Global Optimization of the Matching Section and Full Remote Alignment

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  • A. Herty, H. Mainaud Durand, A. Masi, M. Sosin [WP15.4]
  • J. Uythoven, M. Zerlauth, J. Wenninger [Machine Protection]

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  • D. Wollmann [WP7]
  • J. Metselaar, M. Sisti [WP9]
  • V. Baglin (WPL) [WP12]
  • M. Amparo [WP15.1]
Summary

- Full Remote Alignment
  - Present baseline and new proposal
  - Alignment strategy and required stroke
  - Advantages
  - New possibilities for full Matching Section Optimization

- Matching Section Optimization
  - The magnet system simplifications
  - The QRL-QXL optimization
  - The Cold Powering
  - The Warm Powering

- Conclusions
Full Remote Alignment
Full Remote Alignment and Matching Section Optimization

**Objectives**

- Reduce dose to alignment team
- Cope with Experiment vs. machine misalignment in RUN IV after the machine and experiment installation completion
- Yearly correct ground motion drift without man intervention in the machine
- Provide tool to eliminate or at least minimize the residual alignment error using beam as reference
- Cope with unexpected source of misalignment avoiding losses in performance of physics time

**By products**

- Gain aperture margin in various equipment
- Matching Section Optimization
- Reduce the requirement on the Matching Section orbit Corrector System
- Mitigate spurious orbit deviations in the triplet (simplifying non linear corrections)

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**FRA**

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**By products**

- Gain aperture margin in various equipment
- Matching Section Optimization
- Reduce the requirement on the Matching Section orbit Corrector System
- Mitigate spurious orbit deviations in the triplet (simplifying non linear corrections)
IP1 and IP5 HL-LHC
Synoptic of adjustment system only
Baseline vs Full Remote Alignment

- Motorized adjustment system, remotely controlled: adjustment during run, from CCC
- Manual adjustment system: adjustment during LS, YETS, TS, personnel in the tunnel, access in front of element (special for TAXS)
- Remote alignment compatible

Full Remote Alignment applied to HL baseline optics not to optimized one
Vacuum lay-out analysis and reconfiguration

Fixed
Remote aligned
Remote aligned
Remote aligned
Remote aligned
Remote aligned
Remote aligned
Remote aligned
Remote aligned
Fixed

1 DRF
DN (273) / ID 250

TAXN

Single bellow VM with ion pump (520 mm)
VVG – DN 100 / ID 100

D2

HC=6.7 / VC=6.9
VVG – DN 100 / ID 100

CC1

2 DRF
DN 150 / ID 80
HC=8.2 / VC=8.4

2 DRF
DN 150 / ID 80
HC=7.1 / VC=7.4

CC2

Courtesy WP12 team
## Possible alignment strategies with fully remote alignment

<table>
<thead>
<tr>
<th>Scheme 1: During operation or TS up 2.5 mm</th>
<th>Scheme 2: During TS Larger than 2.5 mm</th>
<th>Scheme 3: During YETS</th>
<th>Scheme 4: During LS 2 year RP cool down</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Machine conditions</strong></td>
<td>Machine operating conditions</td>
<td>Magnet cold but empty during movement</td>
<td>Magnet cold but empty during movement</td>
</tr>
<tr>
<td><strong>Max stroke</strong></td>
<td>+/- 2.5 mm</td>
<td>±10 mm (jack excursion other limits apply)</td>
<td>±10 mm (jack excursion other limits apply)</td>
</tr>
<tr>
<td><strong>Time required per IP side</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1 to D1</td>
<td>30 min</td>
<td>60 min</td>
<td>60 min</td>
</tr>
<tr>
<td></td>
<td>No access</td>
<td>No access</td>
<td>No access</td>
</tr>
<tr>
<td><strong>Time required per IP</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1 to Q5</td>
<td>30 min</td>
<td>2(L)+2(R) days</td>
<td>2(L)+2(R) days</td>
</tr>
<tr>
<td></td>
<td>No access</td>
<td>Access for int. components. De-interconnection of the RF guides (from time point of view this fits into a TS)</td>
<td>Access for int. components. De-interconnection of the RF guides (from time point of view this fits into a TS)</td>
</tr>
<tr>
<td></td>
<td>CD: NA</td>
<td>CD: &gt;12 mSv</td>
<td>CD: 2.8 mSv</td>
</tr>
<tr>
<td><strong>Time required per IP side</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1 to Q6</td>
<td>Not possible</td>
<td>2 TS</td>
<td>Measurement, computation and re-alignment in the YETS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TS1: measure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Between TS1 and TS2 compute</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TS2 realign</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NA</td>
<td>CD: &gt;13 mSv</td>
<td>CD: 3.2 mSv</td>
</tr>
</tbody>
</table>
The needed stroke

