

POWERING TESTS BEFORE LHC WARM-UP

WHAT IS NEW FROM CHAMONIX 2011?

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Abstract

At the end of 2012, the Large Hadron Collider will enter its first programmed long stop (LS1). The problem at the origin of 2008 incident will be definitely treated and the main circuits will then be able to run at the design current value without protection issues. At Chamonix 2011, a proposal was done for a series of powering tests to be performed just before the LS1 to investigate other potential limitations in the machine, which could be fixed during the same maintenance period. A review of these powering tests is presented, together with the list of investigation to be performed by the electrical quality assurance (EIQA) team. A tentative planning is as well proposed. Moreover, following complementary activities during the LS1, a huge campaign of individual system tests will have to be as well performed during the shutdown. Attention will be put on the preliminary list of needed re-qualifications.

INTRODUCTION

After three years of beam commissioning and start of routine operation, the LHC will be shut-down at the end of 2012, to carry out a serious of maintenance and upgrades. The objective is to ensure, for the coming years, a safe and reliable operation.

The interventions that are being planned by the equipment owners are numerous, but the main one is, of course, the consolidation of the 13 kA splices [1], which were at the origin of the incident in 2008 [2]. After this consolidation, there shall be no more limits to the increase of the machine energy to 7 TeV. This is why a proposal was done in Chamonix 2011 [3] on special tests (mostly powering) to be performed on the machine to check possible limitations (for design energy) other than the splices. An agreement was then reached to allocate two weeks, at the end of 2012 run, to carry out these special tests. And an update of the tests to be performed is contained in this paper. This is therefore an on-going discussion and the final list of tests and actions will be defined in the course of 2012.

For obvious reasons, the 13 kA circuits will not be part of this exercise and are not considered in this paper, unless differently specified.

POWERING TESTS TO BE PERFORMED BEFORE LS1

Looking back at the status of commissioning in 2008 (when the design performance was the objective), it appears that most of the circuits were commissioned to 7 TeV equivalent current; apart sector 34 (which went through the repair and has to be considered as a new sector), the circuits that did not reach 7 TeV are:

- RQX.L5, commissioned to less than 5 TeV, due to change in nominal current;
- RD3.R4 and RD4.R4, where the nominal current was changed after commissioning, which then resulted in less than 7 TeV (6.6 and 6.3 TeV, respectively);
- RD2.R8, which quenched 4 times (5816, 5788, 5856 and 5854 A) at less than 6.8 TeV;
- 142/410 600 A circuits, “jeopardized” due to the reduction of target current/energy and to the change of specifications, resulting in commissioning to 5 TeV or even below;
- some 80-120 A circuits, not commissioned for 7 TeV
 - o RCBYV5.L4B2 suffered three quenches without training (limited to 50 A)
 - o RCBYHS4.L5B1 had a hardware problem and was limited to half the energy (limited to 50 A)
 - o RCBYHS5.R8B1 had a ramp-down quench after attaining the nominal (limited to 20 A)
 - o RCBYH4.R8B1 had a ramp-down quench after attaining the nominal (limited to 50 A).

The first, obvious proposal is to try and commission, before LS1, all the above circuits to 7 TeV, in particular RD3.R4, RD4.R4, RD2.R8 and RQX.L5; the same will have to be done with all the circuits of sector 34.

What to push higher: the Landau octupoles and the lattice sextupoles

In Evian '11, the request came [4] to commission the Landau octupoles to their nominal current for 2012 operation; in fact, last year they were used in operation at 400 A and more could be needed (if we don't manage to go down to low chromaticity values) to control beam instabilities.

According to some experts [5], 550 A could be sufficient at 7 TeV but tests will be needed in MD in 2012; others [6] estimate that we might need 600 A, if not more. That's why the commissioning current for 2012 has been increased to 550 A [7] for the Landau octupoles, and the feasibility to go to a higher current has been analysed.

Similar considerations apply for the lattice sextupoles, where current values larger than the nominal would help in case of special optics [6], and where also the acceleration could be a limiting factor for the length of the squeeze to very low beta*. Unfortunately, with the present acceleration, the quench protection system is at the limit of the detection threshold, and a new generation of controllers (less sensitive to the inductance) should be available only after LS1.

There is a common consensus to push, at the end of 2012, the octupoles and the sextupoles to their ultimate value of 600 A. On the other side, the proposal of pushing further these circuits is not obvious.

From the point of view of the performance of the circuits in the machine, if in 2011 they had been limited to 400 A, in 2008 they had been already pushed to 550 A in all sectors excluding sector 34, 45 (just a test step missing) and 56. Among those tested to 550 A, very few quenches had been observed. Also some of the circuits had been tested in the lab to values close to 800 A [8].

