Magnet quench tests of the shielded HL-LHC beam screen

M. Morrone, C. Garion,

With contributions and materials from:
O. Sacristan, M. Guinchard, L. Fiscarelli

WP3 Meeting

TE-VSC-DLM 16 - 01 - 2019
Outline

• Magnet quench test
• Physics of the problem
• Instrumentation
• Results and comparison with simulations
• Conclusions and next steps
Outline

• Magnet quench test
• Physics of the problem
• Instrumentation
• Results and comparison with simulations
• Conclusions and next steps
Test plan

Start date of the test in SM18: 10th October 2018
End date of the test in SM18: 18th October 2018

Time required at cold

- HV, transfer function at 80 K: ½ day
- HV, transfer function at 1.9 K: ½ day
- Beam screen & training verification: 2-3 days
- Protection studies: 3-4 days
- HV, transfer function at 1.9 K: ½ day
- Other tests?: ?

Total: ~8 days

54 quenches
(CLIQ, quench heater, training, extraction, high quench integral, ramp rate)
Aim of the test

• Training verification of the MQXFS4b at 1.9 K.

• Flux jump effect on the current studies, both during other tests' ramps and during dedicated exponential cycles;

• Magnet protection studies, including CLIQ discharges in different configurations, QH delay and performance and QH-only discharges;

• Effect of CLIQ on the beam screen studied with over 20 runs dedicated to that measurement;

• Measurement of the magnetic field during CLIQ and quench heater discharge by means of dedicated pickup coils in the beam screen;
Test conditions

- Q1 beam screen version compatible with the CLIQ discharge (pins and W block geometry modified);
- Beam screen immersed in the 1.9 K helium bath;
- Temperature: 1.9 K (significant change of the electrical resistivity of Cu due to temperature and magneto-resistivity \(\rightarrow\) reduced thickness of Cu inner layer for the prototype, from 75 \(\mu\)m to 25 \(\mu\)m);
- Magnetic field decay representative of the HL-LHC conditions, including the CLIQ system;
- Vertical position of the beam screen within the cryostat.

Inner copper layer reduced from 75 to \(\sim\) 25 \(\mu\)m

2 versions of thermal link and elastic rings tested
BS quench test prototype -Q1 type-
2 m
Outline

• Magnet quench test

• Physics of the problem

• Instrumentation

• Results and comparison with simulations

• Conclusions and next steps
Physics of the problem

\[ \vec{f} \propto \frac{B \dot{B}}{\rho} r \]

 Courtesy of Emmanuele Ravaoli

$B \dot{B}$ ($\dot{B}$ has a change of sign) is not monotonic in the first phase of the CLIQ discharge! Therefore, opposite forces are expected in the same component.
Integrated forces induced in the W block

Region 1: Most critical!!

<table>
<thead>
<tr>
<th>component</th>
<th>Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Torque [N m/W block]</td>
</tr>
<tr>
<td>Cold bore</td>
<td>253</td>
</tr>
<tr>
<td>Heat absorber</td>
<td>280</td>
</tr>
<tr>
<td>Octagonal pipe</td>
<td>81.5</td>
</tr>
</tbody>
</table>

Region 2: Less severe than phase 1
Region 3: Less severe than without CLIQ

E.g. $F_y$ for the tungsten block:

$Q_{1_{NO CLIQ}} \approx 233.5 \ [N/mm] > Q_{1_{CLIQ}} \approx 200.5 \ [N/mm]$
Assumption of the numerical model

- No magnet coil modelled;
- The electro-dynamic of the magnet is not considered (No IFCC, ISCC);
- Magneto-resistivity of copper considered;
- Heat load affecting the electrical properties considered;
- Measured magnetic field assigned as input for the comparison of the experimental results with the simulations in this presentation.
Animations

First phase

Second phase *

* For visual purposes only as the W blocks are not welded.
Outline

• Magnet quench test
• Physics of the problem
• Instrumentation
• Results and comparison with simulations
• Conclusions and next steps
42 Strain gauges distributed in 3 sections along 4 diametrically opposed faces of the beams screen in axial and transversal directions.