The Survey team has linked the experiment cavern movement with the ones of the LSS

- For the vertical plane via the deep references (GITL) that are in machine tunnel for ATLAS and CMS
- For the radial plane via the GISB references points that are in the UPS survey galleries

<table>
<thead>
<tr>
<th>Δz [mm/y]</th>
<th>Δr [mm/y]</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP1</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>IP5</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Δz 0.7 mm/y locally at 150 m from IP where the “new” LHC civil engineering join the LEP tunnel

The proposed value of \( \pm 2.5 \text{ mm} \) would allow covering the movements from LS to LS with a safety factor at least 2 (vs. 0.3 mm) avoiding major realignment intervention during other time slots.

Yearly changes shall be much smaller in the range of 0.2/0.3 mm
This meets the requirement of the experiment that asks for the possibility to compensate +/-2 mm of IP shift and fits with the experimental vacuum system design and capability

In addition at LS3 partial overcompensation in the vertical plane (even in the assembly position of the inner tracker as proposed by CMS) could be applied on the base of the measurement that will be taken during LHC RUN III, allowing to factorize in possible impact of the HL-LHC excavation that will have been completed in LS2

Courtesy WP15.4 team
Machine Protection
(As agreed with subset of the MPP, full discussion in MPP in the next weeks)

- Interlocks
  - Interlocks shall be implemented to avoid that nearby elements move separately in dangerous way, putting at risk the mechanical integrity
  - Key-type interlocks shall be implemented to avoid that the machine can be moved in non-safe conditions

- Machine re-qualification is required after each movement. This would make of the end of the TS the most suitable moment to intervene.
- Experience using the system will allow possible operational optimization
- Integrating part of the Full Remote Alignment is the tracking and logging of the movement of the elements/interconnects. This is needed to know their exact position before applying any correction

Results of initial verifications with J. Uythoven, M. Zerlauth, J. Wenninger, D. Wollmann.
Full discussion at MPP 09/11/2018
Orbit corrector strength requirements and aperture without and with remote alignment

Right Point 5, H crossing.

**Crossing:** ±295 μrad  
**Separation:** ±0.75 mm  
**IP Offset:** ±2.0 mm  
**Luminosity scan:** ±100 μm  
**Crab knobs:** ±1-0.5 mm (baseline only)  
**Imperfection (2σ):** from uniform distribution of mainly ±0.5 mm quad. Alignment and 0.5 mrad / 20 units dipole errors.

**FRA:**
- Orbit bumps reduced at the crab cavities
- IP offset performed by alignment
- Limited crab beam adjustment still possible

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>FRA</th>
<th>Base</th>
<th>FRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAXS</td>
<td>16.3</td>
<td>16.3</td>
<td>14.0</td>
<td>14.0</td>
</tr>
<tr>
<td>IT</td>
<td>12.0</td>
<td>13.1</td>
<td>11.8</td>
<td>12.7</td>
</tr>
<tr>
<td>TAXN</td>
<td>15.4</td>
<td>17.3</td>
<td>12.4</td>
<td>13.9</td>
</tr>
<tr>
<td>D2</td>
<td>15.5</td>
<td>18.6</td>
<td>12.9</td>
<td>14.7</td>
</tr>
<tr>
<td>Q4</td>
<td>14.5</td>
<td>18.3</td>
<td>10.4</td>
<td>13.0</td>
</tr>
<tr>
<td>Q5</td>
<td>24.8</td>
<td>28.2</td>
<td>17.6</td>
<td>19.9</td>
</tr>
<tr>
<td>Q6</td>
<td>25.5</td>
<td>25.9</td>
<td>18.0</td>
<td>19.3</td>
</tr>
</tbody>
</table>

