This presentation will focus on LHC quench detection systems as the part of the circuit protection mostly affected by HL-LHC operation.

See as well contributions by J. Spasic, E. de Matteis, T. Podzorny and J. Steckert

R. Denz
Outline

- Useful expected lifetime of LHC quench protection systems with respect to HL-LHC
- R2E related issues affecting protection equipment
- Upgrade of quench detection systems
- HL-LHC beam operation and specific requirements for quench detection systems
- QPS supervision & HL-LHC
- Upgrades for system diagnostic, test and maintenance
- Summary
Useful expected lifetime of LHC quench detection systems with respect to HL-LHC

- Useful lifetime is critical for equipment installed in the LHC tunnel due to the relatively large quantities requiring an LS to perform major changes
- QPS equipment in UA, UJ, RR … can be upgraded during YETS
- Useful lifetime estimated to 25 years (if sufficient spares)
- Likely a major upgrade during LS4 is needed (nQPS & MB protection)
### R2E related issues affecting protection

Some equipment installed in the RR may still need to be upgraded to more recent technology
- E.g. for replacing ΣΔ ADC by more radiation tolerant and recent SAR type

<table>
<thead>
<tr>
<th>Location</th>
<th>Expected radiation level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HEH (cm⁻²yr⁻¹)</td>
</tr>
<tr>
<td>LHC arc</td>
<td>1×10⁹</td>
</tr>
<tr>
<td>Dispersion Suppressor</td>
<td>1×10¹⁰</td>
</tr>
<tr>
<td>(below dipoles)</td>
<td></td>
</tr>
<tr>
<td>UJ (IP1 and IP5)</td>
<td>5×10⁹</td>
</tr>
<tr>
<td>UL (IP1 and IP5)</td>
<td>1×10⁸</td>
</tr>
<tr>
<td>RR (IP1 and IP5)</td>
<td>3×10⁹</td>
</tr>
<tr>
<td>RR (IP7)</td>
<td>2×10⁸</td>
</tr>
</tbody>
</table>

R. Garcia Alia 2017 HL-LHC collaboration meeting
R2E related issues – DS areas

- Simulations show strong gradients in the estimated radiation load → equipment location to be verified and possibly optimized
  - Relying strongly on input from R2E project
- Some equipment needs to be replaced
  - Field-bus couplers based on MicroFIP™ ASIC to be replaced by new design using the NanoFIP IP core (developed by BE-CO)
  - Bus-bar splice protection systems type DQQBS to be replaced by new more radiation tolerant version
    - Technology available (radtol SAR ADC + flash FPGA)
QPS equipment installed in DS areas (half cells 8 – 11) around IP1 and IP5

<table>
<thead>
<tr>
<th>Equipment</th>
<th>4 x DS / LHC</th>
<th>R2E safe?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quench heater discharge power supply type DQHDS</td>
<td>176 / 6076</td>
<td>Yes</td>
</tr>
<tr>
<td>• 96 possibly vulnerable elements in IP1 &amp; 5 matching &amp; dispersion suppressor areas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Some problems visible in 2018 when operating with TCL6 open</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quench detection board type DQQBS</td>
<td>48 / 2048</td>
<td></td>
</tr>
<tr>
<td>Crate controller type DQCSU</td>
<td>32 / 1232</td>
<td></td>
</tr>
<tr>
<td>Field-bus coupler types DQAMC/DQAMG</td>
<td>48 / 2016</td>
<td></td>
</tr>
</tbody>
</table>
DS areas – maintenance strategies

- In order to avoid to get too close to the TID limits derived from radiation tests, pre-emptive maintenance will be necessary
  - Replace equipment from “hot” areas on a regular basis, e.g. during LS, or rotate with systems installed in low radiation zones
- Radiation tests may need to address not only SEE and TID but as well dose rate effects
Upgrade of quench detection systems

- Symmetric quench detection for insertion region magnets
  - Beam induced quenches more likely with higher intensity
  - Considering that LHC power converters operate as voltage sources, any rapid change in the circuit resistance results in a $\text{didt}$ significantly higher than the maximum ramp rate of the circuit $\text{didt}$ sensors are very safe in detecting quenches.
  - The capability of the timely detection of symmetric quenches is a prerequisite for increasing BLM thresholds → affects LHC availability.
Upgrade of quench detection systems II

- Fast quench loop controllers
  - Required for sectors 6-7 and 7-8 after 11 T dipole installation (4 units)
  - Fast (<1 ms) transmission of circuit abort signal to powering interlock controller → required to dump the beam prior to quench heater firing in 11 T dipoles

- Reconfiguration of the nQPS layer in sectors 6-7 and 7-8 after 11 T dipole installation
  - 11 T dipoles cannot serve as reference magnets for aperture symmetric quenches
HL-LHC beam operation and specific requirements for quench detection systems

- Requests for faster ramp rates and acceleration for some correctors circuits
  - Some tests to be done at the end of this year

For the readout of the didt sensors a new radiation tolerant (RR level) quench detection board is under development. The board is compatible with existing QPS crates and may be used either for IPQ, IPD or 600 A circuits.

- No problem for IP1 and IP5 after LS3 (next generation of orbit correctors with “improved” instrumentation) but challenging for IP2 and IP8

- For both requests didt sensors could be an adequate solution
QPS supervision & HL-LHC

- Field-bus networks
  - The deployment of the radiation tolerant field-bus coupler in the DS areas will imply major changes in the low level communication layer
  - Ethernet based field-busses will be used for the supervision of the HL-LHC circuits in IP1&5
    - This solution could be relatively easy extended to all QPS systems installed in the UA, RR underground areas

- In general the QPS supervision architecture will need to be adapted to:
  - Redundant DAQ systems, higher resolution and sampling rates, enhanced device control, automatic tools for diagnostics and maintenance …
Upgrades for system diagnostic, test and maintenance

- Reduce LHC access as much as possible
  - ALARA: RP classification for DS areas around IP1&5 may change with HL-LHC
  - Time required for access = \textbf{substantial} part of total QPS downtime

- Enhance remote capabilities for system diagnostics, test, configuration and maintenance
  - Auto-recovery of certain faults e.g. communication problems (transparent for LHC-OP)
  - Advanced software tools for fault diagnostics and recovery
Summary

- The successful HL-LHC operation not only requires the installation of new protection equipment for the HL-LHC circuits but a substantial upgrade of the existing system.
- Particular attention should be drawn to protection equipment installed in the dispersion suppressor areas around IP1/5 and its resistance to ionizing radiation.
- QPS availability has meanwhile reached 98.8% but HL-LHC operation may require more.