RE-COMMISSIONING OF THE SUPERCONDUCTING CIRCUITS

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Abstract

During LS1, the first planned LHC long shutdown, several modifications have been carried out on the technical systems, besides the superconducting circuits consolidation, with the goal of increasing the system performance and availability, while raising the energy to its design value. The plan and present status of the superconducting circuits re-commissioning is presented.

THE LS1 MODIFICATIONS

Besides the Superconducting Magnet And Circuit Consolidation (SMACC) project, many other interventions have been carried out during the LS1. A big maintenance campaign was performed with the scope of increasing the availability of the machine and various special modifications have been carried out to increase the performance and modify the functionality of different systems; all these changes might impact the machine efficiency. As a consequence, they have to be carefully tested, to ensure a safe re-start of the accelerator [1].

THE SHORT CIRCUIT TESTS

During LS1, a campaign of short circuit tests has been performed in the LHC, in order to validate the warm part of the superconducting circuits and spot potential problems early enough to implement necessary corrections. For these tests, a short circuit block is installed at the end of the water-cooled cables, at the level of the Distribution Feed-Box (DFB). The current then flows from the power converter through the cables and (if present) into the Energy Extraction (EE) system. These tests allow verifying the cooling system for the different circuits, the current sharing into the EE, the quality of the conical connections and the global ventilation in the area where the power converters are located.

After a long preparation phase that started in October 2012, these tests were done in different configurations in all points of the machine. Some problems (i.e. few wrong interlock cabling, several lose conical connections and few cable damages) have been spotted and the necessary corrective actions taken.

One of the water-cooled cables of the RQX.L5 that have been exchanged during LS1 was found defective, several weeks after the completion of the short circuit campaign. The cable was then removed, repaired and re-installed. A new heat run of this circuit will be done, once the intervention is completed.

The Copper Stabilizer Continuity Measurement

The Copper Stabilizer Continuity Measurement (CSCM) is a series of tests meant to validate all interconnect splices, all bypass diode paths and all current lead to busbar connections on the DFBAs. The test reproduces similar conditions to those during a quench, but with no energy stored in the magnets, so that an interlock process can safely stop the thermal runaway. This is achieved by doing the test at a temperature of about 20 K; in this condition the magnets are no longer superconducting then the current passes through the bypass diode, connected to each magnet. In case of a thermal runaway, a special configuration of the Quench Protection System (QPS) boards issue an interlock and stop the current that quickly reaches 0 A, as there is very little energy stored in the circuit. An analysis and a resistance measurement cycle are needed between all steps in order to verify the integrity of the circuit and calculate the QPS compensation parameters for the following test.

This measurement will be performed on all main dipole circuits of the LHC to assess the quality of the system before commissioning and operation at 6.5 TeV equivalent current. The test has been fully automated to reduce the risks due to manual operation. The principle of the test is that the absence of thermal runaway proves the integrity of the circuit.

The CSCM consists of seven test steps at increasing current level to gradually reach 11.1 kA. Due to the very low inductance of the circuit, the current rises quickly to reach the maximum level and after a 2 s plateau decreases exponentially. At the moment of the writing two out of eight main dipole circuits have been already fully validated.

POWERING TESTS

A large campaign of powering tests has also to be carried out on all superconducting circuits to ensure their correct performance and functionality and, above all, to push the main circuits close to the design energy.

Strategy and Changes

A total of more than 10.000 powering steps have to be performed and analyzed in less than four months. In 2009 the LHC was commissioned with a completely new QPS system in a similar amount of time. Nevertheless, the other systems had not undertaken massive changes (3 sectors were not even warmed up) and the main circuits were only commissioned for energy of 3.5 TeV. To cope with this challenge the powering tests campaign has to be carefully planned and the tools optimized.

A team in charge of the “organization and coordination” will coordinate the powering tests campaign, while the “automation” team is in charge of ensuring the correct functionality of the software infrastructure; finally a renewed MP3 (Magnet circuits, Protection and Performance Panel) is entitle to assess the magnet and circuit protection and performance.

