The quench limits for transient losses

Mariusz Sapinski BE/BI for many people participating in quench tests and now in the analysis
1. Quench limits overview.

2. What transient losses affect collimation?

3. Quench limit investigations for transient losses:
   - Ultra-fast losses,
   - Millisecond-timescale losses.

Motivation: decrease of the quench limit

Energy needed to quench a magnet decreases for shorter losses so short “spikes” on collimators can potentially lead to magnet quench even if steady-state cleaning is safe.
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Energy needed to quench a magnet decreases for shorter losses so short “spikes” on collimators can potentially lead to magnet quench even if steady-state cleaning is safe.
What kind of transient losses?

- UFO losses – small amplitude seen on collimators, large in UFO location.
- Losses at capture are probably 'slow': they depend on the dipole ramp rate.
- Losses at end of ramp are also generally slow (tails cut by closing collimators).
- Losses during the squeeze were often correlated with orbit drifts and OFB.
- Losses at the end of squeeze due to instabilities.

Failure losses:
- Failure warm separation dipoles D1 (thesis of A. Gomez Alonso, 2009)
- Asynchronous dump – losses on dump protection collimators.
1. Ultra-fast = much shorter than 1 ms.

2. Easy to compute:
   - see LHC-Project-Note-044 (1996):
     \[ \Delta H_{\text{wire}} = H_{\text{wire}}(T_c) - H_{\text{wire}}(1.9K) \]
   - parametrization of specific heat
   - implemented in ROXIE.

3. Several tests at injection
   (CERN-LHC-Project-Note-422, 2008):
   - QL from Note044: 31 mJ/cm³,
   - QL from Geant4: 13-50 mJ/cm³.

4. Operational quenches during Run 1:
   only ultra-fast at injection.

5. One test at “above 4 TeV”.
Q6 quench test

- Performed on 2013.02.15

- Emittance from SPS: $H \sim 0.5 \, \mu m$, $V \sim 0.5 \, \mu m \Rightarrow$ impact parameter $4.5 \, \sigma$ (full beam intercepted).

- Pilot bunch $6-6.5e10p^+$ (probe beam limit increased to $1E11p^+$).

- Q6.L8 Current steps: 1000 A, 1500 A, 2000 A and $2500A$ ($\sim 6 \, \text{TeV}$) $\Rightarrow$ Quench!

- Fluka studies ongoing, will give us very good quench limit at 6 TeV.
Quench limits difficult to compute (LHe plays crucial role, various heat transfer mechanisms).

Two tests done, both motivated by UFO losses:

- wire scanner (2010),
- fast ADT and orbit bump (2013).

```
3.5 TeV, MB
Note 44
QP3
THEA
```
Wire scanner quench test

- Performed on Nov. 1st, 2010.
- Beam energy 3.5 TeV.
- Intensity $1.53 \cdot 10^{13}$ protons.
- Wire speed 5 cm/s.
- Quenched MBRB dipole (4.5K).
- 33 meters downstream wire scanner.
- Analysis and FLUKA simulations presented in CERN-ATS-2011-062 (IPAC11)

### Table 1: Comparison FLUKA and QP3 quench levels

<table>
<thead>
<tr>
<th>energy</th>
<th>FLUKA [mJ/cm$^3$]</th>
<th>QP3 4%He [mJ/cm$^3$]</th>
<th>QP3 no He [mJ/cm$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>cable average</td>
<td>11.6</td>
<td>20.5</td>
<td>15.6</td>
</tr>
<tr>
<td>maximum</td>
<td>18.8</td>
<td>31.8</td>
<td>24.2</td>
</tr>
</tbody>
</table>
**Fast ADT and orbit bump quench test**

**Procedure:**
- Inject and ramp 10 bunches (to have multiple attempts).
- Scrape a single bunch by vertical blow to intensities < $10^9$ p (special collimators setting).
- Create horizontal orbit bump (Q12L6).
- Excite single bunch in horizontal plane by MKQ kick and then by ADT using sign flip mode (anti-damping).
- If no quench – scrape less next bunch.

Procedure proposed by Wolfgang Hofle

**Challenges:**
- For damper: ultra-low sensitivity mode: $5 \cdot 10^7$ protons.
- For instrumentation: measure intensity and emittance of low-intensity bunches.

We were prepared: 4 MDs, additional instrumentation.
• Performed on February 15\textsuperscript{th}, 2013.
• Quench with $7.7 \cdot 10^8$ lost protons.
• No quench with $4 \cdot 10^8$ lost protons.
• Loss duration: 5-10 ms:
  • 2-3 ms expected,
  • UFO: shorter than 1 ms.
• Spiky loss time-structure:
  • UFOs are gaussian.

