Status of beam screen, cold bore, interconnect and CWT design & production

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on behalf of WP12

HL-LHC annual meeting, Geneva, 18th November 2018
Status of cold vacuum system design & production

Outline

• Design update
  • Beam screen / cold bore
  • Beam screen extremities and interconnections
  • Cold/warm transitions

• Validation tests
  • Beam screen
    • Thermal: Heat transfers
    • Mechanical: Quench tests
  • PIM

• Manufacturing status

• Summary
1. Design update
Beam screen – cold bore design

Tungsten alloy blocks:
- Chemical composition: 95% W, ~3.5% Ni, ~ 1.5% Cu
- Mechanically connected to the beam screen tube: positioned with pins and titanium elastic rings
- Heat load: 15-25 W/m
- 40 cm long

Beam screen tube (BS) at 60-75 K:
- Perforated tube (~2%) in High Mn High N stainless steel (1740 l/s/m (H2 at 50K))
- Internal copper layer (75 μm) for impedance
- a-C coating (as a baseline) for e-cloud mitigation
- Laser treatments under investigation

Cooling tubes:
- Outer Diameter: 10 or 16 mm
- Laser welded on the beam screen tube

Thermal links:
- In copper
- Connected to the absorbers and the cooling tubes or beam screen tube

Cold bore (CB) at 1.9 K: 4 mm thick tube in 316LN

Elastic supporting system:
Low heat leak to the cold bore tube at 1.9K
Ceramic ball with titanium spring

Pumping slot shield
Nominal behaviour
Simulations of the temperature profiles

Requirements:
• Heat loads on the absorbers [WP 10]: 25 W/m for Q1, 15 W/m for Q2-D1
• Temperature windows for the inner copper layer: 60 – 80 K
  ➢ Helium gradient from 60 to 75 K (from Q1 to D1) + 5 K temperature difference between helium and internal copper layer.

The heat transfer is ensured by copper thermal links:
• 6 links per blocks (40 cm long)
• 10 layers, 0.1 mm thick, 5 mm wide

→ Temperature difference between helium and internal copper layer below 1 K.
Influence of misalignment on the behaviour during a magnet quench (1)

→ With CLIQ discharge, internal torques and tangential forces are generated in the beam screen during the transient. No net force is observed for perfectly aligned beam screens.

→ For misaligned beam screens, disequilibrium is introduced and net forces are expected.

Misalignment and twist have been studied with 2D and 3d model.
Influence of misalignment on the behaviour during a magnet quench (2)

Results for an initial twist:

- For D1, net torque is marginal.
- For quadrupoles, high net torques are generated during a quench, but counterbalancing the initial twist. Global effect is acceptable.

Maximum torque during quench @ Fixed point: ~110 N.m
Natural vibrations of the beam screen have been studied, based on:

- beam elements
- discretized elastic supports
- beam screen bellows at one extremity

**Natural frequencies [Hz]**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Q1 type</th>
<th>Q2 type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st mode</td>
<td>13.2</td>
<td>19.5</td>
</tr>
<tr>
<td>2nd mode</td>
<td>13.6</td>
<td>20.2</td>
</tr>
<tr>
<td>3rd mode</td>
<td>14.9</td>
<td>22.5</td>
</tr>
</tbody>
</table>

High damping by Coulomb friction is expected for high order modes.
Beam screen extremities and interconnection design

Main modifications in 2018

- Centering of beam screen extremity and the flange
- Thermalisation of the absorber by clamping
- Fixed point redesign (pegs) to ease the fabrication
- Modified flange to ease the transverse alignment and assembly
Beam screen extremities and interconnection design
Integration of welding and cutting machines

Orbital welding machine and tooling around the PIM

Orbital welding machine for the fixed point flange assembly

Orbital weld head

Cutting machine
Beam screen extremities and interconnection design

Assembly sequences

Beam screen assembly

Cooling tubes bending

Beam screen extremities and interconnection
Beam screen extremities and interconnections
Interconnection module

Design of the compensation system of the beam vacuum line interconnections is reported in EDMS 2012795.

Copper Beryllium deformable RF bridge:
- Circular aperture
- C17410
- 0.1 mm thick, 3 mm width, gap: 1.4 mm
- 3 convolutions

Static RF fingers

Longitudinal constraint, due to the finger extension limitation, is reduced thanks to the static RF fingers and the springs.

20 titanium G5 springs (total prestress: ~360 N)

Expected behaviour and working conditions of the RF bridge

Deformable RF fingers

as installed in operation
Cold/Warm transitions

D1 C/W transition

Q1 C/W transition

Helium vessel extension

New BPM implemented

Study of temperatures profiles and heat transfer ongoing.
2. Validation tests
Thermal validation of the shielded beam screens

Requirements:
• Temperature windows for the inner copper layer: 60 – 80 K
  ➢ Helium gradient from 60 to 75 K (from Q1 to D1) + 5 K temperature difference between helium and internal copper layer.
• Heat transfer to 1.9 K: <500 mW/m
• Heat loads on the tungsten absorbers: 25 W/m for Q1, 15 W/m for Q2-D1

