

COORDINATION OF THE COMMISSIONING OF THE LHC TECHNICAL SYSTEMS

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Abstract

The Large Hadron Collider operation relies on 1232 superconducting dipoles with a field of 8.33T and 400 superconducting quadrupoles with a strength of 220 T/m powered at 12kA, operating in superfluid He at 1.9K. For dipoles and quadrupoles as well as for many other magnets more than 1700 power converters are necessary to feed the superconducting circuits. A sophisticated magnet protection system is crucial to detect a quench and safely extract the energy stored in the circuits (about 1GJ only in one of the dipole circuits) after a resistive transition. Besides, in such complex architecture, many technical services (e.g. cooling and ventilation, technical network, electrical distribution, GSM network, controls system, etc.) have to be reliably available during commissioning. Consequently, the commissioning of the technical systems and the associated infrastructures has been carefully studied. Procedures, automatic control and analysis tools, repositories for test data, management structures for carrying out and following up the tests have been put in place. This paper briefly describes the management structure and the tools created to ensure safe, smooth and rapid commissioning.

LHC: ACCELERATOR SYSTEMS AND INFRASTRUCTURES

The Large Hadron Collider (LHC) layout [1] has an eight-fold symmetry with eight arcs, separated by eight straight sections (Fig.1). From the point of view of the commissioning, the LHC can be seen as eight separated machines, which can be commissioned in parallel without any interference with respect to the powering chain, cryogenic and vacuum systems.

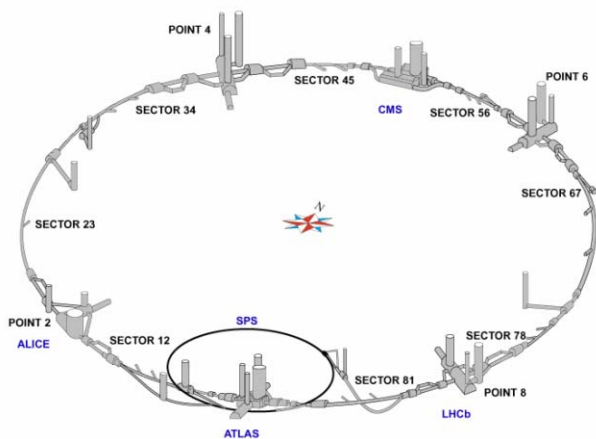


Figure 1: LHC layout.

If we look in detail at the components of an arc, we may recognize elementary blocks, called cells, which are 106.9 m long: 23 regular cells are contained in an arc. Every half cell contains one quadrupole and three dipoles, plus a number of lattice, spool piece and close orbit corrector magnets. The unprecedented energy foreseen for the operation of the LHC lays on the superconducting technology of its components: a bending field of 8.33 T requires dipole magnets working at 1.9 K, to carry the nearly 12 kA current necessary to generate such a field. The complex cryogenic system [2] is capable of feeding superfluid helium to the magnets of an almost 3 km continuous cryostat.

Together with the superconducting elements and cryogenic equipment, there are three main systems necessary for the safe and reliable commissioning and operation of the LHC:

- The quench protection and energy extraction systems (QPS and EE) [3] protect the superconducting circuits in case of unwanted resistive transition (an energy of about 1 GJ has to be safely and rapidly extracted from the dipoles during a quench [4]); the EE counts 32 systems protecting the 24 13kA circuits and 202 systems protecting an equal number of 600A corrector circuits
- The power converters (PC) provide the conversion AC/DC prior to energize the magnets; a PC can be divided in a power part acting as a voltage source and two independent current transducers, plus a digital Function Generator Controller (FGC), which performs the current regulation and makes the link with the control network
- The powering interlock controller (PIC) [5] is the backbone of the safety control of the powering chain. A total of 36 controllers are installed and the correct signal exchanges between the linked systems were verified.

The ancillary systems completing the picture are: the AC distribution, the cooling and ventilation for the equipment in the tunnel, the DC cable distribution, the Ethernet, Wi-Fi and fieldbus communication networks, the access control system, the radiological monitoring and all the personnel safety systems distributed along the tunnel and service areas

All the above mentioned systems have being extensively tested by the equipment owners under the coordination of the Hardware Commissioning team.

THE HARDWARE COMMISSIONING

The LHC is the first high energy particle accelerator for which a specific hardware commissioning phase has been defined. The main part of the literature, regarding commissioning of colliders, is focused on the tests and performance of the systems during beam commissioning; there has never been a global approach to the commissioning of the technical systems in terms of information management, database design and activity coordination (e.g. detailed schedule, planning, resources study, quality assurance, project control, etc.).

The closest antecedents of the LHC are the String I and String II projects: a LHC prototype half-cell and a full arc cell respectively, which were installed, commissioned and operated at CERN between 1994 and 2003. These yielded precious information on the collective behaviour of the technical systems during operation, as well as the first estimations of time and resources required for the machine commissioning.

The mandate

The Hardware Commissioning (HC) Team received the mandate of:

- Defining the commissioning programme to be applied to the sector as a whole after the individual system tests. This task includes the definition of the procedures, their sequencing, the refinement of the time required for the commissioning, as well as the identification of the conditions required to start, those required during the commissioning and the conditions which determine the end of the commissioning.
- Coordinating the tests for the qualification of the individual systems (vacuum, cryogenics, interlocks, magnet protection, powering, etc).
- Following-up the preparation work of the assemblers and the specialised teams checking their systems in order to ensure that the conditions required for the hardware commissioning of the sector are present (infrastructure, assembly, safety) in time
- Carrying-out and coordinating the hardware commissioning in the time frame allocated by the General Construction and Installation Schedule
- Carrying-out validation and specific studies on the first commissioned sector
- Report to the project management and the steering committees.

