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 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

<table>
<thead>
<tr>
<th># installed</th>
<th>System</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>EE13kA</td>
<td>Energy extraction 13kA circuits</td>
</tr>
<tr>
<td>202</td>
<td>EE600</td>
<td>Energy extraction 600A circuits</td>
</tr>
<tr>
<td>6084</td>
<td>DQHDS</td>
<td>Quench heater power supplies</td>
</tr>
<tr>
<td>1624</td>
<td>iQPS</td>
<td>QDS base layer for MB and MQ circuits</td>
</tr>
<tr>
<td>4032</td>
<td>DQQDL</td>
<td>Quench detector</td>
</tr>
<tr>
<td>436</td>
<td>nQPS</td>
<td>QDS second layer for MB and MQ</td>
</tr>
<tr>
<td>1632</td>
<td>DQQDS</td>
<td>Symmetric quench detector</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th># installed</th>
<th>System</th>
<th>Function</th>
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<tbody>
<tr>
<td>4096</td>
<td>DQQBS</td>
<td>Splice supervision board</td>
</tr>
<tr>
<td>76</td>
<td>QPSIPX</td>
<td>QDS for individually powered dipole- quadrupole- and inner triplet magnets</td>
</tr>
<tr>
<td>360</td>
<td>nDQQDI</td>
<td>Rad tol. quench detector</td>
</tr>
<tr>
<td>48</td>
<td>DQQDT</td>
<td>Quench detector IT</td>
</tr>
<tr>
<td>1124</td>
<td>DQQDC</td>
<td>Current lead quench detector</td>
</tr>
<tr>
<td>114</td>
<td>QDS600A</td>
<td>QDS for 600A circuits</td>
</tr>
<tr>
<td>624</td>
<td>DQQDG</td>
<td>Quench detector</td>
</tr>
<tr>
<td>212</td>
<td>nDQQDG</td>
<td>Rad. tol. quench detector</td>
</tr>
<tr>
<td>1672</td>
<td>DQQDC</td>
<td>Current lead quench detector</td>
</tr>
</tbody>
</table>

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.
Between the 2015 and 2016 Runs 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 TS2 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 radiation sensitive circuits 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 sub-system, the result changes. As shown in Figure 5, the nQPS system caused the most raw fault time which accumulates to 24.2 h 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](image)

**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**

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