PERMANENT MONITORING OF THE LHC LOW BETA TRIPLETS: LATEST RESULTS AND PERSPECTIVES

H. Mainaud Durand, A. Herty, M. Acar, A. Marin, CERN, Geneva, Switzerland.

Abstract

Since 2008, alignment systems are installed on all LHC low beta triplets. These systems allow the monitoring of the triplets with a micrometric precision through the different phases of installation, commissioning and operation. After a short reminder concerning the configuration of sensors on the triplet, this paper deals with significant results of monitoring on short and long term periods. First conclusions are drawn concerning these alignment systems, their associated mechanical supports and acquisition solutions. As an outlook, the modifications foreseen for the consolidation and upgrade phases are presented.

INTRODUCTION

The low beta triplets of the LHC, located on both sides of the 4 points of collision, are equipped with HLS and WPS systems monitoring their position continuously [1]. Each triplet is composed of three quadrupoles: two short ones (Q1, Q3: ~ 8.5 m long, 13.2 t), and one long (Q2: ~ 13 m long, 17.5 t). Three HLS sensors by quadrupole (plus an additional one located at the sag of Q2) monitor vertical displacements as well as two angles, while the WPS sensors provide transverse position information and two angles. These sensors are installed on fiducials located above the cryostat, determined with respect to the mechanical / magnetic axis of the cold mass during fiducialisation, operations to +/-0.1 mm [2].

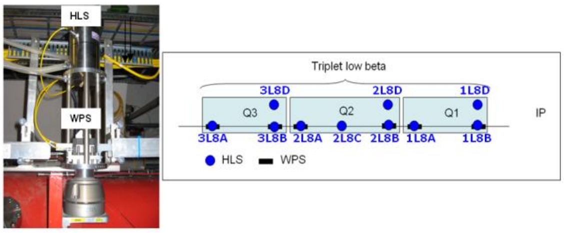

Figure 1: Configuration of sensors on triplet

These systems, now operating since 2008, led to monitoring the position of triplet in the different phases from the installation and commissioning through to the operation. Significant results from these different phases are presented in the first part of this paper. In the second part, the consolidation of these systems, the first conclusions on systems, as well as the planned improvements will be described .

SHORT TERM MONITORING RESULTS

Some miscellaneous examples are presented concerning triplet position monitored by alignment systems during installation and commissioning.

Warm-up of a cryostat and associated constraints

A deviation at the level of triplet 8 L (of more than 150 microns in vertical and 450 microns in radial on fiducial 1L8A) triplet was recorded beginning of July 2008 during two days.

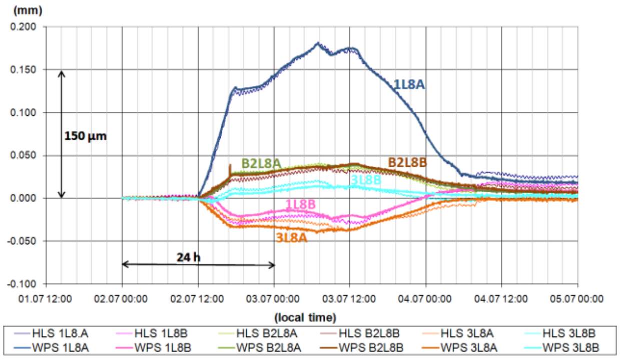

Figure 2: Vertical misalignment of triplet 8L (02-04 /07/2008).

The comparison of HLS and WPS readings located above the same fiducials showed a very good correlation, and confirmed that it was a real displacement and not a problem on one of the alignment systems. After less than two days, sensors readings came back to their original position.

After analysis, the increase of temperature of triplet helium bath resulted in an increase in internal pressure (limited to 17 bars by safety valves). Therefore, the internal stresses developed thwart stresses due to the insulation vacuum and generate a move towards Intersection Point (IP) and in radial of quadrupole Q1 [3].

