OUTCOME OF THE COMMISSIONING OF THE READOUT AND ACTUATION CHANNELS FOR THE CRYOGENICS OF THE LHC

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INTRODUCTION

The LHC is the largest cryogenic installation ever built. For its operation more than 14 000 sensors and actuators are required. The 27 km circumference of the accelerator is divided into 8 sectors: like for the rest of the hardware and in particular the cryogenics, the commissioning of the cryogenics instrumentation has been performed sector by sector.

INSTRUMENTATION AND CONTROLS LAYOUT

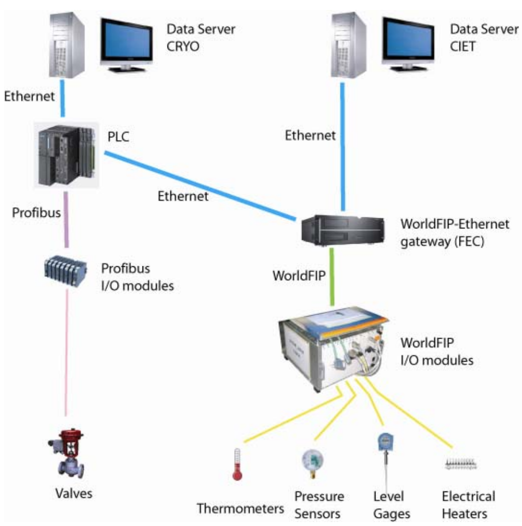

Figure 1

The instrumentation readout is performed through two types of field-busses:

- Profibus® that is not meant to operate on radioactive environment, and therefore is confined to zones outside the accelerator tunnel. It is used for the valve signals and some special heaters. For each sector, remote I/O modules, located in four underground “protected areas”, are connected through optic fiber to the two PLC (one for the arc, one for the Long Straight Sections, LSS) that are located on the surface.

- WorldFIP®, that carries the data from the thermometers, pressure sensors, level sensors and heaters. For each sector, 80 stand-alone crates, holding the radiation-tolerant electronic modules, are evenly distributed along the arc inside the LHC tunnel. Other 20 crates per sector are in protected areas, and are dedicated to the instrumentation of the LSS. On each sector, eight Front End Controllers (FEC) PCs running Linux, are used as a gateway to interface data from the WorldFIP® I/O modules to the Siemens Profibus® PLC.

Two supervision systems (SCADA) operate in parallel: the CRYO used for the LHC cryogenic operation, and the CIET used for the access to the full data of the WorldFIP® instrumentation channels.

COMMISSIONING STRATEGY: PRIOR STEPS

The whole instrumentation and controls system for the tunnel cryogenics rely on several databases. The ones dedicated to the instrumentation and controls - typically storing calibration tables for thermometers and pressure sensors or logic parameters for the control - are used and defined solely by the instrument and control specialists, while the ones defining functional positions of equipment (Layout DB) and tracking equipment manufacturing and test data (MTF DB) have support services at CERN level.

Sensors

Amongst the different sensors and actuators, the most stringent requirements concern the cryogenic thermometers covering the range from room temperature down to 1.6 K, that apart from being RadHard, require an accuracy of +/- 5 mK at 1.9 K. This has determined very precise manufacturing, mounting, qualification, calibrating and test procedures. A quality assurance policy was defined to ensure the correct identification of each thermometer in the final assembly. To achieve the required accuracy, individual calibration of each thermometer was performed and stored in a database for the use in the control system. Conformity tests were performed and traced on “Traveler” documents at the different stages prior to the final commissioning in the tunnel, all of which are accessible in MTF.

Pressure sensors have also been individually calibrated before installation, and as for the temperature sensors, the resulting tables are used by the control system.

All instruments are electrically tested along the different procurement and installation steps. Some sensors like liquid helium level gauges and thermometers cannot be completely validated until reaching nominal operating conditions.

Electronics

The manufacturing of the WorldFIP® electronic modules developed at CERN was outsourced. The contract specified that the contractor would ship to CERN the electronics already assembled in crates as they would be installed in the LHC. To ensure the proper performance of the delivered equipment, CERN provided an automatic test-bench that would accept or reject each electronic module according to operation and accuracy specifications.

The validation procedure at the production site consisted in:

- Testing thoroughly the individual cards with the test-bench for functionality and accuracy evaluation.
- Building each of the uniquely identified crates required for the LHC using only compliant cards.
- Running with the test-bench a final check of the functionality of the complete crate, and cross-check the configuration with the requirements provided by CERN.

