# QPS/LHC ACTIVITIES REQUIRING IMPORTANT TUNNEL WORK DURING A FUTURE LONG SHUTDOWN

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*Abstract*

The MPE/circuit protection section is presently establishing a road map for its future LHC activities. The tasks comprise essential consolidation work, compulsory upgrades and extensions of existing machine facilities. The results of a first round of engineering exertion were presented and evaluated at a MPE activity review in December 2010. The technical and financial aspects of this program will be detailed in the 'QPS Medium and Long-Term Improvement Plan', to be published shortly.

The QPS activities in the LHC tunnel during a future, long shutdown are closely related to this improvement chart. A project-package based program for the interventions has been established and will be presented in this report, together with estimates for the associated human and financial resources necessary for its implementation.

## INTRODUCTION

The different parts of the consolidation and upgrade package are motivated and justified by a variety of different circumstances, for which the main incentives are:

- Mandatory repairs to maintain a high level of system availability
- Improvements for performance enhancement, based on operational experience
- Adjustments required for the future energy increases
- Modifications imposed by new machine integration layouts
- Extension and completion of the enhanced quench protection system (nQPS)
- Upgrades imposed by R2E features
- Maintenance prior to magnet training with requirements for highest QPS performance
- Installation of pilot facilities of next-generation QPS and EE equipment

The shutdown work with tunnel interventions has been defined in five separate project packages:

**Package 1:** DQHDS: Improvement and extension plan for the 6'078 quench heater power supplies. Comprises repair work, introduction of new hard- and software and integration into the DQLPU's.
**Package 2:** nQPS: Completion of the existing enhanced protection scheme and its extension to circuits outside the arcs.
**Package 3:** EE: Consolidation and upgrade plans for both the 13 kA and the 600 A energy extraction facilities.
**Package 4:** Controls and ACQ topics: General and specific upgrades.
**Package 5:** R2E: Mitigation and relocation programs.

## PROJECT PACKAGE OVERVIEW

***Package 1:***

Important changes are foreseen for the quench heater powering circuit and its monitoring features. The modifications endeavour an improvement of the acquisition as a tool for making early diagnostic of a faulty heater, a reduction of the stress on the heater strips during discharge testing, introduction of a permanent circuit continuity check and some repair work.

I) *Introduction of a discharge current and voltage measurement as a complement to the existing capacitor charge voltage monitor.*

The combined measurements will provide information about the phase and amplitude of the load impedance at any moment during the discharge and herewith increase the chances for early fault detection. Only in rare cases (fig.1) the voltage measurement alone could allow a disclosure of a heater defect prior to a breakdown which could have a potential risk of damage to the cold mass.

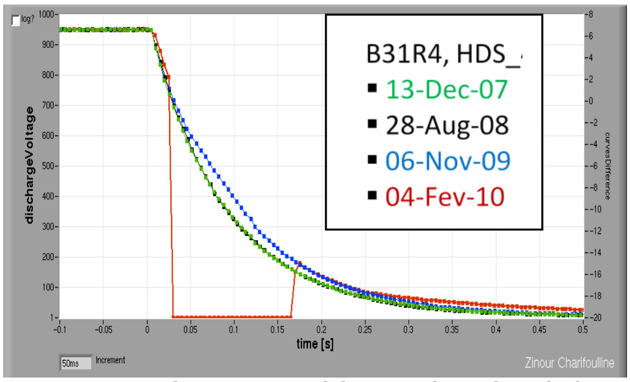



Figure 1. One early warning possibility was observed on discharge voltage plots (November 2009).

The new baseline design features a 1 mΩ, 1%, 7 W shunt resistor (272 mJ/cycle), a RADhard isolation amplifier and ADC, located in a separate compartment, possibly a part of a renewed 'Crawford' shuffling box, reducing to a minimum the interventions on existing hardware. The upgrade will require new DQAMC boards (1700 units) as the required 8 additional analogue channels are not available in the existing dipole controller, neither the 4 channels in the quad controller. The sampling frequency shall be increased from 200 Hz to at least 500 Hz. Verification of discharge voltage and current profiles will

comprise automatic, point-by-point comparisons with stored data from earlier discharges.
The estimated resources for the tunnel work associated with this upgrade total 1.7 FTE, not including the required extension of the MicroFIP network. The estimated resources are included in the cost figure of point 1.

