# THE LHC FUNCTIONAL LAYOUT DATABASE AS FOUNDATION OF THE CONTROLS SYSTEM

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*Abstract*

For the design, construction, integration and installation of the LHC, the LHC Layout database manages the information on the functional positions of the components of the LHC. Since January 2005, the scope of this database has been extended to include all electronics racks in the tunnel, underground areas and surface buildings. This description of the accelerator and the installed controls topology is now used as the foundation for the on-line operational databases, namely for controls configuration and operational settings. This paper will sketch the scope of the Layout database, and explain the details of data propagation towards the respective controls data consumers. The question whether this approach is applicable to the rest of the accelerator complex at CERN will be addressed as well.

## REFERENCE DATA

### *Layout of Functional Positions*

In 1998, the LHC Layout database (DB) was designed to manage the functional positions (commonly referred to as *slots*) of the LHC ring components (mainly magnets). The aim was to provide input files to the MAD software simulating beam behaviour of the future machine, checking and validating the studied LHC optics.

In 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 infrastructure.

Thus, the Layout DB was rapidly enriched by the detailed description of the electrical circuits (links between power converters, current leads, warm/cold cables, etc) that power the magnets.

The new database model enables to manage the mechanical topology (layout) of functional positions for any type of equipment (Cryogenics, instrumentation, vacuum, surveying, cooling, ventilation, electrical boxes, etc) and their mechanical dependencies (interfaces) [1]. The DB was extensively used for the overall mechanical integration in the tunnel. The 3D digital mock-ups and drawings, generated from a dedicated toolkit relying on the database, were essential tools for the installation phase.

As from 2005, the scope of the Layout DB was extended towards the controls system infrastructure, driven by the installation and commissioning of the electronics that are to pilot the LHC components [2]. Hundreds of racks had to be installed in the tunnel alcoves, under the cryostats, and also in the underground areas and surface buildings.

The DB model was also enhanced to manage the physical or logical connections (e.g. power cables, backplanes, WorldFIP/Profibus field bus, Ethernet) between individual slots.

Using the Layout DB and its associated tools (Web interfaces, Oracle Forms), control teams can describe their infrastructure, the layout of their racks, crates, modules, plugs and their pins, channels and signals. Since everything resides in the same generic database structures, they can also define the mechanical and logical dependencies between their slots and other infrastructures. They can get the "global picture" on distributed systems: from actuators and sensors linked to machinery down in the tunnel, to field devices, and up to the process control components in surface buildings.

### *Quality Assurance*

Right from the start, the Layout DB has implemented the Quality Assurance Plan (QAP) [3]. The rules on syntax and semantics of the slot identifiers are implemented in the database business logic (PL/SQL procedures triggered by table insert or update events). The generic format of an official slot name is as follows:

**<Equipment Code>.<Location>.<Function>**

Equipment codes are verified and slot names are generated, for example, for a dipole magnet and for a field-bus tap box in exactly the same way.

The Layout DB has evolved into a source of reference data for a wide variety of users and systems, which now includes the LHC control system.

## OPTICS

The automatic generation of the MAD input file with the up-to-date data from the database was the first objective of the Layout DB. To reach that goal, not only the mechanical positioning of the components are stored, but also the strength variables (deduced from the electrical circuit description) of the magnetic components that will define the beam optics. The resulting Twiss parameters are also used in the operational applications (*Settings* database, see further) for closed-orbit corrections, beam squeezing, luminosity tuning, etc.

A daily running database job refreshes the LHC MAD sequence (14,000+ elements), aggregating various layout data in a single dedicated table. Subsequently, on user demand, the LHC layout web site (.NET) dynamically retrieves the data as XML and formats the output file using an XSL style sheet.

# CONTROLS CONFIGURATION

## *Hardware configuration*

The controls front-end deployment has a variety of industrial (PLC-based) and custom (PC and VME-based) components, connected as distributed systems. All these systems are customized to the needs of the equipment group (i.e. Beam Instrumentation, Radio Frequency, Cryogenics, Vacuum, Powering, Safety, Quench Protection (QPS), Interlocks, etc).

With their infrastructure already described in the Layout DB, the equipment groups have the initial information for configuring their front-end computer or industrial PLC. For each crate, hostname, and internal electronic module, their classification, internal positioning and wiring are aggregated from the generic layout base tables in a dedicated materialized view granted to the Controls Configuration Database (CCDB). Once the layout data are imported, the CCDB is the place where the configurable controls data can be completed manually or automatically.

For the custom VME-based systems, the configuration relates to drivers, straps, interrupts, memory offsets, connected signals, start-up sequence of the executables – necessary after front-end reboot–, etc.

## *Software configuration*

On the front-end computers (FEC), software objects are deployed following a device-property model [4]. The mapping between these software constructs and the actual low-level I/O channels allows the communication and control. For the instantiation of these devices, the in-situ FEC as well as their internals are propagated to the CCDB as seen before.

This is the solution used to configure the FESA [4] gateways of the QPS. From the descriptions of the QPS infrastructure, magnets layout and the electrical circuits stored in the generic layout DB tables, a dedicated view (automatically generated by a database job) combines and formats these related data according to the QPS logic. This post-processed layout data is then combined with the FESA data stored in the CCDB, from which configuration files can be generated. These files are passed to the FESA deployment tool which configures the concerned gateways.

The same DB view is also the data source of files generated dynamically from the layout web site by the QPS team to automatically set up their PVSS SCADA system.

# OPERATIONAL DATA

The operational data is managed and used in online databases, necessary for the continuous exploitation of the accelerator complex from the control room.

