THE INTEGRATION OF THE LHC CRYOGENICS CONTROL SYSTEM DATA INTO THE CERN LAYOUT DATABASE

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Abstract

The Large Hadron Collider's Cryogenic Control System makes extensive use of several databases to manage data appertaining to over 34,000 cryogenic instrumentation channels. This data is essential for populating the software of the PLCs which are responsible for maintaining the LHC at the appropriate temperature.

In order to reduce the number of data sources and the overall complexity of the system, the databases have been rationalised and the automatic tool, that extracts data for the control software, has been simplified. This paper describes the main improvements that have been made and considers the success of the project.

INTRODUCTION

The LHC Machine

The **LHC Machine** is a 27 km hadron collider, laying 100 m underground, and comprising eight sectors; each one is made of 2 long straight sections and an arc, with 23 regular cells of 107 m in a continuous cryostat.

The Controls Architecture

In each sector, the cryogenic instrumentation is controlled by two Siemens-S7® Programmable Logic Controllers (PLCs) [1, 2].

The man-machine interface for the operators is based on a SCADA (Supervisory Control And Data Acquisition) built using the commercial PVSS® software package developed by ETM, a Siemens subsidiary.

CIET (Cryogenics Instrumentation Expert Tool) is a dedicated SCADA tool used by the cryogenic instrumentation experts.

All cryogenics software (SCADAs and PLC software) conform to the CERN UNICOS (Unified Industrial Control System) framework [3] and is automatically produced by a UNICOS generator. The UNICOS generator takes as an input a specification file containing a list of instruments and parameters. The main aim of this project is to generate this file directly from the databases.

The Databases

Since 2005 the Cryogenics Group has been intensively using several databases (DBs) to manage data appertaining to 34,000 instrumentation channels.

The **Layout DB** is the principal database for centrally maintaining the topology of all CERN installations [4].

Thermbase is a dedicated DB containing the calibration data for all thermometers in the LHC. Its successor **Sensorbase**, is under development and aims to consistently manage all of the metrological data for pressure sensors, level gauges and heaters, in addition to thermometers.

The **MTF** (Manufacturing and Test Folder) **DB**, holds information about individual pieces of equipment. This includes properties, test measurements, status flags, and strict follow-up of the steps of manufacturing, assembly & test procedures.

The **Controls Layout DB** acts as an interface, combining the data from Layout, Thermbase, Sensorbase and MTF into database views which provide the complete set of information used to automatically generate the specifications for the control system.

WHY USE THE LAYOUT DATABASE FOR CRYOGENIC INSTRUMENTATION

The Layout database was initially developed in 2003 for planning the installation and commissioning of the components in the LHC. It aims to capture the system architecture and the details of the installed components in the accelerator complex. Therefore most of the Groups who are responsible for accelerator equipment describe their architecture in this database. Figure 1 shows a few examples of domains currently using Layout; however in principle any domain can be described.

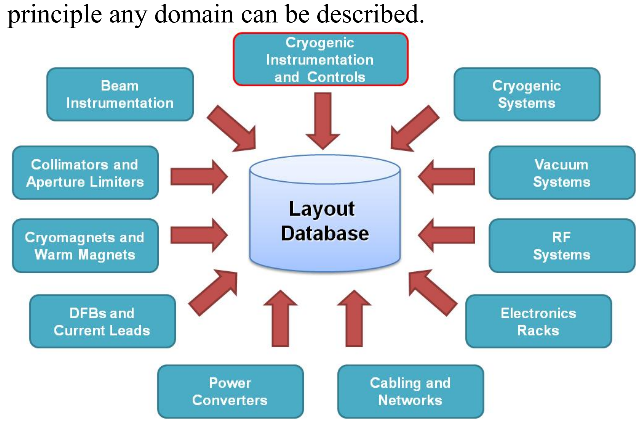

Figure 1: Domains which use the Layout Database.

Unexploitable Data

In 2005, the Cryogenic Instrumentation and Control Section needed to structure a large amount of operational data in a database so that it could be used to define the configuration of the front-end crates, for manufacturing, and also to produce the specifications for the control system.

