QPS PERFORMANCE DURING THE 2016 LHC RUN

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Abstract

The LHC quench protection system consisting of more than 13000 quench detectors and more than 6000 actuators (quench heater power supplies and energy extraction systems) reached an impact availability of 99.49% during the 2016 proton run. This is an improvement by 80% compared to the 2015 figures. Changes to the systems in the YETS 2015/16 comprise the introduction of the new radiation tolerant 600A quench detectors in the RR-areas as well as a firmware update of the crate controllers of the nQPS system throughout the LHC tunnel. Preventive maintenance had been performed on all 13kA energy extraction systems as well as on selected 600A energy extraction systems. The 2016 performance is compared system by system to the 2015 figures. Radiation to electronics effects, a big issue in 2015, has not lead to a false trigger of a quench detector in 2016 although two crate controllers might have been affected during the proton-ion run.

QPS OVERVIEW

The quench protection system (QPS) of LHC's superconducting magnet circuits is located in the LHC tunnel and adjacent underground areas. As a large distributed system, it consists of approximately 29000 circuit boards equipped with active components. This number accounts only the quench detection part of the system, and excludes the energy extraction systems which itself consist of several thousand elements. Once a quench is detected, dedicated hardware interlocks transmit the information to other systems as power converters and the beam interlock system (BIS). In total 14000 circuit boards capable of activating these interlocks are installed in the QPS system. Since each of these interlocks can trigger a beam dump via the BIS, the system has to be extremely reliable and available. The table below shows the systems' main elements and their quantity installed in the LHC. [1]

Table 1: Main interlocking elements of the LHC QPS

# installed	System	Function
32	**EE13kA**	Energy extraction 13kA circuits
202	**EE600**	Energy extraction 600A circuits
6084	**DQHDS**	Quench heater power supplies
1624	**iQPS**	QDS base layer for MB and MQ circuits
4032	DQQDL	Quench detector
436	**nQPS**	QDS second layer for MB and MQ
1632	DQQDS	Symmetric quench detector
4096	DQQBS	Splice supervision board
76	**QPSIPX**	QDS for individually powered dipole- quadrupole- and inner triplet magnets
360	nDQQDI	Rad tol. quench detector
48	DQQDT	Quench detector IT
1124	DQQDC	Current lead quench detector
114	**QDS600A**	QDS for 600A circuits
624	DQQDG	Quench detector
212	nDQQDG	Rad. tol. quench detector
1672	DQQDC	Current lead quench detector

In 2016 the system showed a MTBF per element of approximately 4Mh

ACTIVITIES DURING YETS 2015/16

During the year end technical stop of LHC (YETS) of winter 2015/2016 several maintenance activities had been conducted and some systems had been upgraded:

- Replacement of 600A quench detectors type DQQDG with radiation tolerant version nDQQDG in RR13/17, RR53/57 and RR73/77
- Upgrade of RU-circuit QDS to nDQQDG quench detectors and installation of a DCCT for current measurement to replace the noisy hall probe.
- Firmware updates for nQPS systems on 436 crates in all sectors enhancing stability of local communication and enhancing intelligent fault management.
- Conducted annual maintenance of 13kA energy extraction systems
- Selective maintenance on 600A energy extraction systems which showed signs of degradation

SYSTEM PERFORMANCE

In the following sections the system performance throughout the year 2016 will be shown and compared to the systems' performance of 2015. The analysis is based on data registered in LHC's accelerator fault tracking system (AFT).

Performance of 2016 pp run

Figure 1 shows the LHC impact fault time and the impact availability of the QPS during the 2016 pp run.

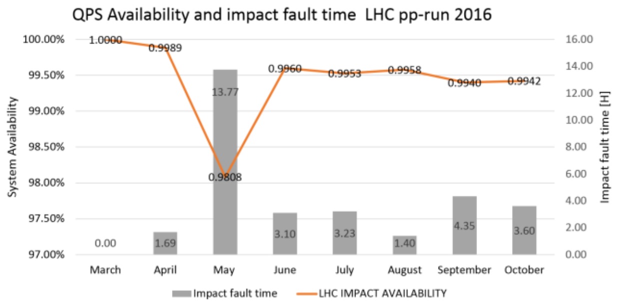

Figure 1 QPS Availability and impact fault time during 2016 LHC p-p run

The average availability of the system during the proton run was 99.49% which is well above the target availability for the QPS which had been set to 98%. Even in May 2016 where some technical problems with the RU protection systems lead to an increased amount of impact fault time the availability was above 98%. In terms of impact fault time the system caused in average 3.9h per month.