## *Settings*

The most mission-critical database for accelerator control – the *Settings database* (SDB) – contains the actual and historic settings of all controllable parameters. The parameter space goes from the physics level (e.g. betatron tune) to hardware device level (e.g. power converter current). The exhaustive set of devices, their identifiers and controls characteristics, are propagated to the SDB from the Layout DB (in certain cases –via the CCDB). Likewise, electrical circuit, power converter and magnet features (min/max current and voltage, resistance, inductance, etc.), and the mapping between magnets and power converters –essential for calculations of parameter values– are also propagated. The data propagation is done by invoking database procedures which copy relevant data into the appropriate tables via a database link.

## *Measurements and logging*

The Measurements database provides short-term data persistence on equipment I/O channels and (future) LHC measured beam data. Those data useful for long-term analysis get stored in the Logging database. In order to be able to validate the data channels into these data stores, the meta-data needs to be declared beforehand.

Channel names and descriptions are generated from the Layout database, namely for power converters and the quench protection system, accounting for roughly 100,000 signals.

The dead-band filtering criteria for power converter data between Measurements and Logging are generated based on current rate limits, referenced in the Layout database.

# ASSETS

The manufactured, physical equipment that is actually installed in the corresponding layout slot is declared in CERN's asset management system. This dedicated data store –the equipment management folder– is an essential aspect of the QAP. The original functionality: *manufacturing and test folder* MTF, now also comprises installation and commissioning information. This represents the electronic traveller of each individual piece of equipment ensuring the history and traceability during its lifetime. Any equipment maintenance such as testing, repair or replacement is recorded with the dedicated interfaces in the MTF environment.

The two-way synchronization between the Oracle instances Layout and Assets is ensured by scheduled database jobs that update tables and refresh materialised views on both sides of a database link.

# DATA AVAILABILITY

This enormous source of information is also accessible for the interactive end-user, by means of a public web interface. From different viewpoints (controls-specific, geographical, functional, electrical) the detailed data can be consulted efficiently by means of strong navigational capabilities. During the last six months, more than 113,000 pages were dynamically generated for some 500 different users. This does not only serve the goal of documentation, but is also aimed at diagnostics purposes. Users can search their slots and navigate through infrastructures using the mechanical and logical dependencies between slots. They can jump to external web interfaces like MTF or the network database.

For data maintenance, access is provided to the equipment data owners through web deployed Oracle Forms interfaces. This solution is currently sufficient to respond to most requests. A record of each data modification is kept for traceability.

## CRYOGENICS INSTRUMENTATION AS LAYOUT CLIENT

The cryogenics instrumentation is a large and distributed system. Its complexity is fully described in the Layout database, and the usage of this data is widespread. A single de-normalized source table is read-accessed through a dedicated account, in which customized views serve specific purposes.

### *Crate Assembly*

The manufacturing of the 800 required controls crates is performed by a private company in Finland. In order to do so, an Excel file is generated from the layout data which outlines the assembly of the crate with its components, including a generated visual layout of the crate. The Finnish technicians complete the Excel file with the individual LHC-compliant part identifiers of the components. The returned file is transformed into an appropriate XML template for upload into MTF. At their arrival at CERN, the crates undergo a series of inspections in the lab and on the test bench. At that time, the coherency between the hardware configuration and the captured information is ensured. Consequently, the crates can be installed in the tunnel alcoves and under the dipole cryostats.

### *Cabling and Cable Inspection*

From a table dedicated to cabling, Excel files are generated with detailed cabling information. These files are used to carry out the physical connection from all connector pins on the cryostat flange up to the crate plug pins, by means of the identified cables. The subcontractor's technician marks in the file the completion for each connected cable. With this information, explicit files are generated, used by the inspectors for cabling verification, which is essential for quality assurance.

### *Commissioning*

In order to make integration tests and commission the complete electronics chain to the instruments, mobile test benches are hooked up to the crates in the tunnel. A Labview program is configured by means of an XML file generated from the Layout data. In this procedure, the configuration and connections are tested by the software and part identifiers are checked with barcode readers. The number of discrepancies turns out to be very low. The non-conformities are primarily cabling errors, which are rectified on the spot.

### *Software Configuration*

The Layout data is combined with specific local controls information (e.g. actuator min/max values) to generate the configuration files for the PLC and gateways. Similarly, expert supervision systems (PVSS SCADA) are configured to allow full control and monitoring of the cryogenics instrumentation.

### *System Debugging*

At any one moment, the people working in the tunnel require information on the equipment they are working on, mostly for debugging problems and checking inconsistencies. The Layout database can be accessed from the underground area from a laptop through the web interface. By navigation or via search criteria, the required information is rapidly found, as the data on cryogenics instrumentation is 100% complete (17,000+ instruments). On few occasions, the database specialist needs to be consulted for a particular query.

## FUTURE

With the LHC almost ready and the data infrastructures in place, we have observed that the LHC Layout database is an essential tool that centralizes and makes available reference data, including for the control system. The complementarities with controls configuration, operational data and assets will be enforced and maintained. The scope will be gradually extended to the complete accelerator complex. This has started already with the injection and dump lines of the LHC, and the CNGS transfer line. Imminent needs concern the Linac4 which is under design and the existing SPS ring. Eventually, covering the complete PS-complex can only be beneficial for a coherent data management.

During the exploitation phase of the LHC, the controls configuration database will become the active area, where modifications to the control system will be declared. At that moment, any modification with an impact on the layout will have to be propagated in the Layout database. This will ensure a globally coherent view of the controls infrastructure, consistent with the actual installation.

## REFERENCES


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