Tests at cryolab with WP9:
• 80 cm long Q2 type beam screen prototype, equipped with heaters
• Assessment of:
  ➢ Heat transfer from the tungsten absorbers to the cooling tubes
  ➢ Heat leak from the beam screen to the cold bore, cooled at 1.9 K

Details in the talk “Thermal qualification of the HL-LHC beam screens for the inner triplets, Patricia Tavares, Torsten Koetting, Wednesday PM.”
Thermal validation of the shielded beam screens

Heat transfer from the absorbers to the cooling tubes

Heat load deposited in the tungsten absorbers is transferred to the cryogenic cooling circuit by thermal links:

- 3 thermal links per blocs (40 cm long),
- Copper multilayers, 10 * 0.1 mm thick, 5 mm wide
- Vacuum brazed on the absorber, interface plate welded on the cooling tube

- Very good thermal decoupling between the absorbers and the beam screen tube. Temperature difference inner surface/helium well below 5K.
- Temperature of the absorbers 9 to 15K higher than the temperature of the cooling tube.
- Very good agreement between simulations and experiments.
Thermal validation of the shielded beam screens

Heat transfer from the absorbers to the cooling tubes

The beam screen is supported in the cold bore by sets of titanium springs and ceramic ball. Springs are only installed in the bottom part of the beam screen. Heat leak to 1.9 K by conduction through the supporting system and radiation.

- Very good agreement between simulations and experiments.
- Heat load to the 1.9 K bath below the 500 mW/m requirement.
Mechanical validation of the shielded beam screens

**Requirement:** The shielded beam screen must withstand the Lorentz forces induced by Eddy current during a quench.

**Quench tests** with WP3:
- Q1 model (MQXFS4)
- Tests at 1.9 K.
  - Copper layer and thermal links scaled to get similar Lorentz forces.
- First test on modified Q1 beam screen prototype, 2 m long.
- Strain measurements on the cold bore by optical fibers.
- Strain measurements on the beam screen by strain gauges.
- Measurement of the displacements of the beam screen and absorbers.
- Tests carried out with CLIQ at -30% and +25% of nominal, in term of (dl/dt)*I
Mechanical validation of the shielded beam screens

First results (18.5 kA)

- Beam screen withstand 25 quenches, up to ultimate current.
- Elastic overall behaviour of the beam screen.
- Detailed analysis of the test data to be done.
Mechanical and RF validations of the PIM

Mechanical tests with offsets (longitudinal and transverse).

RF tests:
• With/without bellows
• In nominal or with misalignment configurations

Module ready for tests to be done with BE/RF and BE/ABP.

Deformable RF bridge prototype
3. Manufacturing
Manufacturing status
Beam screen facility

Beam screen facility under construction:
- Laser welding machine commissioned
- Cold test bench under manufacturing
- Welding bench commissioned for LHC type beam screen (to be updated for HL-LHC type)
- Assembly, insertion, aC coating benches to be designed
Manufacturing status
Component procurement

Contract management:

- High Manganese High Nitrogen stainless steel for beam screens and cooling tubes: Received.

- Cooling tubes: Received.

- Co-lamination: Received.

- Beam screen punching, forming and welding:
  - IT-4395 done. Discussions ongoing.

- Tungsten absorbers:
  - Qualification of 4 suppliers done (EDMS 1973451).
  - IT in preparation. To be sent by the end 2018, FC: March 2019.
  - Pre-series: Summer 2019.
Manufacturing status
Component procurement

Contract management:

• Thermal links:
  • Interface plates:
    • Co-laminated strip ordered (March 2019).
    • Copper scrapping tests ongoing: mechanical or etching.
  • Copper links:
    • two assembly technologies considered: vacuum brazing, US welding.
    • IT early 2019.

• Ti springs & rings:
  • MS: ongoing (options of 3D printing or classical manufacturing methods).
  • IT: early 2019, Pre-series: September 2019.

• Pumping slot shields:
  • Design to be finalized.
  • Price inquiry to be done mid/end 2019.
Manufacturing status
Component procurement

Contract management:

- Cold bore
  - Raw material:
    - First bars in October 2018.
    - Next batch: March 2019.
  - Machining:
    - Contract approved by FC, being placed.
    - Pre-series: End March 2019.
4. Summary
Summary

Thermal and mechanical studies of the beam screen – cold bore system have been carried out. Additional mechanical studies (misalignment, vibrations) have been done in 2018.

Validation tests are ongoing:

• Thermal tests on a complete beam screen prototype have been successfully done. Very good results, in agreement with simulations, have been obtained.
• Quench tests have just been done on a Q1 beam screen prototype. First hints indicate that the beam screen integrity is preserved and quench tests have been passed successfully.
• RF bridge module prototype is ready for mechanical/RF validation tests.

Contracts for manufacturing of main components are being placed. The construction of the beam screen finishing facility is ongoing. Discussions with WP3 on the assembly sequence have started.
Thank you for your attention

Many thanks to WP3, WP9, EN/MME and all VSC team for their significant, valuable and important contributions.
Influence of misalignment on the behaviour during a magnet quench (3)

Results for a transverse misalignment:

- Initial transverse offset is increase during a quench until the beam screen goes in contact with cold bore (nominal expected behaviour).