THE COMMISSIONING OF THE LHC TECHNICAL SYSTEMS

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Abstract

The LHC is an accelerator with unprecedented complexity where the energy stored in magnets and the beams exceeds other accelerators by one-to-two orders of magnitude. To ensure a safe and efficient machine start-up without being plagued by technical problems, a phase of "hardware commissioning" was introduced: a thorough commissioning of technical systems without beam. This activity started in June 2005 with the commissioning of individual systems, followed by operating a full sector, one eighth of the machine; the commissioning is expected to last until spring 2008 when commissioning with beam will start. The LHC architecture allows the commissioning of each of the eight sectors independently from the others, before the installation of other sectors is complete. An important effort went into the definition of the programme and the organization of the coordination in the field, as well as in the preparation of the tools to record and analyze test results. This paper discusses the experience with this approach, presents results from the commissioning of the first LHC sector and gives an outlook for future activities.

THE MACHINE LAYOUT

The LHC [1] is a two-ring superconducting proton-proton collider made of eight 3.3 km long arcs separated by 528 m long straight sections. While the eight arcs are nearly identical, the straight sections are very different. Four straight sections house physics experiments, ATLAS CMS, ALICE and LHCb; the latter two also include the beam injection systems. Two insertions are for the beam cleaning systems capturing off-momentum and halo particles, one insertion is for the superconducting RF cavities and beam instrumentation and finally, one insertion is for the beam dumping systems to deposit the two beams onto external dump blocks.

PREPARATION

The experience with the LHC Test String [2], a full-scale prototype of an LHC arc cell, confirmed that the systematic approach to the commissioning of the LHC sectors is indispensable. Systems to be commissioned in the cold sections of the machine include magnets, vacuum, cryogenics, power converters, current leads, quench detection and energy extraction systems as well as the associated utility systems such as AC distribution, water cooling, ventilation, access control and safety systems. Therefore, the study of a methodology of the individual technical systems and their interactions was started well in advance the commissioning activity.

The Phases of the Commissioning Activity

In the first phase each system and each utility is tested and qualified independently. This is followed by a second phase where most of the equipment in each sector is globally tested together. This approach, where the machine is subdivided into eight parts, is possible because the utilities and machine systems are sectorised and therefore made to act on one sector at a time. The first commissioned sector is being type-tested in order to validate the technical systems globally and carry-out specific studies.

A team composed of specialists/owners of the different systems was mandated to work out a commissioning strategy, evaluate the resources needed, build the necessary environment (documentation, test folders, analysis tools, logbooks, collaborative tools, web pages, reporting structure, etc) and finally carry out the commissioning.

Procedures and Documentation

The main outcome of this preparation activity was the documentation of test procedures foreseen by each equipment owner and procedures describing the commissioning of complex systems made up of several sub-systems. Examples are the powering procedures of the superconducting electrical circuits, the injection system, the dump system, etc. Together with *detailed steps* to be carried-out during the commissioning, these documents describe the *conditions required to start the tests, those necessary during the tests and those which define the test is completed*. These conditions range from the availability of utilities, status of the equipment, access conditions, safety measures and signalling. A complete list of this documentation can be found on the web pages of Hardware Commissioning Coordination (HCC) [3].

1-4244-0917-9/07/$25.00

An important effort was deployed to define and describe the data recorded during the tests and to configure the Manufacturing and Test Folder (MTF) tool to receive this data. Each equipment owner automatically uploads to the MTF the test results upon completion of the commissioning activity. As a result, reports which are always up to date are generated and are made available on the HCC web pages.

Procedures for Commissioning of the Superconducting Circuits

As an example, we focus on the superconducting magnet circuits which are representative of the strategy and of which there are more than 1500 in the whole machine.

During cool-down, all the circuits go through different electrical quality assurance tests at several temperature levels. Before the cryogenic conditions for powering are met, all electrical circuits with corrector magnets go through their first interlock tests for validating the correct communication between the quench protection system, the power converters and the powering interlock system.

The powering tests of the LHC superconducting circuits [4] start as soon as the cryogenic conditions for powering are met, 1.9 K and 4.5 K for the circuits in the arc and the long straight sections respectively.

