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# Validation of the Data Consolidation in Layout Database for the LHC Tunnel Cryogenics Controls Upgrade

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**Keywords:** LHC, Cryogenics

**Abstract**
The control system of the Large Hadron Collider cryogenics manages over 34’000 instrumentation and actuator channels. The complete information on their characteristics and parameters can be extracted from a set of views on the Layout database, to generate the specifications of the control system; from these, the code to populate PLCs (Programmable Logic Controller) and SCADA (Supervisory Control & Data Acquisition) is automatically produced, within the UNICOS framework (Unified Industrial Control System). The Layout database is, since 2003, progressively integrating and centralizing information on the whole CERN Accelerator complex. It models topographical organization (layouts) as functional positions and relationships. After three years of machine operation, many parameters have been manually adjusted in SCADA and PLCs; they now differ from their original values in the Layout database. Furthermore, to accommodate the upgrade of the UNICOS Continuous Process Control package to version 6, some data structures and values have been modified. This paper describes the methodology to update and validate the new data, and the software tools developed for that purpose.

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# VALIDATION OF THE DATA CONSOLIDATION IN LAYOUT DATABASE FOR THE LHC TUNNEL CRYOGENICS CONTROLS UPGRADE

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## *Abstract*

The control system of the Large Hadron Collider cryogenics manages over 34'000 instrumentation and actuator channels. The complete information on their characteristics and parameters can be extracted from a set of views on the Layout database, to generate the specifications of the control system; from these, the code to populate PLCs (Programmable Logic Controller) and SCADA (Supervisory Control & Data Acquisition) is automatically produced, within the UNICOS framework (Unified Industrial Control System). The Layout database is, since 2003, progressively integrating and centralizing information on the whole CERN Accelerator complex. It models topographical organization (layouts) as functional positions and relationships. After three years of machine operation, many parameters have been manually adjusted in SCADA and PLCs; they now differ from their original values in the Layout database. Furthermore, to accommodate the upgrade of the UNICOS Continuous Process Control package to version 6, some data structures and values have been modified. This paper describes the methodology to update and validate the new data, and the software tools developed for that purpose.

## INTRODUCTION

The Layout data base is the principal CERN-wide database for centrally maintaining the topology of all CERN installations, aiming to capture the system architecture. It was originally designed to manage the functional positions of the LHC ring components (mainly magnets). However since 2003 the database model was reshaped, in order to be more generic and scalable; its scope was then extended geographically and opened to any LHC machine domain [1].

## CRYOGENIC INSTRUMENTATION DATA IN THE LAYOUT DATABASE

The cryogenics instrumentation and control teams used the Layout Database to structure a large amount of operational data in a so that it could be used to configure several types of equipment for manufacturing, to produce the global specifications for the cryogenic control system, and to help install, maintain and debug the instrumentation channels.

The cryogenic data in the Layout database describes the physical instrumentation attached to magnet assemblies and cryogenic distribution, as well as the electrical components of the controls infrastructure [2] including the cables, connections, pin-outs, electronic modules, crate and racks. The data is structured in the Layout Database in a way that models precisely the physical implementation of each instrumentation channel, to a very high level of detail.

Over time, the scope of the original Layout data model was broadened as it was acknowledged to be flexible enough to accommodate a wider range of objects and properties [3]. Thus, it became possible to apply a coherent treatment to both physical and conceptual objects required by cryogenic control system.

Therefore it is not only storing data about individual physical IOs but also other software objects required for the control system which are high-level relationships between sensors and actuators. These conceptual objects, Process Control Objects, Controllers and Alarms were also successfully integrated into the database, using the same model.

The control system of the Large Hadron Collider cryogenics currently manages over 26500 physical instrumentation and actuator channels, 8000 spare and virtual channels and more than 30000 conceptual objects. All of the objects and parameters necessary for configuring the cryogenic control system are stored in the Layout database, apart from calibration data which is stored in a dedicated calibration database. The code to populate PLCs and SCADA is automatically produced within the UNICOS framework []from a control system specification file_holding all the necessary data to specify the functioning of all the objects used.

