EXPERIENCE WITH THE INFRASTRUCTURE SYSTEMS DURING THE COMMISSIONING OF THE LHC

R. Saban

Abstract

The commissioning activity which started in October 2005 consists in the short circuit tests, the commissioning of the non cryogenic systems and the finally the powering tests of the superconducting components of the LHC. During all theses phases, the infrastructure systems are brought into operation, their performance assessed and validated for the routine operation of the collider. This paper presents the experience gained during this activity and reports recent incidents with some infrastructure systems suggest that they could have a non negligible impact on the downtime of the LHC.


1 INTRODUCTION

Most of the commissioning effort has gone in the preparation for operation of the superconducting electrical circuits of the LHC. These are complex systems which rely on equipment with special functions (interlocks, quench detection, energy extraction, power converters, the magnets, etc.) for the safe powering and which stretch over up to 3 km. Figure 1 below schematically describes the most complex of them: the dipole circuit of one arc.

Figure 1: The dipole circuit

In each of the eight sectors, there are 154 dipoles which are connected in series and have a total circuit inductance close to 16 H [1]. The magnetic energy stored in the dipole circuit at nominal current is 1.12 GJoule enough to heat and melt 1.5 tons of copper. On either side of the arc, the electrical feedboxes (DFB) allow the thermal transition of the powering lines between room and cryogenic temperature. Two systems, consisting of a switch and a dump resistor, on both sides of the arc are used to extract the energy from the magnets after a quench. Each magnet is individually monitored to detect a quench and fire the heaters; in addition, the circuit is globally monitored to detect a quench of the busbar.

The LHC is electrically and cryogenically sectorized in eight. This sectorization permitted the independent commissioning of each of them. Each sector contains around 200 superconducting circuits which range from simple, single magnet circuits to circuits containing up to 154 large magnets. Two of the sectors contain the RF cavities around Point 4 operating at 4.5 K.

In addition to the cryogenic components, the LHC relies on a number of warm system for its operation. These include the conventional warm magnets, the septa, the kickers, the collimators, the beam instrumentation, etc.

All rely on the infrastructure systems which supply electricity, the ventilation, the cooling water as well as cables and communication infrastructure.

2 THE SHORT CIRCUIT TESTS

This test represent the first phase of the commissioning where the warm part of the superconducting circuits is validated [2]. It is during this phase that the infrastructure systems are extensively tested and validated. These tests were carried out in the 15 underground powering areas of the LHC (Figure 2).

Figure 2: The underground powering areas of the LHC
During these tests, the DC cables which are normally connected to the electrical feed boxes (DFB) are short circuited as shown in Figure 3 below.

Figure 3: The short circuits in the tunnel outside the powering areas (UA, UJ, RR) of the LHC

2.1 The TS Department deliverables

The objective of the short circuit tests is to validate the following infrastructure systems [3] delivered by the TS Department.

Electrical power is distributed to the underground powering areas via the AC distribution chain. 18 kV is supplied underground where it is either directly used for the main dipole converter (18 kV AC/190V DC) or transformed into 400 V for the rest of the systems: smaller converters, EE systems, machine systems (e.g. cryogenics, vacuum, beam instrumentation) and general services, etc. An Uninterruptable Power Supply (UPS) provides 15 minutes of autonomy to a limited number of systems in case of the interruption of the main supply.

The DC cables link the converters to the DFBs which interface the warm part to cold part of the circuits. The cables carrying more than 2 kA are water cooled while the others are air-cooled. The cables pass from the service areas to the tunnel side through ducts. In order to test the converters on a resistive load, a specially designed copper piece short-circuits the cables at the DFB end.

The heat dissipated by the converters, the DC cables, EE systems, the transformers, the UPS and the AC distribution system is exchanged with the ambient air of the services areas. The ventilation system is dimensioned to remove this heat from the service areas. During the short circuit tests the ventilation system is for the first time tested and validated with stringent constraints.

The high current cables as well as the converters above 120 A are cooled by the demineralised cooling water system. The water flow is monitored by flow-meters connected to the interlock system or the controller of the power converter to protect the equipment in case of loss of coolant. Here we find many filters which have often been found clogged [5] with fine dust as well as copper oxide crystals (Figure 4).
The access control system which was gradually put in place [6] and now ensures the absence of personnel in the vicinity of the superconducting magnets during the tests with current.

2.2 The procedure

The individual commissioning of each power converter in short circuit is followed by a 24 hour heat run of all the power converters at their ultimate current which corresponds to the maximum design current of the magnets. The stability of the current in the magnets, the AC distribution and 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 (Figure 5).

The 24-hour run ends with an interruption of the general AC supply in the cavern in order to verify that the equipment is connected as expected either directly to the 400 V or via a UPS. Also, when power is re-established, the recovery procedure following the interruption is validated.

