QPS OPERATIONAL ASPECTS

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Abstract

The status of the quench protection system after LS1 is reviewed, between challenges and major faults. The energy extraction issues are also analysed. Attention then focuses on the operational software tools and interfaces. The foreseen major modifications and improvements during YETS are discussed.

QPS IN NUMBERS

The Quench Protection System is one of the most complex and extended systems in the LHC; it protects in fact more than 500 circuits: the 32 main dipole and quadrupole circuits, 94 insertion region magnets and hundreds of 600A circuits. Because of this, the reliability, availability and maintainability are the major challenge and concern, also given the huge number of electronic components (detection systems, quench heater power supplies, DAQ boards) and signals to be managed.

CHANGES IN LS1

During the Long Shutdown 1, three main modifications affected the QPS, in addition to an overall firmware upgrade:

- A major revision of the main dipole protection system, with
  - Upgrade of the DAQ systems, especially for the enhanced supervision of the main dipole quench heater circuits (FPGA based)
  - The addition of the voltage feelers, to measure the voltage of the magnet coil vs ground, as an early detection of insulation issues or analysis tool in case of short to ground
  - Change of field-bus configuration to double transmission capacity, with enhanced remote control options
  - Full adaption to redundant UPS powering
- For interaction region magnets and inner triplets
  - Most of the detection systems were upgraded to radiation tolerant FPGA based systems; the IT systems were re-located to radiation free areas (UL14, UL16 and UL557)
  - Warm instrumentation cables for some magnets re-routed to improve the immunity in case of perturbations of the electrical network
- Concerning the energy extraction systems:
  - During LS1, the 13kA EE systems went through several interventions of upgrade, maintenance and measurement
  - For the 600A EE systems, the interventions aimed at improving circuit-breakers availability/reliability.

THE QPS AFTER LS1

Detection board issue

In LS1, new boards were developed and installed to perform the Copper Stabilizer Continuity Measurements (CSCM): the so-called mDQQBS boards, in opposition to the previous DQQBS. The objective of the CSCM campaign was to reliably validate the integrity of the splices, the diodes and the diode busbars, by injecting a pulse of very high current in a 20K-cooled dipole circuit and measuring the voltages across all segments. Since the circuit is not superconducting, the voltages to be detected are in a range not accessible by the high sensitivity (low voltage) DQQBS boards, plus a new dV/dt-based detection algorithm had to be developed to cope with the high ramp rates. These boards were installed during the LS1 and were supposed to be removed before beam, but were finally left in, to save time. Unfortunately some components of these new boards proved to be not radiation hard, and the mDQQBS boards started to be affected by single event upsets when the beam intensity started to be pushed up. About 60 SEUs were detected during the first part of 2015 operation, 11 of which triggered the opening of the interlock loop. To fix the problem, an unsuccessful firmware update was first tried, after which all boards had to be replaced during the technical stop 2.

150 interventions were carried out in 2015 (114 interventions were done in the last year of Run I) by the protection system piquet; and this was largely dominated by the SEU on the mDQQBS boards. After their replacement in TS2, a net improvement in availability was observed. Concerning the SEUs, after TS2 they were almost absent:

- On the DAQ systems there were 139 transparent -mitigated- errors recorded (some 40 with ions), with no fault, no downtime, no dump, no blocked uFIP (automatic recovery is active for 1232 devices)
- Concerning the 600 A detection systems, 2 cases were recorded which caused beam dumps (RR13 on 17/10/2015 and RR57 on 31/10/2015); this is less than expected, as the devices have not been updated yet to a radiation tolerant version (the update for RR13, 17, 53, 57, 73 and 77 will take place during the end of year technical stop)
- Two additional events were then observed on the other detection system (including standard DQQBS boards re-installed during TS#2) during the ion run, at hot spot

- No R2E problems for any re-located equipment in (UL14, 16, 557) were observed, nor for upgraded detection systems type nDQQDI (ProASIC3E).

