Performance Analysis of the TCDQ system for different load cases

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Load Cases

• Three load cases are considered

1. Asynchronous dump (failure case – few per year)
   • Aim to prevent damage to Q4

2. Normal dump – abort gap population (few per day)
   • Aim to prevent quenches at regular beam abort

3. Secondary Halo with low lifetime (few per day)
   • Aim to prevent quenches
Schematic Layout
Assumed Settings

- Beam sizes and nominal TCS and TCDQ settings

<table>
<thead>
<tr>
<th>GeV</th>
<th>Beam size $\sigma$ [h/v]</th>
<th>TCS setting</th>
<th>TCDQ setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>450</td>
<td>2.0 / 1.2 mm</td>
<td>7 $\sigma$ / 14.1 mm</td>
<td>8 $\sigma$ / 16.1 mm</td>
</tr>
<tr>
<td>7</td>
<td>0.51 / 0.3 mm</td>
<td>9 $\sigma$ / 4.6 mm</td>
<td>10 $\sigma$ / 5.1 mm</td>
</tr>
</tbody>
</table>

Schematic layout at 450 GeV

Schematic layout at 7 TeV
Asynchronous dump load

- TCDQ intercepts ~36 bunches @ 7 TeV
- Each bunch contains $1.7 \times 10^{11}$ p+ (ultimate intensity)

(same profile assumed for the spurious particles in abort gap during normal dump)
Secondary halo load

- For 0.2 h minimum lifetime $6 \times 10^{11}$ p+/s are lost around LHC
- TCS/TCDQ load obtained by scaling the cleaning inefficiency

450 GeV Secondary halo profile

7 TeV Secondary halo profile

Assumed load at 450 GeV

Assumed load at 7 TeV
Simulation Layout

- TCDQ
- TCS
- TCDQM
- MQY
- MCBY

Materials:
- Graphite
- Copper
- Iron
- SC (92% Cu)
- SC (60% Cu)
- Stainless steel
- Aluminium
- Vacuum
Magnet scorings are polar coordinate meshes centered on each beam tube.
Fluka Settings

• **Energy loss**
  – Point-like: (in)elastic recoils, low energy n°
  – Distributed: ionization by charged particles

• **Localized energy deposition below threshold**
  – Ionization energy converted to δ-rays distributed around ionizing track
  – Multiple scattering down to Molliere limit

• **K.E. thresholds**
  - Charged particles: 100 keV
  - Photons: 10 keV
  - Neutrons: 19.6 keV
Example fluence scoring for async dump MCBY power load for async dump

MCBY power load for async dump

Energy deposition (GeV/cm³) in TCDQ under asynchronous load
Post Processing

- Fluka scorings processed directly as 3D mesh using MatLab
- Instantaneous temperature increase derived by integration

\[
\frac{dE}{dV} = \rho \int_{T_0}^{T_0+\Delta T} c_p(T) dT
\]

- Energy deposition taken in the adiabatic limit
- For large deposits \( C_p \) is not constant (neglected for Fe)

\[
c_p^{\text{graph}}(T) = 528.75 - 205.9T^{1/3} + 154.21T^{1/2} - 1.53T + 9.15 \times 10^{-5} T^2
\]

\[
c_p^{Cu}(T) = 381.12 + 0.16T - 1.09 \times 10^{-4} T^2
\]
7 TeV asynchronous dump
450 GeV Halo Results (1)
450 GeV Halo Results (2)
## 7 TeV async dump summary

- Summary of instantaneous load due to async dump at 7 TeV

<table>
<thead>
<tr>
<th>Component</th>
<th>Peak load (J/cm³)</th>
<th>ΔT (K)</th>
<th>Max radial flow (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCDQ (front)</td>
<td>2139</td>
<td>712</td>
<td>-</td>
</tr>
<tr>
<td>TCS (right)</td>
<td>2283</td>
<td>679</td>
<td>-</td>
</tr>
<tr>
<td>TCDQM</td>
<td>44.5</td>
<td>12.8</td>
<td>-</td>
</tr>
<tr>
<td>MCBY</td>
<td>26.2</td>
<td>-</td>
<td>262</td>
</tr>
<tr>
<td>MQY</td>
<td>38.0</td>
<td>-</td>
<td>1836</td>
</tr>
</tbody>
</table>

- Q4 instantaneous damage limit = 87 J/cm³ [OK]
- Graphite melting point = 3650 °C [OK]
450 GeV Halo Summary