The results of each individual card tests as well as the complete crate checks are stored in the MTF equipment database. These subsequent verifications allowed the direct installation of the delivered equipments in the LHC tunnel without an additional check at reception.

Controls

The software for the controls relies mostly on automatic generation tools using data coming from databases. All the programs for the PLC, FEC, CIET and CRYO data servers for each sector are generated automatically from an Excel® specification file. This file holds the definition of all the channels for one sector including their logic relation, the calibration characteristics of the sensors, the configuration parameters for the electronics, PLC etc… The source data for the specification file are automatically extracted from the MTF equipment database, the Controls and the Layout database as well as from complementary logic templates. All these layers of automation in the generation of the software imply intermediate checks before putting the control programs into production:

- PLC hardware configuration and verification on the field for the correct implementation and recognition of the controls hardware: communication busses, I/O modules, etc…
- Automatic check of the specifications file before the generation of the programs for PLC, FEC and supervision data servers.
- After generation, visual check of existence, availability and correct definition of all the objects through the supervision applications.
- Control logic verification: regulation loops, alarms, interlocks etc… This is carried out on a "mirror" so as not to interfere on the other commissioning activities.

PROCEDURE FOR THE COMMISSIONING OF THE HARDWARE

Once all the hardware was installed, the commissioning on site of all the instrumentation channels on the WorldFIP® bus has been based in the consecutive use of:

- The Mobile Test Bench (MTB)
- The Cryogenics Instrumentation Expert Tool (CIET)

The **MTB** is conceived for the "in-situ" validation of the hardware installed in the tunnel downstream of the communication field-bus. It is housed in a 1.5 m high 19 inches wide rack equipped with wheels in order to move to the location of each instrumentation crate, where it has access to the signals coming from the sensors and to the electronics in stand-alone operation.

The MTB is able to perform four separate tests:

- checking the coherency between the equipment on the field and the databases,
- checking the cabling, connections and availability of the installed sensors at the input of the electronics,
- checking the functionality of the electronics,
- checking the correctness of the data available to the WorldFIP® field-bus.

Most of the tasks are performed automatically and require properly updated database information. The operator is needed for the connection of all cables, and for the evaluation and reporting of the non-conformities observed. Each of these tasks is performed for every channel. This means that the test of one complete instrumentation crate can last from 2 h for the simplest ones in the arc, to more than 10 h for the most complex ones in the LSS. Three MTB were built and have been operated in up to two shifts per day.

The results have been uploaded to the MTF equipment database. This information has then been analyzed and in many cases has lead to repair interventions on sensors, cabling or electronics, as well as corrections of mismatches in databases. Often a new iteration with the MTB has been launched after the repair.

The **CIET** is a dedicated tool based on the same software and hardware as the control system for the operation of the LHC cryogenics and it allows the access through Ethernet® and the communication field-bus to the different features of the electronics.

During the commissioning phase CIET has been used to check thoroughly the availability, coherency and the qualitative correctness of the physical value associated to every single channel required by the controls and the cryogenics operation. It has contributed to the detection and correction of mismatches in the databases; it has helped revealing wrong identification of instruments and calibration tables; it has pointed out new failures in the electronics, cabling or sensors occurred after the commissioning with the MTB and it is fundamental as diagnostic tool for the support from the surface to the interventions underground.

The non-conformities encountered during the CIET verification are recorded in the MTF database for future reference.

These 2 stages of commissioning with MTB and with CIET were initially intended to be in sequence but have eventually proved to be complementary when overlapping.

SUMMARY OF THE RESULTS

Concerning the MTB activity, of the 800 electronic crates installed in the LHC (80% in the tunnel and 20% in the protected areas), except for the ones in sector 7-8, all have been tested at least once with an average of 1.7 repair-test iterations for the crates in the tunnel and 2.4

iterations for the crates in the protected areas. In the periods of higher activity, the operation of the 3 MTB has involved 8 persons on the field in shifts, plus 3 persons on the surface for support and analysis. Because of the singularities of the different LSS, the crates in the protected areas demand more testing time and a higher number of iterations. In principle the duration of the first pass test for one sector with the MTB was evaluated between 10 to 15 working days when operating two MTB in parallel in two shifts per day (2-3 crates /MTB/shift for the tunnel, and 1 crate/MTB/shift for the protected areas + transportation and access coordination). However due to LHC re-scheduling reasons, only one sector was commissioned in one go.