Unfortunately, after installation of the old DQQBS boards, an already known communication problem (it appeared in the initial commissioning, then disappeared and was never reproduced in the lab) appeared, affecting the DQLPU type S (sitting below the B dipole). This fault has the consequence of losing communication with the various detectors, but the protection functionalities are not compromised. Nevertheless, even if not safety critical, a faulty communication is twofold problematic:

- By removing the QPS-OK, it interlocks the injection through the SIS, even if it does not prevent operation (i.e., ramping)
    - A mask is needed to continue injecting – per se no safety issue but it degrades the interlock redundancy: we could miss a stalled board or ramp to high energy with two QHPS off (1 h delay before removal of power permit)
- It prevents re-powering a main circuit if the converter was set off (trip, access, loss of cryogenic conditions), as PIC does not grant the power permit in the absence of the QPS-OK.

To re-activate the communication, a power reset procedure was set, which was initially not optimized: if not done properly, quench heaters were discharged in the attempt of re-establishing the communication. About 170 quench heaters were discharged at zero current from the end of the commissioning in March ’15 (Figure 1 and 2), and most of them because of this communication issue.

A firmware upgrade is ready and will be deployed during the YETS on all units (436) affected by the communication bug. It will be carefully tested at the end of YETS, but should be transparent for re-commissioning.

Energy Extraction (EE) problems

Several problems were affecting the energy extraction systems, mainly for the 600 A circuits. For them, in fact, few switches had to be replaced in 2015, but this is, in general, a “statistically normal” replacement of failing components. 13 tunnel interventions were done on the 600A EE system (over the total 202 systems):

- 2 interventions due to missing communication
- 2 low voltage power supply replacement
- 1 cases of loose wires (post-LS1 effect?)
- 5 breakers changed (4 old one plus 1 replaced again due to closing failure)
    - 2 cases of the main acting part which got lose (1 per year on average)
    - 1 micro-switch problem
    - 1 holding coil
    - 1 unknown
- 3 remote interventions: could be reset remotely but 2 were leading to on-site interventions.

As future development, the experts are developing a pre-warning tool to pre-trigger an early alarm in case of issues. In addition, they are working on a pre-cycle monitoring tool, to systematically provide the internal resistance of the breakers during a pre-cycle (no new hardware needed, only software) and a counter of switch openings.

Concerning the 13 kA EE systems, only two hardware component failures were observed in 2015:

- On 22nd of July, the impossibility of closing the switches of RB.A34-odd side; the intervention on the spot revealed a broken diode bridge rectifier of a holding coil auxiliary circuit, with the result that four out of eight switches could not get closed
- On 3rd of November, the impossibility of closing the switches of RQD.A34, where the stator coil of one cooling fan was burned and tripped the local circuit breaker; it led to a constant presence of an interlock "over temperature" and all switches of the system could not get closed.

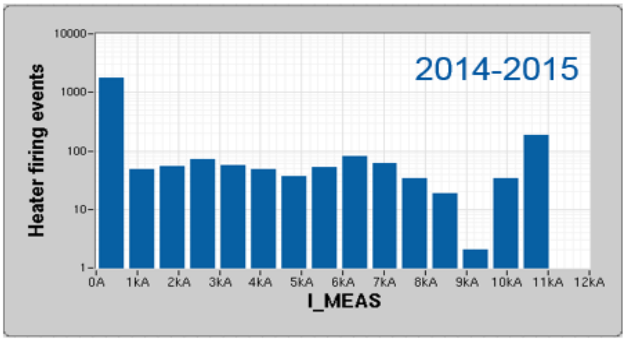

Figure 1: Quench heater firing since October 2014 (QPS-IST included); about 2525 were fired at full charge, while about 1650 were fired at zero current.

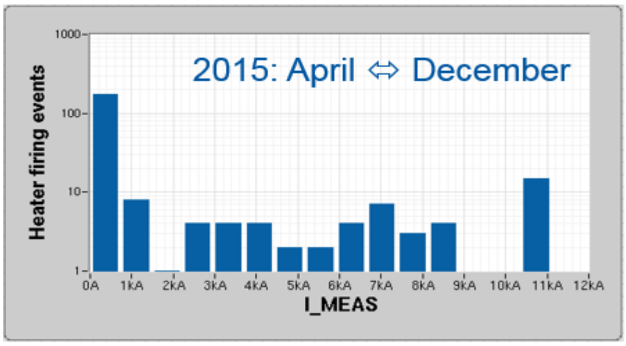

Figure 2: Quench heater firing since April 2015 (1st beam in the machine); about 234 were fired at full charge, while about 170 were fired at zero current.

