THE REMOTE POSITIONING OF THE LHC INNER TRIPLET

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Abstract

On account of stringent alignment tolerances and severe environment (high radiation fluxes and magnetic fields), the LHC inner triplets are equipped with permanent instrumentation (a combination of WPS and HLS) and are supported by motorized jacks, allowing their remote positioning thanks to the sensors' readings. This paper describes the alignment systems and motorized jacks from the technical choices to the installation and commissioning in the LHC tunnel. It also details the associated databases, analysis software and supervision tools implemented for this remote positioning.

Introduction

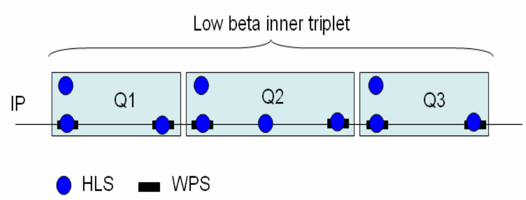
For the first time at CERN, the low beta quadrupoles will be repositioned remotely according to the readings of the alignment sensors attached to them. Motorized jacks located under the magnets cryostats will allow this remote positioning. More than 7 years were needed to decide, integrate, carry out, install and then commission the alignment systems and the motorized jacks involved, not counting the energy needed in order to justify such a repositioning system and to obtain the infrastructure and necessary budgets.

This paper describes successively the alignment systems and the motorized jacks, detailing their configuration, the associated technical choices, the installation steps and the commissioning. Then, the global strategy concerning the remote positioning is introduced, as well as the associated databases, analysis software and supervision tools.

THE LOW BETA ALIGNMENT SYSTEMS

The sensors configuration

The position of each of the 3 low beta quadrupoles is determined according to 5 degrees of freedom, thanks to a combination of two alignment systems: the Wire Positioning System (WPS) and the Hydrostatic Levelling System (HLS). The longitudinal position of the magnet is not monitored because it is less stringent than the other degrees of freedom. The sensors configuration allows some redundancy and is described in [1]; this paper will not deal with the link between two triplets.



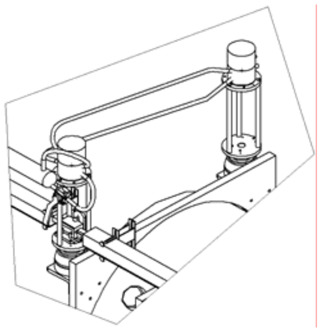


Fig. 1: The sensors configuration.

The alignment and monitoring sensors are located on fiducials which have been defined using laser tracker measurements [2].

The main technical choices

Due to the high radiations level expected in the low beta quadrupoles areas (around 16 kGy / year), the electronics of the sensors are remote in a safer place and the cables linking each sensor to its electronics are radiation hard. Radiation tests have been carried out showing that the sensors can tolerate total doses greater than 300 kGy with no damage [3].

Also, due to the delay in the installation of the equipments, some more elaborate reception tests were carried out on the sensors, showing that the HLS and WPS sensors are not calibrated to be interchangeable better than 100 microns [4]. So, dedicated procedures and benches were implemented in order to improve this determination.

As far as the acquisition of the sensors is concerned, it was decided to use the WorldFIP field bus for data transmission. This implied the development of a new acquisition device allowing the powering and A/D for the sensors, named Survey Acquisition System (SAS) [5].

Concerning the hydraulic network associated to the HLS sensors, two technical choices were considered:

- The hydraulic network is independent from the magnets to be aligned. It is supported by pillars screwed on the tunnel ground, and the HLS sensors are connected to the main common air/water network (Ø 50 mm), by means of 2 separate air and water tubes.
- For a fast stabilization of the network requested in the tilt HLS readings, a separate air and water network links the two sensors on each magnet.

Concerning the wire, the emphasis was laid on its protection: the carbon peek wire is entirely hidden in an assembly of 2 metallic U-shaped profiles, and the 15 kg weight for the tension of the wire is surrounded by a special mechanism preventing it from falling on the ground in case of wire cut.

The storage of information

100 HLS sensors, 64 WPS sensors, 24 dimensional sensors, and more than 60 temperature probes are being installed in the LHC tunnel. The calibration parameters of each sensor shall be managed. In addition, as 2 or more sensors are installed on the same fiducials and as they are not exchangeable, the management of their localization is absolutely necessary. The fact that the LHC tunnel has a slope adds another difficulty: the wire follows the slope, and the hydraulic network follows the geoïd. Thus, on each support, the distance between the WPS, HLS sensors and the fiducial on which they are located is different, and must be determined precisely if the sensors readings are to be compensated to the fiducial level.

