

## SHORT CIRCUIT TESTS: FIRST STEP OF LHC HARDWARE COMMISSIONING COMPLETION

E. Barbero-Soto, B. Bellesia, F. Bordry, M. P. Casas Lino, G.-J. Coelingh, G. Cumer, K. Dahlerup-Petersen, J.-C. Guillaume, J. Inigo-Golfin, V. Montabonnet, D. Nisbet, M. Pojer, R. Principe, F. Rodriguez-Mateos, R. Saban, R. Schmidt, H. Thiesen, A. Vergara-Fernández, M. Zerlauth, A. Castaneda Serra, I. Romera Ramirez, CERN, Geneva, Switzerland

### Abstract

For the two counter rotating beams in the Large Hadron Collider (LHC) about 8000 magnets (main dipole and quadrupole magnets, corrector magnets, separation dipoles, matching section quadrupoles etc.) are powered in about 1500 superconducting electrical circuits. The magnets are powered by power converters that have been designed for the LHC with a current between 60 and 13000A. Between October 2005 and September 2007 the so-called Short Circuit Tests were carried-out in 15 underground zones where the power converters of the superconducting circuits are placed. The tests aimed to qualify the normal conducting equipments of the circuits such as power converters and normal conducting high current cables. The correct operation of interlock and energy extraction systems was validated. The infrastructure systems including AC distribution, water and air cooling and the control systems was also commissioned. In this paper the results of the two year test campaign are summarized with particular attention to problems encountered and how they were solved.

### INTRODUCTION

The LHC is an accelerator with unprecedented complexity [1]. To ensure efficient and safe start-up with beam and to avoid a plague of technical problems, a phase of hardware commissioning was introduced. The thorough commissioning of technical systems started in June 2005 with the commissioning of individual systems. The Short Circuit Tests (SCT) are the first tests involving several systems at the same time. In this paper the main results are presented.

### THE LHC AND THE SCT

The LHC layout has an eight-fold symmetry with eight arcs, eight straight sections and four caverns hosting the particle detectors. The accelerator systems tested during the SCT are installed in a maze of underground zones, namely (Fig. 1):

- UA (underground areas) are parallel tunnels to the accelerator housing a large number of power converters plus other LHC equipment (vacuum, cryogenics and beam monitoring systems, injection and extraction, RF, interlocks, etc.).
- RR caverns and UJ (junction chambers) are enlargements of the main tunnel hosting power converters and other electrical equipment.

The short circuit test campaigns were performed per powering area, in total 15 test campaigns.

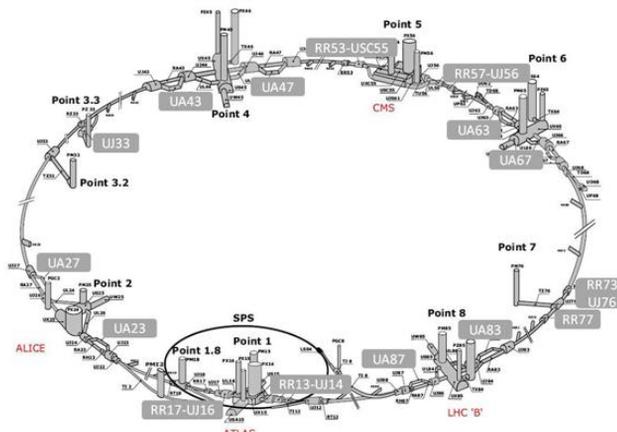


Figure 1: LHC underground zones and SCT areas.

### SCT: Test Layout

The SCT are intended to validate the normal conducting elements of the LHC electrical 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 DC cables) [2]. The tests are done by short-circuiting the power cables at their extremities, at the location of the connection to the feed through from warm to cold in the Distribution Feed Box (DFB; Fig.2).

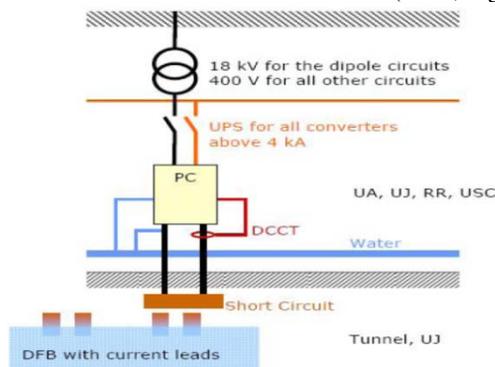


Figure 2: SCT: power converter (PC).

The individual commissioning of each power converter is followed by a 24 hour heat run where all the power converters of a test zone are ramped together. The circumstances during this test are tougher than for beam operation since the current is set to the maximum design level and the length of a fill will be shorter [1]. The stability of the current is recorded together with the temperature of the demineralised water, of the air, of the electronics and of the cables in order to validate the

correct functioning of all systems in the area (Fig. 3). The test ends with an interruption of the general AC supply in the cavern in order to check the correct implementation of switching-off recovery.