### *Cryo Control System Specifications*

Until 2010, the control system specifications were produced by a complex automatic generator that extracted data from several databases and various external files before applying a complex set of rules and calculations. It contained a large amount of code to handle each special case and exception; and thus it became difficult and time-consuming to maintain. It was crucial to remove all of the knowledge embedded in the generator code and transfer it to the Layout database. However the rules to generate part of the control software - logic parameters required to generate process logic code - were not simply recoded. Instead, the resulting data values produced by the rules were imported directly into the database as instrument proprieties [3].

Furthermore, the following methods were applied to ensure coherence of data: coherent structure to the database, dedicated rules to validate the consistency of data and the production of a set of views.

Each view extracts and assembles the necessary objects and parameters from the structured data model within the Layout database and presents the data in a format which corresponds exactly to the structure of each type of I/O channel as they are classified in the control system specification. They are defined in a specific Controls Layout database which acts as an interface for assembling the data from Layout DB and Sensorbase; the cryogenic calibration database.

To obtain the control system specification a simple application which extracts all of the required data from each view was developed.

## METHODOLOGY OF THE VALIDATION

### *System Consolidation*

The original values of parameters used to build up the first deployment of the control system were defined before the LHC was operational and they were often estimates. During the first tunings and operation periods for the LHC machine various consolidations and improvements of the control system and its Layout DB were implemented on the fly [5]. In parallel, the database views were prepared for future redeployment of the control system by taking into account all requirements for the new UNICOS CPC6 framework.

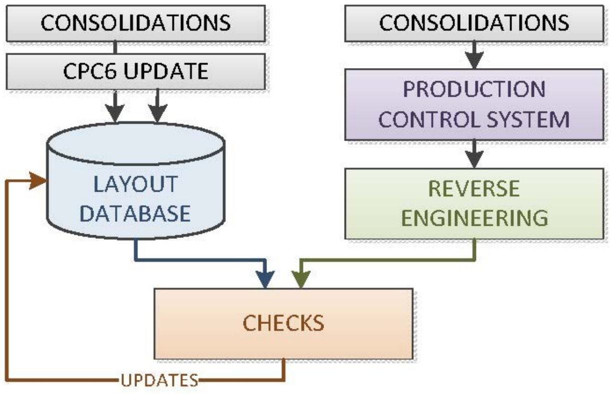

Figure 1: Consolidation of the Layout DB.

The consolidation of the Layout DB [Figure 1] was done in a process of homogenization and standardization where all instruments channels with the same function should have identical values for some specific parameters such as range, scale, dead band and data format. Although these corrected parameters were grouped by functionality, they were propagated to the Layout database as properties of individual channels. This allowed future adjustments at channel level if an exception to the general rule was observed during operation.

During the LHC machine tuning period and through three years of operation many of the process parameters had been manually adjusted in PVSS by experts and operators in order to improve the performance of the control of the cryogenic system. Storing these values in the database safeguards these modifications when the control system software is regenerated.

Several corrective patches were implemented on the software following the technical requirements and feedback from cryogenic operation to improve the control system. All changes were realized directly in the PLCs and SCADA rather than generating the whole code from the UNICOS framework because the impossibility of commissioning the complete system during the machine running.

In order to cope with Single Event Upset induced by radiation failures on remote I/O modules an automatic routine detecting communication failure and then executing a power-cycle reset was successfully tested and implemented in the PLCs.

Furthermore, a review of the tunnel cryogenics power-supply architecture enforced by radiation-induced failures conducted to a new design improving redundancy and protection selectivity. New physical I/O channels for automatic resets and power supplies diagnostics were integrated into the control system.

Control loops for a specific type of circuit were optimized and complemented with new objects and logic. This modification allowed a smooth operation during injection of particles beam in the LHC machine

In order to improve the accuracy of the superconducting magnet temperature regulation, 750 channels were progressively equipped with the missing electronic cards and channels were activated.

Following all consolidation of the control system around 500 channels together with their relationships were created in both PLCs and SCADA and afterwards propagated to the Layout DB.

The upgrade of the UNICOS programming environment to version CPC6 did not imply any changes in the data or the underlying database structure, but new database views corresponding to the new file formats had to be developed. However, a new set of parameters needed to be added or adapted to cope with the new features that the new version of the framework was offering. New object classes were added; others were eliminated or were changed according to new object classification given by CPC6.

