Continuous position determination: concept and status of integration

Andreas Herty
overview

- LHC: layout, measurement concept and experience
- HL-LHC: layout and continuous position determination
- Sensors and components: LHC vs HL-LHC
- Status of integration
HL-LHC: continuing the LHC monitoring and alignment concept

- Continue monitoring concept based on
  Hydrostatic levelling sensors (HLS) for vertical and roll measurements
  Wire positioning sensors (WPS) for radial and vertical measurements

- Reuse existing infrastructure
  Survey galleries (UPS14, UPS16, UPS54 and UPS56) providing link to experimental caverns of ATLAS and CMS + left to right side

- Experience gained from LHC
  Operation of LHC system over 20 years
  Consolidation of P2 and P8 during Long Shutdown 2
  Remote validation concepts introduced in LHC
  Calibration of sensors at CERN
LHC measurement concept

RADIAL MONITORING

VERTICAL/ROLL MONITORING

○ Hydrostatic Levelling Sensor
□ Wire Positioning Sensor
HL-LHC layout compared to LHC

Not taking into account, environmental sensors and actuator equipment.

In addition to the sensors:
  - 4 wire stretching devices
  - approx. 1 km of wire and wire protection
  - approx. 1 km of hydraulic network
  - remote diagnostic tools for sensors and systems
continuous position determination systems

- wire to wire measurement
- main hydraulic network
- QXL side
- inclinometer
- wire
- beam
- internal measurement
- transport side
- longitudinal measurement
- HLS
- WPS
- wire protection
Radial and vertical measurement solutions

- Hydrostatic Levelling Sensors
  Manufacturer FOGALE nanotech
  with CERN added value: absolute determination within 10 µm
  . in-situ check methods

- Wire Positioning Sensors
  Manufacturer FOGALE nanotech
  with CERN added value: absolute determination within 5 µm
  . use of twisted pair cables
  . in-situ recalibration
  . application of methods of calibration developed in the CLIC project
Radial and vertical measurement solutions

- **Drawbacks**
  - Very expensive
  - Dependent on one manufacturer
  - Electronics is a «black box»
  - Limited signal cable length
  - Choice of components not guaranteed from one manufacturing batch to the other
  - Same technologies are impacted by the same environmental factors
  - HLS and the associated piping system is difficult to integrate on a platform system

- **Developments**
  - interferometric HLS: iHLS and HLS-LINES
  - in-house WPS
  - in-house remote electronics: digital signal, components traceability, remote diagnostics
  - inclinometer
  - Acquisition systems compatible to CERN DAQ protocol
Longitudinal measurement solutions

- Distance Offset Measurement Sensors
  - Manufacturer FOGALE nanotech
  - Limited range by manufacturer, range extension by CERN

- Drawbacks
  - Very expensive
  - Very sensitive to electrical ground

- Developments
  - Alternative under study: short range MT-FSI (< 10 cm)
Wire to Wire (W2W) measurement solutions

- Combination of invar rods equipped with targets plus two DOMS and two WPS sensors
  - Manufacturer of sensors FOGALE nanotech
  - Invar rods are CERN development

- Drawbacks
  - Four sensors to establish one measurement
  - Complicated support of invar rods
  - Calibration was very fastidious
  - Invar is sensitive to magnetic field (of experiments)
  - Invar bars were damaged several times due to very limited space available
  - Air tightness between experimental cavern and tunnel difficult to establish
  - Costs

- Developments
  - Alternative under study: long range MT-FSI (11 m to 15 m)
CERN designed solution for wire protection

**Drawbacks**
- Current solution too fragile
- LS2 consolidation solution good stability, but too expensive
- Both cases: based on manual installation and replacement of wire

**HL-LHC requirements**
- Due to radiation levels, necessity to develop a **semi-automatic solution**
  - Install wire from area with little radiation (typically beyond Q5)
  - Wire is pulled from Q5 to Q1 in an automated way, with no intervention from personnel
  - Old wire is cleared during the same operation by the system
- The wire protection system has to be **modular** in order to be only partially dismounted in case of replacement of a component
**Measurement wire**

- **Carbon-PEEK wire**
  - Manufacturer FOGALE nanotech
  - Conductive
  - High tension over linear mass, stretched at 15 kg (2/3 of elastic limit)

- **Drawbacks**
  - Manufacturing issues to have an homogenous wire; scale factors between reels

- **Solutions**
  - Short term: carbon-Kevlar wire, stretched at 20 kg
    - Wire sag is more important
    - Huge influence of humidity over 200 m
  - HL-LHC: new wire under development with EMPA*

*EMPA: Swiss Federal Laboratories for Materials Science and Technology*
HL-LHC: introducing additional features

- Longitudinal monitoring
  concept as already installed for cryostats in LHC since YETS 2017/18 and LS2

- Internal cold mass monitoring
  request to determine the cold mass position and not only cryostat position
  testing and validation of concept for crab cavities and dipole measurements

- Permanently monitored reference points
  deep references (GITL) for vertical network to be installed

- Inclination sensors
  additional concept either for HLS redundancy or where no HLS can be diploid

- Different measurement technologies
  capacitive sensors and Multi Target Frequency Scanning Interferometry
continuous position determination systems

- Hydrostatic Levelling System
  - was: capacitive HLS sensor
  - interferometric sensor MT-FSI

- Wire Positioning System
  - was: capacitive WPS sensor
  - capacitive in-house sensor & new electronics

- Longitudinal measurement
  - was: capacitive DOMS sensor

- Short range MT-FSI

- Inclinometer

- Wire to wire measurement
  - was: invar rods, 2 DOMS, 2 WPS

- Long range MT-FSI, 2 WPS
Integration: key points WP15.4

- Accessibility of the reference points during complete lifecycle of components (installation, operation, dismounting)
  - Compatibility with standard geodetic measurements
  - Provide interfaces for linking LSS to the arc sections of LHC

- Little as possible «interruption» of measurements in case of component exchange
  - Main hydraulic network behind the components
  - Wire protection system to be modular per component

- Installation and operation environment
  - Influence of adjacent equipment or infrastructure
  - Bake-out of beamline / gas line components
  - Temperature and humidity in the tunnel
  - Dust protection of the measurement systems
  - Different air pressure systems: tunnel vs. cavern
Integration: transport volume

Wire protection
is a single, straight volume
Crab cavities define position

sensor supports
some cannot be installed an thus not fiducialised before transport
fiducialisation measurements on site
Integration: WP15.4 systems

The HL-LHC is a very crowded machine in a lot of places!

- completed
  - space reservation for systems and infrastructure (thank you Marian!)

- next steps
  - design of supports and detailed layout of sensor support
  - design will be related to system consolidation during LS2 (copy and improve)
  - all «additional» equipment, such as supporting structures
    - Wire stretching devices
    - Borehole covers
    - Routing of hydraulic network
    - Remote validation systems
Summary

Measurements
- 3 axis measurement system
- from pseudo absolute to true absolute measurement system
- Q1-Q3 & CC: from cryosat monitoring to cold mass measurements

Sensors and Systems
- Individual sensors and components are tested as prototypes
- Volumes compatible with «currently used sensors»
- Concepts for measurements during installation to be refined

Integration
- next: from space reservation to design
- Full Remote Alignment approved – integration and design
- Define interfaces on components, e.g. inclinometer, supports for W2W system, supports for wire protection