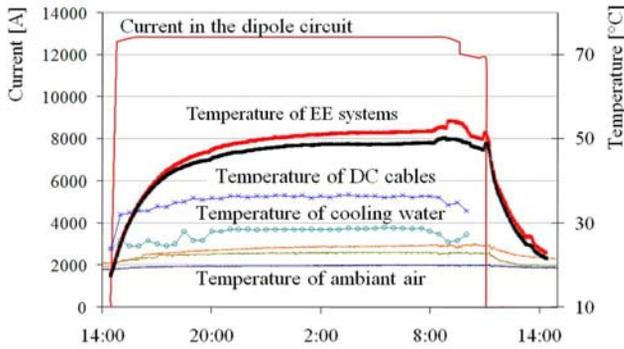


Figure 3: SCT carried out in UA83.

### SCT RESULTS: ACCELERATOR SYSTEMS AND INFRASTRUCTURES

The accelerator systems and the infrastructure commissioned during the SCT are listed below.

*Power converters (PC)* provide the AC/DC conversion. A power converter has a power part acting as a voltage source and two independent current transducers. A digital electronics (Function Generator Controller, FGC) controls the current functions, performs accurate current regulation and links to the control network. In Table 1 the different power converter types are listed. During the test the current stability, the FGC temperature, the water flux through DC cables and converters and the power cable connections are verified. During the SCT all the converters were commissioned to be ready for the subsequent powering test of the magnets [3].

Table 1: PC types tested during SCT (IPQ/D: Individual Powered Quadrupoles and Dipoles; IT: Inner Triplet)

PC type	DC [A,V]	Qty
Main Dipole	[13kA/±190V]	8
Main Quads	[13kA/18V]	16
IPQ,IPD and IT	[4..6kA/8V] [5..7kA/8V]	174
Lattice Corr.	[±0.6kA/±10V and ±40V]	437
Dip. Orbit Corr.	[±120A/±10V] [±60A/±8V]	1042

*Energy extraction (EE) systems* are among the systems to protect the superconducting circuits against damage in case of unwanted resistive transition. A current breaker and a resistor in parallel to the breaker are connected in series with the power converter. In case of a quench, the switch opens and the energy stored in the electrical circuit is discharged into the resistor. There are 32 EE systems for the 24 main quadrupole and dipole circuits, and 202 EE systems protecting of 600 A corrector circuits. The 600A EE systems are mounted in pairs in their 43U euroracks and rely for their cooling on natural convection and the ambient temperature, which should not exceed

30°C. In 3 of the 15 LHC underground areas (UA27, UA67 and UA87) the temperature inside the racks exceeded the maximum operation temperature of 40°C by 4°C and in another 3 areas the temperature approached 39°C (Fig.4). In the RR areas no temperature problems were observed. The SCT were particularly useful to monitor the temperatures inside the 600A EE racks and the 13kA EE cages, the ambient temperature around systems, the operation of all the breakers at design value of the current, the power losses inside the systems and the current sharing between redundant breakers. Some non-conformities were discovered and solved [4].

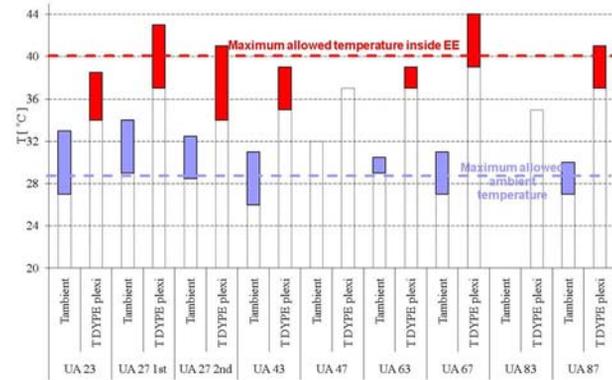


Figure 4: Ambient and EE racks temp. ranges in UAs.

*Powering Interlock System* is the backbone for the safety of the powering systems and includes links to power converters, quench protection and energy extraction system and some utility systems. A total of 36 powering interlock controllers are installed and the correct signal exchange between the different systems was verified [2].

*DC cables* link the power converters and the DFB. Cables carrying more than 2kA are water cooled while up to 2kA the cables are cooled by air convection. In order to test the converters with a resistive load, a copper piece short-circuited the two cables of the circuit. During the test the external temperature was constantly monitored to validate the mechanical/electrical properties of the cables during the operation. In Fig. 5 the maximum temperatures of the DC cables recorded in the underground zones at the end of the heat runs are shown. The upper limit was set at 85°C [6]. In one case (UJ33) the limits were exceeded. The DC cable routing was modified to have a more effective ventilation of the cables. The test had to be repeated three times, finally, a successful re-routing of the DC cables was achieved.