The data became inconsistent as a result of all these variation of values, modifications of objects and their logic. To ensure data quality and consistency between the Layout database and the production control system, all data had to be retrieved from the PLCs and SCADA by a reverse engineering process and afterwards compared and checked against the database content.

### *Reverse Engineering*

Reverse engineering was necessary to obtain a set of values stored in the SCADA data servers that defined the link to all objects stored in the PLCs as well as the behaviour of the their appearance, filtering and archiving. It also had to be used for retrieving the parameters from the old source code used to generate the software of the PLCs and finally to gather the data held in the PLCs related to the process control.

Several tools were developed to retrieve data from the production control system:

- Tool 1 was created to be able to connect to a data server from SCADA & CIET (Cryogenics Instrumentation Expert Tool) [6] and collect all the information stored, such as names and description of the objects, ranges, dead bands, smoothing values and archiving configuration [Figure 2]. In total 88'000 objects together with their parameters were retrieved and classified according their application in 18 control system specifications.
- Tool 2 extracted information from objects representing field equipment from the last version of the PLC source code which is not stored in the PLC nor in the SCADA. This code could have changed because of machine protection – interlocks – or initialization values.
- Tool 3 was able to gather the values from the PLC code which were tuned by cryogenic experts from the operation machine such as parameters from closed loop controllers, settings for the alarms and the data which was not stored in the SCADA system.

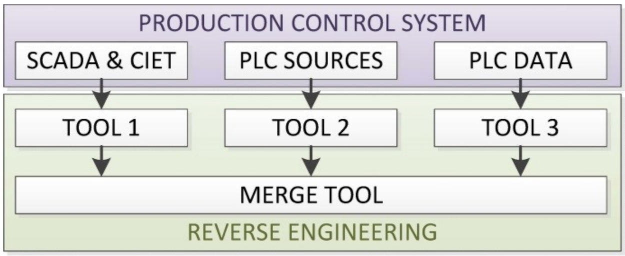

Figure 2: Production Control System.

All the information collected by the tools was treated in several steps to assure the correct validation of the information. The merge tool used several rules in order to take the data from different sources and merged them to the values of the objects of the system. This task was relatively complex as there were a lot of exceptions. For instance, some values used as standard coming from the homogenization had to be overwritten by values chosen by the cryogenic experts because of the particularities of the machine operation.

The merge tool was dealing with the data for 18 PLCs with more than 34451instrumentation channels, 5971 alarms, 5733 parameters, 4562 calculated objects and 3650 closed loop controllers, with an average of 50 values to be checked for each one, representing nearly 3 million values per tool.

At the end of the merging process, the Layout database was ready to be validated.

## *Data Validation*

Data validation had to be done in several steps, checking values in the database, comparing them with the parameters from SCADA and finally comparing them with data from PLCs.

The first step for validating the data was to ensure that all objects which were found in the production control system were also present in the updated database [Figure_3]. Since no changes could be applied to the system while it was in normal operation, all objects added to the SCADA system were in fact existing spare objects whose names were changed in the supervision layer. After consolidation, objects with new properly defined names were linked to spare objects in database by index number. Mismatching names could be retrieved and corrected in Layout database.

Characteristics of objects used in the process control – like identification, PLC and SCADA characteristics, archiving… - are defined in Layout database as slot properties. There are also two sets of custom parameters which are used to define the security of the equipment and to generate specific source code for the logic of the system. For instance, the parameters for a control loop could be used with several sensors as input, a valve as output and several other parameters for the logic definition, which describe the behaviour of the controller under certain conditions such as operation modes or alarms.

The next stage in the validation process was to compare the parameters stored in the database with the parameters extracted from the production system using the tools described above. The purpose of this comparison was to test the validity of the data in order to generate the source code for the control system.

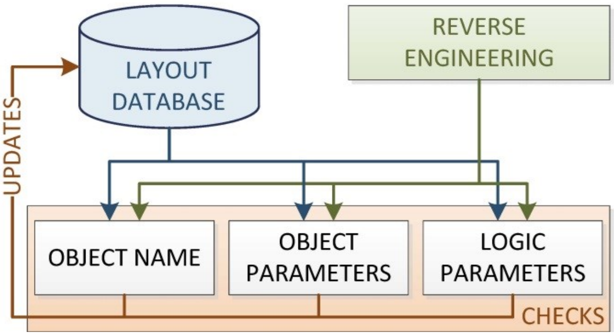

Figure 3**:** Updated database system.

