Parametric Study on the Thermal Performance of Beam Screen Samples of the High-Luminosity LHC Upgrade

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Outline

- High-Luminosity LHC upgrade
- Beam screens for the insertion regions
- Experimental test set-up
- Sample geometry
- Results: beam screen thermal pathways
- Results: supporting structure conductance
- Concluding remarks
From the LHC to the HL-LHC

LHC beam screen
- 4 – 20 K operating $T$
- Low mass flow (1 g/s)
- Supercritical He at 3 bar
- No absorber (just screen)

HL-LHC beam screen
- 60 – 80 K operating $T$
- High mass flow (10 g/s)
- Supercritical He at 20 bar
- Tungsten-based absorber
HL-LHC beam screens

cold bore
$T = 1.9 \text{ K}$
cooled by He II

thermal link
connects the absorber to the cooling tube

cooling tube
$T = 60 \text{ K to } 80 \text{ K}$
circulates He at 20 bar

beam screen
EM shield

absorber

radiation shield

ball bearings / springs
supporting system

T$
T = 60 \text{ K to } 80 \text{ K}$
circulates He at 20 bar

T
HL-LHC beam screens

BS samples

Supporting structure

cold bore

thermal link

beam screen

ball bearings

absorber

cooling tube
Scope of thermal performance studies

BS samples:

- Characterise two thermal pathways
  - Through the beam screen
  - Through the thermal link

- Requirements:
  - No max. $T$ defined for absorber
  - Max $\Delta T$ between heat sink and inner beam screen surface of 5 K
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Supporting structure:

- Characterise heat transfer from beam screen to cold bore by conduction

- Requirements:
  - Total heat load transferred (conduction+ radiation) < 500 mW/m of beam screen
Sample geometries and test set-up

 Beam Screen sample

 Supporting Springs sample

 Tungsten block (heated surface)
Experimental set-up

**BS samples:**
- Base temperature varied from 50 K to 80 K
- Heat load varied from 0 to 400 mW (0 to 25 W/m)
- Tungsten block-beam screen compression 0 and 1.82 N

**Supporting structure:**
- Base (cold) temperature kept between 2.7 K and 3 K
- Warm end heated up to 100 K
- 7.5 N (nominal) and 15 N compression
Results – Beam screen sample

- Maximum temperature increase of relevant beam screen components was measured for a Q2-type magnet, heat load 15 W/m

<table>
<thead>
<tr>
<th></th>
<th>Nominal compression</th>
<th>No compression</th>
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<tbody>
<tr>
<td>Base $T$ (K)</td>
<td>W block $\Delta T$ (K)</td>
<td>W block $\Delta T$ (K)</td>
</tr>
<tr>
<td>60.00 ± 0.16</td>
<td>14.00 ± 0.06</td>
<td>13.50 ± 0.06</td>
</tr>
<tr>
<td>75.00 ± 0.23</td>
<td>14.00 ± 0.09</td>
<td>13.50 ± 0.09</td>
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- Temperature difference between the inner surface of beam screen and the cooling source kept below the 5 K threshold

- Tungsten block reaches a maximum temperature of $75 + 14 = 89$ K at the nominal heat load towards the high temperature end
Results – Beam screen sample

- **Nominal compression**: 79% heat load flows to the heat sink through the thermal link, 21% through the beam screen

- **No compression**: 89% through TL, 11% though BS
Results – Beam screen sample

Thermal link pathway - 79% heat load, nominal comp.

- Conduction per metre of B.S. (W/K)
- Tungsten block
- Beam screen pathway - 21% heat load, nominal comp.
- Thermal link pathway - 79% heat load, nominal comp.

Thermal Link $T$ (K)

Conduction per link (W/K)

- Thermal link to heat sink
- Along the thermal link
- Overall conductance
Results – Beam screen sample

Thermal link pathway - 79% heat load, nominal comp.

Beam screen pathway - 21% heat load, nominal comp.

Thermal link to heat sink
Thermal link pathway - 79% heat load, nominal comp.

Along the beam screen
Overall conductance

Tungsten block

Overall conductance
Supporting structure – Q2 assembly

Supporting structure
- Nominal compression: 7.5 N
- 80 spring+sphere sets per metre of beam screen → 560 mW/m
Nominal compression: 7.5 N
80 spring+sphere sets per metre of beam screen → 560 mW/m
Summary

Beam screen thermal link at the nominal heat load of 15 W/m:

- Maximum $T$ of tungsten block is 89 K (14 K gradient to cooling tube)
- $\Delta T$ between the cooling fluid and the inner surface of the beam screen kept below 5 K
- Results similar for nominal (1.82 N) and no compression
- Major thermal pathways have been analysed and design validated, and agree with simulations

Spring support structure to cold bore:

- Conductance around 0.08 mW/K for the 75 K – 95 K range to 3 K
- An average of 560 mW per metre of beam screen needs to be considered
- Little influence of compression force (less than 10%)