MAGNETIC AXIS AND GEOMETRIC MEASUREMENT FOR THE LHC CRYOMAGNET

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Abstract

The LHC cryomagnets are made with several types of magnets which all need to be aligned. Both magnetic and geometric axis need to be well known before the installation in the LHC tunnel.

These measurements require integrated controls for optical, magnetic and geometric measurements systems. The measurement sequence as well as the analysis should be adapted to each type of magnet. To perform the measurement, a mole, equipped with a reflector, a CCD camera and Hall probe sensors should be moved along the tubes of the 15 metres long dipole magnets and rotated around its axis. The geometrical measurements are made with an industrial Laser Tracker system. Homemade systems have been developed for the image and magnetic measurements. Each part can be driven separately and form the lower layer of the system. The control, as well as the interaction of these systems, has been integrated into a single system using UDP communication. The harmonic analysis allows verification of the quality and the orientation of the magnetic field of the magnet.

The geometric measurement program has been designed as a master, thus controlling all sub-systems and the quality of the acquired data. In order to operate the magnetic and geometric measurement independently, a remote control application has been made.

The structure of these two major parts, geometric and magnetic, has been designed so that new functionality can easily be added.

INTRODUCTION

The next large accelerator project at CERN is the Large Hadron Collider (LHC), which is foreseen to be installed in the existing LEP tunnel and scheduled to be in operation in 2007. For this project 1232, 15 metre long dipole magnets need to be tested at CERN in warm and cold conditions on dedicated test benches that are being constructed.

Two important features of the magnets are the magnetic [1] and geometric axis [2] determination. Control software has been developed to perform these measurements in the LHC magnets by integrating one commercial system and two home made systems.

The top-level software, called the Dipole Geometric Measurement (DGM), controls three subsystems: the Leica Geosystem™ program, the image program and the magnetic program.

MEASUREMENT ARCHITECTURE

Leica program

The geometric measurement system uses a Leica Geosystem™ Laser Tracker, which is a commercial system, delivered with a measurement program. The Laser Tracker is able to perform 3D measurement by means of a Michelson interferometer. A CERN built mole carries the reflector needed by the Laser Tracker to determine the geometrical axis position [3].

Image program

The image program determines the offset of the mole centre compared with the centre of the tube. When the mole is inside the cold bore tube of the magnet, gravity pulls it down into a low position. To measure this centring error, the mole is equipped with four LEDs and a CCD camera. Each LED will give a primary spot from the direct beam and secondary spot created by its reflection inside the tube. The computer performs a best fit of a circle crossing each of the four spots to determine each centre (Figure 1). The video signal is read-out through a video card from National Instruments™ and analysed by the image software. Calculating the distance between both centres give the offset of the mole.

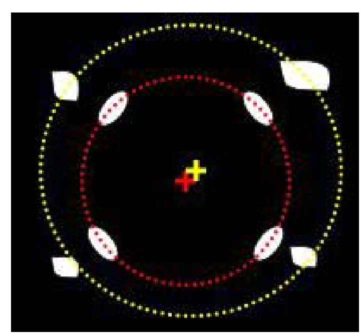

Figure 1: Picture from CCD camera

Magnetic program

The magnetic program is used to determine the magnetic axis inside the cold bore tube. Four Hall probes, mounted on the mole driven by a motor, which levels the mole to gravity, deliver signals proportional to the magnetic field. The four Hall probes are positioned at 90 degrees from each other so that the magnetic axis can be determined. The signals are read through an ADC card, configured and read-out by the computer.

Mole description

The mole has been designed to enter in a 50 mm tube and is 50 cm long. It has an attachment on one side for the pulling cable and a reflector on the other side (Figure 2). A longitudinal motor is pulling the mole inside the cold bore tube of the magnet from on side to the other. This motor is controlled by a DAC card. Four LEDs are connected on the cable side of the mole and in the middle four tangential Hall probes are mounted. Inside the mole is the level motor with a claw to attach to the tube, which is controlled by a second DAC card.

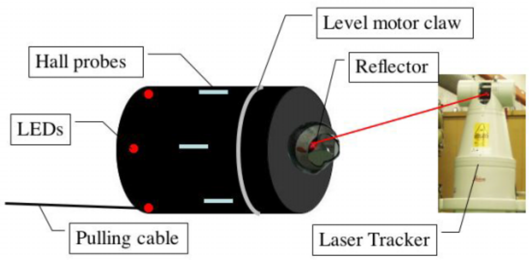

Figure 2: Mole equipment

DGM program

The DGM is the top-level program, thus controlling each sub-system (Figure 3).

