Alignment systems: status of development

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Review of HL-LHC Alignment and Internal Metrology (WP15.4)
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Outline

- Capacitive measurement system R&D summary
  - Capacitive sensors electronics and DAQ system
  - Polyamide PCB WPS (P-WPS) sensor prototype
  - Wire replacement system
  - New wire R&D

- MT-FSI instrumentation – reliability driven
  - Internal metrology equipment (Insulated reflectors, Vacuum FSI heads)
  - Glass ball reflectors
  - iHLS, DoublePass iHLS
  - Inclinometer
  - Short distance measurement
  - Long distance measurements

- Conclusions
New RAD-TOL capacitive sensors
acquisition electronics

Low cost WPS sensor
Capacitive Wire Positioning System

WPS sensor
- X-Y measurement w.r.t. stretched conductive wire
- Accuracy < 5µm, Resolution < 1µm
- Limited cable length (max. 30 .. 50 m)
  - Conditioning electronics need to be RAD-TOL
Why new electronics and WPS sensors?

- **FOGALE solution**
  - „BLACK BOX” solution
  - Delivered in sets (sensor + conditioner + cable)
  - No remote diagnostic possibility
  - Expensive

- **CERN P-WPS + universal capacitive sensor conditioner**
  - Simple and cheap
  - Compatible with current supports
  - Adopted to vacuum wire replacement system (round aperture) – **Broken wire replacement function**
  - Radiation tolerant
  - Designed for use with all capacitive CERN sensor (WPS, HLS, DOMS)
  - Provides remote diagnostics of electronics, sensor performance
  - Provides remote parameters tuning
Layout of HL-LHC control/monitoring system

- Capacitive conditioners electronics in radiation zones due to cable length limitation
- Needs to be radiation tolerant
New electronics – standardized modules

- Standardized capacitive sensors signal conditioner
- Same hardware for WPS, HLS, DOMS
- 'Deep' diagnostics of signals and sensing chain
- RAD-TOL (200Gy)
Unified main-board for all kind of used modules

- Single hardware and software development
- HL-SAS chassis for RAD-TOL and safe locations
- Design pending with cooperation of BE/CO (https://wikis.cern.ch/display/DIOT/Distributed+Tier+chassis)
WPS Conditioner – UPS test

UPS test (started @ TS1 2018): test of conditioner in real radiation and noise environment

- Overall installation commissioned and launched in UPS 54
- No issues observed during 6 months of operation with beam beam in LHC
Capacitive Position Sensors Conditioner - status

- Digital version of conditioner designed and under upgrade to be compatible with DIOT crate
- Pre-test with all sensors types has been done
- Most of FPGA Firmware developed
- First long term test provides good results
- Thermal tests ongoing
- Radiation tests to be planned when final conditioner PCB ready
- Test with multiple (40..50) sensors on single wire necessary (check possibility of interferences)
Low cost P-WPS (Polymide PCB based WPS sensor)

- Electrodes deposed on Polyamide (UBI Upilex Polyamide)
- Al. alloy body + 10um anodization Epoxy glue (Araldite 2011) [rad-hard]
- 25um UBI Upilex Polyamide[250Mrd ~ 2.5MGy]
- 5um Copper
- 1um gold layer as electrode

Electrodes gluing tooling
Low cost P-WPS sensor - summary

- Initial series of sensors preliminarily tested with Fogale and CERN electronics
  - Sensors shows the same performance as original Fogale sensors
- Radiation tests of Polyamide samples glued on aluminium done in Autumn 2018 in Fraunhofer
  - No issues observed (TID 5MGy)
- Next series (15 pieces) of sensors for TT1 tests ready for assembly
- Thermal tests of sensors pending
Wire replacement systems

New wire development
Why we need wire replacement system?

- Residual radiation levels not allow for fast wire replacement in case of break
- Manual replacement feasible only during long technical stop after appropriate "cooling" time
Vacuum Wire Replacement System

1. Wire
2. Vacuum tube
   - WPS Sensor is a part of vacuum tube
3. Ball-lock-mechanism
4. Wire stretcher
5. Bead
Pulling and clamping of the wire
Ball lock mechanism and final bead design

- Ball lock mechanism under manufacturing
  - Initial tests September 2019
- New beads with wire locking feature initially tested
  - Issues with Carbon-PEEK wire, which is breaking – modifications of bead design pending
WPS – pneumatic wire replacement system

- TT1 installation – full size HL-LHC mock-up
  - 140m of vacuum tube + sensors mock-ups installed
  - Initial tests with different beads and pulling/cleaning scenarios performed in July - August 2018
  - System showed satisfactory performance
- Initial radiation tests of vacuum tubes done
Car wire replacer system

- Wire replacing system based on motorized "car" unit and open WPS sensor
- Series of prototypes under preparation/investigation by M. Rousseau, B. Perret
New wire development

- Development of new Carbon based wire with EMPA with INO Swiss founding
- Carbon-Kevlar wire assumed as a spare LHC solution in case when R&D of new wire will be delayed
  - 20kg load needed to reach same sag as for currently used Carbon-PEEK wire
Multi-target Frequency Scanning Interferometry Instrumentation

- Triplet and crab cavity internal monitoring vacuum FSI heads
- Optical targets
- Interferometric iHLS sensor for magnets and TAXN
- Inclinometers for magnets, masks and collimators
- Longitudinal (short distance) position sensors for magnets
- Long distance (UPS vs. Triplet) measurement
Multi-target FSI

See presentation „Introduction to FSI systems”

\[ f_{\text{beat}}[n] = \alpha \tau = \alpha \frac{2D_n}{c} \]

\( \alpha \) – is a sweep rate of the laser (\( \alpha = \frac{dv}{dt} \) - laser frequency change in time);
\( c \) – speed of light;
\( n \) – refractive index of light transmission medium;
\( \tau \) – time of flight of laser to the target

\[ D_n = c \frac{f_{\text{beat}}[m]}{2 \frac{dv}{dt} n} \]
Reliability driven optical sensors design

High radiation levels (see morning G. Lerner presentation) and difficult access forces surveyors to deploy possible-maintenance free systems.