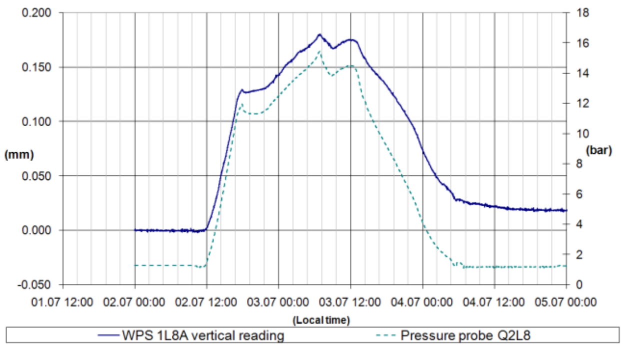

Figure 3: Correlation between vertical WPS readings and internal pressure probe

As the displacements were monitored at the level of the fiducials located on the cryostats, it is not possible to know the real displacement of the cold masses. An additional examination of the data from the 8 triplets showed that an increase of internal pressure always causes a misalignment of the triplet, variable according to the triplet (tens to hundreds of microns).

The redundancy of measurement of the HLS and WPS systems has helped us track the impact of the internal mechanical stresses on the external position of the fiducials. This highlights that it is important to know the internal settings of a cryostat, even in the case of external measurements: for example, measuring the position of detector components (or the components of the Long Straight Section in the tunnel) with respect to the low beta triplet thanks to "traditional" means must always be performed under the same conditions of temperature and pressure of cold masses.

Case of a remote displacement: resolution of the sensors

Each cryostat is supported by three actuators 2 axes that allow displacement according to the 6 degrees of freedom. All degrees of freedom apart from the longitudinal axis are motorized over a +/-2 mm range, with a resolution below 10 microns. Taking into account the redundancy of measurements above the same fiducial, HLS and WPS readings can be compared during a motorized displacement.

The graph below shows raw readings of three independent sensors (one WPS, two HLS linked to two separate hydraulic networks) located on the same support right above a fiducial.

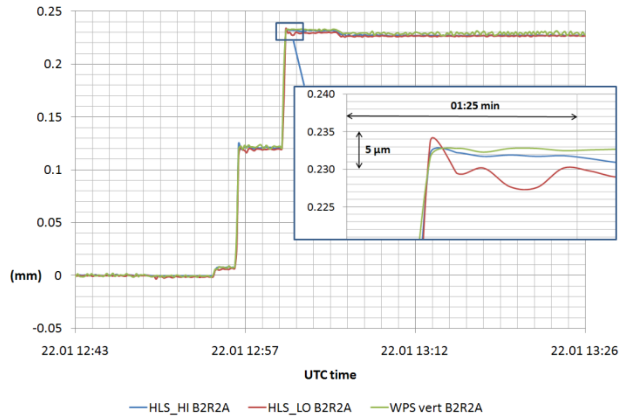

Figure 4: Raw HLS and WPS readings right above the same fiducial during a motorized displacement

Displacement of 220 microns is recorded by the 3 sensors to better than 5 microns. Note the very short time of stabilization of HLS sensor: it comes from the fact that the hydraulic network is supported by pillars fixed directly on the ground settlement, independent of the displaced cryostats.

The importance of redundant and independent measurements

All motors associated with the displacement axes of jacks are equipped with angular encoders, confirming that the number of steps requested has been carried out. The example described below concerned quadrupole Q2 of the triplet 2L. As Q2 is a long quadrupole, it has a special configuration of jacks: a fourth central jack, free in longitudinal and radial supports the sag of the cryostat.

Following the smoothing performed in this area, this quadrupole had to be brought back to its theoretical position to a millimeter, thanks to the stepper motors. Although displacements had been carried out according to the number of steps requested and validated by the angular encoder, sensors on the cryostat detected no movement. The relevant sensors were WPS and HLS belonging to two totally independent measurement systems; this confirmed clearly that no movement had taken place.

After analysis, it became evident that heads of 2 axes jacks were no longer in contact with the interfaces below the cryostat: the entire load of the quadrupole was applied on the central jack; other actuators were working in an empty space. As a result, the loads applied on each of the external jacks of the seven other Q2 quadrupoles in LHC have been measured. Three other quadrupoles have been diagnosed with a load on the central cylinder exceeding 12 t. A mechanical solution has been implemented on the 4 quadrupoles concerned to better apply the load on the external actuators.