However, there are some technical limitations to consider for going to higher currents. The power converters, first of all, are limited to 600 A, and it would not even be easy, from the regulation point of view, to put two of them in parallel. The current leads, then, are dimensioned for 600 A and have been validated for this value: larger current would require further testing at a different temperature regulation (overcooling) [9]. For the QPS, finally, the current sensors are limited in range to ± 600 A and there is a programmed interlock at ± 610 A, meaning that one cannot exceed this current [10].

Re-training

Surprises might appear when we'll try and reach the nominal performance, namely the de-training of some circuits. It happened in fact, in 2010, that some of the circuits already commissioned to 7 TeV equivalent current experienced a de-training and their current had to be reduced; among them, some of the known weak circuits, but also other ones, mainly 600 A circuits, plus some 120 A circuits.

That's why a strategy has to be discussed in case a serious limitation is found, mainly pointing on applying different nominal currents according to the real needs of operation, but also discussing how many quenches are acceptable, if a limitation is acceptable for the machine or if a different optics is suitable. All this will be treated in details before and during the powering tests together with MP3 responsible.

What else do we need to test?

Other tests have been identified as important before LS1. Due to the known incompatibility between the quench protection system for the RQTD/F circuits and the tune feed-back, new QPS boards will have to be tested, with a different logic able to withstand the feed-back requests. Also, tests will have to be done to understand the problem on the circuit RCBXH3.L5 (out of order since 2010). The idea of firing all quench heaters to their full voltage was also proposed by the equipment owners, to check if critical cases are present in the machine (a monitoring tool will be in place only during TS1, which compares the discharge with a reference [11]).

CSCM

Another kind of measurement that could be performed before the LS1 is the Copper Stabilizer Continuity Measurement (aka, thermal amplifier), a technique originally proposed by H. Pfeffer and lately developed by H. Thiesen, to investigate the thermal runaway of faulty splices of an entire 13 kA line. The method consists in keeping the magnets at 20 K, ramping to 500 A with 20

V/s to open all diodes and then ramping to high current with 300 A/s ramp rate; once at flat-top, the current is quickly extracted if one of the splices undergoes a thermal runaway.

All technical aspects of the CSCM were addressed in various workshops and meetings [12-14] and another review is foreseen for summer 2012: even if many critical details emerged, no showstopper has been so far identified.

The conditions of the thermal amplifier measurements are the same as in case of a magnet quench: when a quench occurs, the voltage inside the magnet increases; the diode starts conducting and the current flows inside the bypass line. Since the diode is resistive, it heats up. The heat could propagate through the cable up to the splice and eventually quench it, which means that serious damages could be produced if the splice is not well done.

Quench tests were performed during 2011 to address this issue. As a collateral discovery, it turned out that the resistance during discharge via the by-pass is much higher than expected. An example of the resistance developed in the by-pass path is shown in figure 1. For more details, see [15].

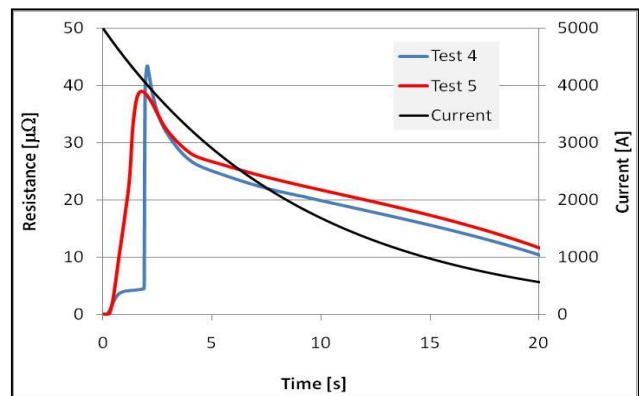


Figure 1: Example of quench test, with the discharge of the current through the by-pass diode; the resistance of the by-pass segment is shown.

The CSCM could be used to quickly measure the resistance of all by-pass segments in a sector, highlighting critical cases, if any.

The complexity of the CSCM technique is high and the effort associated is not negligible; this is why no time was allocated for these measurements before 2012 run, and a slot has been reserved for a type test, in one sector of the machine, during the warm-up at the beginning of 2013.

ELQA TESTS

During the yearly electrical qualification (ELQA) of the machine, "each circuit is energized individually with respect to ground using a DC voltage source limited to a current of 2 mA ... during the test of a given circuit, all other circuits of the same electrical safety subsector are grounded for safety reason" [16]. It was recently noticed that this is not the condition of maximum stress for the circuits, since they are normally powered all together. In

the future, the maximum operational voltage against any neighbouring circuit will be taken into account. This is the reason why, before entering LS1, all circuits will be tested for higher voltage withstand, considering circuits with bus-bars running in the vicinity and nested circuits, and adding a safety margin of 20%. The resulting voltages to be applied to the different circuits are shown in Table 1.

