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THE CONTROL SYSTEM FOR THE CRYOGENICS IN THE LHC TUNNEL [FIRST EXPERIENCE AND IMPROVEMENTS]

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Abstract

The Large Hadron Collider (LHC) was commissioned at CERN and started operation with beams in 2008. Several months of operation in nominal cryogenic conditions have triggered an optimisation of the process functional analysis. This lead to a few revisions of the control logic, which were realised on-the-fly. During the 2008-09 shut-down, and in order to enhance the safety, availability and operability of the LHC cryogenics, a major rebuild of the logic and several hardware modifications were implemented. The databases, containing instruments and controls in-formation, are being rationalized; the automatic tool, that extracts data for the control software, is being simplified. This paper describes the main improvements and sug-gests perspectives of further developments.

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INTRODUCTION

The LHC Machine

The LHC is a 27 km proton collider, lying 100 m underground, and comprising eight sectors; each one is made of 2 long straight sections (**LSS**) and a curved part (**ARC**), with 23 regular cells of 107 m in a continuous cryostat.

Along one sector, a repetitive sequence of dipole and quadrupole superconducting magnets steers the particles; a cryogenic distribution line (**QRL**) runs alongside the magnets, to feed them with cold helium.

At the extremities of each sector, several electrical feed boxes (**DFB**) hold and cool the superconducting current leads, through which the magnets are powered.

Controls Architecture

In one sector, a large amount of cryogenic instruments (2000) is distributed over a great distance (3300 m); industrial field networks (Profibus® and WorldFIP®) connect them to two high-end Siemens-S7® Programmable Logic Controllers (**PLC**), each running some 250 control loops and 500 alarms and interlocks [1].

The man-machine interface is based on a SCADA (Supervisory Control And Data Acquisition), built on PVSS®. The control software conforms to the UNICOS framework (UNified Industrial COntrol System) of CERN [2].

CONTROLS

Operability - PCOs, Sequencers & New Signals

The process logic is supervised by a hierarchy of Process Control Objects (**PCO**); the master is the sector-PCO; below, there are one per PLC, corresponding to the ARC and LSS; under these, there were originally one PCO dedicated to each cryogenic cell (e.g. 13 in ARC).

From the experience, it became clear that all cells were usually operated together, as they are simultaneously fed from the QRL. Therefore, all the individual cell PCOs were replaced by only four, associated to the different hydraulic circuits, which are common to all cells (Fig. 1).

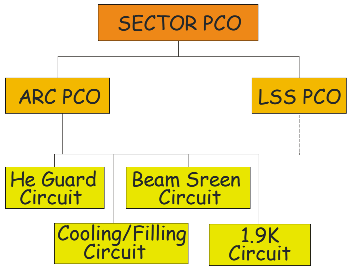

Figure 1: New PCO structure.

The **phase s equencer** had initially been designed to handle eleven phases and all possible transitions between them. Besides, the sequencer was replicated at all levels of PCOs.

In order to improve operability the cool-down sequence was simplified, by grouping in merely two phases the original eight different ones. Furthermore, this shortened phase sequencer was kept just in the middle-level PCOs, and removed from the other levels.

Moreover, this cool-down sequence is activated only when the master sector-PCO is in the newly defined **option-mode** ‘cool-down’. The 3 non-cool-down phases (emptying, stand-by, warm-up), of the original sequencer, have also been defined as option-modes of the sector master PCO, but without any sequencer (Fig. 2).

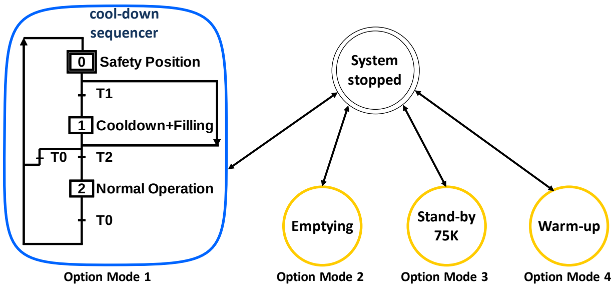

Figure 2: New simplified sequencer and option-modes.

This reduction in the number of PCOs, sequencers and phases, and the introduction of the option-modes, greatly simplified the tasks of the operators that had to manage and monitor them.