This example illustrates the importance of having displacement control systems completely independent from the moving axis. Furthermore, redundancy of measurement means confirmed immediately that the problem was at level of the jacks and not at the level of alignment systems.

WPS readings during a ramping

Very unusual picks appeared on vertical and radial WPS measurements during specific phases of commissioning and operation.

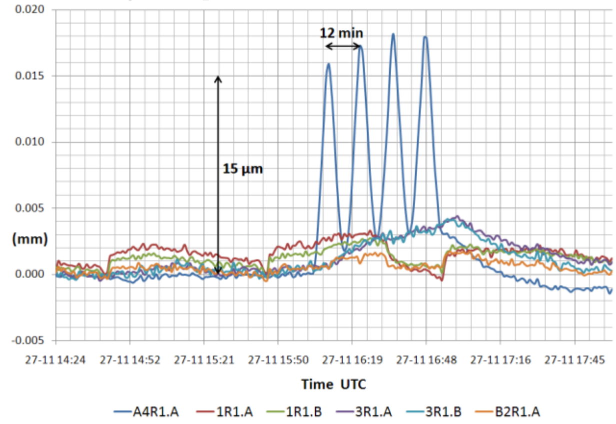

Figure 5: Raw radial WPS readings on 27/11/2009

They are perfectly correlated to the phase of ramping of magnets. Did triplet movements take place during the ramping or was there an influence on the alignment system during this phase (earthing of the wire for example)? This displacement of 20 microns maximum has been recorded in vertical and in radial on the warm D1 magnets located on the triplet. The displacement monitored by WPS sensor is confirmed by capacitive sensor DOMS linking the stretched of the tripet to another stretched wire providing a reference on the other side of the experiment. There is unfortunately no HLS sensor on the D1 magnet to conclude concerning the vertical movement.

In 2008, this same kind of question was raised at the powering of these magnets: ten microns radial displacement were recorded by WPS and DOMS sensors: were there disturbances due to a parasitic magnetic field from magnets directly influencing the sensors readings or mechanical movements due to a slight electro motive power from the magnet coils acting on the jacks? The use of independent measurement means fixed on ground settlement confirmed the second assumption: that of real displacements [5].

LONG TERM MONITORING RESULTS

A few miscellaneous "long-term" examples concerning triplet position monitored by alignment systems are proposed in this second chapter.

Case of triplet 2L

The triplet 2L, on the left side of ALICE detector, is located in two distinct areas: the end of the quadrupole Q2 and quadrupole Q3 are based on the tunnel floor while the beginning of the quadrupole Q2 and Q1 are located on concrete blocks installed on the detector cavern floor. Long term measurements performed by HLS illustrate the settlement of these concrete blocks during the installation of triplet and of the surrounding shielding blocks.

Case of triplet 1L

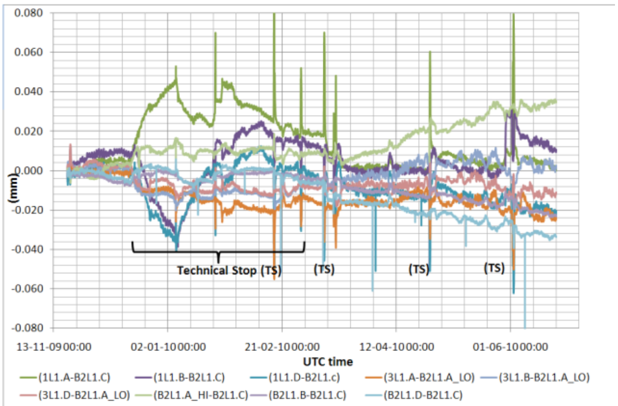

Figure 6: long term HLS levellings on triplet 1L

The graph above shows the levellings between HLS sensors located on the 1L triplet (on the left side of ATLAS detector) from the operation of LHC with beam (since November 2009). It highlights the vertical stability of the triplet (levellings between +/-50 microns over more than 7 months), with revealing peaks corresponding to access periods to the triplet (technical stop) or global warming of cold masses. This confirms the difficulty of achieving micrometric measurements during periods of access / work in the tunnel. Also, for future accelerators of particules with high resolution alignment requirements, specific periods will have to be dedicated for micrometric measurements in the global schedule.