In order to facilitate the management of the sensors and the recovery of their data and that of their support, the official database of CERN named MTF (Manufacturing and Test Folder of a Component) is used. It ensures close follow-up and control of all equipment installed in the LHC tunnel.

The installation sequence

Two conditions are needed concerning the installation of the alignment systems:

- Because of the risk of breaking the wire due to co-activities, the interconnections between magnets must be closed,
- The triplet shall have been pre-aligned with respect to the geodetic network, and smoothed with respect to the Long Straight Section magnets and the triplet on the other side of the collision point.

Before the installation, the sensors supports are assembled, the parameters are measured. The sensors, their associated cables and electronics need also to be checked [6].

After the correct adjustment of the fiducials with respect to the local vertical, the installation of the alignment systems and their supporting parts can start. The HLS system is always the first to be installed and validated, as it is located above the wire and it is less fragile.

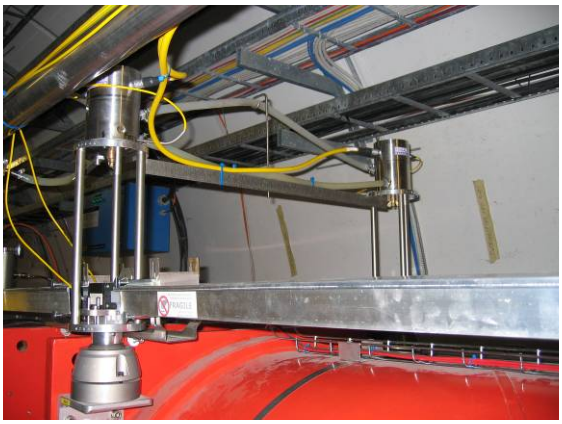


Fig. 2: Sensors and motors installed on a low beta quadrupole

The commissioning

The HLS system is commissioned thanks to the filling and purging of its hydraulic network: the difference in height seen by each sensor must be the same within a few microns.

The WPS system is commissioned thanks to the displacement of the wire on one extremity: each sensor shall be able to detect a displacement of the cryostat proportional to its position along the wire, within a few microns [7].

Then, the measurement chain must be controlled from the output of the sensor to the supervision, to be sure that the good measurements are stored at their right place.

In addition, as these quadrupoles have been pre-aligned with standard tools (stretched wires, optical levelling, and LTD measurements) during a previous stage, the position given by the alignment sensors has also to be coherent.

The first results

Five triplets out of eight triplets are now equipped with their alignment systems. Each installation on a triplet takes between 2 and 3 weeks, depending on the level of preparation and on the problems encountered during the installation (mainly interference problems with other equipment).

Despite a lot of co-activities around the stretched wire, the protection implemented was rigid enough to prevent the wire from breaking.

The design of the hydraulic network answers the requirements for the repositioning. The stabilization between the two tilt HLS takes about 100 seconds (stabilization better than one micron), and 10 minutes are needed for the stabilization along the whole hydraulic network.

One major problem still needs to be solved: it has been found that Electro-Magnetic Interferences (EMI) disturb the sensors readings, with effects that are not negligible (up to 0.1 mm for sub-micrometric sensors). Some studies concerning the sensors have been undertaken, while some investigation to identify the equipment responsible for these EMI effects is under way.

THE MOTORIZED JACKS

The motorized jacks configuration

Q1 and Q3, weighing 15 t, which are ~10 m long, are considered totally rigid, while Q2, weighing 18 t, which is 14 m long, needs a control of its vertical sag between support points with a central jack. The configuration of the jacks and their axes of displacement is the following.

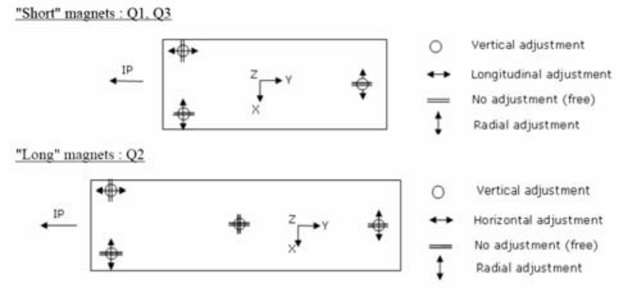


Fig. 3: The jacks' axes of displacement

Only 5 degrees of freedom are motorized: the longitudinal position of the magnet being less stringent than the others.