In order to reach the goal energy of 6.5 TeV, a training campaign has to be performed on the main dipole circuits; a strategy with a maximum acceptable number of training quenches per sector (after which the situation will have to be assessed) has been defined; in total, on all eight main dipole circuits, about 100 quenches are expected to be needed in order to reach the current of 10980 A (6.5 TeV equivalent).

The MP3 team in collaboration with the system responsible has updated all powering procedures in order to cope with the new functionality and interlock. A detailed mapping of which tests have to be executed to ensure correct re-commissioning has been done.

The separation of powering phases [2] in Phase 1 and Phase 2 implying different access restrictions has been also updated:

- Phase I: all circuits are limited to the current value corresponding to 100 kJ stored in the magnets. None is allowed into the tunnel where powering tests are ongoing. No restriction for the service areas. A special procedure has been defined to allow special tests that need the presence of experts in he tunnel. In this case, only one circuit can be powered, to the current corresponding to a maximum of 30 kJ of energy stored in the circuit.
- Phase II: none is allowed in the sector (both tunnel and service areas) where powering tests are carried out. In addition, restrictions to the adjacent sectors are also applied [3].

All tools for the automated execution and analysis of the powering tests have been updated with enhanced functionality. The procedures to power the different circuits and the related software sequences have also been updated.

The Present Status

In this paragraph the status of the LHC powering tests at the moment of writing is described.

Only one (sector 67) of the eight LHC sectors is at nominal cryogenic conditions. In two sectors the final non-conformities found during the SMACC are being repaired. The remaining five sectors are presently being cooled-down.

Prior to the powering tests, a campaign of electrical tests (ElQA) has been performed on all circuits of sector 67 to assess their electrical insulation and proprieties. During the validation of one of the lines of the main dipole circuit, a breakdown appeared.

Due to an error in the documentation layouts, the installed QPS cards (called mDQQBS v.2) cannot withstand 2.1 kV to ground, provoking a breakdown which leads to the HV part be directly connected to a supply voltage (this problem does not appear on the v.3 of the cards). A campaign was then performed to check the diodes status, as the high voltage transients during the breakdown could have generated degradations; no problem was found. It was then decided to change the ElQA procedure:

- Hi-pot at 2.1 kV the cold masses with only the so-called old QPS (oQPS) connected (the old QPS is the original system that contains the magnet quench protection, the current leads protection and the global quench detection);
- Hi-pot at 1.5 kV the full system once the so-called new QPS (nQPS) is connected. This decision was taken, as the nQPS instrumentation does not "see" the voltages developed internally in the magnet coils during a quench (the new QPS is the second layer of the system, added in 2009 to provide the symmetric quench and the busbar splices detector).

After solving minor problems, the full system was validated.

Present powering status:

- 60 A circuits: all circuits have been powered, their commissioning is presently completed at 97%;
- 80-120 A: commissioning status 72%;
- 600 A: the commissioning of the 47 systems is ongoing, presently at 36%;
- IPQs – IPDs: QPS preparation still needs to be completed (radiation-hard board under preparation);
- 13 kA: QPS preparation is ongoing; the triggering cables check is completed and the quench heater power supplies are undertaking the individual tests, including current discharge. The QPS validation will last one more week.

Due to the large amount of software changes implemented during LS1 and despite of the dry-runs performed before the powering tests campaign, minor problems and bugs were expected to appear in the software system. Several minor malfunctions were indeed found and corrected during the first weeks of powering tests:

CONCLUSIONS

The LHC superconducting circuit re-qualification has been carefully studied and its planning started already in October 2012.

Besides the general maintenance, many changes have been applied with the goal of increasing availability, reliability and performance of the different systems. These modifications will have an impact on the time needed to re-start the LHC and on the machine efficiency. To limit this effect and to ensure a safe re-start, various test campaigns are planned.

During the short circuit tests campaign several NCs were highlighted then fixed and all polarities verified.

The ongoing powering tests and CSCM campaign are crucial for a quick and safe re-start of beam operation; the team is ready to take the challenge ahead.

ACKNOWLEDGMENT

The authors wish to express their sincerest thanks for the useful discussion, corrections and suggestions to all the teams involved in the LHC superconducting circuit tests.

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