Simplified and robust optics to be used in all systems:

- **Divergent beam** as a *standard solution*, to avoid designing adjustable opto-mechanics.
- When possible - the **bare-fibre ferrules** are used as a **divergent beam** launch.
- **Glass ball reflectors** considered as the *standardized solution* – cost optimization, reliability.
- When possible – single interferometer channel for measurement of multiple distances.
- Multi-reflection sensors to increase intra-sensors system performance.
MT - FSI vacuum head

Cost optimized, multi-target, divergent beam FSI head for HL-LHC

- Single metal body ISO-K chassis, no movable parts, minimum amount of optical components, low price -> high system availability targeted

- Prototype tested on DIPOLE
  - No problem with target alignment on the dipole flanges
  - Negligible loss of intensity even with cold mass full contraction
FSI: Cryo-compatible prism support

Status

- New DIPOLE test in SM18 under preparation
- The new (4th) generation of targets designed - more robust to shock and rigid insulator shape
- Insulator support 3D printed
Cheap, hollow retroreflector already used in dipole test

- Refractive index ≈2 glass ball as an alternative to hollow retroreflectors or replicated reflectors (~40€ vs. ~2k€ vs. 300 €)
- Radiation tests of hollow and glass reflectors (5MGy) done – no impact on measurement
- Coated glass ball reflector and cheap hollow retroreflector used in dipole test – no specific issues observed with MTFSI
- Coated glass ball reflector measurable by laser tracker
Multi-Target FSI – cost optimized *interferometric* Hydrostatic Levelling Sensor (iHLS)

Simple HLS sensor = water wessel + fibre ferrule
- Minimized cost of the sensor
Multi-Target FSI – cost optimized interferometric Hydrostatic Levelling Sensor (iHLS)

Cost optimized, divergent beam FSI HLS sensor for HL-LHC

- Single metal body ISO-K chassis, no movable parts, minimum amount of optical components, low price -> high system availability targeted
- Measurement uncertainty < 5µm
- Precision ~1 µm
- Prototype assembled and under tests

Initial tests shows very good performance of the sensor
Multi-Target FSI – cost optimized *interferometric Hydrostatic Levelling Sensor (iHLS)*

- Long term stability tests pending in Bld. 169 laser lab
- Comparative measurements of 2 iHLS with 2 cHLS
- Very good performance - capacitive and optical sensors measurements are coherent
Multi-Target FSI – cost optimized *interferometric Double-Pass Hydrostatic Levelling Sensor (iHLS)*

Due to the tunnel slope HLS network is split to several levels

- Possibility to measure multi-water level HLS network is needed
- Double-pass iHLS is under design, to provide double water-surface measurement within single laser sweep
- Intra water-level measurement uncertainty < 5µm
Multi-Target FSI – Optical Interferometer

Optical inclinometer prototype

- Expected resolution 10 µrad
- Differential pendulum measurement to anticipate thermal expansion effects
- Flexural pendulum suspension + magnetic break
- Prototype assembled and under tests in optical lab
Optical inclinometer prototype tested in the laboratory

- Stability test – OK
- Precision tests: 20 μrad
  - Pendulum length to be extended (increase of precision needed)
  - Next tests planned after design update
  - Long term stability test pending (validation of pendulum suspension stress impact on measured angle)
Multi-Target FSI – Short distance measurement sensor

Distance measurement sensor (short distance, range ±5 .. 10mm)

- To replace current capacitive sensor
- Design with thin wall bellow protection against the dust

- Expected measurement uncertainty < 5µm
- Precision ~1 µm
- Maximally simplified (bare-ferrule + glass ball reflector) to increase reliability
Multi-Target FSI – Long distance measurement

Distance measurement for UPS vs. Tunnel radial reference transmission

- ~15 m distance
- Standardized collimated optics to be used

- Expected measurement uncertainty < 40µm
- Precision ~5 µm
- Tests to be performed November-December
Instrumentation R&D conclusions

- Prototyping and tests of most of sensor solutions in advanced stage
  - Capacitive electronics prototype under tests, with performance similar to FOGALE
  - Prototype of P-WPS sensor tested and showed performance as for FOGALE sensor
  - Polymide technology passed initial irradiation tests (5MGy)
  - Optical sensors design driven by required high reliability
    - Simple construction
    - Limited amount of movable parts
    - Cost optimized
  - iHLS prototype tested, showing very good performance
    - Good reflection of laser light from the water Surface
    - Long term comparative (with cHLS) showed good sensor performance
  - Double-Pass iHLS prototype under design
  - Optical inclinometer prototype preliminarily tested
    - Update of pendulum length needed
    - Long term stability tests pending

- Sensor prototypes planned to be validated before end of 2019
- Final prototypes design for optical sensors to be ready 2nd quarter 2020
Thank you for your attention

Many thanks to all Team members helping in design and test of all described solutions: