Machine Protection and Operational Aspects of the Full Remote Alignment System

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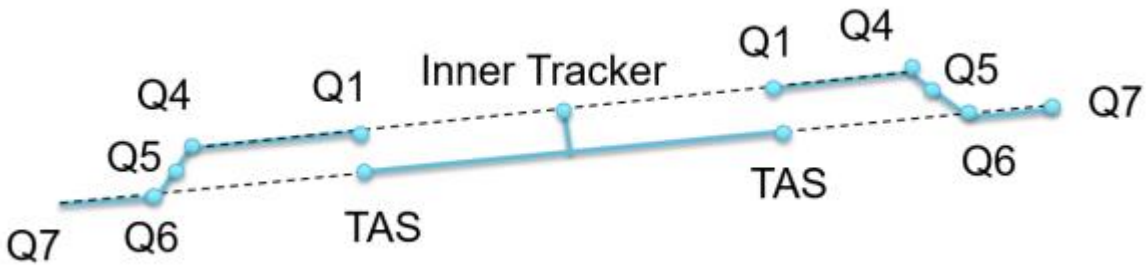
Outline

- Machine Protection and Operational Aspects of the Full Remote Alignment System
  - Definition and experience so far
  - What Machine Protection does not treat
  - Hardware Interlocking
  - Software Interlocking
  - Procedures
  - Crabs and BBLR
  - Conclusions

HL Remote Alignment System for IT

- Remote alignment of machine elements between Q1 and Q5 L/R of IP1 and IP5

Max remote stroke: ± 2.5 mm



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2166298	0.9	DRAFT

REFERENCE : LHC-_-ES-0044

FUNCTIONAL SPECIFICATION

FULL REMOTE ALIGNMENT SYSTEM

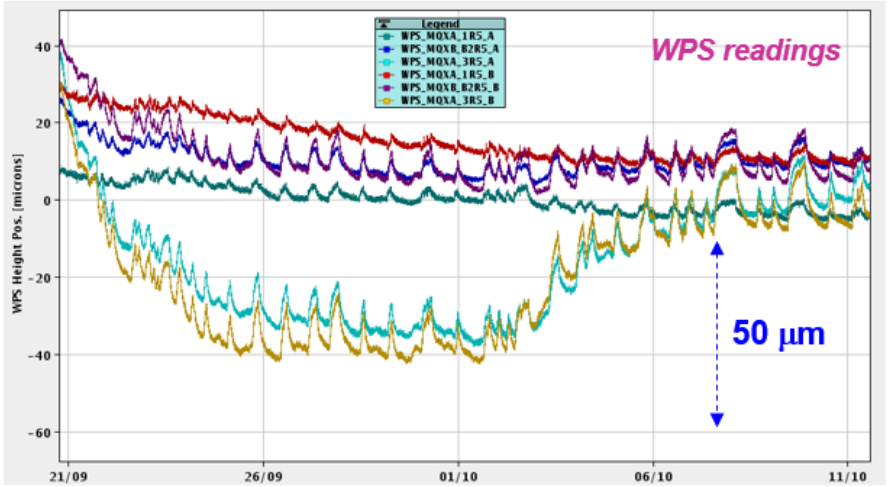
Abstract

This document concerns the Full Remote Alignment System (FRAS) implemented in the LSS1 and LSS5 for the HL-LHC project. It first describes the functional requirements of the FRAS. It then reviews the impact of FRAS on the components.

See also:
P. Fessia in MPP meeting 9/11/2018 and HL TCC 15/11/2018

Present Interlocking of Triplet position

- Actual triplet can already be remotely re-aligned
- No connection to the Beam Interlock System
  - Protection to move with or without beam based on
    - Key required to power motors
    - In possession of the Survey group – their responsibility
- Software Interlock System
  - Injection BIS interlocked by SIS, stops injection if any WPS sensor is more than 250 µm away from reference value
  - It never stopped the beam (JW)
  - SIS interlocking on motors was disabled; too many false triggers



