

INDUSTRIAL CONTROLS FOR TEST SYSTEMS FROM SUPERCONDUCTING STRANDS TILL MAGNET FIDUCIALISATION IN THE TUNNEL FOR THE LHC PROJECT

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ABSTRACT

The LHC project requires construction and test of a large number of complex components, such as superconducting strands, cables and magnets, most of them produced in industry. To qualify these components, different test systems based on industrial controls were developed and installed at the production site, but also at CERN.

This paper describes a test system concept based on NI LabVIEW and alliance-members products that can be adapted to the needs of the component or assembly to test. This concept simplifies design and optimises reusability of LabVIEW modules. It will be further used in systems for commissioning the LHC, before particle beams will circulate in the machine.

INTRODUCTION

During last years the main activity of our team was focussed on providing data acquisition and measurement systems for LHC [1] components or assemblies, either to be used at CERN or the manufacturer's production site. Electrical insulation, quench performance [2], magnetic and geometric characteristics [3] take part in the acceptance chain of every magnet [4] starting from the cable production, and are essential parameters for magnets distribution in the tunnel.

Taking into account the total time required to test all components, this is on the critical path of the LHC project schedule. For this reason tests have to be done reliably and as automatically as possible, especially if the test systems are used in the industries.

To match our requirements we have decided to use as much as possible industrial controls and custom systems only where required, carefully integrated together [5]. The solution we have chosen was to use LabVIEW whenever possible in combination with hardware from National Instruments or closely related suppliers. Dedicated development in other programming languages, where needed, has been integrated keeping in mind the modularity and the reusability of such a system.

An important motivation of our choice was the availability of several thousands of free LabVIEW libraries to drive external devices via a computer and on the capability of this language to easily integrate all the needed functions to manage the interaction between hardware and the graphical user interface, which allows us to focus on high level system functionality.

Following the specifications of our clients in charge of the components quality insurance, over 10 different data acquisition systems ranging from some tens to a thousand channels for recording transient phenomena in superconductors and over 15 different magnetic and optical measurement systems controlling devices to vary parameters, such as current, rotation or displacement of probes, were developed with this concept and used in many places in the magnet manufacturing chain.

This paper describes, choosing an example, some of these systems used in CERN and industries, following the life of an LHC dipole from the cable to the introduction into the tunnel.

FROM STRAND TO COIL

To verify the quality of the superconducting strands that are used to manufacture the superconducting cable two measurement systems have been developed, one to determine the critical current of the strand, the other for the residual magnetic field. The systems have an identical base, which consists of a Sun workstation with LabVIEW and controlling power supplies and digital voltmeters through GPIB and serial interfaces.

The difference between the systems is that for the residual magnetic field measurement a motor is used to move the strand in and out of an external field and measurements are performed in cycles, while for the critical current determination a power supply is being ramped to the highest expected critical value at several strand temperatures.

A cable test system has been developed on an identical basis as that of the critical current system, but with additional equipment to be controlled such as a 16 kA power supply for an internal 9.5 T magnet and an industrial temperature regulation for the cable under test.

Then in industry sites, after the winding, every coil is tested to check the insulation and to measure the main electrical parameter using the fast electrical discharge method with a dedicated LabVIEW application that drives a high voltage pulse generator and a DAQ scope card. The pulse is sent into the coil and the discharge curve is analysed to evaluate from the damped oscillation, the resistance and inductance of the coil. This test can detect short-circuits between windings and allows to continue to the next magnet production stage [6].

FROM COIL TO COLD MASS

In order to evaluate the main field, the magnetic length and the field harmonics of the dipole series production at the factories, the Dipole Industry Magnetic Measurement (DIMM) application [7] has been developed. It is used for the acceptance tests, firstly of the collared coils, then of the cold masses, at the earliest production phases.