*Ventilation System:* the heat dissipated by the converters, the DC cables, EE systems and transformers is exchanged with the ambient air of the services areas. The ventilation system should keep the temperature constant below the maximum allowed value of 30°C. The temperature control is done by cooling units that use chilled water as heat sink with an extraction power between 15 and 25kW. The high ambient temperature measured in the UA27 and UA67 (see Fig.3) required thermal analysis of the underground zones. It was found that UAs needed an added thermal

power extraction to ensure a better control of the ambient temperature at the locations of the 600A PC and EE systems (see Fig.4). An installation campaign in order to upgrade the ventilation in that zone was launched and the new systems re-tested and validated.

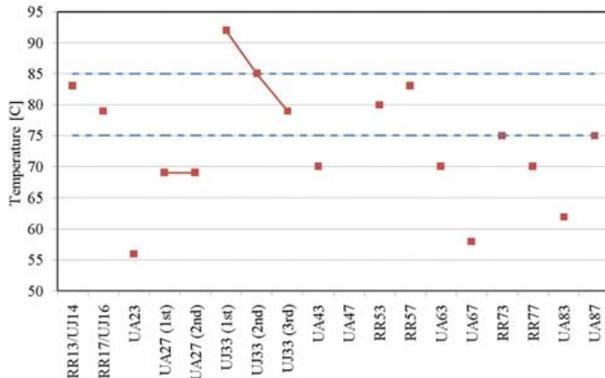


Figure 5: Max. T of the DC cables during the SCT.

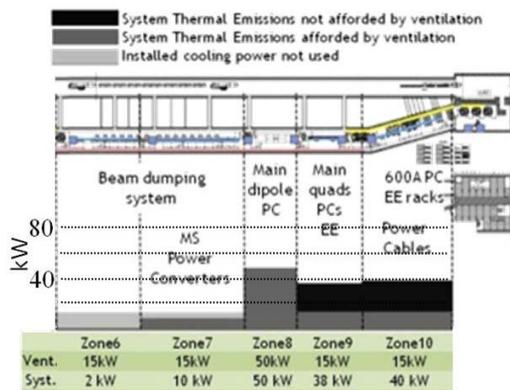


Figure 6: UA67, ventilation power calculations.

**Water Cooling systems.** All the power converters except the 60A and 120A converters are connected to the demineralised water cooling supply as well as the high current cables. The values of water flow and pressure drop to apply to each system are evaluated from the power dissipated. A factor 1.5 is applied to guarantee sufficient margin during operation. To control the correct flow, each converter and the associated power cables are interlocked via flowmeters which are normally calibrated prior to each SCT campaign; particular tests are also performed to verify the correct signal routing. The flowmeters are positioned at the output of each individual water circuit to guarantee the integrity of the circuit. The wrong positioning of these flowmeters was sometimes corrected during the tests. Problems with the flowmeters were encountered, which were related to the reduced flow in the pipes because of the clogging of the downstream filters. The actual grain size of the filters used is 50µm. An increase to 200µm is being discussed because the filters get often clogged and cleaning requires blocking the water circuit, dismantling and cleaning the filters.

**AC distribution** has already been used for LEP (except the UAs installations). In each LHC point the network provides 66kV. On the surface the AC is transformed into 18kV and then delivered to the underground areas as

direct input for the main dipole power converters and transformed to 400V for other users. During the SCT the current and the reactive power from the AC side are monitored (see Fig. 7). To the AC distribution system belong also the Uninterruptable Power Supplies (UPS), which provide 10 minutes of autonomy in case of a breakdown of the main distribution. This was tested at the end of SCT by means of a provoked emergency stop. The main problem experienced during the SCT campaign was an accident occurred in UA27 on an 18/0.4kV transformer caused by an internal fault in the transformer. The transformer was substitutes and the repetition of the SCT validated the new installation.

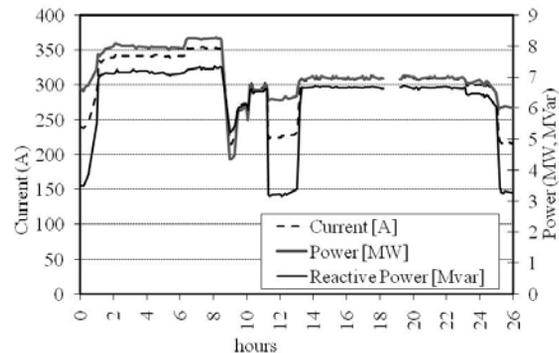


Figure 7: Current and power (real and reactive) delivered by the 18kV network in LHC Point2.

**World Factory Instrumentation Protocol (WorldFIP)** network is dedicated to serve the real-time control and to transfer the monitoring information from the underground areas to the control room. The network is linked to the different systems. During the SCT the signal transmission from the equipment in the tunnel to the supervision applications in the control room was successfully tested.

## CONCLUSIONS

During the Short Circuit Tests, a certain number of non-conformities related both to the systems and to the infrastructure were discovered and solved. About 1500 PC and the 234 EE system installed in 15 underground areas have been commissioned and ready for the next step of the commissioning [7].

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