The validation process applied to this detailed data was carried out by a set of semantic checks with data validation rules. These rules had to be defined in a way which ensured that all of the data used to generate the source code for both PLCs and SCADA from the database was valid. The set of rules was divided in two parts [Figure 4], a generic set coming with the UNICOS framework (which is valid for any control system created in UNICOS environment) and an additional set of custom rules performing checks for the LHC cryogenic tunnel control system. The first set of rules validates all of the generic characteristics of UNICOS objects – such as whether object names are properly defined (i.e. comply with restrictions regarding length and characters used), the existence of objects defined as inputs outputs or higher level objects, or if all data required for selected type is present and properly defined.

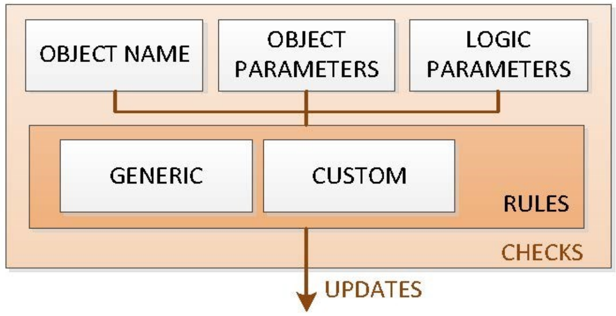

Figure 4: Rule sets: Generic UNICOS and custom LHC cryogenic sets.

The custom set of validation rules performs validation on specific object properties:

- Checking cross-object dependencies, such as the presence of input object of certain types requiring the presence of a corresponding field object and output.
- Checking if objects of certain type have properly defined parameters. Each type of object should have a defined set of parameters i.e. objects representing sensors should have ranges defined depending of types of sensor – temperature, pressure, flow… –.
- Cross-application checking if corresponding communication objects are defined in a proper and coherent way on both sides, for sending and receiving.

When an issue is found, a corrective action is applied by a semantic checker. The set of custom checks is continuously increasing as new constraints are being identified.

Such extensive validation allows the identification and correction of most of the issues within the data which would cause errors during the source generation from UNICOS framework or later during normal operation.

## CONCLUSION

The validation of the Layout database has been achieved, making the database once again the only data source required for producing the specifications used to automatically generate the code for the LHC tunnel cryogenics control system within the UNICOS framework.

The changes to the data after three years of the operation of the LHC as well as the upgrading of the UNICOS framework has presented a challenge which has been resolved satisfactorily by applying a methodology for the treatment of data and the use of the new tools developed for the task.

As a result, the database is ready to be used to generate the process control system for the LHC tunnel cryogenics, using the new UNICOS 6 framework and other upgrade that will certainly arrive in the future life of LHC accelerator.

## REFERENCES

[1] P. Le Roux et al., “The LHC functional Layout database as foundation of the controls system”, ICALEPCS07, Knoxville, USA, Oct-2007, p. 526.

[2] P. Gomes et al., “The control system for the cryogenics in the LHC tunnel [First Experience and Improvements]”, ICALEPCS09, Kobe, Japan, Oct-2009.

[3] E. Fortescue-Beck et al., “The integration of the LHC cryogenics control system data into the CERN Layout database”, ICALEPCS2011, Grenoble, France, Jul-2011, p. 147.

[4] Ph. Gayet, R. Barillére, “UNICOS a framework to build industrial-like controls systems principles methodology”, ICALEPCS05, Geneva, Switzerland, 2005.

[5] Fluder et al., “Main consolidations and improvements of the control system and instrumentation for the LHC cryogenics”, ICEC24, Fukuoka, Japan, May-2012, p. 35.

[6] E. Blanco, Ph. Gayet, “LHC cryogenic control system: integration of the industrial controls (UNICOS) and front-end software architecture (Fesa) applications”, Proceedings of ICALEPCS2007, p. 281.