Figure 6 and 7 show more detailed temperature measurements which aim at validating the correct layout of air cooled cables as well as ventilation ducts cooling the electronics.
One of the major defects which appeared after the short circuits tests was the presence of chlorine in the hoses of the water cooled cables. This became apparent when water leaking from a hose, which was later found containing a manufacturing defect, corroded the lug and the DFB cryostat below. Samples were collected from all the hoses: three out of four types were found to be containing chlorine and therefore not conform to specifications.

While the manufacturer agreed to exchange all the cables, the decision was taken to postpone the operation in the light of the possible damage to already installed fragile equipment in the vicinity of the cables. The manufacturer however committed to exchange the cables in case of need for the coming ten years.

2.3 The corrective actions

The corrective actions, which resulted from these tests, range from simple operations –but time consuming operations– like the cleaning of filters and balancing of water distribution circuits to campaigns consisting in the reconfiguration of cable layouts of ventilation ducts as well as the installation of new cooling units. Without these corrective actions, the operation of the powering areas could not be envisaged. The reasons for the mismatch between the needs and the installed infrastructure capacity were traced to powering area layout last-minute changes rather than incorrect supply of infrastructures.

The warm magnet tests, the injection and dump system tests consist in the same type of operations which validate the operation of the infrastructure systems and yield the same type of consolidation actions.
3 THE POWERING TESTS

The powering tests of the superconducting circuits are carried out following their electrical qualification (integrity, insulation, etc) at cold and the individual system tests of the protection system, the power converters and the energy extraction system. After the first qualifications of these systems, tests are carried-out at different current levels in order to validate the protection strategies under the different failure scenarios and the evaluation of the behavior and of the performance of the magnet chain, the current leads and the power converters during a normal LHC ramp, in steady state and during a ramp down of the current [9].

The powering tests rely on the availability of nominal cryogenic conditions supplied by the complex refrigerator and cold compressors. The latter, in turn, strongly rely on the availability of the infrastructure systems; namely the water cooling, the AC distribution, the communication infrastructure for the distributed control system and, to a lesser extent, the ventilation system.

Experience with the cryogenic system of the LEP superconducting RF cavities and of the LHC Test String has shown that a short interruption on any of these systems, when detected by the cryogenic system, results in a downtime much longer than the original infrastructure interruption. In fact, restarting a cryogenic plant which has shutdown takes hours while the interruption of the infrastructure system can take minutes or hundreds of milliseconds. Recent incidents with the AC distribution and with the cooling system confirm this and even indicate longer times than previously anticipated.

These incidents include for the AC distribution, the interruption of the 400 kV supply due to a corrective maintenance action, the interruption of the 400 V supply due to a false over temperature alarm in a transformer as well as weakly designed 24 Vdc distribution modules feeding components of the cryogenic system. The cooling system has seldom been the direct source of interruption of the cryogenic system: rather, it has suffered from interruptions of the AC distribution which have temporarily stopped equipment; this however has not gone unseen by the cryogenic system.

The most frequent consolidation actions on the cooling water system are the cleaning of filters and the balancing of the water circuits. While the latter is certainly caused by the new equipment which is connected to the circuits and therefore unbalances a previously working circuit, the former are more worrying. In fact, the filters in a number of powering areas which were commissioned as early as November 2005 required cleaning recently although they have undergone numerous cleaning campaigns in the last years. This type of incident has also the effect of unbalancing the circuits as water flow becomes more difficult through a blocked filter.

Last but not least, the chlorine loaded hoses of the water cooled DC cables might prove to be a time bomb if the type of incident so far observed with one cable becomes recurrent: the exchange of these cables, besides being a very delicate operation, is very time consuming.

4 CONCLUSIONS

The level of service and availability of infrastructure systems required by systems like cryogenics imposes very stringent requirements on the MTBF and the MTTR of infrastructure systems.

Recent incidents with some infrastructure systems suggest that they could have a non negligible impact on the downtime of the LHC. Therefore consolidation actions must be taken quickly and the behaviour of all these systems must be closely monitored in order to take swift corrective actions.
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. The test campaigns could not have been carried-out without the participation of all as one team: together we have laid out the basis for the type collaboration which will be needed during the operation of LHC.

REFERENCES


[2] Procedures for the short circuit tests of power converters and automated commissioning of interlocks for electrical circuits of the LHC, LHC-D-HCP-0005-10-00, EDMS doc. num: 571449

[3] Procedures for the short circuit tests of power converters and automated commissioning of interlocks for electrical circuits of the LHC, LHC-D-HCP-0005-10-00, EDMS doc. num: 571449


[5] G. Arnau Izquierdo, Microscopic and microanalysis inspection of metallic filters from cooling circuits of LHC power converters and water cooled cables in UA83 and UA27, EDMS doc. num.: 926612


[8] Commissioning of the power cables in the lhc underground area, LHC-D-TP-0002 – EDMS doc. num.: 477134

[9] Powering tests of the superconducting circuits of the LHC: brief summary - LHC-D-ES-0007-10-00, EDMS doc. num.: 847695