II) *Introduction of a 'tickling' circuit.*
Continuous verification of the integrity of each heater discharge circuit will be provided by associating the above voltage and current measurement feature with the insertion of a small d.c. source in mA range. Apart from the moment of discharge, where this 'tickling' circuit will be disconnected and isolated, the circuit will produce an alarm in case of increased heater circuit resistance. Also these sources will be located in the new shuffling module.

III*) Implementation of a low-voltage (low-power) trigger to allow regular verification of heater integrity through safer discharge tests.*
A software solution is considered safer and simpler than options requiring additional hardware. A special test mode will allow thyristor firing at a programmable threshold voltage (100-300V). The discharge will be triggered during the capacitor charging so to have the controls powered. This method requires no modification to the existing installation or any addition of new hardware. The new test mode will be power permit prohibiting. It may occasionally replace the full power test. The procedure will be tested at Technical Stops in 2011 and implemented everywhere during the long shutdown.

IV) *Replacement of the failing switches for power input and internal capacitor discharge.*
Now that the origins of the switch failures (design and production mistakes) and the likely continuation of the failure process are understood, the decision to replace this component by a new, qualified switch on all 6'078 DQHDS units is taken. Substitution of the first 1'000 units took place in the 2010-11 winter stop, involving all LHC quadrupole heaters. Every TS of 2011 and 2012 will be used for further replacements on the dipoles, starting at the most inaccessible areas (points 3 and 7). With an exchange rate of 62 units/day approximately 2'000 units will remain for replacement in the long shutdown 2013, representing 0.53 FTE.
It shall be noted that new DQHDS failure alarm and abort interlock system will partially make the problem transparent to operation. Repair will be in the shadow of other mandatory tunnel interventions and will not cause any additional machine-down time.

***Package 2:***
The completion of the first phase of the existing nQPS system is related to the arc magnets, whereas its extension concerns new circuits to be equipped with distributed busbar detectors and new detection boards.

I) *Completion of the 'Voltage-to-Ground' measurement system – nQPS / DQQDE, phase 1 and 2.*
When fully deployed, the system will allow continuous monitoring of the busbar voltage w.r.t. ground at the dipole 'B' and at the quad of each half-cell. Furthermore, it will allow busbar-to-busbar voltage monitoring such as QF-QD, QF-QF, QD-QD and RB-RB, for voltage distortion or short-circuit detection. Phase 1 comprises the installation and commissioning of 30 DQQDE boards (fig. 2) in the three main circuits across a single sector, foreseen for TS#8, March 2011. At the same time the associated software will be checked. The rest (phase 2, 1278 boards) will be installed in either the winter stop 2012 or in the long shutdown. The required resources represent 0.1 FTE.

II) *Extension of the nQPS-BS splice monitor to cover the individual busbars of all stand-alone magnets.*
One hundred powering circuits are affected by this extension (all IPQ's, IPD's and IT's). The principle of 'one circuit – one detector crate' will be applied, requiring design, production and installation of 30 new DQGPU crates, 30 new DQAMG controller boards and at least one cable patch per circuit. The associated signal cables, however, were already installed during the nQPS arc cabling campaign in 2009.
It shall be noted that opposite the BS systems in the arcs, the SAM systems will exclusively be allocated to precision resistance measurements of the busbars; an additional interlock is not required as the present, global detector provides full protection of both magnet and busbars.
A few prototype systems will be available for installation in the winter stop 2012. For the installation and connection in the tunnel of the series 0.5 FTE is required.

III) *Partial upgrade of the digital detection boards (nDQQDI) in radiation exposed areas (RR's) in LHC points 1 and 5.*
The logic controller of the new cards (fig. 3) is based on the FPGA ProASIC3, such as the DQQDS detector. They feature display of data from both boards 'A' and 'B' and also post-mortem files are created for both detectors. The new boards are designed for direct replacement in the existing crates. Estimated resources for installation is 0.1 FTE.

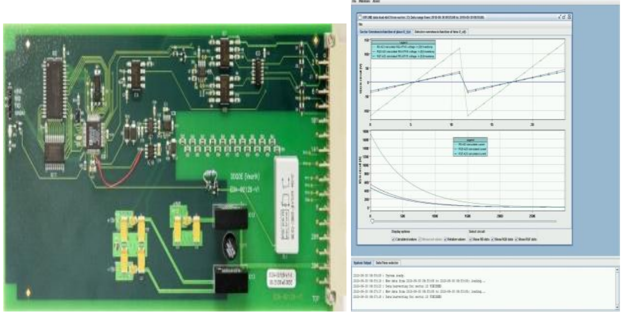


Figure 2: DQQDE board and simulated voltages to ground across one sector.