Fault time evolution 2015 to 2016

The plot below shows the availability of the QPS during the 2015 and 2016 pp runs.

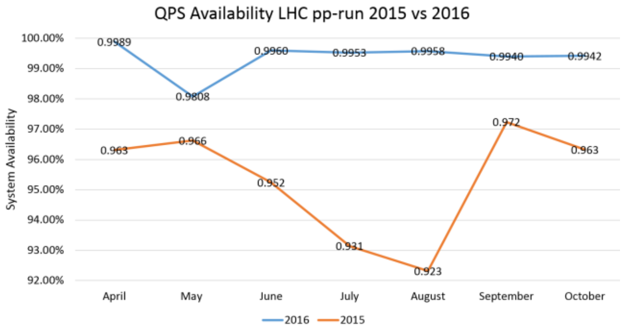

Figure 2 System availability comparison between 2015 and 2016

As it can be seen the year 2016 shows a significant improvement of the system availability over the year 2015. A main contributor to this improvement was the exchange of some radiation sensitive circuits boards during TS#2 2015 which already reflects in increased availability of the months September to October 2015.

Figure 3 shows the evolution of the fault times caused by the various QPS subsystems

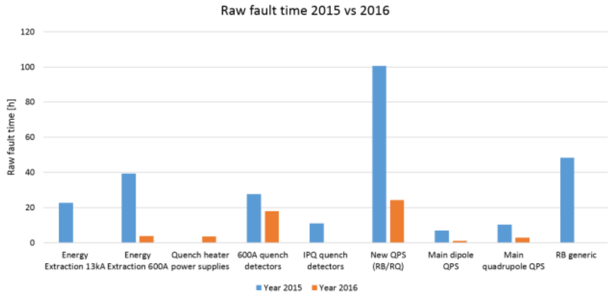

Figure 3 Raw fault time evolution by system

Between the 2015 and 2016 run only a few but effective interventions had been performed. For the energy extraction systems the preventive maintenance was very effective in reducing the downtime. Also the software update of the nQPS systems and the replacement of the mDQQBS board in TS#2 2015 lead to an improvement of almost 80% in down time. For the 600A quench detectors the effect is not as clear since a complete upgrade including commissioning with new detectors was performed. This lead to some trips due to sub-optimal configuration. It is expected that the availability of the new boards improves once there is enough experience with the new systems.

Fault analysis for the year 2016

To gain a better understanding of the QPS faults in 2016 the number of raw faults as well as the raw fault times had been determined by sub-system. This analysis was performed on base of the raw fault times to exclude the effects introduced by the impact fault methodology. Figure 4 shows the number of raw faults per QPS sub-system in 2016.

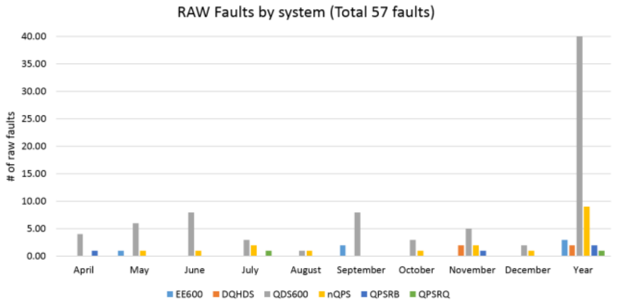

Figure 4 Raw fault occurrence by system 2016

As it is clearly visible, most faults are caused by the 600A QDS. This is clearly an effect of the introduction of the radtol detector boards on which we gained operational experience during 2016. The second most faults (9) had been created by the nQPS system where a loss of internal communication lead to difficulties re-starting the system after a fast power abort.