Stability of LHCb cavern w.r.t tunnel

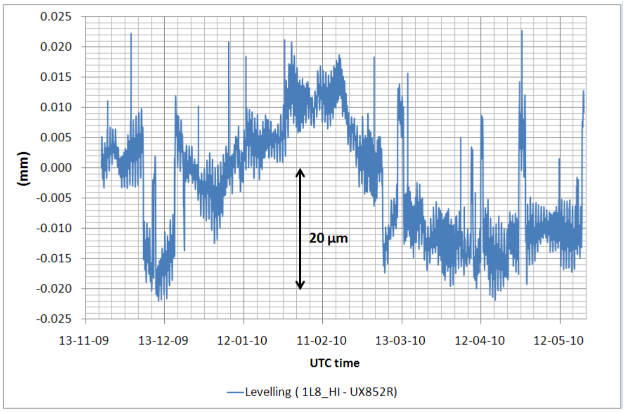

Figure 7: long term stability of LHCb cavern w.r.t tunnel

This graph shows the levelling between the raw vertical readings of two HLS sensors (one located in the cavern of LHCb, the other in the tunnel) and highlights the stability between the two areas: the levellings are included in +/-20 microns over more than six months. The quality of readings is demonstrated by the earth tides.

Correction of earth tides on HLS readings is the subject of a PhD thesis entitled « Analysis and Modelling of the effect of tides on the Hydrostatic Levelling Systems at CERN », which is in progress at CERN [6].

STATUS AND FIRST CONCLUSIONS

After more than two years of operation, some early conclusions can be drawn:

- Sensors are in good running order, since no failure was encountered on more than 100 HLS and 60 WPS operation. One HLS sensor had to be dismounted for linearity issues highlighted during filling/purging tests of hydraulic network.
- Hydraulic networks are now in "closed" mode: there is no “air aperture” along the network. This configuration was chosen when significant offsets were monitored on sensors along the same hydraulic network. This network was equipped with two “air apertures” located in two distinct areas of ventilation. The two “air apertures” had

remained opened and sensors were following differences in pressure between areas!

- Only one stretched wire broke among all triplets (10 wires are stretched permanently in LHC with lengths ranging from 40 m to 120 m). Some carbon peek wires are stretched over more than three years now and have resisted constraints during installation: various hardware (cables, tools, scale, and clothing) laid on the protection of wires, opening of interconnections located just behind the wire protection equipment.
- Wire validations have proved to be necessary to verify that the wire is still free in its protection, especially after works carried out by other persons in the same area.
- Additional WPS sensors will be added, coupled to the wire stretchers, in order to have a clear definition of the reference of alignment, independent from the magnets to be aligned, and to ease the analysis of data.

Installed sensors perform relative measurements of about a few microns, and "absolute" measurements (with respect to the beam) of a few tenths of mm. In fact, in the case of 'absolute' measurements, many uncertainties are added to the sensors repeatability: determination of fiducials on cryostats, stability of the position of the cold masses in the cryostats, the determination of the supports on which sensors are installed. These "absolute" measurements have been validated by comparison with measurements performed by standard means (leveling, laser tracker and offset to a wire). This illustrates the challenge of the CLIC pre-alignment, for which alignment systems will need to provide a few microns “absolute” measurements.

Some additional variables have been added in beam coordinate system for operational purposes. These variables are the following ones: average horizontal and vertical offsets, and rotation angles with respect to the nominal position of the magnets. They will allow on-line monitoring in the CCC (being displayed under PVSS environment) and a-posteriori analysis (being kept in the logging database) [7].