Figure 3: nDQQDI board with Actel ProASIC3

***Package 3:***
The upgrade of the 234 EE facilities is defined in eight sub-packages.

*I) Installation of snubber capacitor banks in the RQF/RQD circuits.*
Following the successful deployment of the dipole snubbers and the validated results from type testing of the quad units it has been decided to prepare for their installation across the DQSQ’s during the long shutdown. Routine testing of the 16 installations will begin shortly, along with the production of the auxiliary components and the protection circuits. The estimated installation time is 0.8 FTE total.

II) *Relocation of the two DQSB extraction switch assemblies in point 3 (4.5 m displacement on both sides).*
The integration phase requires close coordination with TE/VSC for co-existence with beam pipes and other vac equipment inside the DQSB shield enclosures. The cable adaptations will be outsourced to EN/EL. Relocation of the DQRB’s and the DQRCS seems not necessary. The resources from QPS are estimated to 0.4 FTE for the two sides.

III) *Upgrade of the DQRB’s (53 units):*
Replacement of all H.T. thermostats has become necessary after discovery of a drift in the transition point of the existing, Curie-temperature based thermo-switches (a CERN/IHEP development). Replacement will be with conventional bi-metal units.
Second issue concerns the capability of the DQRB’s to (exceptionally) absorb without damage twice their rated energy, i.e. 440 MJ each. During a double-energy test at IHEP, RU, simulating an accidental non-opening of one of the two extraction switches, the risk of damage to the H.V. power bushings and even short-circuit of a part of the resistor related to the thermal expansion was revealed. The intervention consists of modifying the current feedthroughs (fig. 4). Because of the co-existence with the Roman Pots in point 1, access to the dump resistors requires temporarily removing them and supporting the beam pipes during the intervention. The two issues require 0.30 FTE.

IV) *First complete overhaul of the 256 extraction switches of main dipole- and quadrupole circuits.*
This preventive maintenance program includes the adjustments of the gaps and contact pressures in the electro-mechanical systems for main- and arcing contacts as well as execution of the voltage withstand tests according to the instructions of the manufacturer. The associate resources total 0.18 FTE.

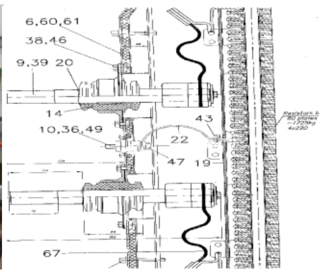
V) *Replacement of the arc chambers on the quadrupole breakers for a 500 V version (if necessary and approved).*
This task is required only if the decision is to continue operating the quad circuits with a 9.6 s time-constant at energies above 4.5 TeV [1]. The resources needed are 0.05 FTE.

VI) *Consolidation of the ‘holding coil’ assembly of the 600A extraction switches.*
During the first year of operation of the EE facilities, QPS has detected five cases of unclamping of the so-called ‘holding coil’ which provides the contact pressure on the breaker’s main contacts for closing and maintain. The intervention consists of applying a reinforcement to the coil clamping system (fig. 4). A method which allows an installation without removing the switches from the rack is under development. If applied everywhere the intervention will need allocated 0.3 FTE.

VII*) Further improvements:*
The mitigation package contains two further tasks:
-Replacement of the voltage dividers for $U_{dump}$ by a non-linear electronic meter for precision monitoring of both $U_{dump}$ and $\Delta U_{switch}$ in closed state. Estimated 0.25 FTE needed.

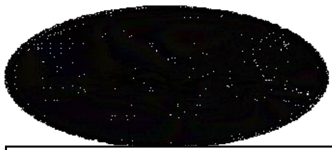
VIII) *Pilot EE systems based on water-cooled IGCT static switches for the 600A corrector circuit protection.*
Two existing 600A EE racks will be replaced by four pilot switches based on bipolar, integrated gate, commutable thyristors combined with blocking diodes and a non-RADTol gate drive electronics. The purpose is to perform final validation of such systems under real operating conditions. The estimated resources for the installation / connection of the four systems are 0.15 FTE.

Quad Snubber Caps with protection circuits




DQR feedthrough modification

IGCT
**Package**



Fixation system for ‘holding coil’

Fig. 4. Issues related to the EE upgrades.