The Powering Test activity is divided in two phases. The *Preparation of the Powering Test* includes*:*

i. electrical quality assurance at cold
ii. tests of the Quench Protection System at cold
iii. interlock tests without current in the magnets
iv. commissioning of the electrical feed boxes (DFBs) without current

When these activities are finished, the power converters are connected to the current leads and the *Powering Tests* follow:

i. interlock tests at minimum operational current
ii. validation at different current levels followed by powering to nominal current

The procedures for powering to nominal current depend on the type of the circuit. Depending on its type, the circuit goes through some or all of the following tests at different percentages of nominal current level (20, 50 and 70%): ramp up to the test current, verification of the current leads performance, forced energy extraction, provoked quench, simulation of a Fast Power Abort from the powering interlock, simulation of a failure of the converter and a simulation of a Slow Power Abort by the powering interlock.

The aim of these tests is the validation of the *protection mechanisms under the different failure scenarios* and the *behaviour of the components of the circuit during a normal LHC ramp and steady state*.

THE COORDINATION IN THE FIELD

During the tests, daily meetings are organised with all the involved parties, possibly close to the location where the tests are being carried-out. The program of the day is revisited and the results or faults briefly analysed. Also, these meetings allow flexibility for the rescheduling activities to cope with unexpected situations.

In addition to the coordination meetings, the HCC team provides support in the field for scheduling, posting of signs, safety, requirements from utilities, etc.

FIRST RESULTS

Short Circuit Tests

The power converters for the hundred odd circuits of each sector are located in the underground caverns. The purpose of the tests in short circuit, is to validate the warm elements of the circuits (the power converters, the energy extraction switchgear, the interlocks, the normal conducting cables) together with the utilities (demineralised water for cooling, ventilation, AC current supply and cables, etc.). The individual commissioning of each power converter in short circuit is followed by a 24 hour heat run of all the power converters at nominal current. The stability of the current and the trends of the temperatures of the demineralised water, of the air, of the electronics and of the cables are recorded in order to validate the correct functioning of the area as a whole.

This operation ends with an interruption of the general AC supply in the cavern in order to check the correct implementation of the recovery.

At the end of the test campaign the results of the tests are analysed. If necessary, corrective actions are taken and the tests are partially repeated. The figure below shows current and temperature profiles acquired during a typical 24-hour heat run.

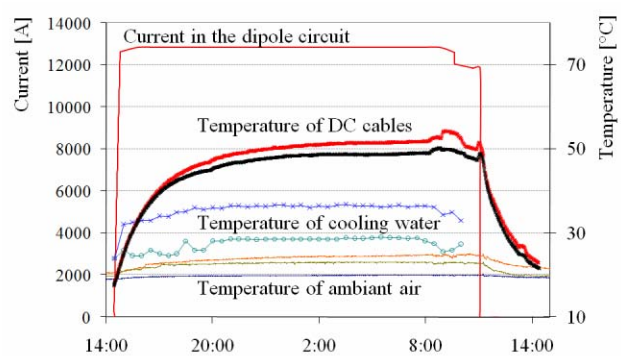

Figure 1: Current in the warm circuits and temperatures during a typical 24-hour heat run of the converters in one of the LHC powering areas.

Cooldown and Powering Tests

Since January 2007 the commissioning of the first sector between Point 7 and 8 (Sector 78) started with the preparation for the cool-down and the cool-down itself (Fig.2). After the magnet cold masses were cooled down to about 80K a campaign of electrical quality assurance took place: the continuity of the voltage taps and the insulation of the electrical circuits (coils to ground, coils to heaters, heaters to ground) were checked. Before the high temperature superconductors of the current leads became superconducting the continuity of their voltage taps was again verified.

The commissioning of the DFBs started just before the powering tests. Condensation, helium levels, temperatures and flow rates were tuned and validated. The performance of the DFBs was then validated with current.