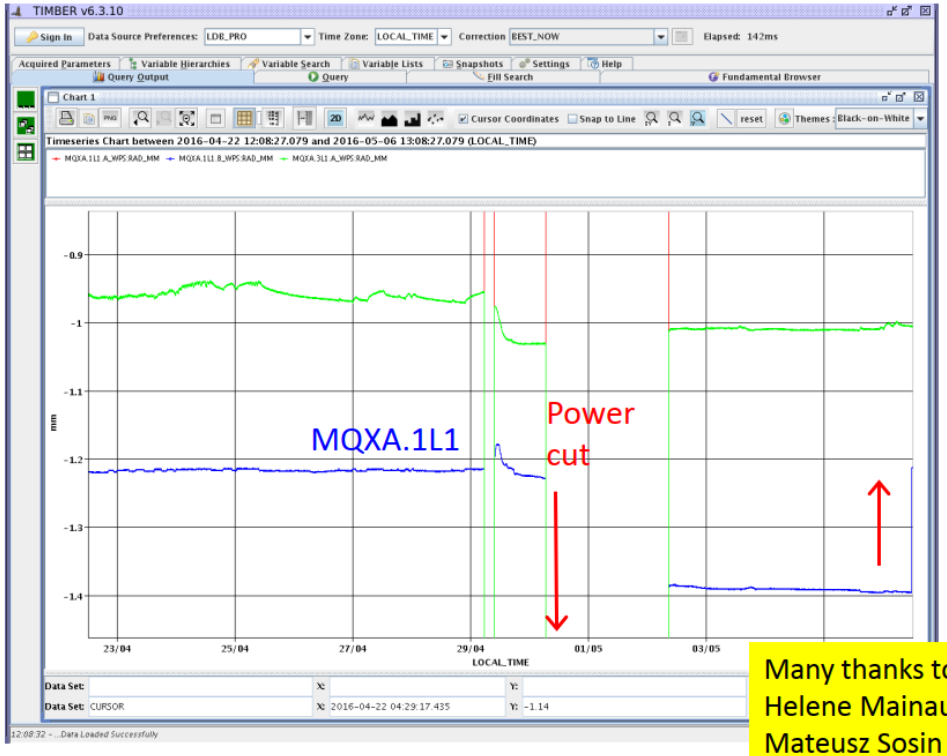
Triplet R5 'walking away' after a TS (Sep-Oct 2017)

Experience so far

- See also presentation by Jorg in Full Remote Alignment Specification meeting 12 June 2019
  - https://indico.cern.ch/event/808303/
- Includes Operational aspects and Machine Protection aspects. It makes reference to two occasions when remote alignment was used
  - 6 May 2016 after the weasel event → warm-up / cool-down cycle caused triplet to move
    - Re-aligned remotely **without** beam, moved it back
    - Use WPS for reference. Still in re-start phase of the machine, with loss maps and intensity ramp up, 3 bunches, see link to slide of 830 meeting.
    - No issues

Remote alignment 6 May 2016
IT 1L1

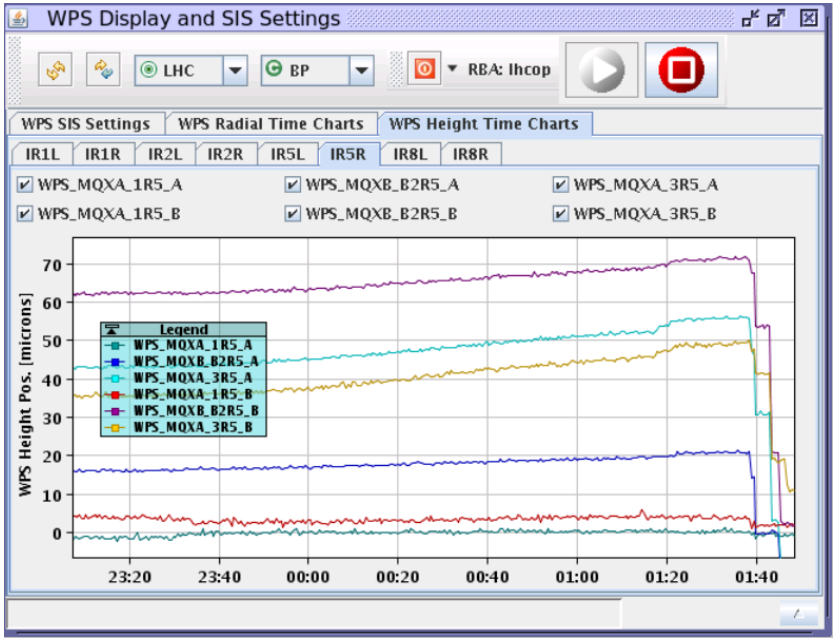
IT movement (Horizontal)