I*) Field-bus changes.*

The operation of the present QPS, nQPS and EE equipment loads the existing DAQ transmission system to 90% of its capacity. An extension of these systems will rapidly saturate the data transmission lines. Consequently, a gain in the margin of the transmission bandwidth will be required. This task involves a reconfiguration of the present field-bus from 4 to 8 segments per sector, a doubling (from 2 to 4) of the tunnel gateways, a doubling of the number of repeaters and some infrastructural changes. Furthermore, the extension comprises the installation of new optical fibers in the tunnel and in the shafts, from the alcoves to the surface, representing a total length exceeding 2/3 of the LHC circumference. It will heavily involve BE/CO and EN/EL with resource requirements estimated at 0.40 FTE / sector.

II) *New controller boards.*

New DQAMC boards for the local protection units shall feature:

- -minimum 8 additional analogue input channels
- -integration of the new nanoFip
- -a built-in remote rest unit
- -a programming plug on front panel for easy loading of modified software

New firmware will be developed for these new controller boards which will be tested in the winter stop 2012 in some selected LHC areas. Their installation will have minimum impact on the shutdown planning.

**Package 5:**

*I) R2E Mitigation: Changes to firmware for overcoming the consequences of SEU events.*

The experience from operating the quench detectors during the first year of LHC exploitation indicates that charged particles cause triggers due to their interference with sensitive electronic components, e.g. digital isolators. Such cases mainly occurred during the ion runs and in the higher loss areas L2, R8, point 3 and point 7, affecting the AMC controllers. The interferences did never impinge on the protection features but created unwanted post-mortem triggers after which the DAQ entered into a stalled state, with loss of the QPS_OK signal (injection permission) and no return to logging condition. Also a new PM buffer filling was inhibited.

Mitigation consists in a modification to the associated firmware by forcing a re-launch of the logging and resetting of the PM system. The upgrade was successfully implemented in points 7 and 8. The required resources for extending the improvement to points 2 and 3 and then the rests of the machine are estimated to 0.2 FTE.

*II) Relocation of Quench Protection Equipment.*

Bringing QPS equipment to more shielded areas is only relevant in the locations P1 left, P1 right and P5. In each case the move concerns the inner triplet protection systems, i.e. the RQX quench detector crate, its associated eight quench heater power supplies and the seven IT corrector protection units RCBXH1, RCBXV1, RCBXH2, RCBXV2, RCBXH3, RCBXV3 and RQSX3.

Each of the three equipments consists of two instrumentation racks (DYPG01/02). The UJ14 and UJ16 racks will be moved to UL14 and UL16 whereas the UJ56 racks will go to UL55.

The estimated resources are 0.15 FTE, plus outsourcing to EN/EL of the re-cabling.

## CONCLUSION

QPS will not wait for the long shutdown to undertake the improvement and extension campaign for the quench detectors, heater firing equipment and energy extraction systems, such as defined by the consolidation and upgrade project packages. As it was the case in 2010, every technical stop will be used to advance the various programs. However, tasks which require important re-commissioning are planned for the long shutdown.

With this long shutdown, now scheduled for 2013, the total resource estimate for execution of the QPS project packages in the LHC tunnel during this stop amounts to 8.9 FTE. To this figure shall be added 4 FTE for assistance with logistics, Q.A. and tests.

External resources shall be obtained through contracts and collaboration agreements with traditional partners:

-FSU (occasionally up to eight people): For package I activities mainly.

-UPAS from AGH, Cracow (5 people): For Package II and V.

-UPAS from IHEP, Protvino (4 people): For package III activities.

TE/MPE staff: For packages IV and V - and supervision of the other project packages.

The budget estimates related to the installation work amounts to 4.11 MCHF, with 3.60 MCHF for equipment, materials and consumables and 510 kCHF for the cost of external labor. The figures do not include the expenses related to the associated R&D.

Many on-going QPS issues are not included in the above project listing as they are meant to be completed and implemented before the long shutdown. This concerns the EMI sensitivity reduction campaign on all IPQ's and IPD's, de-commissioning of the eight 'global' busbar detectors (now obsolete), the '4L Undulator' upgrade for noise reduction and new reset procedure, the new closing procedure for the 600A extraction breakers and the improvement of the QPS acquisition tools.

## REFERENCES


[1] Implications of increased beam energy on QPS system, EE time constants, PC. Jens Steckert. Chamonix 2011 LHC Performance Workshop.