The main technical choices

In order to carry out the remote displacements, it has been decided to motorize the standard LHC cryo-magnet jacks and to use them for the low beta magnets. Some modifications were needed to meet the specific requirements of the inner triplets: a minimum effective displacement of 0.01 mm and a motor plugging/unplugging time inferior to 15 minutes. The major modifications were the enhancement of the jack stiffness (75 kN/m) and the incorporation of the necessary features for their motorization [6].

A mechanical interface, an adaptor, was designed through a collaboration frame with the Center of Advanced Technology (CAT) in India, allowing the plugging of a motor assembly on the jack axis. Two types of adaptors were carried out:

- 48 transverse adaptors, providing motion in roughly "horizontal direction", through an Oldham coupling, chosen for its high torsional stiffness between the pentagon socket of the jack and the gear head output shaft.
- 80 vertical adaptors dedicated to the vertical axis, using a polyurethane block as hydraulic fluid.

Once the design of these adaptors was determined, the characteristics of the motorization needed were defined: a 120 Nm output torque, a 25 Nm/arc-minute overall torsion stiffness, a 230 mm maximum length and a 10 t radial force capability. Then, the technical specification concerning the motorization was written and sent to the industry. The Slovak firm ZTS vvu KOSICE A.S. delivered the 128 motors needed.

The adaptor and motor were both tested individually according to a given procedure. Then the assembly of these two devices, the "motor assembly", was tested and pre-adjusted under a spare 15 t magnet. Each motor assembly includes a mechanical gear, one stepper motor, an angular encoder, 3 mechanical switches (two ends and a median one), and 2 external connectors. It provides a ± 2 mm range of displacement on each jack axis, once installed, within a few microns resolution.

The storage of information

All information related to the motor and adaptor (type, serial number, reception report) is attached to each jack position in the MTF database, and contrary to the sensors, no particular parameters concerning the motor assembly is needed for the repositioning.

The installation sequence

Before the installation of the motor assembly, two conditions must be fulfilled:

- The alignment systems are installed and validated.
- The sensors data are accessible through Ethernet and can be displayed locally, close to the jacks to be equipped.

The motor assemblies are installed quadrupole per quadrupole, in no particular order. The sensors data are recorded just before the installation: as a matter of fact, during the installation of the assembly, a small displacement, smaller than 0.1 mm may occur, monitored by the sensors. Then, the sensors are brought back to their initial values using the motors through local command, and this position is considered as the medium range position of the motor assembly: the 2 safety end switches and the medium one are adjusted consequently.

Fig. 4: Motor assemblies plugged on jacks

The commissioning

The local command of the motor assemblies is tested during the installation process when the motors are adjusted with respect to the sensors reference readings, using the same service command tool for all motor assemblies.

These installation parameters are then transferred to the dedicated command racks, and the control of the commands can be performed from the racks.

The next step will be the commissioning of the quadrupole repositioning in a remote mode. This will be done first according to the displacements given by the sensors, then at the level of beam.

REMOTE REPOSITIONING

The repositioning of the quadrupoles will not be closed loop, e.g. that there will be no displacements as soon as the sensors readings leave their set point. The moment for the repositioning will be chosen by the physicists. They will have a continuous access to the positions of the two ends of the magnets. When these positions are no longer acceptable for the quality of the beam, the parameters for better positions are calculated. First, these values will be translated in relative displacements to be done at the level of the magnet fiducials. Secondly, the data will be translated into displacements to be performed by the motor assemblies. Once these displacements have been carried out, the new position of the magnet is computed, thanks to the new sensors readings.

Such a strategy implies a large number of information stored in databases (concerning the position of the sensors, the association of their calibration polynomials), calculations and corrections to be carried out. In particular, mean least squares method will be used as far as the redundancy of the measurements is concerned, and corrections as the geoïd effect, the earth and water tides or the temperature effects on the sensors readings shall be applied. Thus, a complete structure has been implemented.

The repositioning sequence

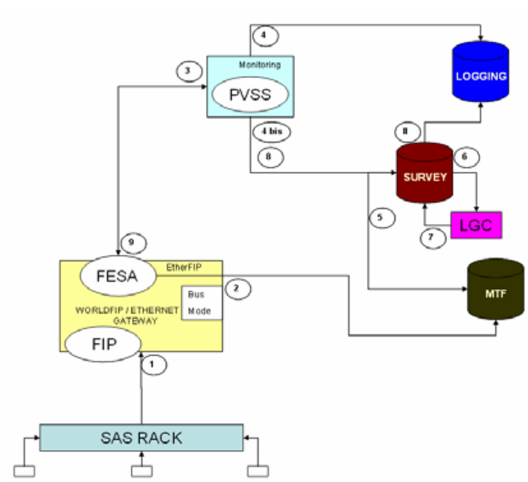


Fig. 5: The repositioning sequence

The data recovery

The sensors readings (0-10 V) are transmitted through WorldFIP field bus to a Gateway WorldFIP/Ethernet (1), where they are converted into millimetres or degrees Celsius, taking into account the calibration parameters stored in the MTF database (2). The raw and converted sensors readings are then transferred to the PVSS supervision via the FESA (Front End Software Architecture) protocol. (3)