For 2.56 ms (typical dump by UFO) signal is higher by factor 6 than expected. Potential increase of BLM thresholds on all cold magnets!

<table>
<thead>
<tr>
<th>BLM signal integ. time</th>
<th>Signal (Gy/s)</th>
<th>S/Quech</th>
</tr>
</thead>
<tbody>
<tr>
<td>640 μs</td>
<td>1.99</td>
<td>2.1</td>
</tr>
<tr>
<td>2.56 ms</td>
<td>1.46</td>
<td>6.1</td>
</tr>
<tr>
<td>10.2 ms</td>
<td>0.73</td>
<td>12.0</td>
</tr>
</tbody>
</table>
**Analysis:**

- Simulate loss pattern using MadX.
- Use MadX loss pattern as input for FLUKA/Geant4 simulations.
- "Control" the FLUKA/Geant4 results comparing with measured BLM signal.
- Obtain energy deposited in the coil.
- Use FLUKA/Geant4 radial energy gradient in the coil as input to QP3.
- Compare QP3 and FLUKA/Geant4.

*Plot by Vera Chetvertkova*
Conclusions

1. Quench limits for transient losses investigated in 4 types of experiments:
   A. Ultra-fast at injection
   B. Ultra-fast at ~6 TeV
   C. Millisecond with wire scanner
   D. Millisecond with ADT and orbital bump

2. Agreement between QP3 estimations and FLUKA-based analysis in case C.

3. Agreement between enthalpy limit and Geant4-based analysis in case A.

4. Cases B and D in analysis, but:

5. larger than expected quench limit for UFO-timescale losses
   (possible increase of BLM thresholds on all cold magnets).
Thank you for your attention
Extra slides
# Beam induced quenches

<table>
<thead>
<tr>
<th>No</th>
<th>date</th>
<th>beam energy [TeV]</th>
<th>loss duration [s]</th>
<th>quenched magnet</th>
<th>location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2008.08.09</td>
<td>0.45</td>
<td>(\sim 10^{-9})</td>
<td>MB</td>
<td>8L3</td>
</tr>
<tr>
<td>2</td>
<td>2008.09.07</td>
<td>0.45</td>
<td>(\sim 10^{-9})</td>
<td>MB</td>
<td>10R2</td>
</tr>
<tr>
<td>3</td>
<td>2009.11.20</td>
<td>0.45</td>
<td>(\sim 10^{-9})</td>
<td>MB</td>
<td>12L6</td>
</tr>
<tr>
<td>4</td>
<td>2009.12.04</td>
<td>0.45</td>
<td>(\sim 10^{-9})</td>
<td>MB</td>
<td>15R2</td>
</tr>
<tr>
<td>5</td>
<td>2010.04.18</td>
<td>0.45</td>
<td>(\sim 10^{-9})</td>
<td>MB+</td>
<td>20R1</td>
</tr>
<tr>
<td>6</td>
<td>2010.10.06</td>
<td>0.45</td>
<td>1</td>
<td>MQ</td>
<td>14R2</td>
</tr>
<tr>
<td>7</td>
<td>2010.10.06</td>
<td>0.45</td>
<td>1</td>
<td>MQ</td>
<td>14R2</td>
</tr>
<tr>
<td>8</td>
<td>2010.10.06</td>
<td>0.45</td>
<td>1</td>
<td>MB</td>
<td>14R2</td>
</tr>
<tr>
<td>9</td>
<td>2010.10.17</td>
<td>3.5</td>
<td>6</td>
<td>MQ</td>
<td>14R2</td>
</tr>
<tr>
<td>10</td>
<td>2010.11.01</td>
<td>3.5</td>
<td>(10^{-4})</td>
<td>MBRB (4.5 K)</td>
<td>5L4</td>
</tr>
<tr>
<td>11</td>
<td>2011.04.17</td>
<td>0.45</td>
<td>ns</td>
<td>MB+</td>
<td>IP8</td>
</tr>
<tr>
<td>12</td>
<td>2011.07.04</td>
<td>0.45</td>
<td>ns</td>
<td>MB</td>
<td>14R2</td>
</tr>
<tr>
<td>13</td>
<td>2011.07.28</td>
<td>0.45</td>
<td>ns</td>
<td>MQXB+</td>
<td>IP2</td>
</tr>
<tr>
<td>14</td>
<td>2013.02.15</td>
<td>4.6</td>
<td>(10^{-9})</td>
<td>MQM (4.5 K)</td>
<td>6L8</td>
</tr>
<tr>
<td>15</td>
<td>2013.02.16</td>
<td>4.0</td>
<td>(10^{-3})</td>
<td>MQ</td>
<td>12L6</td>
</tr>
<tr>
<td>16</td>
<td>2013.02.16</td>
<td>4.0</td>
<td>20</td>
<td>MQ</td>
<td>12L6</td>
</tr>
</tbody>
</table>