Other contributions to improve operability, by enhancing clarity and facilitating process diagnosis:

- new time derivative of the average temperatures of cells: to follow the evolution of the cooling rate by cell and for whole sector; also used in calorimetry;in SCADA provided new links: from actuators to interlock diagnostic panels and from sensor to database, with corresponding electrical and metrological information; soon available: the link from PCOs and dependent objects to the corresponding logic definitions;

- list of signals exchanged between the tunnel PLCs and with external systems: simplified (non-essential signals removed) and adapted to the new process requirements;
- operator beep call: evolved from single-level to 3-levels (warning, reduced-capacity, full-stop), in order to homogenise with other cryogenic systems controls;
- new control loop evenly and smoothly distributes, through available magnet heaters, the power needed to adapt a sector's heat load during transient operation;
- new sector-level Cryo-Start/Maintain: interlock to start or maintain the powering of magnets, now combining all partial signals from sub-systems.

Availability – Nominal Conditions

In order to limit the down-time of magnet powering, the availability of the machine in nominal cryogenic conditions is expected to improve with the implementation of:

- median filters on all sensors, to avoid spikes;
- first-order low-pass filter at the input of control loops, e.g. to stabilise the level of liquid helium;
- new LT object with more accurate parameterisation;
- control loops reviewed and optimised;
- interlocks list fully reviewed, with non-essential ones moved to the actuators' logic instead.

Safety –Quench Valves & DFBs

In case of damage of the magnets' helium enclosure when the machine is filled with dense helium, and in order to avoid or minimise helium release into the tunnel, the new logic of the quench protection valves is now able to automatically trigger a discharge into the QRL, independently of their mechanical threshold being reached.

The hard-wired vacuum-quality signals were upgraded to provide more detailed information. For each vacuum sub-sector, a new signal of confirmed-loss-of-insulation has been cabled between the vacuum PLC and the cryogenics PLC. Combined with a confirmation by cryogenic signals (like pressure measurement), this signal can activate the opening of the quench valves in the corresponding sub-sector.

New hardware signals notify the operator, via beep call, of potential degradation in DFBs operating conditions:

- 117 thermal switches, which become active when the DFB safety valves are expelling cold gas, thus warning about helium release into the tunnel;
- 107 pressure switches, which become active when the dry air pressure decreases in the bags surrounding the current leads, thus warning about condensation risk.

Software Production

The various modifications on PCO structure, phase sequencer, control loops, interlocks, and a new version of the UNICOS programming environment, implied a significant rebuild of the logic templates used by the PLC code generators and of the functions with repetitive code for objects families.

The tools for automatic generation and for automatic validation of the controls specifications were modified too. Of course, several SCADA panels had to be changed accordingly. Moreover, a PVSS script was developed to simplify the activation of the remote-reset command to the Profibus equipment.

DATABASES

The First Approach

Since 2006 the Cryogenics group has been intensively using several databases (DBs) to manage data appertaining to 25 000 cryogenic instrumentation channels. The information extracted from these DBs is essential for the production of the controls software and of the documents used in electronics manufacturing, cabling and testing.

The **Layout DB** is the principal database for maintaining the topology of all CERN equipment [2]. It contains all the details of the cryogenic instrumentation attached to magnets and to other cryogenic accelerator equipment; the electrical components of the controls infrastructure, including cables, connections, pin-outs, electronic modules, crates and racks, are also defined there.

Thermbase is a dedicated DB containing the calibrations for all thermometers in the LHC. **Sensorbase**, its upgrade now under development, aims to consistently manage the metrological data of other sensors too.

The **MTF** DB (Manufacturing and Test Folder) holds information about individual pieces of equipment, in particular status flags and property values.

The **Controls L ayout** DB acts as an interface that combines the data from Layout, Thermbase, Sensorbase and MTF, into views directly used by the automatic **Generator** of the **Specifications** for the control system. It also stores parameters and objects that could not be integrated into the Layout DB structure.

Consolidate the DB

The tasks from October 2008 till mid 2009 were focused on updating the data, in order to cope with the physical changes in the LHC installation; this concerned the addition of new instrumentation channels and the update of parameter values. It is typically an ongoing task, which will continue throughout the operation of the machine.

Rationalise the Data

At the beginning of the project, a global view of the data was not yet achieved; also, the Layout DB had limitations about the type of data it should store. Therefore, only the topology of the physical instrumentation in the LHC was initially recorded in the Layout DB.

Several types of conceptual objects, required for the control system, did not appear to fit in the Layout DB structure; examples were 'instruments' which do not physically exist but are derived from others, like calculated flow or max/min values; and variables not easily related to anything physical, like spare objects or information exchanged between PLCs. This kind of objects was initially stored in Controls Layout, in tailor-made database structures such as tables and procedures.

