STATUS OF THE ALIGNMENT OF THE LHC LOW BETA QUADRUPOLES

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1. ABSTRACT

Due to particularly stringent alignment tolerances, the position of the LHC[1] low beta quadrupoles will be monitored using HLS[2] and WPS[3] systems, as well as invar rods equipped at their ends by micrometric sensors. When the offsets between real and reference position becomes too great, the quadrupoles will be moved using remote motorized jacks.

In 2002, the description of this alignment system was purely theoretical; in 2004, the mechanical supports are ready to be installed, the motorized jacks are being manufactured, the sensors have been ordered while a test bench is ready to control them and the acquisition of the sensors has been ordered.

2. INTRODUCTION

The alignment tolerances in the LHC insertions are particularly tight for the low beta quadrupoles [4], e.g.:

- Positioning of one inner triplet with respect to the other: ±0.5 mm (3σ)
- Stability of the positioning of one quadrupole inside its triplet: a few micrometers.

The maintenance of this alignment concerns the quadrupoles Q1, Q2 and Q3 equipped with permanent instrumentation. The position of each cryostat is monitored with respect to a reference position. When the deviations with respect to the reference positions become too great, it is possible to take back each cryostat to its reference position, using the motorized jacks.

Regarding the remote control of one inner triplet, each quadrupole is equipped with WPS and HLS sensors, plugged on the fiducials dedicated to the remote control. The radial position of the quadrupole of one inner triplet is controlled with a wire stretched all along the magnets and considered as a reference. Such a reference line is called the Inner Triplet Line. The vertical position and transversal tilt (roll angle) are controlled with the HLS sensors.

Regarding the relative positioning of the two inner triplets in the horizontal plane, both Inner Triplet Line on left and right side of the Experiment are linked continuously to the same Offset Reference Line (ORL) with 6 invar rods measuring the distance between ITL and ORL with sensors. The ORL line is a 126m long stretched sire, crossing the galleries devoted to

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[1] LHC : Large Hadron Collider
[2] HLS : Hydrostatic Leveling System
[3] WPS : Wire Positioning System

surveying and the experimental cavern. In the vertical plane, a hydrostatic network links the two hydraulic networks installed on each inner triplet. [1]

In 2002, the configuration of sensors for the alignment of the low beta quadrupoles had been determined. The integration of all these alignment systems in official layouts of the tunnel and the experiment areas was under way, as well as the preparation of the installation foreseen at the end of 2004. This paper describes the present status concerning the mechanical support systems, the sensors and jacks to be used in the alignment of the low beta quadrupoles, as well as the progress achieved since 2002.

3. FROM THEORY TO PRACTICE

3.1. Mechanical systems

3.1.1. Mechanical support systems

By mechanical support systems we mean all the interface supports between the fiducials of the quadrupoles and the sensors, all the supports enabling the protection of the stretched wire or the support of the hydraulic network connecting one sensor to another, whether in the tunnel or in the parallel galleries dedicated to the alignment systems.

All the support systems follow the process indicated below:

- Integration of the volumes in the official drawings so as to avoid all possible conflict with other systems of reserved areas.
- Approval by all the units and responsible people concerned
- Designing the detailed drawings
- Production of prototype in the mechanical workshop of the Survey group
- Perfecting of the installation procedures, optimization of the support system
- Industrial manufacturing on a large scale
- Reception and control
- Installation and tuning

3.1.2. Invar radial system and its support

The invar system and its support must answer to the following characteristics:

- A determined length of 16.47m
- Contained in a 12m long borehole with a diameter of 400mm
- Able to be dismantled and mounted again in several parts depending in the width of the tunnel in certain areas (at least 5m)
- Stable in time
- Fitted to the diameter of the boreholes
- Easy to align, especially inside the boreholes.

