Stability of Linear Coupling in Run 2

T. Persson
Introduction

• Investigate the coupling stability at:
  - Injection
  - Flattop
  - Squeezed optics

• Timescales:
  - Short – Minutes to Hours
  - Long – Days to Months
Methodology and nomenclature

- $|C^-|$ is measured through a fit of the two corrections knobs that best fit the measurement
  
  $i.e. \quad |C^-| = \sqrt{\text{CORR}^2_{Re} + \text{CORR}^2_{Sm}}$

- The measurement is either carried out with the AC-dipole or the ADT-AC dipole
  
  - AC-dipole measurements gives better accuracy but can only be used with pilots
    
    - Lower kicks with the ADT
    - Uncertainty of the tunes → Removed with the new tune measurement
  
  - An error estimate from a single measurement is planned for Run 3
    
    - Error bars presented in this presentation are statistical error bars based on several measurements
Injection (short term)

- The decay has been linked to powering of the MCS (b3-spool pieces) attached to every dipole.
  - Change in $|C_-| = 3-4 \times 10^{-3}$ in $\sim 2h$
Measurement with and without MCS (Beam 2)

- Changing the $b_3$-error in the dipoles and the Main Sextupoles (green)
  → Small impact on the $|C^-|$  
- In the end of the test the $Q'$ compensation was switched to the MCS (red).
  → 4 times larger change in $|C^-|$  
  → The MCS have a larger impact on the coupling

Total time of the decay was about 2 h and corresponds to a change in $Q'$ of around 40 units.
Injection

- We have developed a mitigation strategy based on changing the powering of the MCS differently between the different arcs
  - Compensates the $Q'$ drift ($b_3$-compensation)
  - Compensated the global coupling drift in MD
  - Ready to be used in the next run
What about long term stability?

→ Fill-to-Fill variations but no drift of the setting of the coupling knobs throughout 2018
In general larger corrections after a technical stop
What about fill to fill?

The fill-to-fill variation is larger than what can be explained by just the coupling decay.

Larger corrections for Beam 2 than Beam 1. Interesting to understand but no impact for the performance since it is corrected at each fill.
Any changes due to intensity?

- Measured the coupling as a function of intensity at injection
  - No sign of a “skew” Lasslet
Summary injection and outlook

• Changes of the $|C^-|$ up of $\sim 10^{-2}$ between injections
  - Larger than just coupling decay from $b_3$
    → Interesting to understand the fill-to-fill variation

• The corrections strategy used in operation is to use a pilot and correct the coupling and tune → Fill-to-fill variation is corrected
  - Still a drift of the $|C^-|$ to be up to $(3-4) \times 10^{-3}$ in the end of the injection due to the $b_3$-correction
  - With the proposed uneven dynamic $b_3$-compensation : $|C^-|$ drift $< 10^{-3}$
Flattop
Short term Flattop

No indication of drifts of the coupling in time scales of hours at flattop (same for beam 2)
Long term Flattop

Beam 1, $\beta^* = 1 \text{m}$

No indications that the $|C^-|$ has drifted within the precision of the measurement in 2018

ADT
Squeezed
The drift on the coupling is within the measurement precision
→ Drift $|C^-| < 10^{-3}$ (Similar results for beam 2)
Prediction if no correction would have been applied
→ Beam 1: $2.5 \times 10^{-3}$ and Beam 2: $3 \times 10^{-3}$ in 6 months

AC-dipole
Measurements done with AC-dipole and pilots
Well corrected coupling at the end of the run.

Several corrections applied during the year!
Long term 2018 (squeezed)

The measurements support that the change of the $|C^-|$ was $\sim 1-2 \times 10^{-3}$ in 4 month

ADT
Potential explanations

- The tilt of the triplets are measured and recorded
  - Use these measurements as misalignment in MAD-X gives the following results (2016):

Waiting for 2018 data
Long range (squeezed)

Changed filling scheme

Trim of coupling knob (2*10^-3)

Time: ~1 week
Each point is from a different fill (except the last 4)

Measurements rather stable between fills but changes when the filling scheme changes.

ADT
Impact on long range on coupling (PACMAN coupling)

- Investigated during MD

A measurable effect in the order of $\sim 2 \times 10^{-3}$ for the 30 cm and 40 cm.

In commissioning we are correcting the “single bunch coupling” →

More studies and simulations should be performed to see if this is this best correction target.
Conclusion

- The coupling was drifting at injection in run 2
  - The fill-to-fill is corrected by OP with the use of the ADT coupling tool
  - A strategy to compensate the decay in place for Run 3
  - No measured effect of the intensity on the transverse coupling

- Flattop variation less than $10^{-3}$

- Squeezed:
  - Would have drifted $\sim 3 \times 10^{-3}$ in 2017 (6 month) but was corrected throughout the year with the ADT
  - Less precise measurement with the ADT in 2018 but indicates changes around $\sim 1-2 \times 10^{-3}$ in a 4 month period
Outlook

• Injection:
  - The new $b_3$ compensation together with the present correction procedure using the ADT AC-dipole will control the coupling to $\sim10^{-3}$
  - Fill-to-fill variations is interesting to understand from an academic point but has no impact on performance

• Squeezed
  - Regular measurements with the same configuration to determine and correct the changes in the coupling
    - Complement the measurements with the AC-dipole when possible (MDs)
  - The effect of LR on transverse coupling opens the question if the best thing is to compensate for the “single bunch” coupling
Backup
Long term 2018 (squeezed)

At 25 cm there seem to have been a drift of up to $2 \times 10^{-3}$. Note that the time do not align in time with the measurement of the 30 cm so not possible to compare.
Change in $C^-$ due to the MCS powering

<table>
<thead>
<tr>
<th>Arc</th>
<th>Even $[K_2]$</th>
<th>Uneven $[K_2]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCS.A12B2</td>
<td>0.004</td>
<td>0.0030535</td>
</tr>
<tr>
<td>RCS.A23B2</td>
<td>0.004</td>
<td>0.0034902</td>
</tr>
<tr>
<td>RCS.A34B2</td>
<td>0.004</td>
<td>0.0070352</td>
</tr>
<tr>
<td>RCS.A45B2</td>
<td>0.004</td>
<td>0.0027526</td>
</tr>
<tr>
<td>RCS.A56B2</td>
<td>0.004</td>
<td>0.0035134</td>
</tr>
<tr>
<td>RCS.A67B2</td>
<td>0.004</td>
<td>0.0055220</td>
</tr>
<tr>
<td>RCS.A81B2</td>
<td>0.004</td>
<td>0.0027993</td>
</tr>
</tbody>
</table>

The chromaticity between the two knobs were within 1 unit in the two planes
What about fill to fill?

The fill-to-fill variation is larger than what can be explained by just the coupling decay.
Larger corrections for beam 2 than beam 1.