REMOTE ALIGNMENT OF LOW BETA QUADRUPOLES WITH MICROMETRIC RESOLUTION

M. Acar, J. Boerez, A. Herty, H. Mainaud Durand, A. Marin, J.P. Quesnel,
CERN, Geneva, Switzerland

Abstract

Considering their location in a high radiation environment and the alignment tolerances requested, the low beta quadrupoles of LHC will be positioned remotely (controlling 5 degrees of freedom), with a displacement resolution of few microns in horizontal and vertical. Stepping motor gearbox assemblies are plugged into the jacks which support the cryomagnets in order to move them to the desired position regarding the quality of the beam collisions in the detectors. This displacement will be monitored in real time by the sensors located on the magnets. This paper describes the positioning strategy implemented as well as the software tools used to manage it.

INTRODUCTION

The alignment tolerances for the Large Hadron Collider (LHC) region are particularly stringent regarding the low beta quadrupoles:

- Positioning of one inner triplet with respect to the other (left/right side): ± 0.5 mm (3σ)
- Stability of the positioning of one quadrupoles inside its triplet: a few microns.

All the alignment systems will have to work in a high radiation level.

The monitoring of the alignment when the beam is activated (“beam on”) involves 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 position become too great, it is possible to move each cryostat to its reference position or any position, using the motorized jacks. Actually, this action will be activate if the quality of the beam/collision is not acceptable anymore.

Due to these parameters, a remote positioning of these critical magnets is needed.

This paper describes the procedure leading to this state. It introduces successively the alignment systems and the motorized jacks. Then, the general remote positioning procedure is explained as well as the associated components such as databases and software.

THE SENSORS AND MOTORIZED JACKS

Purpose

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 Leveling 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 [1].

The alignment and monitoring sensors are located on fiducials which have been fiducialised using laser tracker measurements [2]. Actually, this operation helps us to make the relation between the beam position and our equipment.

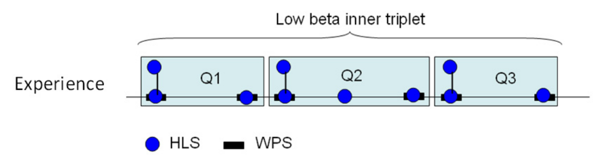

Figure 1

These magnets rest on support jacks, where motor assemblies are plugged in order to move the different axis of displacement.

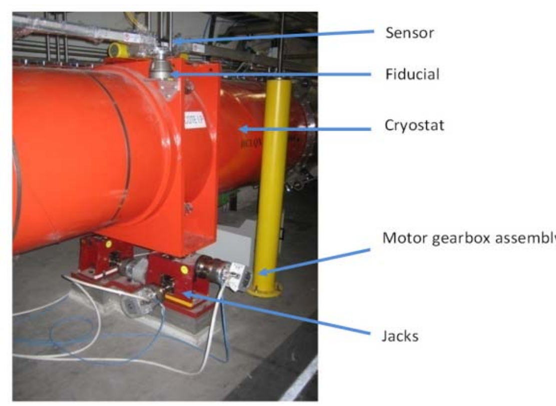

Figure 2: Complete assembly of equipment.

High Precision Equipment

Capacitive sensors measure a distance with respect to a reference (a stretched wire and a surface of water). In an ideal case, e.g. with no vibrations, no radiation fluencies, no magnetic fields, sensors measuring relative displacements have a resolution better than 1 µm. In the tunnel, the sensors are not in such an environment. Important radiation doses are expected (16kGy/year) and so dedicated calibration has to be performed.

Stepper motor gearbox assembly includes electromechanical components as motor, gearbox, resolver and mechanical switches. The technical data of the components fulfill electrical and mechanical requirements defined in tender document. They are used for positioning the low beta quadrupoles. There are 2 types of motor assemblies: vertical and horizontal type. The outputs sin & cos signals are processed by Stepper Motor Controller Board. The read value from resolver is 2 bytes = 16 bits data. For our purpose this data will be reduced to 12 bits. The positions of drivers will be read and will be used only as backup information for control system.

The resolution of 1 step of motor represents approximately 0.6 µm for vertical type and 2 µm for horizontal type. Concerning the resolution of resolver for vertical type, 1 resolver digital step represents 1,373535 µm and 4,395311 µm for horizontal type [3]. In total, 128 motor drivers will be placed in the LHC. These equipments have to resist to the high radiation. This leads us to install equipments with remote electronics (distance of cables between 20-30 m for sensors and 300 m for motors). However, such cable distances significantly increased the noise of the measurements by a factor 5.

Radiation tests

Radiation tests have been carried out showing that the sensors can tolerate high radiation fluencies up to 300kGy without damage [4].

The stepper motor gearbox assembly was tested for full radiation dose defined in tender condition. A complete motor assembly was exposed to radiation dose of 160kGy gamma type particles.

The functionality test of motor driver was taken in 3 steps:

- before radiation test
- after receiving 50% of the total dose
- on the end of the radiation test

The results show that the equipments can be installed in tunnel and can work properly.

THE STRATEGY OF REMOTE POSITIONING

In order to position magnets of more than 15 tons within a few microns, a step by step procedure for repositioning is needed:

- The relative displacement on each end of the magnet to accomplish will be determined by the physicists with the information given by the Beam Position Monitors
- This displacement will be translated into the displacement to be seen by the sensors located on the fiducials of the cryostat.
- The motor command will be sent through the supervision PVSS
- The displacement performed will be monitored by the sensors.