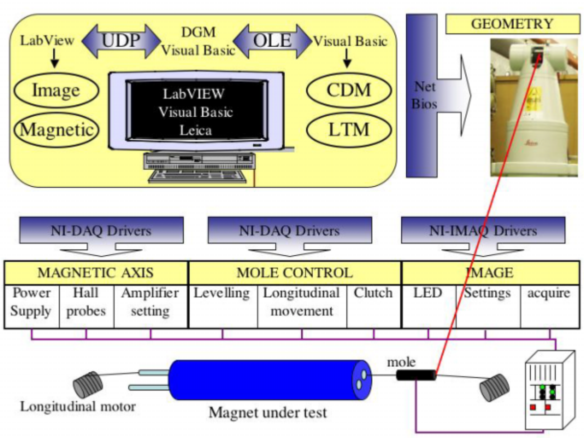

Figure 3: Measuring system architecture

The communication is established between the DGM and Leica™'s program using OLE commands for the geometric measurements. The measurements are performed through the Laser Tracker Module (LTM) after having defined many operational parameters. The results are stored in the Core Data Module (CDM), which is accessible by the DGM for mathematical treatment of the raw data. Data can also be read directly from the Leica™ controller using TCP-IP, without passing through CDM and LTM. The DGM is controlling two LabVIEW™ programs, image and magnetic, using UDP communication. The image program uses an NI-IMAQ™ driver to acquire the data. The magnetic program is controlling the KEPCO™ power supply to create a magnetic field inside the cold bore tube before reading the Hall probe values through NI-DAQ™ drivers. The acquisition, treatment and verification of the data are done in the image and magnetic programs, sending only the result to the DGM. This structure allows each program to run separately and to be used by other applications. The longitudinal movement of the mole is controlled directly by the DGM program.

From the raw data the DGM software computes the geometry of the cold mass and the magnetic axis coordinates, correcting it with the optical results. Finally, it stores the computed results for later offline treatment.

OPERATION MODES AND DATA ANALYSIS

Several functions can be used in the DGM, depending on the type of measurement.

15m tube measurement

In this sequence the mole will be pulled from on side of the magnet to the other, step by step. The operator has to enter the desired step and the speed of the longitudinal motor. The mole must stay still and its 3D position must be known by the software to start the measurement. The LTM is used to read the X, Y, Z coordinates. Then the image is acquired and analysed online so that it can be repeated or stopped. If the spots are not well seen, the software is levelling the mole to 10º and tries to determine the centres anew. As soon as this step is finished the magnetic measurement can take place, also submitted to tolerance. In the case the measurement is out of tolerance, the DGM returns an error message to the operator. In this case the mole cannot be turned as Hall probes must stay in front of the coil to measure its magnetic field. Then the clutch is activated and the mole can be moved to its next position. The DGM prevents the mole from exiting from the end of the tube by stopping the longitudinal movement before there is a risk for the mole to fall.

Corrector magnetic axis

For the construction of the LHC every dipole magnet will be equipped with correctors of three different types. Their magnetic components are also important and need to be determined. As for the dipole the Hall probes must be in front of the coil in order to perform a measurement. For example, a decapole will be measured levelling the mole at 0º, +18º, +36º, -18º and -36º. A cross check is performed measuring twice the same coil with two different Hall probes using opposite angles. For each angle the Laser Tracker is used to make sure that the mole is still longitudinally in the same position. All measurements are then processed to determine the position of the magnetic axis of the corrector. This position is then compared with the magnetic axis of the main dipole. This type of measurement can be done for decapoles, octupoles and sextupoles.

Correctors harmonics

The same hardware is used to determine the harmonics of the correctors. The mole level is limited to ±60º, however, equipped with its four hall probes, data can be retrieved to cover the 360º needed for the harmonic calculation. The program is taking measurements every degree for a mole level going from –45º to +45º. The raw data are saved in a file for offline analysis. An FFT can be performed to get the harmonics and the orientation of the main field. The magnetic centre in horizontal and vertical direction is also calculated.

CONCLUSIONS

The integration of a commercial system and two homemade systems, to perform geometrical, image and magnetic measurements, has produced a versatile automated measurement system. Prior to this system the expert needed to operate these systems manually. The full automation of the process avoids operational mistakes, which could degrade the quality of the results and gives a big time reduction, passing a full measurement sequence from 2 days in manual operation to 3 hours in automatic.

The Dipole Geometric Measurement (DGM) has proved its reliability after being used several months at CERN and in dipole assembly companies for the construction and verification of the cryomagnets for the LHC. The DGM is now being adapted for the quadrupoles, of which 460 will be measured at CERN for the same project.

REFERENCES

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