The data describes the instrumentation attached to magnet assemblies and cryogenic distribution, as well as the electrical components of the controls infrastructure including the cables, connections, pin-outs, electronic modules, crate and racks. Up until this point it was being stored in spreadsheets, plans, drawings and technical documents – usually on team members' local hard disks. Consequently, the data was dispersed, duplicated, incomplete and inconsistent.

This data forms the basis for nearly all of the key tasks performed by the instrumentation team, but without consolidating it in a database, it would be impossible to extract and share accurate, useful information.

Centralising and Consolidating across Domains

By deciding to integrate the majority of their data into the Layout database, the cryogenics engineers benefitted from having just one single, reliable source of information which was accessible to all team members.

Furthermore, due to the centralised nature of the Layout DB, they profit from the global integration with data from other systems, such as PLCs, field buses, magnets, cryogenics distribution, electrical circuits, etc. This integration means that maintenance across domains is easier to manage and greatly helps the machine operators to diagnose problems more rapidly.

Data Accessibility

The existing Layout web interface can be used to browse the data, easily traversing the data structure and the relationships between objects through hyperlinks. Also, since Layout is fully integrated with MTF, it is possible to directly access, via the web interface, all of the manufacturing and test data concerning the specific piece of equipment which is installed in a particular Layout position. This integration with MTF facilitates traceability, as the database can track over time all of the locations in which a component has been installed and also all repairs it has undergone. This is essential information required by international regulations on nuclear safety.

The seamless integration between UNICOS, Layout and MTF allows direct access from any instrument in SCADA to its functional information on the Layout web interface, and then to its individual properties and history in MTF.

Other useful inbuilt features of the Layout DB include versioning and the ability to track changes to the data.

EVOLVING FROM A FIRST APPROACH

Initially, only the topology of the LHC's physical instrumentation was recorded, with a limited number of object types.

Hence, conceptual objects required for the control system were not catered for in the Layout DB structure. These objects included '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 status information exchanged between PLCs.

Therefore tailor-made database structures such as tables and procedures were implemented in a supplementary Controls Layout database in order to either store or dynamically generate these new types of objects.

Rationalising the Physical and Conceptual Channels

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. Thus, it became possible to apply a coherent treatment to both physical and conceptual objects.

The major benefit of grouping data in the Layout DB and treating all types of instrumentation channels the same way was that the overall data structure became simpler and the data was easier to maintain. In addition, the views for the controls specifications became less complex, as it was no longer necessary to maintain distinct pieces of code to separately retrieve each category of instrument.

The Need for Inheritance and Relationships

The Layout DB supports inheritance. This means that derived instrumentation channels could automatically inherit properties from their parent, thus eliminating inconsistencies which could have been introduced if modifications to the parent instrument were not explicitly reapplied to the child.

As well as implementing conceptual objects in Layout, new types of conceptual relationships between instruments have also been defined; for example the link between a virtual flow meter and the instruments used in the flow calculation, such as its upstream thermometer or valve aperture, as illustrated in Figure 2.

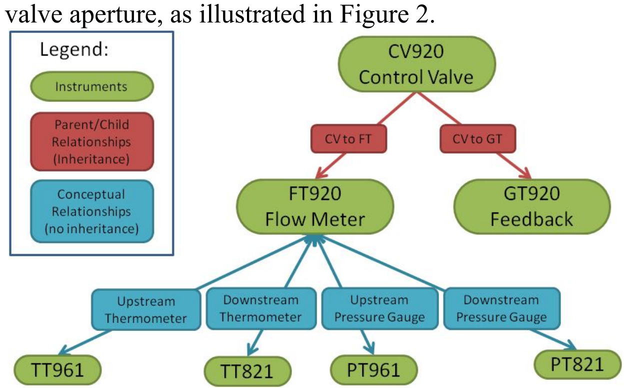

Figure 2: Inheritance and conceptual relationships.

The Introduction of Systems

Up until this point the emphasis had been focused on implementing the individual IOs in the Layout database. However there were other software objects required for the control system such as Process Control Objects (PCO), Controllers, Alarms and Interlocks, which are high-level relationships between sensors and actuators. These objects were successfully integrated into the Layout DB by defining them as "Systems", which are groups or hierarchies of Layout objects.