Over time, the scope of the original Layout data model was broadened; it was acknowledged to be flexible enough to accommodate, with only minor modifications, a wider range of objects and properties. Thus, it became possible to apply a coherent treatment to physical and conceptual objects. In addition, the multiple channels of some instruments, which were handled as a mix of DB objects, could also be integrated and linked.

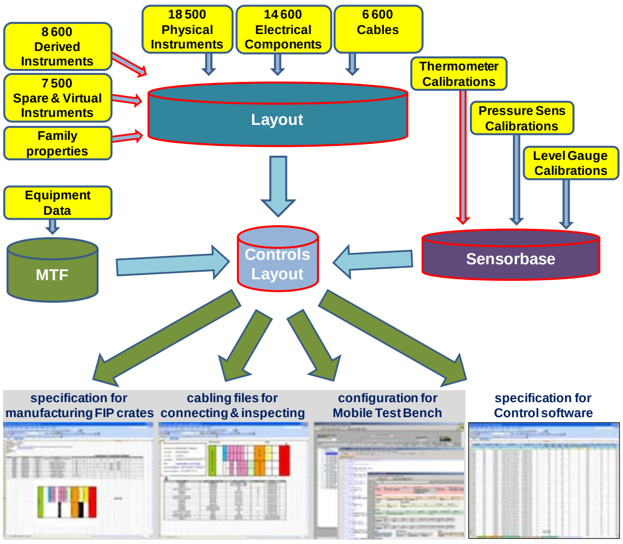

Figure 3: New databases organisation.

Grouping as much data as possible in the Layout DB (Fig. 3), and treating all types of instrumentation channels the same way, is highly rewarding: the overall data structure is simpler and easier to access and to maintain; the views for the controls specifications become less complex, as no longer is necessary to maintain distinct pieces of code to separately retrieve each category of instrument; derived instruments can automatically inherit properties from their parent; the existing Layout DB web interface can be used to easily browse data, and to traverse the data structure following relationships between conceptual objects and physical instruments; as Layout integrates data from other systems, like PLCs, fieldbuses, magnets, electrical circuits, etc., it is easier to perform analysis, diagnosis and maintenance across domains. Other inbuilt features of Layout DB include versioning logging of data modifications.

One of the main long term objectives is to develop an interface for the users to manage and update their own data. With a single coherent data structure, the user can easily modify all objects through the same technique.

Simplify the Generation of Specification Files

The Specifications Generator extracts data from several DB views and also from external spreadsheets; it then applies a set of rules and calculations, to derive parameter values, relationships and secondary objects.

Historically, it has undergone a lot of re-patching and contains an enormous amount of logic to handle every special case and exception, like the DBs before their rationalisation. It became difficult and time-consuming to maintain, with part of its code now obsolete.

Presently, that the LHC cryogenics configuration and the set of derived instruments are stable, there is no more need to automatically re-generate certain tables; therefore, the results of most of those rules are being imported to Layout DB as data items. However, simple rules that depend on the sorting of the instrument list, like the calculation of PLC addresses, are coded in a view or procedure.

The data externally stored or embedded in the Specifications Generator is also being transferred to Layout DB. All variables and conceptual objects will thus be available from the DB and not hidden in the generator code or dispersed in files. Any future corrections for individual exceptions can be manually implemented; if it is the original rule that changes, data can be re-imported in batches.

Once this data is complete and coherently structured in the DBs, a set of views will replicate each page of the instruments specifications. The maintenance of both the generator and the database will then be much simplified.

Other items of the specifications, such as relationships between sensors and actuators in a control loop, might be integrated into the database; the treatment of higher-level objects as alarms or process-controllers is being analysed.

A particularly useful view, still under construction, is the one with the PLC hardware configuration, whose contents is easily built from the database and which will be directly importable into the S7 development environment.

CONCLUSION

Database work is well advanced but far from beeing finished. In parallel, effort is being put into maintaining the functionality of old views, in order to minimise the non-negligible modifications to the specifications generator's code, if an emergency run becomes necessary.

Also in the line with keeping documentation up to date, the electrical and fieldbus network diagrams are being refreshed; their correctness is vital for maintenance and for prompt and efficient support to operation.

We have evolved towards simplicity in process control, databases, and generator of specifications; we have combined cumulative patches and eliminated features that were intended to cover a wide range of possibilities during the machine start-up. The control system is now more reliable and user friendly and much adapted to regular operation.

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