Many thanks to EN-ACE-SU
Helene Mainaud Durand
Mateusz Sosin

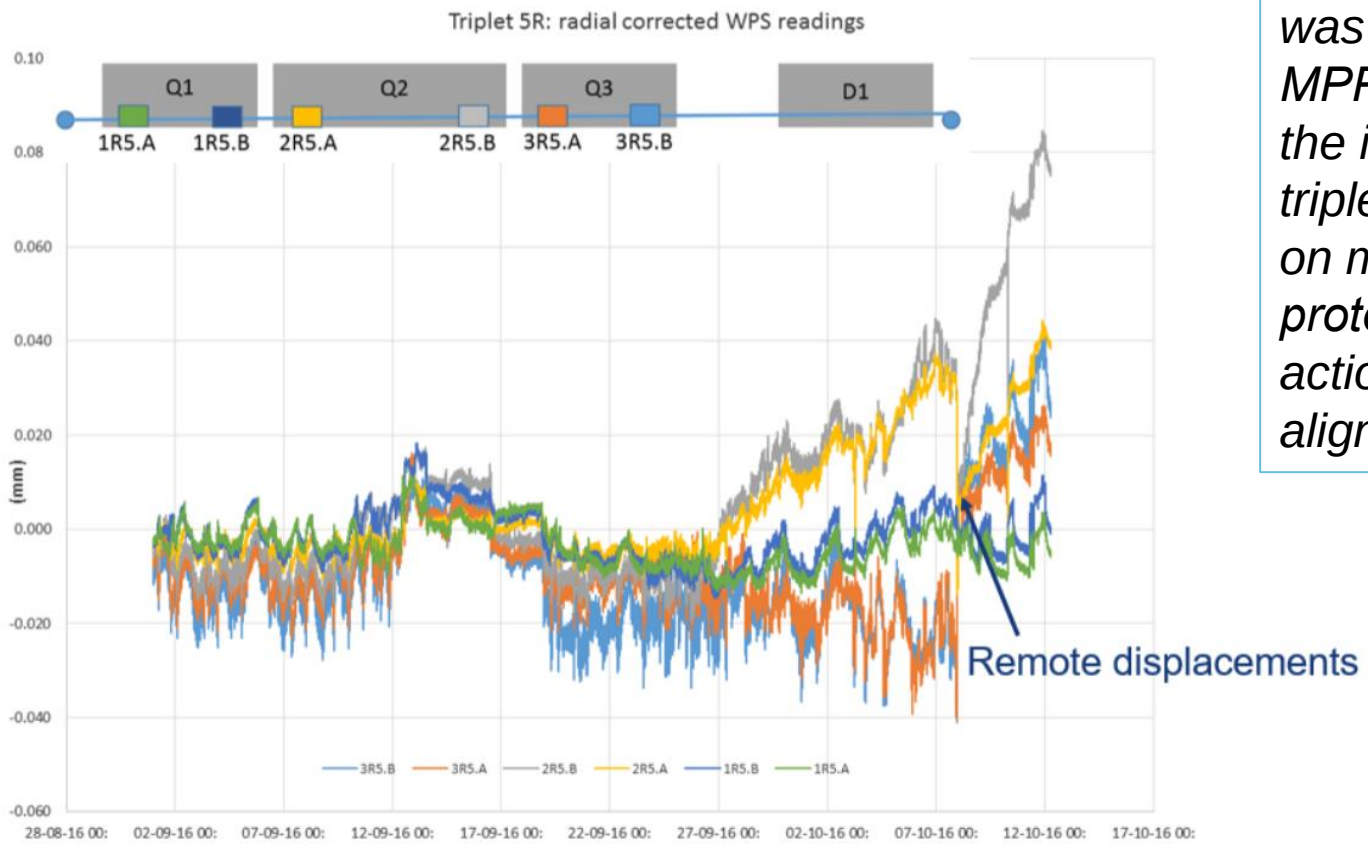
Only one re-alignment with beam

- Saturday 8/10/2016 @ 01:30. Re-alignment of R5 triplet in H and V-plane at injection energy
  - Experience was good, see report 830 meeting here
  - Followed by a 2 bunch fill
  - Followed by betatron loss maps in collision
  - Followed by 10 bunch fill
  - Discussion on what needed to be done *at the moment of the action*, no agreed upon procedures, not treated in the MPP meetings
    - Not satisfactory



LMC 12/10/2016, HMD
Not mentioned that re-alignment was with beam

Radial data since September 2016



In this LMC there was an action for MPP to "understand the impact of the triplet movements on machine protection". Not an action on remote alignment.