3 custom made displacement measuring heads inside the beam screen to measure:
- Beam screen expansion
- W block tilt
- Magnetic field

4 lines of fibers installed in 4 diametrically opposed generatrixes of the cold bore: 12 biaxial strain measurement points.
Strain gauges

42 Strain gauges distributed in 3 sections along 4 diametrically opposed faces of the beam screen in axial and transversal directions.
3 custom made displacement measuring heads inside the beam screen to measure:
• Beam screen expansion
• W block tilt
• Magnetic field

Expansion
Beam screen

Tilt
W bock

UNDEFORMED CONFIGURATION
DEFORMED CONFIGURATION

M. Morrone, C. Garion
Measuring probe

3 custom made displacement measuring heads inside the beam screen to measure:
- Beam screen expansion
- W block tilt
- Magnetic field

Before the quench test

After the quench test
Cold bore fibers

4 lines of fibers installed in 4 diametrically opposed generatrixes of the cold bore: 12 biaxial strain measurement points.
Outline

- Magnet quench test
- Physics of the problem
- Instrumentation
- Results and comparison with simulations
- Conclusions and next steps
General overview of all the strain gauges

No plastic deformation. Due to some artefacts.
General overview of all the strain gauges

The behaviour observed at the points located at M_F2 can be explained by the extra thickness induced by a slight surplus of the adhesive used for the bonding of the strain gauges which entered in contact with the tungsten block. It can be seen in the red frame on the picture above on the left. It is also noticeable that a strain gauge got detached (picture on the right).
Results at 8.2 kA
(Strain gauges, measuring probe)
B measured at r = 75 mm in front of each pole.

8 kA Face Center (P2) Transversal Strains

Strain [µm/m]

Time [s]

dB/dT*B [T^2/s]

Time [s]
B measured at r = 75 mm in front of each pole.
8 kA CLIQ Discharge Induced Tilt

B measured at r = 75 mm in front of each pole.
Results at 18.2 kA
(Strain gauges, measuring probe)
B measured at r = 75 mm in front of each pole.
18.2 kA Beam Screen Expansion

B measured at r = 75 mm in front of each pole.
Cold bore
(optical fibers)
B measured at r = 75 mm in front of each pole.
B measured at \( r = 75 \text{ mm} \) in front of each pole.
B measured at r = 75 mm in front of each pole.
Thermal link (17.8 kA)

The forces induced in the external links are driven by the current flow of the W block.

\[ F_z = 212 N \]
Thermal link
Outline

• Magnet quench test
• Physics of the problem
• Instrumentation
• Results and comparison with simulations
• Conclusions and next steps
Conclusions

• The mechanical integrity of a Q1 beam screen prototype has been demonstrated. The behaviour of the beam screen remains elastic after 54 quenches up to 18.2 kA of current (ultimate current 17.8 kA);

• The thermal links, the elastic rings and the centring pins have been inspected after the quench test and no damage nor unexpected deformation has been observed;

• The beam screen behaves as expected during a quench:
  • The torque induced during the first phase of CLIQ has been observed;
  • The beam screen goes in contact with the cold bore;

• The mechanical response of the beam screen is directly correlated with the magnetic field measurements.

• A good agreement with simulation has been found;
Next steps

• Test of a Q2 type beam screen with the correct material (P506 instead of 316 L) and aC coating:
  • Magnetic field quality measurements;
  • Quench test.
A big thanks to the colleagues of WP3, SM18 and EN-MME. In particular:

Thank you
Back up slides
Numerical results: baseline (17.8 kA)

CLIQ phase 1

<table>
<thead>
<tr>
<th>component</th>
<th>material</th>
<th>Elastic limit</th>
<th>( F_{y,\text{max}} ) [N/mm] -per eight-</th>
<th>( \sigma_{\text{max}} ) [MPa]</th>
<th>( \delta_{\text{max}} ) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold bore</td>
<td>Ss 316 LN</td>
<td>860 MPa (at 4 K)</td>
<td>12.3</td>
<td>624</td>
<td>1.51</td>
</tr>
<tr>
<td>Heat absorber</td>
<td>Inermet</td>
<td>1284 (at 77K)</td>
<td>22</td>
<td>&gt; 1284 (loc.)</td>
<td>-</td>
</tr>
<tr>
<td>Octagonal pipe+ Cu layer</td>
<td>Ss P506</td>
<td>1350 MPa (at 50 K)</td>
<td>5.3</td>
<td>&gt; 1350 (loc.)</td>
<td>-</td>
</tr>
<tr>
<td>Pin</td>
<td>Ss P506</td>
<td>1350 MPa (at 50 K)</td>
<td>-</td>
<td>&gt; 1350 (loc.)</td>
<td>-</td>
</tr>
</tbody>
</table>
Numerical results: baseline (17.8 kA)
signal of the compensator probe at 8.2 kA
Cold bore and beam screen instrumentation layout