First Results of the Compensation of the Beam-Beam Effect with DC Wires in the LHC

Outlook

- Introduction on the wire compensation.
- Experimental constraints and optimization of the wires settings.
- Experimental objectives and results.
- Benchmarking with simulations.
- Next steps and summary.
- Experimental tests of DC wires in SPS, RHIC and DAΦNE. Long range compensation never demonstrated in hadron collider with operational configurations → need for direct experiments in LHC.
The wire compensation principle I

1. The electromagnetic kick of the long-range beam-beam effect is similar to the one given by a DC wire.

2. Analogy of the wire field with standard multipole magnets $\rightarrow$ Resonant Driving Terms compensation [S. Fartoukh et al., PRST-AB 18, 121001]
Since 2018 four wire demonstrators have been installed in LHC (B2, IR1+IR5) with the aim to explore the potential of the wires in (L. Rossi, MOYPLM3).
Wire-in-collimator demonstrator

- LHC wire demonstrators are embedded in the jaw of operational tertiary collimators.
- 1-m long Cu wire of 2.48 mm diameter capable to carry up to 350 A.

Max Current
$I_W = 350\ A$

Courtesy of F. Carra

Courtesy of L. Gentini
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Longitudinal position of the wires

- The longitudinal position of the wires was determined by the present position of the collimators and the integration constraints.
- Symmetric position in the IR5.

<table>
<thead>
<tr>
<th>Wire demonstrator</th>
<th>s from the Interaction Point [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1, collimator not-used in operation</td>
<td>-176.17</td>
</tr>
<tr>
<td>R1, tertiary collimator</td>
<td>145.94</td>
</tr>
<tr>
<td>L5, IP debris collimator</td>
<td>-150.03</td>
</tr>
<tr>
<td>R5, tertiary collimator</td>
<td>147.94</td>
</tr>
</tbody>
</table>
The wire are installed in the crossing plane of the Interaction Region, i.e.,
- vertical in IR1,
- horizontal in IR5.

Given the constraints of the LHC collimation hierarchy, two classes of experiments were performed

1. **LI: Low Intensity** experiment (only 2 bunches in Beam 2) with wire-collimator just in the shadow of the primary collimators

2. **HI: High-Intensity** experiment (bunch trains in Beam 2) with wire-collimator at the operational position.

<table>
<thead>
<tr>
<th>Wire demonstrator</th>
<th>LI experiment</th>
<th>HI experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>beam-wire distance [mm]</td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td>-7.41</td>
<td>not powered</td>
</tr>
<tr>
<td>R1</td>
<td>7.42</td>
<td>9.83</td>
</tr>
<tr>
<td>L5</td>
<td>-7.15</td>
<td>not powered</td>
</tr>
<tr>
<td>R5</td>
<td>8.24</td>
<td>11.10</td>
</tr>
</tbody>
</table>

1 An $\varepsilon_n=3.5$ mm mrad assumed.
In the **LI experiment** the first bunch of B2 see only two head-on’s (in IP1 and IP5) and the second bunch experiences head-on and long-range encounters.

In the **HI experiment** we 3 trains with beam-beam interactions as during operation.
Wire current settings I

- The experimental setup allowed to minimize only two Resonance Driving Terms.

- We set the wire currents to compensate the \((4,0)\) and \((0,4)\) RDT: first order amplitude detuning.

- For the HI experiment, due the larger beam-wire distance, the current for the compensation is not compatible with the standard wire configuration.
In the wire-collimator, both jaws house a wire.

In the LI experiment only the wire of one single jaw was powered.

For the HI experiments the wires of both jaws were powered: this allowed to double the integrated strength of the quadrupolar, octupolar, etc., components.

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<tr>
<td>L1</td>
<td>350 x 1</td>
<td>not powered</td>
</tr>
<tr>
<td>R1</td>
<td>320 x 1</td>
<td>350 x 2</td>
</tr>
<tr>
<td>L5</td>
<td>190 x 1</td>
<td>not powered</td>
</tr>
<tr>
<td>R5</td>
<td>340 x 1</td>
<td>350 x 2</td>
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Objectives of the experiments

- Prove a beneficial effect of the wire demonstrators in a regime dominated by long-range beam-beam effect. The compensation should not degrade the lifetime of the head-on bunches.

- We need to guarantee the beam-wire alignment and that the linear effects of the wire (orbit and tunes) are compensated with feedforwards.

- The main observables are the beam losses, its lifetime and the bunch effective cross-section ($\sigma_{\text{eff}}$).
A rich experimental campaign was performed during the last 2 years: the compensation effect was systematically observed.
Low-Intensity experiment

Almost full compensation, even at reduced crossing angle, for regular bunch whereas head-on bunch not degraded.
HI experiment (operational conditions)

- Compensation provides a reduction of B2 losses of ~20%.
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Simulations of the LHC experiments

- The experimental configuration was simulated using Dynamic Aperture (DA) tracking.

- Correlation between DA and beam lifetime was studied in D. Pellegrini et al., Incoherent beam-beam effects and lifetime optimization, 8th LHC Operation Evian Workshop, 2018.

- Simulations show a large compensation area corresponding to the (4,0)-(0,4) RDT minimization. A clear effect on the compensation is also visible by parametric studies on the tunes space.
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Simulations of the HL-LHC case

- A systematic numerical study was performed for the HL-LHC scenarios (focusing on round optics).

- In the HL-LHC (round optics), up to 2 $\sigma_{\text{beam}}$ in DA can be gained with the wire compensation. The results suggest the possibility to trade-off beam-wire distance with wire current.

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Following these encouraging results, it was proposed:

- **to use the wires routinely** during the next LHC operation period in the High-Intensity configuration.
- **to equip also the Beam 1** with wires by moving two wire demonstrators (L1 and L5) from Beam 2 to Beam 1.

First iterations for a **HL-LHC wire design** are on-going.
Next steps and proposals

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  - to use the wires routinely during the next LHC operation period in the High-Intensity configuration
  - to equip also the Beam 1 with wires by moving two wire demonstrators (L1 and L5) from Beam 2 to Beam 1.

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Summary

- In 2017-18 a rich measurements campaign was performed to explore the potential of the wire compensation for HL-LHC. For the first time in a hadron collider, the positive effect of the compensation was systematically observed in operational-like conditions. Following these results we proposed to use the wire demonstrators operationally for the next LHC run.

- Simulation results are consistent with measurement and the explored scenarios confirm the wire potential for HL-LHC. It can relax the HL-LHC operation in several directions (crossing angle reach, aperture increase and beta* reach, triplet irradiation and available tune space).

- First iterations for a HL-LHC wire design are on-going. Our next objective is to prepare a proposal for a technical review.
Thank you for the attention.

On behalf of the HL-LHC wire compensation team