The Risks

- During and following Remote Alignment of the elements between Q1 and Q5 the following risks have been identified
  - Related to Equipment Protection

    - Vacuum leaks because of bellow movements > limit
    - Cryogenics leaks because of mechanical limits
    - Loss of mechanical integrity
  - Related to Machine Protection

    - Beam induced damage to any equipment in the machine during or after the remote alignment – performed with or without beam

Hardware Interlocks: Proposal

- During normal operation the motors driving the movement of the system should have no power
- The motors can be powered by turning a key
  - This key can be in the CCC cupboard and ideally the ‘lock’ in the CCR (preferred). Turning this lock it will
    - Power the motors for remote alignment in IP1 or IP5
      Propose to have one key for IP1 and one key for IP5
    - Will activate a maskable interlock to the Beam Interlock System (BIS). Connection to the BIS in IP1/IP5
    - The system can only be used when there is no beam or ‘safe beam’. Unsafe beam will be dumped. The beam intensity and energy limit is determined by the Safe Machine Parameter flags
  - Very similar solution as used for the Aperture Kicker (MKA) in Point 4. Only difference is that for MKA there is no danger when operated without beam.
  - *Re-aligning magnets with beam at injection, using a pilot bunch, is probably safer than re-aligning without beam and inject beam into an ‘unknown system’.*

Software Interlocks

- On top of the hardware interlocks, software interlocks can be defined (SIS)
  - To check on drifts relative to reference positions
  - Re-establish the SIS acting on the Injection BIC if quads have moved by > 250 µm. Exact value of the limit to be re-confirmed.
  - Using SIS for tolerances related to bellows, does *NOT* seem the right thing, as it stops the beam and not the movement

Procedures

- Procedures are as important as the hardware interlock
  - Important for alignment with beam AND for alignment **without** beam
- The procedures have to define
  - If the movement of the **cold mass** concerned is smaller than 0.0X mm, no special verification is required.
  - This needs full confidence in the new position measurement system
    - If not → full verification after any powering of the motors
  - For a position change above 0.0X mm it will be required to
    - Perform a test cycle with a given small number of bunches; steering
    - Perform loss maps – at given or all energies
    - Perform an intensity ramp-up with defined steps in intensity and given time / number of fills
- Procedures to be defined and approved before first beam following LS3
- Under the responsibility of the Machine Protection Panel

Responsibilities

- Who keeps the key ?
  - Operations, access via card
- Who check that procedures are followed ?
  - Operations group
- Mechanical integrity
  - Equipment owner – not Machine Protection

- Procedures to be written under the responsibility of the Machine Protection Panel and agreed upon by all parties involved, following edms release procedure
- OP responsible that enforced procedures are followed
- Hardware interlocking to be defined (including tests) between equipment owner and MPP team
  - Does not protect against movement without beam
- Establish the SIS interlocking: OP and MPP

Crabs and BBLR

- Crab Cavities (baseline)
  - Also remote alignment foreseen
  - Same hardware and SIS interlocking required
    - Include in the same hardware interlock ?
    - Procedures to be different if only crabs are moved ?
- Beam Beam Long Range Wire Compensation (not baseline)
  - If installed, same questions as above
- Questions to be answered in the MPP meetings

Conclusions

- A hardware interlock on the powering of the motors, connected to a maskable input of the Beam Interlock System, is mandatory
  - Present situation is probably too risky to align with beam
  - Aligning without beam is even more dangerous for the next injection
  - New IT, more likely that remote alignment will be used
  - However, procedures will be heavy: loss maps, intensity ramp-up
- Software interlocks by the SIS will improve functionality and safety after re-alignment without beam
- Detailed procedures are important
  - To be written and agreed upon, under coordination by the Machine Protection Panel
  - To be followed after re-alignment (with or without beam) of any magnet/CC/BBLR
- The remote alignment system is not to be used lightly, with or without beam. It will not become an operational knob ;-)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