As a result of the CIET commissioning activity, the availability of the different instrumentation channels has been above 97% at the moment of the cool-down for each sector. In particular, control valves, pneumatic valves, quench valves, pressure switches and pressure sensors had to be 100% operational. Electrical heaters and level gauges have been successfully commissioned up to 100% availability during the 'cryo-tuning' phase at cold conditions. The temperature sensors (TT) have been made available in more than 95% of the equipped channels. However in a few cases, doubts persist about the correct identification of the installed sensor, causing inaccurate reading, due to the use of an incorrect calibration table.

The last phase of the commissioning activity has required traced interventions in more than 1200 channels, for diagnostic or repair.

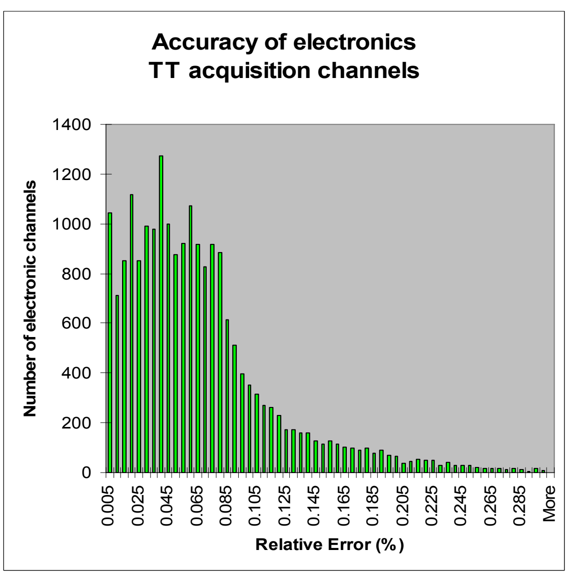

Figure 2

Regarding operational performance Figure 2 shows the distribution of accuracy achieved for the electronics installed in the LHC at the manufacturing test. This particular example regards the TT electronic channels. The operation of the LHC cryogenics requires accuracy better than +/-10 mK at 1.9 K in absolute terms (or +/- 0.5% relative). In order to achieve this specification, the relative error tolerance limit for the electronics resistance measurement was established at 0.3% on the whole acquisition range, while the uncertainty for the sensor itself was limited as previously mentioned to +/- 5 mK. Figures are similar for the electronics of other types of sensors, related to their respective requirements. The accuracy is expected to withstand the LHC radiation environment and in such perspective it is an excellent achievement.

Assuming that every LHC cryogenic cell is isothermal at stable conditions, we can evaluate the overall accuracy of the complete instrumentation channels by analyzing the dispersion in temperature for the different thermometers of the cold masses in each cell.

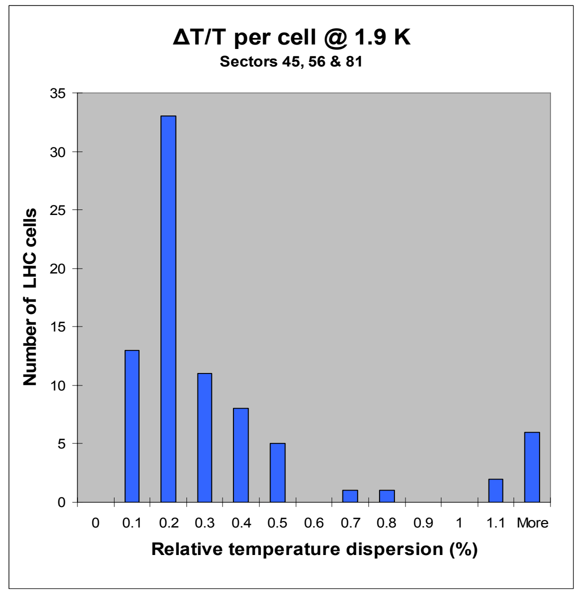

Figure 3

Figure 3 shows these results for 3 sectors. Knowing the above mentioned requirement of +/- 10 mK overall uncertainty at 1.9 K, the difference between the maximum and minimum temperature for one "isothermal" cell should be less than 20 mK in absolute or 1% in relative. We can observe that this is the case for most of the analyzed cells. The values outside specs correspond to cells at the beginning and end of the Arcs not having reached stable conditions, or to thermometers wrongly identified for which the calibration table used is not correct.

CONCLUSIONS

Because of the number and diversity of the instrumentation, the dependence of the project on comprehensive databases is fundamental, from the manufacturing of the equipment to the final test, including the software automatic generation. As a result of the quality assurance policies and systematic commissioning of all the instrumentation channels, the operational performance within specifications has exceeded 97%. To ensure proper operation and maintenance in nominal conditions under radiation, the respect of the procedures and the update of databases will be essential.