Figure 3 shows how high-level PCO systems are defined as a hierarchy of lower-level PCOs, which in turn are hierarchies of controller systems. At the controller level, the systems link to the IOs, as a controller is specified as a group of instrumentation channels.

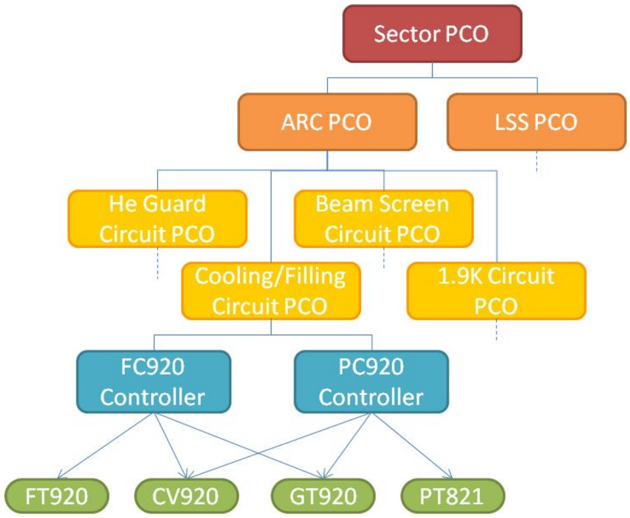

Figure 3: a hierarchy of systems.

COMPLETING THE DATA

After defining the structures of all types of instrumentation channels and control loops in the Layout DB, the data could be completed and all other data sources eliminated. Before this parametric data was integrated into the Layout DB it was thoroughly checked for consistency.

Importance of Data Quality

In the LHC, Instrument functionality is characterised by a dedicated attribute called Tag name. This implies that all instruments with the same Tag name should have similar values for Range, Scale, Deadband and Format due to having the same typical operation characteristics. For example, PT821 pressure sensors found in the magnet cold masses have a typical Range of 0 to 20bar. Whereas the PT891 pressure sensors on the DFB (deltaP line) have an operational range between -350 and +350mbar.

The SCADA display also depends on the Tag name, in harmony with the measurement range. For example, the reading from a PT821 sensor is formatted on the SCADA display as 2 integers plus 2 decimals, whereas a PT891 sensor is displayed as 3 integers. All of this information is stored in the Layout DB and propagated to the control system for use by the operators.

Maintaining Data Consistency

The original values of parameters such as Range, Scale, Deadband and Format were defined before the LHC was operational and were often estimates. Since the machine had been operational for nearly a year, many of these parameters had been manually adjusted in PVSS by experts and operators in order to improve the performance of the control system. Storing these values in the database safeguards these modifications when the control system software is regenerated.

Therefore, for each distinct Tag name present in the Layout DB, the set of current operational parameters were extracted from the SCADA. For those Tag names having conflicting parameter values, the discrepancy was resolved in conjunction with the cryogenics experts.

It was important to review these parameters because of the significant impact they have on the performance of the control system. For example, the Deadband value defines the type of filtering performed by the SCADA archiving. By default PVSS logs data at a rate of 1Hz. Filtering is required to reduce the raw data volumes by eliminating noise and keeping only relevant data long-term.

Although these corrected parameters were grouped by Tag name, they were propagated to the Layout DB as properties of individual channels. This allows future adjustments at channel level if an exception to the general rule is observed during operation.

The Description as a Key Attribute

"Description" is a very important attribute as it indicates the function of an instrument and therefore facilitates the work of the operator. In the SCADA, the description shown on the instrument panel includes the instrument functionality concatenated with field bus address, (the source of both of these pieces of data is the Layout database). This makes it easier for maintenance people to know where to find the instrument in the field bus without having to refer to other data sources.

Before the descriptions were reviewed, some were missing, incorrect or incoherent between instruments with the same tag name or similar functions. All descriptions were rechecked so that they were consistent in content and format across all types of instrument and then updated in the Layout Database.

GENERATING SPECIFICATION FILES

Business Logic in the Application

Until 2010, the control system specifications were produced by an automatic generator that extracted data from several DB views and various external files and applied a complex set of rules and calculations, to derive parameter values, relationships and secondary objects.

This Specification Generator was a very complex application which underwent a great deal of re-patching. It contained an enormous amount of code to handle each special case and exception; and thus it became difficult and time-consuming to maintain. With the rationalisation of the databases, it rapidly became unmanageable.