**Increased corrector margin here applied already to reduce set of correctors**

Courtesy R. De Maria
Full Remote Alignment conclusion

- The deployment of the full remote alignment is feasible:
  - It satisfies the requirement and boundary conditions imposed by the experimental vacuum and experiment requirements
  - It can be made compliant with the Machine Protection requirements
  - All the systems between Q1 and Q5 can be made Full Remote Alignment compliant meaning
    - The vacuum system can be made Full Remote Alignment compliant with
      - Fix sections that provide sufficient aperture to move the beam inside in the $\pm 2.5$ mm range
      - Using when required Deformable RF bridge bellows
      - Having 2 sectors valves per IP side remotely moved on dedicated supports (total 8)
      - Having part of the vacuum system around the crab cavities fixed to the crab cavities and moved with them
      - Allowing to recover more sector valves from the LHC and allowing simplification in very tricky areas as the TAXN-D2
    - 5 collimators/masks per IP side will be equipped with their own dedicated alignment platforms (20 in total)
    - The equipment already foreseen on the triplet will be made more redundant and robust in order to be compliant with the requirement of a system that becomes an operational knob
  - The total cost the deployment is in the original ballpark figure presented at Chamonix 2018
Matching Section Optimization

..... Going back to basic bricks of engineering...
The Large Hadron Collider
The Matching Section Optimization

By products

Gain aperture margin in various equipment

Matching Section Optimization

Reduce the requirement on the Matching Section orbit Corrector System

Opportunities

Re-use present LHC Q4 and Q5 at 4.5 K

Re-optimize the cryogenic distribution reviewing the limits between QRL and QXL

Review the capacity of the foreseen cryo plants at P1 and P5 (and also P4 sect 4-5)

Reduce the number of circuits for the correctors, leading to a reduction of the number of associated Power Converters

Limit the modifications to the DSL: the superconducting link presently feeding the Matching Section from Q6 till D2

Relax the design requirements on the TCLX and TCTX, reduce aperture TAXN for improved protection

FRA

HL – LHC integration team: dreams that shape the reality
Layout changes

Changes with respect to the baseline:

- Q4: reusing existing LHC Q4 cold mass (3 correctors instead of 4), no need of 1.9 K.
- Q5: reusing existing LHC Q5 cold mass (1 corrector instead of 3), no need of 1.9 K.
- Full deployment of remote alignment system to be used with safe beam.
Q5 Left and Right in IR1&5
- Moved of 10.5 m towards the DS
- Polarity remain the same
- Correctors have to act in the same plane
- Both beam screens rotated by 90°
- Temperature remains 4.5K
- Jumper height to be checked if the QRL changes

⇒ Q5 will be reinstalled at their current location after beam screen rotation on surface

Q4 Left and Right in IR1&5
- Moved by 10.5 m towards the DS
- Polarity remain the same
- All correctors have to act in the perpendicular planes
- Correctors positions better in the IP side
- One beam screen rotated by 90° (VV⇒HV)
- Temperature remains 4.5K
- Cryogenic distribution to be adapted (Semi-standalone ⇒ Standalone)
Fulfilling Q4 Optics requirements

Q4L1&5

MQY

Q4R1&5

MQY

Allowing to have level gauges and Temp sensors in the highest side

Hilumi
HL-LHC Project

Courtesy H. Prin

HL – LHC integration team: dreams that shape the reality
From D2 – Q4 (LHC) to Q4 (HL-LHC)
Cooling capacity: is it enough?

Refrigerator Assessment

Results based on model v.3, for existing LHC refrigerators only

Cooling capacity margins will be aligned on other sectors (5-6 higher as no IT nor RF)

No “weak point/sector” created with this alternative
QRL / QXL optimisation in Right of 5

1. Translation of present QRL modules between Q4 and Q5
2. Translation of D2 service module, and use it as 2nd service module for Q4
3. We leave QRLWZ and Q6 service module in place
4. New QXL - QRL Junction Module (11.4 m to be further optimised to avoid interference with CC2 area)
5. New QXL
6. Adaptation pipe elements
7. Jumper extension