Each DIMM bench [8] consists of two sensitive field-measuring probes that rotate inside the apertures of the dipole and move longitudinally along the magnet, a data acquisition system and an on-line analysis program. The harmonic coefficients can be reconstructed applying the Discrete Fourier Transform. At the end of a measurement the results are displayed in graphical and numerical format. This saves time during production, as the factory is able to decide to repeat the measurement in case of doubtful results before dismounting the magnet from the measurement bench. Results are complete: the entire analysis package is included in the program and results are immediately sent to CERN by e-mail at the end of the measurement.

A well-defined procedure, based on our experience, has been set up for measurements at the factory sites. This method provides precise results in a reasonable measuring time. The personnel at the companies can carry out standard measurements of dipoles after only a one-day training course. The complete measurement at each production stage, including the on-line analysis, takes less than 2.5 hours. As of June 2005, about 16 manufactured collared coils have been found out of tolerances thanks to DIMM. All these coils showed real mechanical defects in the indicated positions.

By taking into account our experience in the magnetic measurement domain, it has been possible to re-use for this DIMM application, 80% of the existing code, previously developed for the quadrupole measurement at CERN. Furthermore, some parts of the DIMM code has then being reused to build the MMP6 application, described in next section.

Also the geometry of each dipole cold mass should be verified by the measurement of the axes of the two cold bore tubes [9,10]. The tight tolerances, dictated by mechanical and beam optics requirements impose the use of a high accuracy 3D measuring system. For this reason an LTD500 Leica Geosystem laser tracker, using an interferometer and an absolute distance meter, was chosen to perform the measurements. Different parts of the cold mass have to be either measured or properly positioned throughout the assembly, implying moreover the use of a portable system.

Leica Geosystem provides a tracker with a software package that allows combining a sequence of operations in a single command with a basic interface to the user. We developed a Visual Basic program with direct access to the command library of the Leica Geosystem software, executing every sub-routine of the measurement process. The analysis, requiring mathematical tools, has been developed in LabVIEW as it contains everything needed, plus a nice graphical interface to present the data. The full system is called Dipole Geometric Measurement System (DGM).

The entire assembly is highly automated and few options are left to the operators, reducing from 2 days to 3 hours the time to measure a dipole magnet. During the assembly of the magnet, a file called traveller, is filled in, containing the main results of the measurements and calculations performed, indicating if the components are within the tolerances.

Because the system must work 16 hours per day and 5 days a week and should not stop the magnet production, the software robustness was an essential constraint, but also the modularity of components allowing 10 different programmers working over the last 5 years on several projects based on DGM.

FROM COLD MASS TO MAGNET

The LHC quality assurance plan foresees the test of all superconducting magnets at superfluid helium temperature of 1.9 K. Twelve test stands have been built to make cryogenic and quench performance tests as well as magnetic field measurements up to the nominal field values on all lattice magnets (about 1200 dipoles and 400 quadrupoles) [11].

During the quench performance tests a turnkey DAQ system, built with standard industrial modules by a NI alliance member, acquires data from voltage taps and magnet instrumentation. This data is then processed by a CERN developed automatic analysis program using LabVIEW to extract about 100 parameters in less than half a minute to evaluate the magnet characteristics and to raise alarms if critical limits are exceeded on magnet and quench heater parameters. It is important to receive these alarms quickly, because the next quench can only be authorised if the previous alarms have been understood and cleared. Final results of the analysis are used for the acceptance of the magnet for installation into the LHC tunnel.

In addition, each magnet is tested for electrical insulation at cold condition on the test stand, but also at room temperature before and after the cold tests. An automated measurement system has been developed for these insulation tests that can either operate connected to one of the test stands and integrate into the interlock and configuration system or in a stand-alone mode for the room temperature tests in other places.

Several types of magnetic measurements benches are installed at CERN, with different configuration and setting. But some parts of the system are always in place like a rotating unit, an encoder (for the integration triggering), a VME crate (for the real time acquisition), and a power supply.

MMP6 [12] has been developed to drive and manage all external equipment and measurement modes. Depending on the needs of a specific bench, some added devices should be used: an axial motor to move the coil shaft inside the magnet, a telescope and/or a CCD camera to measure the magnetic and geometric center axis, a multiplexer to read the coil signals on the same integrator, and a set of equipment to execute dedicated measurements (NMR, ADC, DVM, AMPLIFIER).