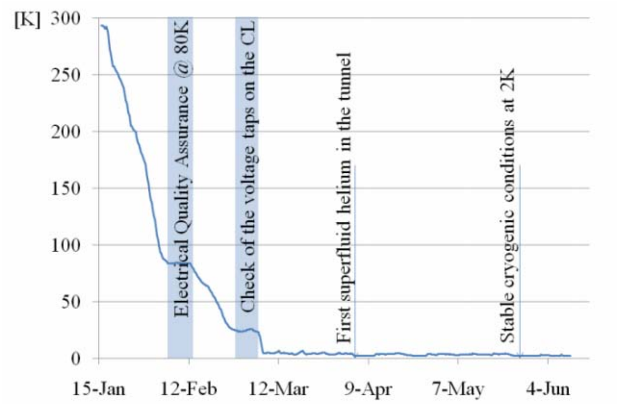

Figure 2: The first cool down of Sector 78

The commissioning continued with the powering tests of the magnets operating at 4.5K situated at both extremities of the sector. Fig.3 shows the current cycle during powering of two matching section quadrupoles Q4 and Q5 left of Point 8 and the recombination dipole D2. D2 and Q4 are powered via the same DFB. During first powering of this ensemble a coupling was observed: after D2 had been taken to its nominal current (6 kA), when the current in one of the two apertures of Q4 was increased, a quench in D2 was observed. Figure 3 shows a later powering where this was not observed. Studies are ongoing to better understand the coupling.

The qualification of the arc magnets operating at 1.9K has just started following the recently achieved stable cryogenic conditions. One notable event was the discovery of a breakdown to ground on one of the branches of the main dipole circuit which was successfully localized in the 3.3 km long magnet string to a single instrumentation feedbox of one of the dipoles. After the venting and the drying of the box, the voltage withstand is very close (1.85kV) to the nominal voltage of 1.9kV. At the time of writing, the powering of the main magnets has started.

CONCLUSIONS

This first experience with the commissioning of Sector 78 has validated the preparation, the environment, the procedures and tools which had been carefully setup during the last two years.

The procedures to commission the power converters together with all normal conducting elements on a short circuit have become a routine operation.

Although only very limited time was available, during the first powering tests of superconducting magnets valuable experience was gained. For the first time all systems involved in the powering have been working successfully together: the power converters, the powering interlock system, the magnet protection system and the associated controls.

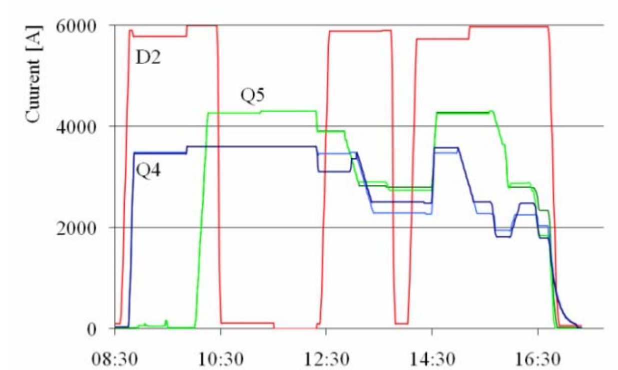

Figure 3: Cycling two apertures of the matching section quadrupoles Q4, Q5 and the separation dipole D2

Tracking of the current reference in the electrical circuits is remarkably precise (better than 10^{-5}). The complex and delicate quench protection system worked well in protecting the magnets and provided data essential in understanding the behaviour of the superconducting circuits. The procedures for powering and the software tools to implement them (process sequencing, transient data recording and analysis, data logging and repository for process data) were brought on-line successfully. A number of non-conformities prevented powering all the circuits to nominal current, for example, commissioning of the inner triplet could not be started. As such, Sector 78 will have to be re-commissioned after the repairs are finished. With the experience gained from the initial commissioning, increased parallelism of the commissioning activities for several sectors at the same time is expected towards the end of 2007.

ACKNOWLEDGEMENTS

The Hardware Commissioning Team is composed of staff from the equipment groups, the infrastructure groups, the Operation Group and the Hardware Commissioning Coordination Team: with the experience gained during the past months, although aware of the intense activity and the challenges ahead, the Hardware Commissioning Team approaches the commissioning of the LHC with confidence.

The authors would like to warmly thank all colleagues who have prepared and participated to the hardware commissioning.

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