Present LHC machine and QRL layout

Courtesy J. Metselaar, M. Sisti and WP9 team
<table>
<thead>
<tr>
<th>Quadrupole</th>
<th>Baseline</th>
<th>Optimized approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q4</td>
<td>MQY</td>
<td>MQY</td>
</tr>
<tr>
<td></td>
<td><strong>1X HCRPHRA R2E-LHC4-6-8kA+08V</strong></td>
<td><strong>1 X HCRPHRA R2E-LHC4-6-8kA+08V</strong></td>
</tr>
<tr>
<td>Correctors</td>
<td><strong>8 MCBY</strong></td>
<td><strong>6 MCBY</strong></td>
</tr>
<tr>
<td></td>
<td><strong>8 X HCRPLBC R2E-HL-LHC120A-10V</strong></td>
<td><strong>6 X HCRPLBC R2E-HL-LHC120A-10V</strong></td>
</tr>
<tr>
<td>Q5</td>
<td>MQY</td>
<td>MQML</td>
</tr>
<tr>
<td></td>
<td><strong>1 X HCRPHSB R2E-LHC4-6-8kA+08V</strong></td>
<td><strong>1 X HCRPHSB R2E-LHC4-6-8kA+08V</strong></td>
</tr>
<tr>
<td>Correctors</td>
<td><strong>6 MCBY</strong></td>
<td><strong>2 MCBC</strong></td>
</tr>
<tr>
<td></td>
<td><strong>6 X HCRPLBC R2E-HL-LHC120A-10V</strong></td>
<td><strong>2 X HCRPLBC R2E-HL-LHC120A-10V</strong></td>
</tr>
<tr>
<td>Q6</td>
<td>MQML</td>
<td>MQML</td>
</tr>
<tr>
<td></td>
<td><strong>1 X HCRPHSB R2E-LHC4-6-8kA+08V</strong></td>
<td><strong>1 X HCRPHSB R2E-LHC4-6-8kA+08V</strong></td>
</tr>
<tr>
<td>Correctors</td>
<td><strong>2 MCBC</strong></td>
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<td><strong>2 X HCRPLBC R2E-HL-LHC120A-10V</strong></td>
</tr>
</tbody>
</table>

Warm powering simplification

Courtesy M. Martino
DSL optimisation in Right of 5

Present LHC machine and QRL layout

HL-LHC Matching Section Optimization layout

LHCDSLE_00

LHC Layout DSLE

HL-LHC Layout DSLE

 Courtesy S. Claudet, A. Perin and WP6A
Conclusion
Matching Section Optimization

A re-optimization of the Matching Section is Point 1 and Point 5 is possible and it would lead to:

- Magnet system:
  - Re-use of the LHC Q5 units with minor modifications
  - Re-use of the LHC Q4 units: jumper shall be turned and second jumper shall added to recover D2 jumper functionality and minimize interventions

- Cryogenic system
  - The present QRL can be modified in order to cryogenically feed the Q4 and Q5 in their new optical positions (collaboration between optics and cryogenics it has been instrumental to find the best solution that has also opened optimization opportunities on the DSL modifications).

  - The return module between the QRL and QXL can be integrated in a new position thanks to the suppression of the options for the second batch of crab cavities. Junction module still requires further optimization
  - The cryo plant power shall be adapted to the new configuration: decrease in the power installed in P1 and P5. P4 capacity for Sector 4-5 needs to be re-evaluated if needed

- Warm powering
  - As corrector circuits are suppressed the corresponding Power Converters are not necessary any more

- Cold powering
  - The DSL modification can be significantly reduced and the fact of keeping the distance between Q4→Q5 fixed from LHC to HL-LHC would allow to rigidly translate those segments of the system

- The above listed actions allow to reduce the linked costs
Conclusions

- The Full Remote Alignment
  - Can be deployed
  - It will be beneficial to reduce radiation to personnel
  - It will increase the window for machine optimization (larger margin in aperture margin and lower $\beta^*$ reach)
  - Less pressure on orbit corrector system
  - Higher machine flexibility and reduced reaction time
  - It opens the possibility to re-optimize the Matching Section

- The Matching Section can be re-optimized
  - Reducing the amount of work to be performed and the extension of the LHC machine modifications
  - It simplifies the design of few elements as i.e. the collimators

- The combination of the two actions make possible a sizable saving for the HL-LHC project
Thanks to everyone, but a special thanks to
Riccardo De Maria

Delio Duarte Ramos

Herve Prin
Michele Martino

Daniel Wollmann

Michele Sisti
*(the character is called Captain Cold)*
Thanks to all the crew of the remote alignment study team
Among others
Andreas Herty, Jan Hansen
A personal “thank you” to them in having helped mitigating this exercise secondary effects on Serge and myself.