Preparation

The Hardware Commissioning team was created in 2004 while the installation phase of the collider was still going on. The activities carried out since then can be chronologically divided in four main phases:

- Preparation of the commissioning documentation and resource allocation
- Individual system tests (IST) and short-circuit tests;
- Cool-down of the different sectors
- Powering tests of the superconducting circuits.

During the preparation phase, the team wrote the commissioning procedure documents, which describe the tests to be carried out with the different systems working together for the first time, and helped the different system experts to define the individual system test (IST) documents, which detail the different tests that each system needs to successfully pass before working together with the other equipment.

During this preparation phase the quality assurance policy and tools together with the safety procedures during the commissioning phase were also defined.

Planning

Two levels of planning tools can be distinguished: the long and the short term planning. The LHC Planning Team is in charge of defining the long term planning, considering the main activities composing the critical path of the project, which are mainly: magnet installation and interconnection, pressure test, cool down, the electrical quality assurance campaigns performed at different stages and the powering tests. Afterwards, HC ensures the accomplishment of the general planning in each sector as well as the execution of the rest of activities to be performed on the field, such as the short-circuit tests [6] or the IST campaigns. In this way, the HC Team defines the detailed short term planning (scope of 2-3 weeks) for each sector and coordinates all the activities on the field. The planning team is as well in charge of the resource allocation.

Indeed, a good communication between HC field engineers and the planning team is a key factor in the smooth advancing of the commissioning. The limited resources and the ambitious strategy adopted for the schedule requires a continuous bidirectional flow of information in order to optimize the global outcome and adapt to the different problems that may arise. In addition, the general planning structure (i.e. the estimated duration of the different activities as well as the possible parallelisms) evolves based on the feedback from the field.

Coordination

In the hardware commissioning of the LHC two different phases may be recognized, which require a different structure from the coordination point of view: the individual test of all systems, with the short-circuit test campaigns and the entire cool-down follow up, and the powering tests, which start with the powering interlock controller tests and end with a global powering of all circuits at nominal conditions.

Hardware commissioning coordination before the powering tests

The coordination structure during this phase is based on four quadrant Hardware Commissioning coordinators (HCC), responsible for managing the activities in two adjacent sectors with the help of the system experts, who organize their teams among the different sectors.

The basic tool used by the quadrant coordinators during this period is the short term planning, which they elaborate taking into account the long term planning.

Meetings are weekly held and additional meetings are called by the HCCs in case of incidences.

Hardware commissioning coordination during the powering tests.

During this second phase, the coordination structure is extended. In addition to the quadrant HCC, the figures of the engineer in charge (EIC) and powering coordinator are required in the control room (the CERN Control Centre or CCC).

The EIC coordinates the tests launched from the CCC and the interventions required in the underground areas during the powering phase. The goal of the EIC is to fulfil the planning of the day (which is elaborated by the quadrant hardware commissioning coordinator and the powering coordinator) and to give the input of the advancement done and incidences occurred during the previous day tests. The quadrant hardware commissioning coordinator has the perfect knowledge of the status of the different systems in the sectors within his responsibility, while the powering coordinator has the general view of the powering status and resources among all sectors.

Daily meetings are held in the morning in order to take decisions on the unexpected problems and define priorities among the different sectors. Daily meetings are also organized between the different shifts in order to make the hand-over of information.

Activity is carried out in 15-hour days with two 8-hour shifts which overlap during one hour for information exchange.

Different tools have been developed in order to allow a more efficient and safer hardware commissioning coordination:

- The LHC tests evolution web page is very useful for the engineer in charge. It allows seeing the powering planning for the day, the tests advancement status, the tests to be repeated or those blocked due to a problem preventing the powering of the circuit.
- A large effort has been put into the development of several automatization tools which allow a fast, safe and reliable progress of the tests, such as the software in charge of running the tests and sending the commands to the different systems as defined in the powering procedures (sequencer), the post-mortem analysis tools, the test result database (MTF), the expert signature handler, etc.
- The hardware commissioning web page is an essential tool which collects the required information by the coordinators and teams involved in the interventions: long term planning, short term planning, daily powering tests planning, circuits with incidences, access status to the different areas, daily reports, minutes and other critical information.

- The ADI, (notice of intervention), is an electronic tool used for any work in the tunnel. In this form the teams, needing to access the underground areas, give a precise description on the tasks, people involved and dates. The quadrant hardware commissioning coordinator, after studying the compatibility with other activities, will sign the ADI and allow the intervention or refuse it and propose an alternative date.

CONCLUSION

As the whole machine has been cooled down and most of the equipments already tested, the LHC project is now approaching its final phase with the commissioning with beam. The hardware commissioning team has been working very intensively the last years for planning the activities and coordinating the tests needed to assure that all equipment work as specified by the project.

Despite of the problems encountered, Hardware Commissioning phase is about to successfully finish and the Hardware Commissioning team is confident in a quick and smooth final phase.

ACKNOWLEDGMENT

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