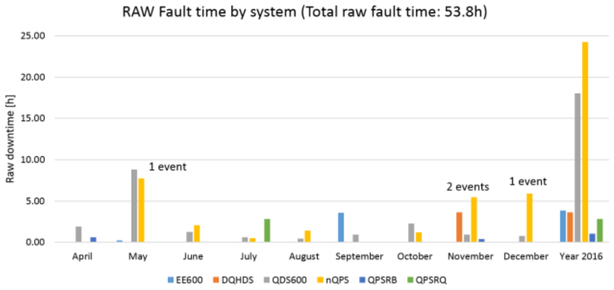

Figure 5 Raw fault time by system 2016

If we look at the amount of raw fault time caused by subsystem, the result changes. As shown in Figure 5, the nQPS system caused the most raw fault time which accumulates to 24.2h while the QDS600, despite the number of faults, is second. The EE600 system however caused 3.8h caused by only two events and is hence on the third place. This shows that the number of errors is not necessarily reflected in total fault time. In the case of the nQPS, the long fault time can be explained by a new error mode which was relatively difficult to analyse during its first few occurrences.

Piquet interventions in 2016

Compared to the year 2015 the number of piquet interventions during 2016 were reduced by 80%. As shown in Figure 6 the number of remote interventions was reduced over-proportionally due to a modification in the treatment of a binary signal blocking the restart of a sector in 2015.

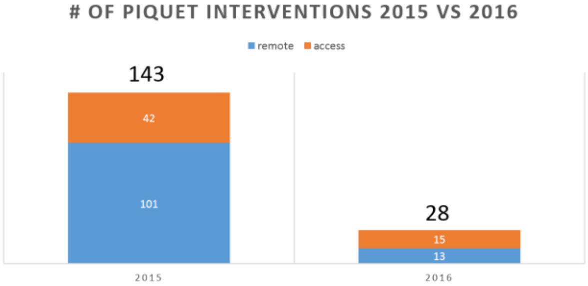

Figure 6 Number of piquet interventions 2015 vs. 2016

DETAILED VIEW ON SEVERAL ASPECTS OF SYSTEM PERFORMANCE

This section will describe several topics of system performance in more detail.

Details of 600A quench detection systems

Due to their complex algorithm, the 600A quench detection systems had been traditionally prone to false triggers often created by external non-quench events. With the upgrade of the systems located in RR13/17, RR53/57 and RR73/77 we introduced a completely new and technically different version of this type of quench detectors [2]. The new design allows to change several operational parameters remotely. With no operational experience with these detectors some filter parameters had been set too conservatively which lead to unnecessary triggers especially during the precycle. With improved filter settings events like the zero-volt crossing of the 600A power converters which leads to a perturbation in voltage and current were mitigated. In the end we identified only two circuits which had been responsible for 46 out of 52 triggers related to zero volt crossings. Another challenge was the parametrization and the cabling of the new 600A quench detectors for the undulator circuits in point 4. Due to the installation of DCCTs for current measurements the cabling layout changed. After two interventions these issues had been solved. Overall the largest source of 600A circuit fast power aborts had been the global interlock which shuts of the power converters which leads to a trigger of the quench detection.

Radiation to electronics

In 2016 no radiation-to-electronics (R2E) induced trigger of the quench detection system had been observed. This shows that the upgrade of the 600A quench detectors to a radiation-tolerant version was successful. Furthermore we could not identify any unmitigated R2E-related malfunction during the 2016 pp run. However two events during the 2016 ion-proton run which lead to malfunction of crate controllers in B8L8 and B9R1 are suspected to be related to R2E effects.

CONCLUSIONS

After numerous upgrades in 2009/10 and in long shutdown 1 as well as the YETS 2015/2016 the system had reached its nominal configuration in 2016. This is reflected by the excellent R2E performance which fully proves the effectiveness of the implemented measures. As consequence none of the quench detectors suffered from mal-function due to radiation. The system availability improved considerably in 2016 which is reflected in the reduction of system raw fault time of 80% compared to 2015. One important factor contributing to this improvement is the absence of faults provoked by the massive upgrade campaigns of LS1. These faults, mostly cables & connectors as well as cards which were not properly inserted, had been corrected during 2015. Most of the faults of the new 600A quench detectors were related to installation and configuration of the new system. As consequence, no major changes to the system are foreseen up to LS2.

REFERENCES

[1] R. Denz, K. Dahlerup-Petersen, A. Siemko, J. Steckert, “Upgrade of the Protection System for the Superconducting Elements of the LHC during LS1”, *IEEE Transactions on Applied Superconductivity*, vol. 24, no. 3 June 2014.

[2] J. Steckert and A. Skoczen, „Design of FPGA-based radiation tolerant quench detectors for LHC” 2017 JINST 12 T04005