Table 1: Voltages to be applied for next EIQA campaigns.

	Tested	Max op. voltage		Proposed voltage
		3.5 TeV	7 TeV	
MB	1900	450	487.5	1900
MQ	240	376.5	520.1	650
MCS	480	376.5	840	1000
MCD	480	339.5	840	1000
MCO	480(200)	199.5	420	480 (200)
MS	600	399	840	1000
MSS	600	301	840	1000
MO	600	406	840	1000
MQS	360	399	840	1000
MQSx	360	399	840	1000
MQ6	360	399	840	1000
MQTL(9)	360	399	840	1000
MQTD/F	360	406	840	1000
IPQ (1.9K)	480	266	420	480
IPD	600	600	600	600
MCB	600 (200)			600 (200)
Undulator	500			500

Another important activity of the EIQA team will consist in filling a reference map to be used during and after LS1, containing:

- MIC, measurements of the quench heater resistance and quench heater insulation (vs coil and ground);
- Transfer function measurements, to be performed at cold and repeated at warm.

Also a series of investigations will be performed on ill circuits, mainly to diagnose shorts (RCOs, 120 A circuits, etc.) and there could be space to re-measure the resistance of internal splices for critical magnets, to confirm the need for replacement (might be possible during technical stops as well).

LS1 AND AFTER

The LS1 will certainly be the occasion for many system upgrade and maintenance activities; some examples are:

- QPS upgrades, with additional systems for the diagnostics of the quench heater circuits or specific transducers for precision measurement of the power pulse during heater discharge;
- all other QPS instrumentation cables need to be checked after LS1 for electrical insulation strength and correct wiring;
- QPS detectors change and firmware upgrade;
- PC modifications (active filters, auxiliary power supplies);
- R2E relocations and cables re-routing.

All the above interventions will demand for a massive campaign of individual system tests, to check for system reliability, protection functionalities and effective QPS-PIC-PC interface. The cable activity will in particular require for short-circuit tests and heat runs to be performed. New powering procedures will be needed (not only for the training of the 13 kA circuits). And finally, we will have (in 2014) a brand new commissioning campaign.

TIME ESTIMATE

A rough estimate of the time needed for the tests before LS1 can be drawn, even if the final list of tests will be defined in the course of 2012; it gives:

- 3-4 days per sector for the powering tests (could do more sectors in parallel)
- 3 days with 2 teams per sector for the MIC
- 2days with 2 teams per sector for the HVQ
- few additional days for special investigations by EIQA

CONCLUSIONS

A lot of tests and measurements will have to be performed before the LS1, to find other possible machine limitations. Among them, the commissioning to nominal current of all circuits (13 kA excluded) and the commissioning to ultimate current (if not more) of the ROD/Fs and the RSD/Fs. The CSCM measurements will be performed on at least one sector. Many EIQA tests will be as well performed. This is a tight planning to be completed in the allocated time.

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REFERENCES

- [1] J.-P. Tock, "LHC Consolidation of the Superconducting Circuits", same proceedings.
- [2] P. Lebrun, "The Sector 3-4 Incident", Chamonix 2009 Workshop on LHC Performance, Chamonix, France, 2 - 6 Feb 2009, pp.34.
- [3] M.Pojer "Which Systems (Except Main Circuits) should be Commissioned/Tested for 7TeV Operation before the Long Shutdown?", Chamonix 2011 Workshop on LHC Performance, Chamonix, France, 24 - 28 Jan 2011, pp.81-84.
- [4] N. Mounet, "Impedance Effects on Beam Stability", to be published in the LHC Beam Operation workshop, Evian 2011 proceedings.
- [5] E.Metral, private communication.
- [6] S. Fartoukh, private communication.
- [7] M.Pojer and M. Solfaroli, "Parameters to be used for the 2012 commissioning campaign of the LHC superconducting circuits", edms no.1184347.
- [8] W. Venturini, private communication.
- [9] A. Ballarino, private communication.

- [10] R. Denz, private communication.
- [11] K. Dahlerup-Petersen, private communication.
- [12] CSCM workshop, CERN Oct.2011.
- [13] Second LHC Splice Review, Nov.2011.
- [14] CSCM Mini Review, CERN Nov.2011.
- [15] A. Siemko, "Beam Energy", same proceedings.
- [16] M. Bednarek et al., "EIQA Qualification of the Superconducting Circuits during Hardware Commissioning", edms no. 788197.