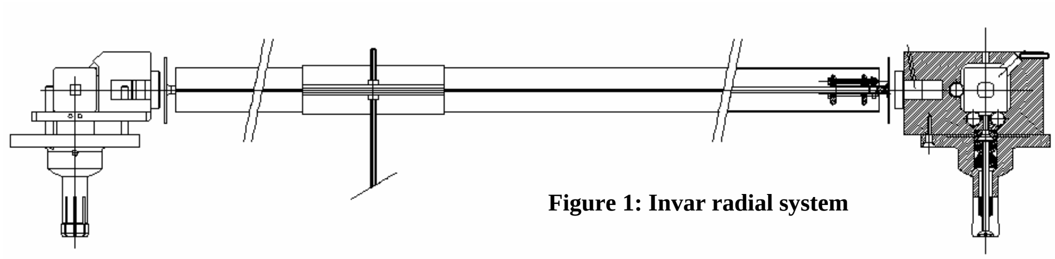

Figure 1: Invar radial system

The present prototype is composed of a 3m long invar rod, resting in a square tube section by means of Teflon washers. Each end of the rod has been given a cone shape which enables the fastening of two consecutive rods by means of a steel ball bearing and a spring securing system holding down the two rods.

Figure 2: Fastening of two consecutive rods

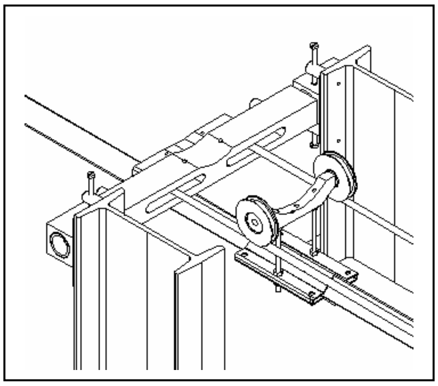

Figure 3: Cable railway

The support system is a cable railway positioned in the boreholes. Wagons fixed along the two parallel cables of the railway support the square tube section containing the invar rod to an accuracy of less than 5 mm for the sag on its whole length.

For greater precision in the determination of the length of the whole assembly, not only the rod will be calibrated, but all the radial system including the socket adapter, the associated sensors, the targets and of course the rods. The radial system will be supported in its entirety with the same configuration as that expected in the borehole.

The first test results concerning the invar rods are very promising. These have been performed in the calibration workshop with the HP 5529A interferometer. The determination of the length of the rod after dismantling and mounting is reproducible at less than 0.02 mm. The rod displacement tests showing the friction of the Teflon washers and torsion have a repeatability of a few micrometers.

A cable railway prototype will soon be installed for more than three months in the calibration workshop in order to follow its overall stability.

3.1.3. Hydraulic network

The results of the TAP facility[4] [1] have shown that it was necessary to have a support of the hydraulic network independent of the magnets to be aligned. When a rapid stabilization of the HLS readings is needed, a separate air and water network is advisable as it is far more reactive. It is possible to calculate an optimum diameter concerning a common air/water tube [2], but in our case, for a length of 40 m, it was impossible to use such a diameter from the point of view of installation and maintenance.

Depending on our configuration of sensors, the WPS sensors will be able to supply information concerning 4 degrees of freedom. The two HLS sensors laid on each side of the magnet will provide the tilt, fifth degree of freedom. These two HLS sensors will be linked by two tubes diameter 12/14 by means of a silicone SIKOLIT FT radiation resistant tube. The other HLS sensors will be connected to the main air/water network, diameter 50 by 2 tubes 12/14 with separate air and water. They will provide redundant measurements.

