POWERING TESTS

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Abstract

During the first, planned LHC Long Shutdown (LS1), several interventions have been carried out on the machine technical systems, besides the superconducting circuit consolidation, with the goal of increasing the system performance and availability, while raising the energy to its design value. In particular the cryogenic system, the power converters and the quench protection system undertook a series of modifications that have to be tested and might impact beam operation. These modifications are presented together with the plan and status of the system re-commissioning and the readiness of the superconducting circuit powering tests.

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 thus they have to be carefully tested to ensure a safe re-start of the accelerator.

Power Converter - interventions

During LS1 many activities have been performed on the Power Converters, both to maintain and consolidate their functionality and to improve their performance:

- General maintenance (cleaning, connection tightening, water leak check)
- Water cooling circuits consolidation:
  - Change of all flexible on internal water cooling circuits of IPQ and IPD.
  - Change of defective 600 A PCs to water cooling connections.
- Change of electrolytic capacitor in the power supply feeding the 60 A electronics.
- Change of rectifier diodes in the output modules of 1-quadrant PCs (RQs, IPD, IPQ).
- Software updates.
- Calibration campaign which could potentially have an implication on the re-start of the machine as, although not expected, some PCs could have drifted away; nevertheless if any wrong calibration is found, the effect can be anticipated and compensated.
- Consolidation of 600 A power supply units to stand high radiation.
- Change of the DCCT on RD4.L4 and RD4.R4 to increase the maximum current, in order to cope with the optics change [1].
- Installation of an additional DC cable for RQ4.L5 and RQ4.R5 to cancel the limitation of the PC [2].
- Replacement of the water-cooled cables of RQX.L5 circuit with higher cross-section cables to increase the di/dt.
- PCs relocation in IP1, IP5 and IP7 (warm magnets) in the frame of Radiation To Electronics (R2E) project.
- Installation of a Free Wheel Thyristor on the output of RB PCs to reduce the 30 Hz voltage oscillations (ERC 1387235).

Almost all these activities should be transparent, but the power converters will be fully re-tested during the short circuit test campaign and the subsequent powering tests.

Quench Protection System – modification

Many modifications were also carried out on the Quench Protection System (QPS):

- R2E consolidation:
  - Relocation (re-cabling) of IT quench protection racks in IP1 and IP5.

- Upgrade of the 600 A protection system in IP1, IP5 and IP7 to cure Single Event Upset (SEU).
  - Upgrade of the IPQ/D protection system.
- Addition of automatic check of the LSA parameters (with a SET possibility).
- Connection of nQPS to the Post Mortem system.
- Additional post mortem functionality to record both A and B cards from the magnets protection system.
- Migration of the system to FESA3.
- Enhanced supervision of the quench heater discharge.
- Implementation of full redundancy of powering of the detector units.
- Enhanced functionality for remote crate power cycle.
- Installation of earth voltage measurement system on nQPS.

Three additional special cases about QPS have to be discussed in details.

First of all, no change has been implemented on the 600 A IT correctors (RCBXs circuits) to avoid simultaneous powering. This remains a weak point and the implementation of a software protection is being studied.

For what concerns the RQTD/F, their protection system is sensitive to inputs sent on the real time channel by the tune feedback system to the power converter. The stability problem could become an issue at higher current, as the design thresholds for the protection system have to be re-assessed. Different possibilities have been studied (also in the light of what is implemented in similar systems in other laboratories), but there seems not to be an easy solution.

The last case is the one of the RU.R4: due to a missing voltage tap, it was used in Run I at a reduced ramp rate (the ramp to 400 A takes 1.5h), to avoid tripping the QPS. No change was done on this circuit during LS1. Nevertheless, tests have been performed on a spare magnet and an upgrade of the protection electronic was done. As a result, the drift on the reading should become negligible, strongly reducing the impact on machine availability.

Overall the QPS system undertook major modifications and has to be considered as brand-new. Its commissioning will be crucial for the powering tests and the beam operation.

Other Systems – modification

A maintenance campaign was also carried out on all energy extraction systems, by cleaning of the circuit breaker contacts and addition of new relays. The snubber capacitors have been also installed on the main quadrupole circuits. The time constant of the 13 kA circuits have been set back to the design values (104 s for RBs and 29 s for RQs).

In order to increase stability and performance of the cryogenic system, a major campaign was also performed, including:

- Major overhauling of compressors and motors.
- R2E consolidation at IP4.
- DFBA consolidations.
- Repairs of QRL compensator bellows.
- Installation of additional T sensors to disentangle heat load in the dipoles and in the quadrupoles, in order to follow more precisely the scrubbing evolution.
- Dedicated electronics for current lead temperature control.
- Installation of a DFBX current lead cooling control system.

The powering interlock system was also affected by the relocation of the rack within the R2E project. In addition, a new PLC was installed in the CCR to improve dependability in the transmission of the access status to the software interlock system for the powering to access protection.

Finally, new water-cooled cables were pulled in some points and the sheath was changed in many locations.

Superconducting circuits – status

After the modifications applied during LS1, the status of many superconducting circuits changed:

- RCBH31.R7B1 condemned due to its resistive coil.
- RCOSX3.L1 is open, condemned.
- RCOSX3.L2, RCOX3.L2 and RCSSX3.L2 are open and condemned after impact with beam. They are a potential limitation for ions operation at very low beta*.
- RCBYH4.R8B1, RCBYV5.L4B2, RCBYHS4.L5B1: I_{PNO} is limited at 50 A if they are used at 0.67 A/s.
- RCSSX3.L1: maximum current reduced to 60 A (nominal 100 A).
- RCBYHS5.R8B1: I_{PNO} limited at 20 A if used at 0.6 A/s.
- RQTF.A81B1: after the bypass of 4 magnets, the circuit is now working.
- RCO.A78B2 and RCO.A81B2: after the bypass of 2 magnets, these circuits are now working.
- RQ5.R2: maximum current reduced to 4100 A (nominal 4300 A) due to slow training.
- RD3.L4: maximum current reduced to 5600 A (nominal 5850 A) due to slow training. The present current value allows energy of 6.74 TeV.

A full detailed list can be found in [3].

THE SHORT CIRCUIT TESTS

During LS1, a campaign of short circuit tests is being 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. The current then flows from the power converter through the cables and (if present) into the Energy Extraction 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 are being done in different configurations (according to the modifications done during LS1) in all points of the machine. Some problems (i.e. wrong interlock cabling, several lose conical connections and few cable damages) have been already spotted and the necessary corrective actions taken. At the end of the campaign a document with the results will be issued.

POWERING TESTS

A large campaign of powering tests has also to be carried out between mid-August and the end of the year, on the superconducting circuits to ensure their correct performance and functionality, and, above all, to push the main circuits close to the design energy. 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. The usual separation of powering phases [4] implying different access restrictions will be used.

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) is under definition.

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 in order to check the new functionalities of the protection system. In order to verify all these changes, a test bench (short circuited power converter with simulated or strapped interlocks) has been prepared to execute dry runs and ensure full debug phase.

CONCLUSIONS

The LHC superconducting circuit requalification 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. In particular, the ongoing preparation of powering tests campaign is crucial for its success thus for a quick re-start of beam operation; a close coordination and problem follow-up is needed to ensure readiness of all systems.

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REFERENCES

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[3] MP3 website: https://twiki.cern.ch/twiki/bin/view/MP3/SummaryIssues

[4] "Access and powering conditions for the superconducting circuits in LHC" EDMS Doc. LHC-MPP-ES-0002 n. 100198