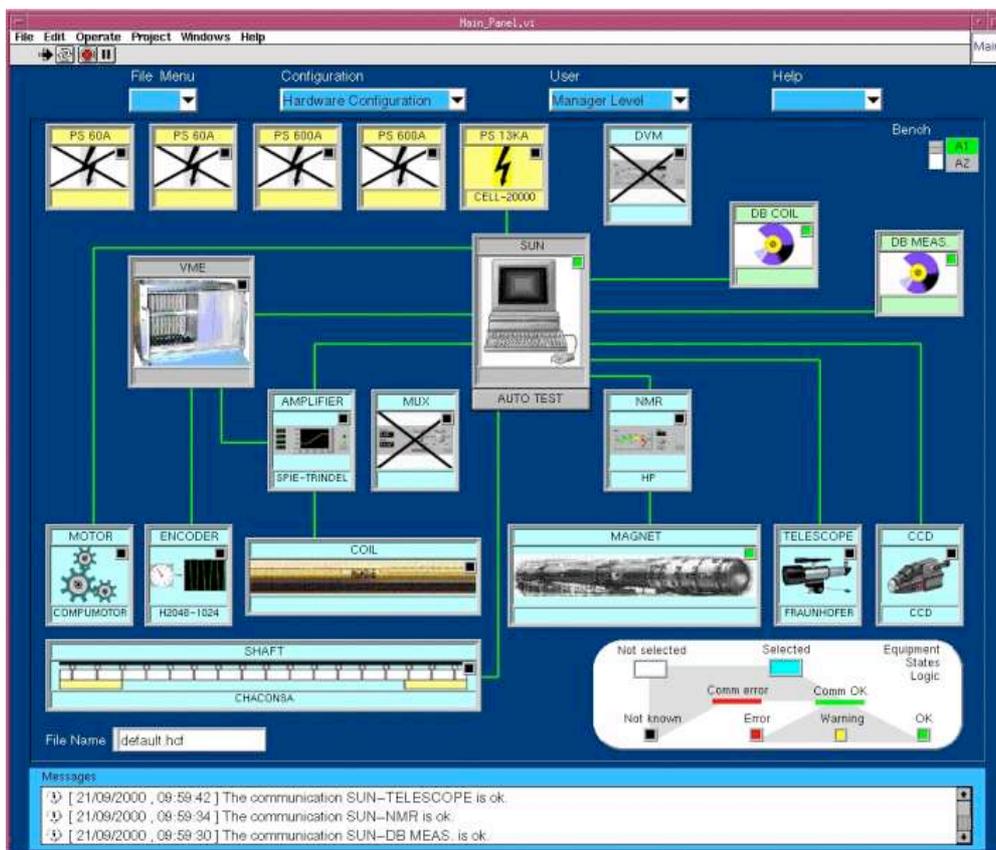


Fig 1. MMP6 synoptic

The MMP6 program represents the physical system by a synoptic panel. In this panel, each device is represented as an object containing its own functionality. From the programming point of view, these objects were made independent from each other, which means that a new object can be added to the program without modifying the existing code. Because they are inside their specific objects, it is much easier for the programmer to find a problem that is related with a certain device.

This MMP6 toolkit is actually used to perform the warm and cold magnetic measurement on 14 benches at CERN. From the operator point of view, it is easy to use and configure. For the software development team, the object-oriented structure and the set of dedicated tools are the keys for an efficient adds-on and modifications management.

FROM MAGNET TO TUNNEL

The LHC cryomagnets are internally composed of several types of magnets that all need to be aligned. Both magnetic and geometric axis need to be well known before the installation in the LHC tunnel and the measurement sequence as well as the analysis should be adapted to each type of magnet.