PVSS (Prozeβ-Visualisierungs und Steuerungs System) is a Supervisory Control and Data Acquisition system. It is used to connect to hardware or software devices, acquire the data they produce, monitor their behaviour and operate them.

Under PVSS, three different visualizations will be accessible:

- An "expert" visualization, dedicated to persons responsible for the maintenance, showing only raw and converted sensors readings.
- A "client" visualization, dedicated to physicists, showing the calculated position of the magnets. This visualization implies the correction of the sensors readings: wire catenary, earth and water tides, temperature, inertial forces and radiations, as well as an adjustment of the redundant information by the least squares method, and the knowledge of the theoretical position of the magnet.
- A repositioning visualization, showing the 3 types of sensors readings: before the repositioning, during the repositioning and the values to be obtained after repositioning according to the calculations, as well as all the motors commands sent.

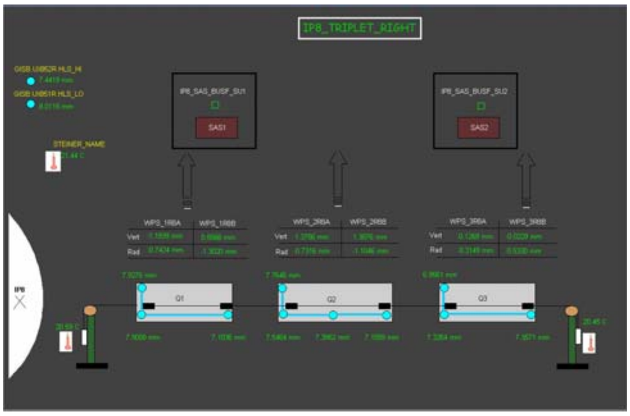


Fig.6: The expert visualization

After visualization under PVSS, all the raw and converted data are stored into the LHC measurements database named LOGGING (4). This allows an a-posteriori analysis thanks to a consultation interface: TIMBER.

The data processing

In order to implement data in the "client" visualization, the Survey database plays a major part. Indeed "SURVEY" is the database of the Large Scale Metrology group at CERN, where all the theoretical positions and offsets to these positioning of the fiducials and beam elements extremities of all the CERN machines are stored.

First, the SURVEY database will allow to generate an input file for the least squares adjustment software named LGC (Logiciel Général de Compensation), compiling the converted data from PVSS (4b), and all the mechanical information stored in MTF (5). This input file is transferred to LGC (6). After calculations, LGC sends back to the SURVEY database an output file containing the offsets of the theoretical position of the magnet beam Start/End. (7) Then these values are recovered by PVSS in order to be displayed (8). For a displacement to be processed, the motors commands are sent to the Gateway (9) through FESA protocol, up to the WorldFIP bus of the motors assemblies' drivers.

The repositioning strategy

There is a sequence of repositioning to follow in order to position the magnet within few microns:

- To adjust the tilt
- To carry out the radial displacements
- To control the tilt and re-adjust the tilt
- To carry out the vertical displacements, knowing that the same displacements must be applied on the tilt jacks in order to keep the tilt adjusted.

The repositioning will be performed within several iterations. The backlash on the jack being important (about 8°), the displacement must always be carried out keeping the same direction.

The first results

At the present time, the repositioning of a triplet can only be carried out on a "local" mode, e.g. the motors commands are sent from the assemblies' drivers and the sensors readings to be obtained are calculated independently from the algorithms and the SURVEY database.

The first tests carried out confirmed that a repositioning within a few microns is possible. After a few seconds, HLS and WPS readings located on the same fiducial show a very good correlation, though the HLS system has a longer stabilization time.

CONCLUSION

The installation of the alignment and repositioning systems started at the end of 2006 on the low beta triplets. Unfortunately, some technical problems on these magnets forced us to dismount all the alignment systems and the motor assemblies. Now, these problems are solved and five triplets out of eight are equipped with alignment and repositioning systems. Apart from EMI effects on the readings of the sensors, both systems seem to meet their requirements. The last pieces of the puzzle are actually being placed in situation, before the circulation of the first beam in the LHC, foreseen this summer.

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