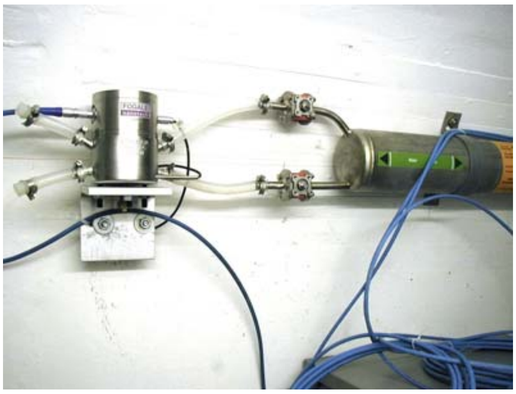

Figure 5: HLS sensor and hydraulic network

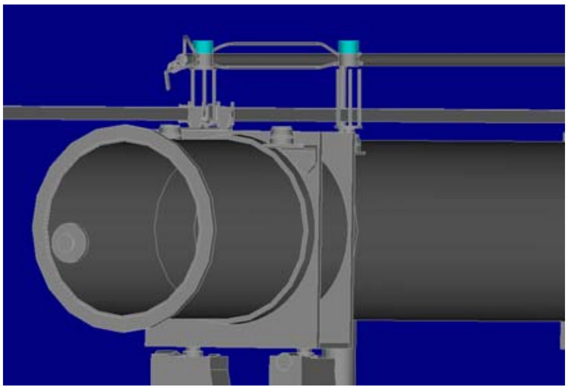

Figure 6: Hydraulic network on the magnets

3.2. Jacks

All the cryomagnets in the arcs and long straight sections will be equipped with so-called "Indian" jacks on account of the being manufactured at CAT[5] in India. Each jack allows a manual displacement following two axes: one horizontal, the other vertical with a 0.05 mm resolution for a vertical range of ±20mm and a horizontal range of ±20 mm.

For reasons of planning, cost and simplicity in the maintenance and the installation procedures, it has been decided that the same jacks will be used for the alignment of the low beta quadrupoles according to the outline below. These jacks will be slightly modified so as to allow a better displacement resolution.

The quadrupoles being remote repositioned according to the readings of the alignment sensors, these jacks must be equipped with adapters acting as a mechanical interface between the axis of the jack to be displaced and a motor. The study and the production of the adapters will be

[4] TAP facility : a cryo-magnet prototype named TAP (Twice Aperture Prototype) used as test facility
[5] CAT : Center for Advanced Technology in India

the object of collaboration between CAT and CERN. The supply of the motors and their control system will be the responsibility of CERN and there will be shortly an invitation to tender.

Figure 7: Quadrupole Q2 on its jacks

Figure 8: CAT standard jack

3.3. Sensors

3.3.1. Choice and strategy

Depending on the configuration that has been selected, the following sensors will be needed:

- 100 HLS sensors (among which 88 sensors with remote electronics and a cable length of up to 30 m between the sensor and its electronics)
- 64 WPS sensors with remote electronics and cable lengths of up to 30 m between the sensor and its electronics
- 24 micrometric and capacitive sensors (range of 10 mm, resolution < 2 μm)

Half the WPS and HLS sensors have been recovered from LEP[6] applications and have been upgraded. The HLS sensors were already used for the vertical alignment of the low beta quadrupoles of the LEP, whereas the WPS sensors were used on various applications such as the LEP spectrometer facility (measuring very accurately some possible slight changes of the Beam Position Monitors during operation of the accelerator), or the monitoring of chosen areas of the tunnel close to massive civil engineering works.

The remaining HLS and WPS sensors have been ordered from FOGALE Nanotech. We were indeed looking for remote electronics sensors which are radiation resistant and have been tried out in numerous applications. To our mind, only FOGALE Nanotech sensors answered to these criteria.

The capacitive micrometric sensors have not been chosen yet. There will be soon an invitation to tender.