To perform this measurement, a mole, equipped with a reflector, a CCD camera and Hall probe sensors must be moved along the tubes of the dipole magnets and rotated around its axis. The geometrical measurements are made with an LTD500 Leica Geosystem laser tracker like for DGM. Custom systems have been developed in LabVIEW for the image and magnetic measurements. Each part can be driven separately and form the lower layer of the system, but the control, as well as the interaction of these systems, has been integrated into a single system. A top-level software, called the GEometric AXis (GEAX) [13] has been designed as a master, thus controlling all sub-systems and the quality of the acquired data.

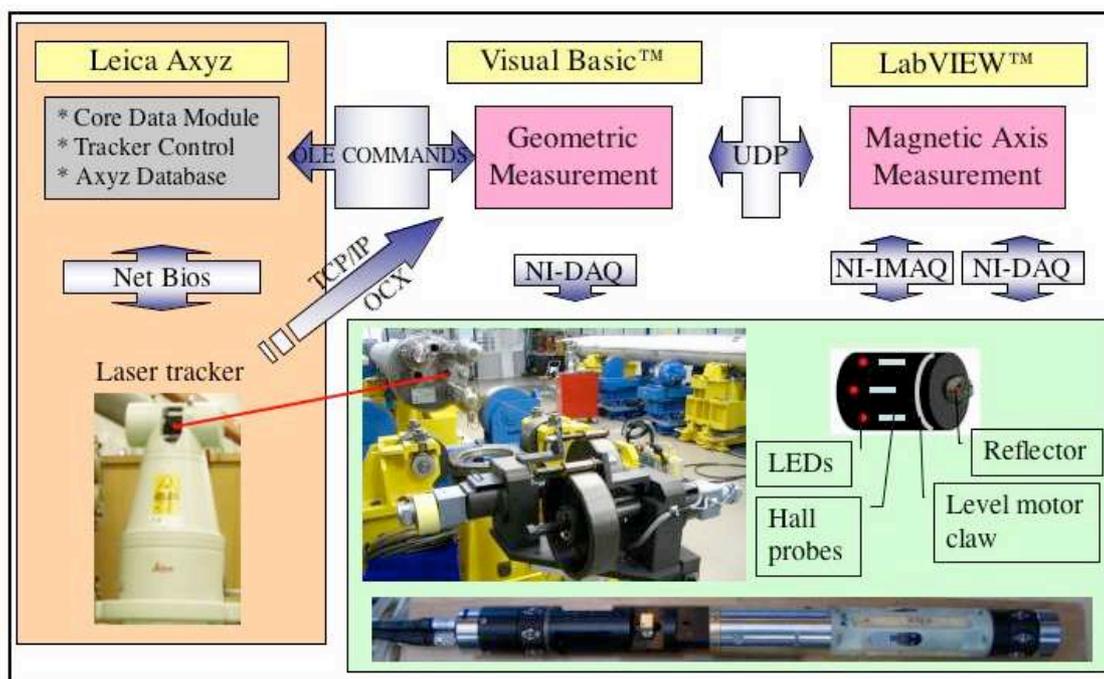


Fig 2. GEAX architecture

In order to realise a connection between the tubes at the end of a cryo-dipole and the tubes of the adjacent SSS with an admissible offset, it has to be verified that the tubes at each end of the SSS are located at their nominal position according to its mechanical geometry.

A new program, based on DGM, has been developed to align and measure the position of the fiducial points (on the top of the cryostat) and achieve the cartography of the magnet. The result of these measurements made on the surface will be used in the tunnel, where cryo-dipoles and Short Straight Sections are connected to each other once aligned.

CONCLUSIONS

Following the construction phases of an LHC dipole from the strands to the cryomagnet ready to be installed in the tunnel we have shown our philosophy of work that we can resume in: use of modular commercial solutions where possible, use of a hierarchical structure to allow parallel development and reusability of the software.

Our primary aim is to save time and manpower as much as possible, while keeping high reliability of the products. This method can be successfully applied to some of the software and systems that still need to be developed for the commissioning and running of the LHC.

In first instance it can be applied to the loosely coupled software, such as the Post Mortem Analysis and the Reference Magnet System, but later a closer integration into the core LHC software will be beneficial to the overall efficiency of the control system.

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