- Load in one second due to secondary halo at 450 GeV

<table>
<thead>
<tr>
<th>Component</th>
<th>Peak load (J/cm³)</th>
<th>ΔT (K)</th>
<th>Total load (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCDQ (front)</td>
<td>0.13</td>
<td>0.057</td>
<td>-</td>
</tr>
<tr>
<td>TCS (left)</td>
<td>2.4</td>
<td>0.98</td>
<td>-</td>
</tr>
<tr>
<td>TCDQM</td>
<td>0.33</td>
<td>0.097</td>
<td>-</td>
</tr>
<tr>
<td>MCBY</td>
<td>0.12</td>
<td>-</td>
<td>?</td>
</tr>
<tr>
<td>MQY</td>
<td>0.12</td>
<td>-</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Q4 localised DC deposition limit = 1 - 10 mW (mJ/cm³ s) [not OK]
Q4 total power deposition limit = 32 W (J/cm³ s) [OK]
7 TeV Halo Summary

- Load in one second due to secondary halo at 7 TeV

<table>
<thead>
<tr>
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<th>Peak load (J/cm³)</th>
<th>ΔT (K)</th>
<th>Total load (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCDQ (front)</td>
<td>0.73</td>
<td>0.30</td>
<td>-</td>
</tr>
<tr>
<td>TCS (left)</td>
<td>0.59</td>
<td>0.25</td>
<td>-</td>
</tr>
<tr>
<td>TCDQM</td>
<td>0.029</td>
<td>0.008</td>
<td>-</td>
</tr>
<tr>
<td>MCBY</td>
<td>0.017</td>
<td>-</td>
<td>1.0</td>
</tr>
<tr>
<td>MQY</td>
<td>0.024</td>
<td>-</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Q4 localised DC deposition limit = 0.2 - 5 mW (mJ/cm³ s) [not OK]
Q4 total power deposition limit = 32 W (J/cm³ s) [OK]
Impact on operation (1)

• Asynchronous dump at 7 TeV
  – Primary objective fulfilled
    • Q4, Arc & Triplet protected from destruction
    • protection elements remain operational
  – Condition for correct operation
    • beam position relative to TCDQ/TCS must be maintained within 0.5 $\sigma$

• Halo during low beam lifetime
  – 7 TeV power loading
    • max Q4 power load $\sim$24 mW/cm$^3$ (0.2 - 5 mW/cm$^3$ limit)
    • total Q4 power load $\sim$ 1 W (32 W/cm$^3$ limit)
  – 450 GeV power loading
    • max Q4 power load $\sim$120 mW/cm$^3$ (1 - 10 mW/cm$^3$ limit)
    • total Q4 power load $\sim$ 2.3 W (32 W/cm$^3$ limit)
  – Condition for normal operation
    • Q4 loading may limit beam intensity if not improved
    • factor $10 - 100$ reduction required at injection and top energy!
Impact on operation (2)

• Normal dump at 7 TeV
  – Simulation gives 40 J/cm³ in MQY
    • calculated on the basis of $1.7 \times 10^{11}$ p+/bunch
    • assumed quench limit is 4 mJ/cm³
  – Condition for correct operation
    • maximum allowed abort gap population = $1.7 \times 10^7$ p+/bunch ($2 \times 10^6$ p+/m)

• Normal dump at 450 GeV
  – Quench limit and stopping power increase \textit{(not yet simulated)}
    • Tolerable abort gap population \textasciitilde 2 orders magnitude higher
  – Condition for correct operation
    • maximum allowed abort gap population = $1.7 \times 10^9$ p+/bunch ($2 \times 10^8$ p+/m)

• Impact on abort gap cleaning/monitoring must be verified
  – Previous assumed limits were $1.1 \times 10^7$ and $10^9$ p+/m \textit{(factor of 5 higher)}
Caveats

- **TCDQM**
  - Aperture conceived to match MQY (70mm)
    - Adapt aperture to beam screen (~56 mm)
    - Should reduce particle fluence into MQY by better shielding of coil

- **Halo shape**
  - Does not consider losses on LHC aperture
    - Should reduce halo load on TCDQ/TCS

- **Naïve geometry**
  - Cold-bore, beam screen, transition not incl.
    - Should reduce Q4 energy deposition due to interception at grazing incident angles

- **FLUKA energy scoring**
  - Cut-off energy for neutrons may be somewhat high
    - Might presently be over-estimating the local peaks of energy deposition

- **TCDQ/TCS settings**
  - Possible to relax these at 450 GeV
    - Damage limit equates to 12 bunches so we can allow a few bunches through to the arc
    - Aperture can relax a few σ - already gives factor 10 less load after 1 σ
  - Not possible to relax these at 7 TeV
    - Damage limit less than 1 bunch

- **Quoted quench limits not Q4 specific, and still seem uncertain**
  - Address at quench/damage workshop?
Future Work

• High priority
  – Combating quench due to secondary halo.
    • Update FLUKA study with new TCDQM profile, beam screen and cold bore in place
    • Revise quench limits with magnet builders
    • Realistic halo simulation at TCDQ
  – Abort gap issues with 5x lower tolerable limit

• Other Priority
  – Determine sensitivity to TCS/TCDQ postion
    • See how much we can safely relax the setting