Something to be finally noticed is the important attempt to reduce the machine downtime, by increasing the portion of remote interventions vs access need, whose percentage went up to about 70% in 2015 from less than 50% in Run I.

SOFTWARE TOOLS AND INTERFACES

QPS macros

Part of the diagnostics and operation of the main circuits is, at present, based on a series of macros (accessible from the QPS_expert_tool) to reactivate the local communication of a QPS board, power reset the nQPS after a trip, activate the voltage feelers after their triggering and send/disable the PM data from nQPS.

These macros were of great importance during the training campaign, but they require a serious of operations and specific knowledge and need to be manually run at every circuit trip (quench, FPA), with the consequence that they are not systematically launched and are error prone.

Present status and future improvements

In case of triggering of the nQPS, a PM file is generated but not sent. In fact, the process blocks the generation of additional PM files: to avoid losing data in case of secondary events, a manual triggering of PM sending is required. A different solution will be deployed during YETS, which foresees the automatic sending of the PM files, but with a (programmable) delay of 10 min; this will as well prevent losing data for the 600 A circuits, where the controller is shared by 4 circuits at a time.

Also, without running the two macros of power reset and voltage feelers activation, the voltage feelers are not activated; as a consequence, we were sometimes running without voltage feelers in some sectors. As from YETS, the voltage feelers will be automatically activated when resetting the nQPS. In addition, the reset could be integrated in the sequence of preparation of a sector and BE/ICS will work on a macro for the sequencer. Complementary, as discussed and requested by LMC, the voltage feelers sampling rate will be pushed from the present 1.25 Hz to 10 Hz after YETS, to improve diagnostics in case of short-to-ground on the main circuits; the compatibility and limits imposed by the tunnel infrastructure will have to be assessed.

QPS sanity check

Following issues emerged in the last commissioning campaign, checks about the status of the QPS elements have been progressively imported into the operational sequencer; an example is the soft reset of the 600 A controller, to reset and check that the controller is live. Such a check has been systematically failing for sector 34 since the beginning due to a condemned circuit (RSS.A34B1), which has not been removed from the logic: BE/ICS should implement a check in the existing macro to exclude this circuit from the evaluation.

A QPS configuration management check has been recently introduced (part of the “Swiss tool” software), which triggers a reading of the configuration from each of the FESA devices, and cross-check against the reference stored in LSA.

In addition, the QPS experts have a maintenance tool which is running constantly, checking “all” values from logging every 10 min.

DATA QUALITY

Many problems emerged during the 2014/15 commissioning campaign for what concerns the QPS data quality. In fact, the data of the QPS Post Mortem files contain many timing errors, saturated points, spikes, which made a dependable analysis and automation very difficult, if not impossible. Non-logical signal and crate naming, signal swaps, polarity issues, and incorrect documentation further complicated the analysis.

The QPS team should provide PM-correctors so that the users can use corrected/filtered data (without changing the raw data files). In addition, the quench (heater) analysis at all levels and for all circuits should be automated, together with the monitoring of protection related signals, earth current and voltage to ground.

A strategy should be proposed by the automation team, with input from MP3, to store analysis results in a database.

Very important should be the set up a realistic test bed of all the soft and hardware of the various types of circuits, in order to properly prepare for a following HWC campaign. This would significantly reduce the software debugging time during the HWC.

UNDULATOR

2 dumps in 2015 (and more in the past) were due to the trip of the undulator RU.L4. The problems with the undulator circuits are related to the detection boards suffering from measuring drift, the very noisy signal due to high inductance and LEM hall probe sensor, with a moving average filter to reduce noise which obliges to keep the acceleration low, plus one has missing parallel resistor.

Actions will be taken during the YETS, which include the replacement of the LEM hall probe sensors by DCCTs (with 10 times less noise) and the use of new detection boards (radiation tolerant implementation using Flash based PGA), which replace the complex auto-ranging analogue input stage by high resolution ADCs: they should not suffer anymore from drift problem of the previous generation.

CONCLUSION

More than 200 primary quenches were detected and actively protected by QPS in 2015: the QPS remains a fundamental system for the LHC!

The reliability has grown during the year, above all after the mQPS boards replacement.

After initial problems, the performance has drastically improved.

On the software side, many things could be automatized, so that very few manual actions will be left to the operators.

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