[6] LEP : Large Electron Positron Collider

3.3.2. Test and calibration bench

All these sensors will be delivered to the CERN within the next few months and will be installed, in certain cases not before 2006. This necessitates the carrying out of a complete control of these sensors as soon as they are received, so as to resolve all installation problems. A control bench is being finalized. It will enable to perform long term stability tests, as well as controlling the state of the sensors, their calibration data and their characteristics (e.g. time needed for heating). Once the first beam will be circulated through the ring, the sensors will no longer be able to leave CERN: the LHC is an INB installation[7]. The creation of a bench in order to calibrate the sensors will therefore be necessary within the next few years. [3]

3.3.3. MTF database

In order to ensure correct maintenance of all these sensors, with their own technology, their past utilisation on various applications, their polynomial calibration, it is necessary to use the official database of CERN which ensures close follow-up and control of the instrumentation: the MTF[8] in which not only the different characteristics of the sensors are stored, but also the control results on reception, after repair or calibration.

3.4. Control command system

After agreement with the group responsible for the equipment and system control of the LHC, it was decided to use the WorldFip ground network for data transmission. Accordingly, all our modules for the acquisition and power supply of the sensors will be equipped with a WorldFip extension, as well as a possibility of local control of the readings of these same sensors.

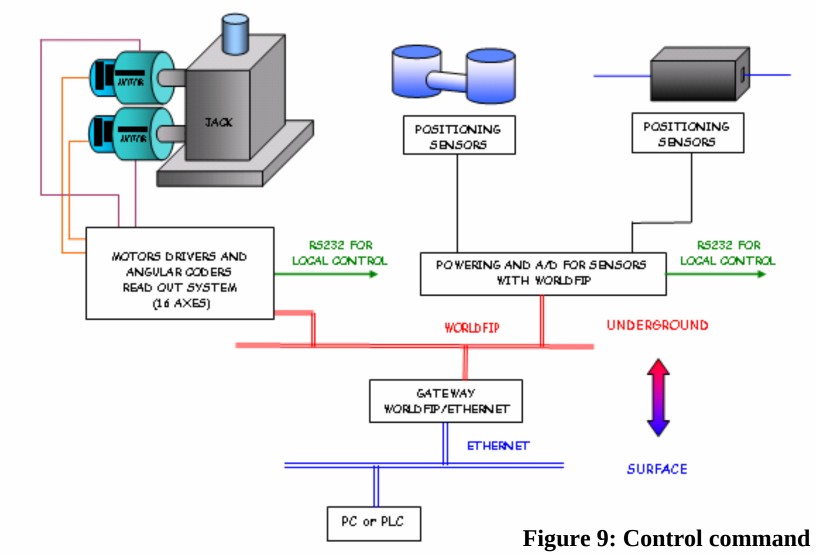

Figure 9: Control command system

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[7] INB installation : « Installation Nucléaire de Base » : a french classification of « nuclear » installations

[8] MTF : Manufacturing and Test Folder of a Component

The figure above shows the control set-up chosen for the low beta repositioning in order to carry out the following stages:

- The alignment of the low beta quadrupoles with respect to each other is determined thanks to the readings of the sensors.
- When a repositioning is necessary, command of the motors is carried out from the control room or possibly near to the motors, during the shutdowns.
- The displacement carried out is then controlled by means of the sensors, or if a problem has arisen, by means of the angular encoder joined to the motor.

4. CONCLUSION

For two years, much preparatory work has been carried out prior to the installation. Most mechanical supports have been designed, manufactured and tested before their large scale production, the HLS and WPS sensors will soon be delivered and will be the object of reinforced controls before they come into operation. The invitations to tender for the capacitive micrometric sensors, the acquisition systems of the different sensors and the so-called Indian jacks have been initiated. The long-awaited installation, expected for 2005 will soon be under way.

Acknowledgements

All these results are the fruit of the work of a team. With Thierry Rénaglia for all concerning the integration and designing of the mechanical systems plans, with Michel Rousseau and André Therville for the carrying out of these same systems, with Antonio Marin for all the electronic work and data acquisition and control, with Andreas Herty for all the work on the sensors and André Mathieu for all that concerns the calibration of the invar rods and the preparation of the installation of the different systems.

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