Transferring the Business Logic to the DB

It was critical to remove all of the knowledge embedded in the generator code and transfer it to the database. However the logic was not simply recoded. Instead, the results given by the rules were imported directly into the database as data items. This could be done because by 2010 the LHC cryogenics configuration was reasonably stable and the set of values calculated by the generator was complete. This meant that it was no longer necessary to automatically recalculate the values. Any future corrections for individual exceptions can be manually implemented; if the original rule changes, the data can be re-imported as a batch.

The main advantage of this approach is that all of the data in the specification files is available in the database, as either persistent or aggregated values. By converting generation rules into data the amount of calculated data and information hidden in the code has been minimized. Consequently, other applications can use this data without having to re-implement the logic. Also, the code in both the generator and the database is simplified, greatly reduced and maintainable.

Simplifying the Specifications Generator

Once all of the data was coherently structured in the database, a set of views were produced which exactly replicate the structure of each page of the IO specifications. These views are stored in the Controls Layout database which acts as an interface for assembling the data from Layout, Sensorbase and MTF.

The Specifications generator has been replaced by a simple application which extracts all of the required data from each view, for a given sector and PLC. It formats the data as either a text file – in the case of the Hardware Configuration Specifications – or as an Excel file.

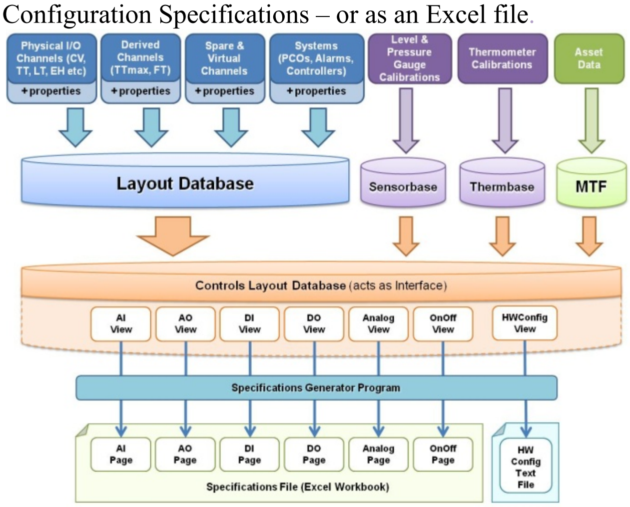

Figure 4: Generating Specifications from the Databases.

It is important to note that there is no business logic in the new generator application and it does not extract any data from external files.

FUTURE IMPROVEMENTS

Aside from on-going maintenance the cryogenics instrumentation data is currently stable.

New Client Requirements

With the upgrade of the UNICOS programming environment to version 6 in 2012, the format of the specifications files will be modified [5]. Currently, the same specification files are used to generate both the Operator's SCADA (based on UNICOS) and the Experts SCADA (CIET), but in the future two separate sets of specification files will be required. This will not imply a change in the data or the underlying database structure, but new database views corresponding to the new file formats will need to be developed. In addition, the generated files should be in xml format which implies a change to the template integrated in the new generator program.

Remodelling of the Layout Database

During 2011 the Layout database will undergo a significant restructuration. However, the specifications views should remain largely unaffected because they extract the majority of their data from an all-inclusive summary view. This complex view will have to be completely rebuilt in order to retrieve the instrumentation data from the new database structures in a way that is transparent for the specifications views.

Improved Access and Availability

A major new initiative planned for 2012 is the development of a read/write interface for the Layout Database. It will combine the browsing functionality of the current Layout web interface with writing capabilities which will allow the equipment owners to introduce modifications, making them fully responsible for their own data. Procedures for maintaining data quality will be established and integrated into the tools.

CONCLUSIONS

We have achieved our primary goal of making databases the only data source required for generating the specifications for the cryogenic control system.

Throughout this project we have strived for an excellent standard of data quality, as it is a fundamental requirement for achieving a fully data-driven system.

By decommissioning the previous Specifications Generator, the databases have become critically important. Therefore, the structure and the data must be meticulously maintained in order to ensure the reliable operation of the LHC cryogenics system.

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