First quench test campaign

Second quench test campaign
First results on proton collimation quench test

B. Salvachua, R. Bruce, S. Redaelli and D. Wollmann

Collimation Group: M. Cauchi, D. Deboy, L. Lari, D. Mirarchi, E. Quaranta and G. Valentino
MP team: R. Schmidt, M. Zerlauth
BLM team: E. Nebot, M. Sapinski, E. B. Holzer
ADT team: W. Hofle and D. Valuch
OP team: J. Wenninger, D. Jacquet
Collimation WG, 25th March 2013
Steady-state dispersion suppressor with protons

Losses in DS IR7

1.05MW in IR7!

Last ramp (out of 3 for actual test)

10^{-3} instead of 10^{-5}

Special collimators settings

BLMQ1.08L7.B2110_MQ = 0.0108259160 Gy/s

800 m
Steady-state dispersion suppressor with protons

Comparison to 2011 quench tests

BCTFR from Post Mortem

- 2013 Ramp 1 (1.3 MJ)
- 2013 Ramp 2 (3.2 MJ)
- 2013 Ramp 3 (5.8 MJ)
- 2011 Ramp 2 (0.6 MJ)
- 2011 Ramp 3 (0.4 MJ)

Power loss [kW]

Time [sec]

Better control of the blow-up with the ADT:

for the same peak loss rate (~500 kW), in 2011 with the tune resonance mechanism the rise time was 1 second while for the ADT could be tuned to 5 seconds. This is important especial for the target power loss of 1 MW, the TSL team requested to have a smooth increase of the losses.

<table>
<thead>
<tr>
<th>Ramp</th>
<th>Power Loss [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp 1</td>
<td>520 kW</td>
</tr>
<tr>
<td>Ramp 2</td>
<td>650 kW</td>
</tr>
<tr>
<td>Ramp 3</td>
<td>1050 kW</td>
</tr>
</tbody>
</table>
Achieved quench limits

BLM thresholds were changed during the test, the table bellow shows the measured losses in Q8 and the BLM threshold during the test.

<table>
<thead>
<tr>
<th>Ramp 3: ~1MW</th>
<th>RS09 = 1.3 s</th>
<th>RS10 = 5.2 s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BLM [Gy/]</td>
<td>Threshold [Gy/s]</td>
</tr>
<tr>
<td>BLMQI.08L7.B2I10_MQ</td>
<td>1.08E-02</td>
<td>0.035</td>
</tr>
<tr>
<td>BLMQI.08L7.B2I20_MQ</td>
<td>3.81E-03</td>
<td>0.019</td>
</tr>
</tbody>
</table>

Taking now the assumed quench limit for each monitor the table bellow shows the achieved quench limit for RS over 1.3 sec and 5.2 sec.

<table>
<thead>
<tr>
<th>Ramp 3: ~1MW</th>
<th>RS09 = 1.3 s</th>
<th>RS10 = 5.2 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLMQI.08L7.B2I10_MQ</td>
<td>1.08E-02</td>
<td>4.65E-03</td>
</tr>
<tr>
<td>BLMQI.08L7.B2I20_MQ</td>
<td>3.81E-03</td>
<td>6.40E-03</td>
</tr>
</tbody>
</table>

No quench!
Steady-state with orbital bump (and ADT)

Plots courtesy Agnieszka Preiebe

Loss scenario has an important impact on quench level as seen in BLMs.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>2.87 mGy/s</td>
<td>2.36 mGy/s</td>
<td></td>
</tr>
<tr>
<td>Threshold</td>
<td>2.29 mGy/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/T</td>
<td>1.3</td>
<td>1.03</td>
<td></td>
</tr>
</tbody>
</table>

no quench    quench (as expected!)
Why is that?

We will need FLUKA/Geant4 simulations to understand this in details but…

CERN-LHC-Project-Note-422 (2009), MB case:

Threshold = \( QL \times \frac{\text{BLM signal}}{E_{\text{dep coil}}} \)

When we smear the loss the amplitude of thinner distribution decreases faster than thicker one.

So more distributed losses lead to higher BLM signal at quench.
The loss rate obtained during this quench exercise was very flat and lasted about 20 s.
But we must be careful extrapolating to UFOs

- According to simulations (backed up by observations in especially equipped cell) maximum energy deposit is due to **neutral particle peak**.

- Ratio of $\text{BLMsignal}/E_{\text{dep\ coil}}$ might be different than in our experiment.

- To make the analysis more challenging the loss pattern during quench test seems to move from turn to turn.

  - Special MAD-X simulations started to understand the time-dependent loss pattern (Vera Chetvertkova).
  - FLUKA/Geant4 simulations also necessary