Data storage plays a key role (sensor's location, polynomial, name and shim's height). As far as measurements are concerned, mean least square method will be used. Also, correction for thermal expansion of support, stretched wire sag, tides, geoids and radiation will be applied.

THE DATA RECOVERY

Step 1: The Acquisition System and The Front End Computer

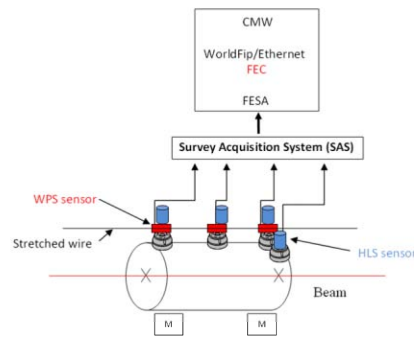

Figure 3: Acquisition system.

Each sensor is connected to the Survey Acquisition System (SAS). This converter realizes the analog data processing. It also includes an Analog Digital Converter (ADC). This system is controlled from supervision (see step 2). This acquisition system can be accessible by two ways of communication: WorldFip (for remote process) and RS232 (for local process/maintenance). The values arrive in analog (0-10V) mode in the SAS and then are transmitted to the FEC (Front End Computer) via the ADC and the multiplexer.

This transmission is done by a WorldFip field bus. These analog values are converted into millimeters or degrees Celsius. In order to do this, the calibration parameters of the sensors are stored into a database named MTF (Manufacturing and Test Folders) are used. FESA (Front-End Software Architecture) is an environment based on the CMW (Control Middle Ware) protocol which is a standard at CERN. On PVSS a check of the consistency between the MTF database and the situation in the tunnel is performed. In case of any changes, the information in MTF will be transferred to PVSS; this action can also be done manually.

Step 2: PVSS

All raw data and converted data are transferred to PVSS (Prozess-Visualisierungs und SteuereungsSystem). PVSS is a SCADA system. SCADA stands for Supervisory Control and Data Acquisition. PVSS will be used to connect to devices, acquire their data and use them for the supervision (e.g. to monitor their behavior and to initialize, configure and operate the devices).

Each 5 minutes, the data are sent to the LHC measurements database named LOGGING. This database is the only way to store our sensors data. PVSS provides also a run time database, where the data from devices are stored, and can be accessed for processing and visualization purpose. It also includes an archiving data in the run-time database can be archived for long term storage, and retrieved later by user interfaces or other processes.

REPOSITIONING

In the following paragraphs the calculation process for repositioning the low beta magnet is shown. This procedure is applied when physicists decide to realign the triplet.

Step 1: Data Calculation and Transfer

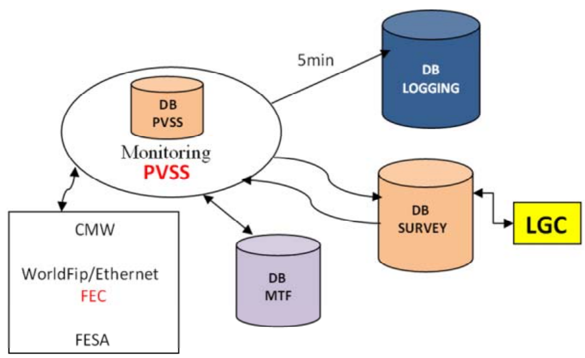

Figure 4: The repositioning strategy.

For repositioning, PVSS database will be used. Physicists enter the relative displacements to be performed at the level of the magnets beam Start/End. These values will be transformed onto the fiducials (our reference). Then the repositioning process starts, using the sensor readings.

At the same time, the connection (data transfer) between PVSS and Logging does not stop.

Moreover, each command for motor sent through PVSS is stored as well in order to have a trace of movement made (correlation motor's movement/ displacement).

"SURVEY" is the database of the Large Scale Metrology group at CERN, where all the theoretical positions and offsets to the position of the fiducials and beam elements extremities of all the CERN machines are stored. An interface named "geode" is used to access to the data. Moreover, all kind of corrections will be applied in geode via oracle forms. The absolute corrections concerning geoids and the tide are taken into account at this level.

Step 2: Motor Movement

Tests performed on a spare Q2 magnet have shown that a displacement made on each motor (which corresponds to a sensor) is linearly proportional to sensor readings. This means that one formula is attached to a motor and sensor.

The number of steps that should be applied on motors is known in advance, in order to move the relative or absolute distance needed. When the direction of the displacement changes, the backlash of the adaptor, which is very small (a few steps to get back), must be take into account. All these formula will be stored in database with its associated sensor (totally 16 for 1 triplet). The goal of this step is to automate the method for positioning. Thus, on the supervision side, when all displacements to realize on each sensor are defined, the number of steps on the motor concerned can be applied directly. The motors commands are sent to the Gateway through FESA environment, up to the WorldFip bus of the motors assemblies' drivers.

Step 3: Keep The Micron in Mind

In order to position a magnet with a precision of few microns with a minimum of iterations, due to residual coupling on the displacement, a strategy has been developed:

- To adjust the tilt (rotation of the magnet)
- To adjust the horizontal displacement
- To control the tilt value and adjust if it's necessary
- To carry out the vertical movement (tilt side) the same steps should be applied on the tilt in order to keep the tilt adjusted.

CONCLUSION

All 128 motors and their drivers have been installed in the LHC. All the commands dedicated to the remote positioning pass through a standard system at CERN. Concerning sensors and motors and to follow this standard way, some specifications have been written in order to generate XML files to PVSS. The result for repositioning was done after assembling all software part. The different tests showed that the remote repositioning of object of 15 tons with a micrometric resolution is feasible.

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