From the machine protection point of view, software has been implemented in such a way that the displacements of the low beta quadrupoles with circulating beam are prevented (except when safe beams during special studies), and cannot be performed when beam is off by non authorized persons.

Interventions on triplet alignment systems are still relatively frequent: they occur one technical stop out of two e.g every 10 weeks, in order to validate the references and sensors of alignment systems (displacement of stretched wire and filling/purging of hydraulic networks), and gain experience about these operations when possible. Taking into account that these areas will become more and more radioactive, improvements concerning these alignment systems will consist of developing and implementing remote validation of the systems, so that no access close to triplet is necessary.

PERSPECTIVES

Consolidation

A remote preventive maintenance is in preparation: designed systems will help move stretched wire reference remotely, to vary the water level of hydraulic networks remotely and detect a broken wire. These changes will be implemented on the triplets during the long shutdown planned for 2012.

Prior to intervention in the tunnel, teams can train on a magnet prototype named "TAP" Twice Aperture Prototype, on which alignment systems supports, wire protection systems, hydraulic networks, are the same than in tunnel. The preventive and corrective procedures of maintenance are tested and optimized on this magnet.

The remote repositioning part will be simplified. Currently, only alignment experts are able to adjust the magnets by moving one after the others the degrees of freedom according to the sensor readings. First, simplification will consist in developing semi-automatic repositioning: depending on the delta position to operate, an iterative and converging process sets components to the desired position. The second step will be to create dedicated knobs, high level parameters allowing to act on each degree of freedom more simply from the CCC. [7]

Upgrade

The upgrade of the low beta triplet initially foreseen during the shutdown 2014-2015 was postponed until 2018.

For this upgrade, the following improvements will be studied:

- The monitoring of the position of the cold mass with respect to the external references on the cryostat. Indeed, currently we monitor the external stability of the cryostat within a few microns, without being able to know what happens concerning the position of the cold mass.
- The extension as far as possible in the tunnel of the hydraulic network of HLS system, in order to have a very precise levelling reference of the triplet displaced in an area with much less radiation.
- Permanent installation of a stretched wire between Q1 and elements of Long Straight Sections (LSS), over more than 150 m to allow standard measurements with the optical ecartometer in order to determine the position of the triplet with respect to other components of the LSS. Such permanent installation would reduce the duration of interventions. And why not to use this same stretched wire for continuous measurements with WPS?

CONCLUSION

Monitoring the position of the low beta quadrupoles by WPS and HLS systems is a success thanks to:

- A clear strategy of development: mechanical and electronic prototypes have been prepared in our workshops, followed by tests, before series production in the industry.

- A multidisciplinary team of surveyors, electronics experts, mechanical engineer, and specialist in control/command coupled with very reactive electronic and mechanical workshops.

The great experience gained in the difficulties encountered will be beneficial to similar or even more demanding projects in term of alignment requirements. Thanks to the good results of these alignment systems, a common analysis is underway with the people responsible for the operation of the LHC towards a better understanding of the impact of the alignment of the triplets on the operation of the LHC.

REFERENCES

[1] H. Mainaud Durand and al, “The remote positioning of the LHC inner triplet”, IWAA 2008, KEK, Tsukuba, 2008

[2] L. Bottura and D. Missiaen, “Definitions of survey and magnetic data systems at IR1, 2, 5 & 8”, LHC-LQX-ES-007, CERN, 2004

[3] Private communication, Ranko Ostojik

[4] M. Acar and al, “the motorized alignment jacks for the LHC low beta quadrupoles”, IWAA 2006, SLAC, 2006

[5] A. Marin, Mesure de mouvements parasites sur capteurs WPS/DOMS autour de l’aimant D1 IP5, edms n° 984778, CERN, 2009.

[6] J. Boerez, « Analysis and modelling of the effect of tides on the Hydrostatic Levelling Systems at CERN », edms n°1084976, CERN, 2010

[7] M. Acar and S. Redealli, “Operational applications for the active alignment system of the LHC superconducting low beta quadrupoles”, LHC-OP-ES-0014, CERN, 2009