst ones;
  - It spares H TCSs (ABD);
  - Highest effects on peak endep in coating layer → could we use this configuration for a test with beam?
- **Option #3:**
  - Impedance-wise, the worst one;
  - Fully spares H/V TCSs;
  - High effects on peak endep in coating layer;
- **Option #1:**
  - Impedance-wise, not bad;
  - Does not spare H/V TCSs;
  - High effects on peak endep in coating layer;
Possible Follow-Up with Simulations

- Accurate Fluka calculations of endep in coating layer;
- Explore configurations with $1\sigma$-retraction;
- Characterize B2;
Spare Slides
Endep in Coating Layer

\[ \beta^* = 15 \text{cm} \]
B1H Loss Maps – $\beta^* = 15\text{cm} – \text{LHC}$
B1H Loss Maps – $\beta^*=15\text{cm}$ – IR7 DS
B1V Loss Maps – $\beta^*=15\text{cm}$ – LHC
B1V Loss Maps – $\beta^*=15\text{cm} – \text{IR7}$

- **B1V, none**
  - $\eta [\text{m}^{-1}]$
  - $5.33 \times 10^6$
  - $4.01 \times 10^6$

- **B1V, config1**
  - $\eta [\text{m}^{-1}]$
  - $5.12 \times 10^6$
  - $4.00 \times 10^6$

- **B1V, config2**
  - $\eta [\text{m}^{-1}]$
  - $5.17 \times 10^6$
  - $3.91 \times 10^6$

- **B1V, all**
  - $\eta [\text{m}^{-1}]$
  - $5.34 \times 10^6$
  - $3.85 \times 10^6$

- **B1V, config3**
  - $\eta [\text{m}^{-1}]$
  - $5.32 \times 10^6$
  - $3.92 \times 10^6$

- **B1V, config4**
  - $\eta [\text{m}^{-1}]$
  - $5.07 \times 10^6$
  - $3.96 \times 10^6$
B1V Loss Maps – $\beta^*=15\text{cm}$ – IR7 DS
B1H Loss Maps – FT – LHC
B1H Loss Maps – FT – IR7
B1H Loss Maps – FT – IR7 DS

B1H, none

$\eta [m^2]$

B1H, config1

$\eta [m^2]$

B1H, config2

$\eta [m^2]$

B1H, all

$\eta [m^2]$

B1H, config3

$\eta [m^2]$

B1H, config4

$\eta [m^2]$
B1V Loss Maps – FT – LHC

B1V, none

B1V, config1

B1V, config2

B1V, all

B1V, config3

B1V, config4
B1V Loss Maps – FT – IR7
B1V Loss Maps – FT – IR7 DS