# Magnet quench tests on the shielded HL-LHC beam screen (Q2 type)

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**WP3 Meeting**

TE-VSC-DLM

09 - 02 - 2022

# Outline

- Aim of the test
- Test conditions
- Test plan
- Simulation study
- Results
- Conclusions

# Aim of the test

**Primary aim of the test:**
Assess the impact of the Q2-type beam screen on the magnetic field quality.

Therefore, the selected beam screen was the series one and could not be equipped of mechanical instrumentation.

**Secondary aim of the test:**
Assess the general mechanical integrity of the Q2 type beam screen during magnet quenches via visual inspection.

In particular, we introduced a new design of thermal links that underwent some deformation during the Q1-type beam screen quench test performed in Oct. 2018 (https://indico.cern.ch/event/780357/).

# Insertion of the Q2-type Beam Screen in the MQXFS4d Magnet

# Test conditions

- Q2 type beam screen, aC coated, immersed in the 1.9 K helium bath;

- The temperature of the test (**1.9 K**) results in a significant change of the electrical resistivity of the copper elements of the beam screen (thermal links, inner layer).
  The nominal forces induced during a quench at the operation temperature (**60 K**) can be reproduced at **8.1 kA**.

- Vertical position of the beam screen within the cryostat.

- No mechanical instrumentation on the beam screen but optical fibres were installed on the cold bore.

# Test plan MQXFS4d

| # | Temp | Phase of the test | Description | Current [kA] |
|---|---|---|---|---|
| 1 | **300 K** | Warm preparation | Usual preparation (no shaft) incld fixing CCT to the bottom of 4d | -- |
| 2 | **4.5 K** | Powering CCT | | 0.53 |
| 3 | **1.9 K** | Powering CCT | | 0.53 |
| 4 | **1.9 K** | Provoked quenches//extractions at ~50% of nominal current | Copper link mechanical test at expected nominal forces | 8.115 |
| 5 | **300 K** | Warm preparation | Removal of the CCT magnet | -- |
| | | | Magnet from insert deinstallation | -- |
| | | | Removal of the beam screen | -- |
| | | | Inspection of the copper link | -- |
| | | | Magnet onto insert installation | -- |
| | | | Installation of the beam screen and magnetic measurement shaft | -- |
| 6 | **1.9 K** | Magnetic measurements | With beam screen and cold bore | 16.23 |
| | | Provoked quenches//extractions at 100% nominal current | | 16.23 |
| | | Magnetic measurements | With beam screen and cold bore. Crosscheck. | 16.23 |
| | | Quench heater discharges with 0 current | Angular position of the shaft must be reviewed and connected to HF. Request by D. Wolman | 0 |
| 7 | **300 K** | Warm preparation | Removal of the beam screen | -- |
| | | | Inspection of the copper link | -- |
| 8 | **1.9 K** | Magnetic measurements | Without beam screen and cold bore | 16.23 |
| | | Training | Training, VI and RR | I max |
| | | Quench heater discharges with 0 current | Angular position of the shaft must be reviewed and connected to HF. Request by D. Wollmann. | |
| 9 | **4.5 K** | Verification | Training, VI and RR | I max |

first cool-down (Jun. 2021): rows 1–4

second cool-down (Nov. 2021): rows 5–6

third cool-down (Dec. 2021): rows 7–9

Row 4: 1 quench @ 8.1 kA

Row 6: 1 quench @ 8.1 kA
1 quench @ 12.2 kA
5 quenches @ 16.23 kA

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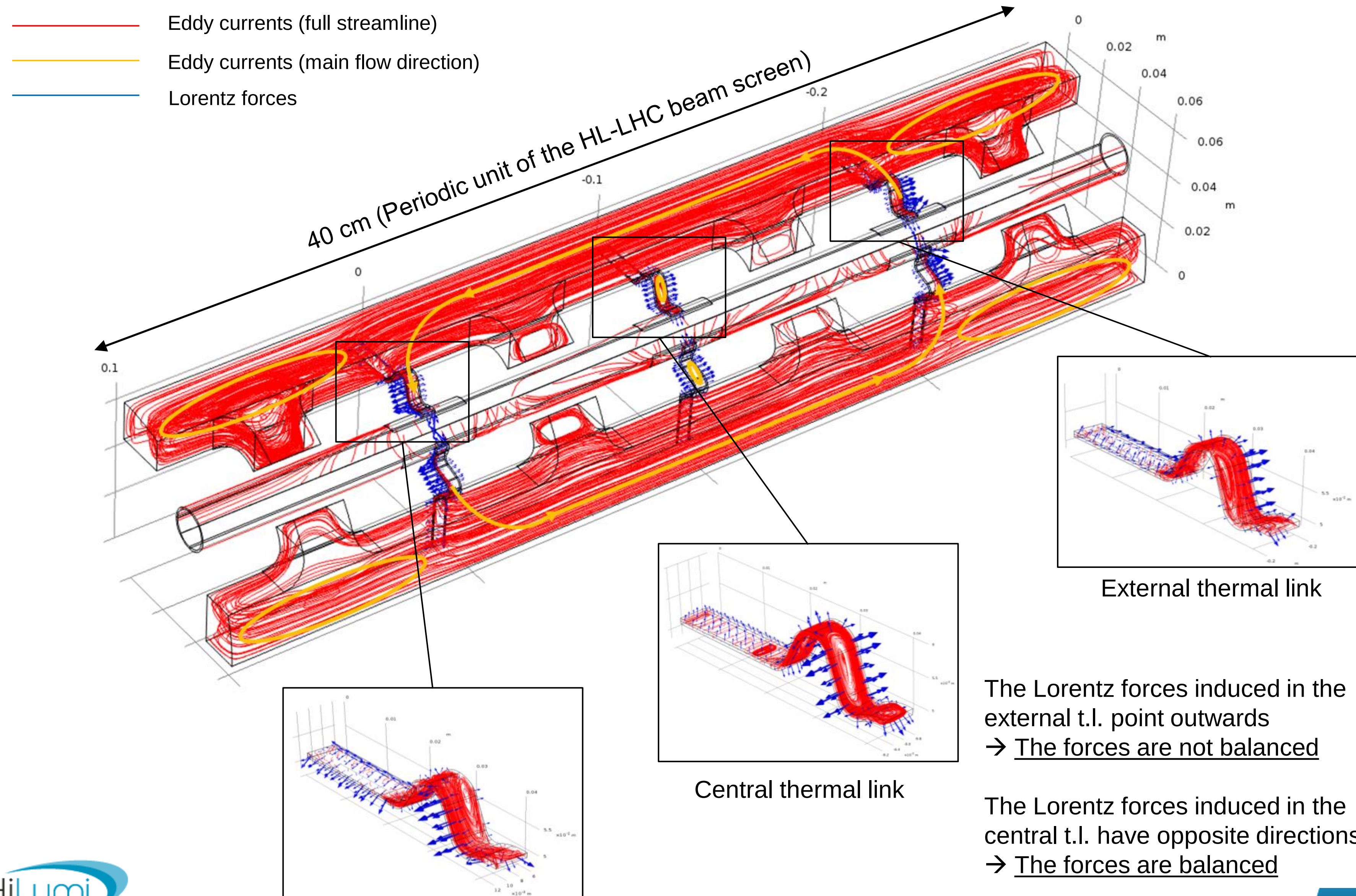
# Simulation study:
## Force distribution of the thermal links during a magnet quench

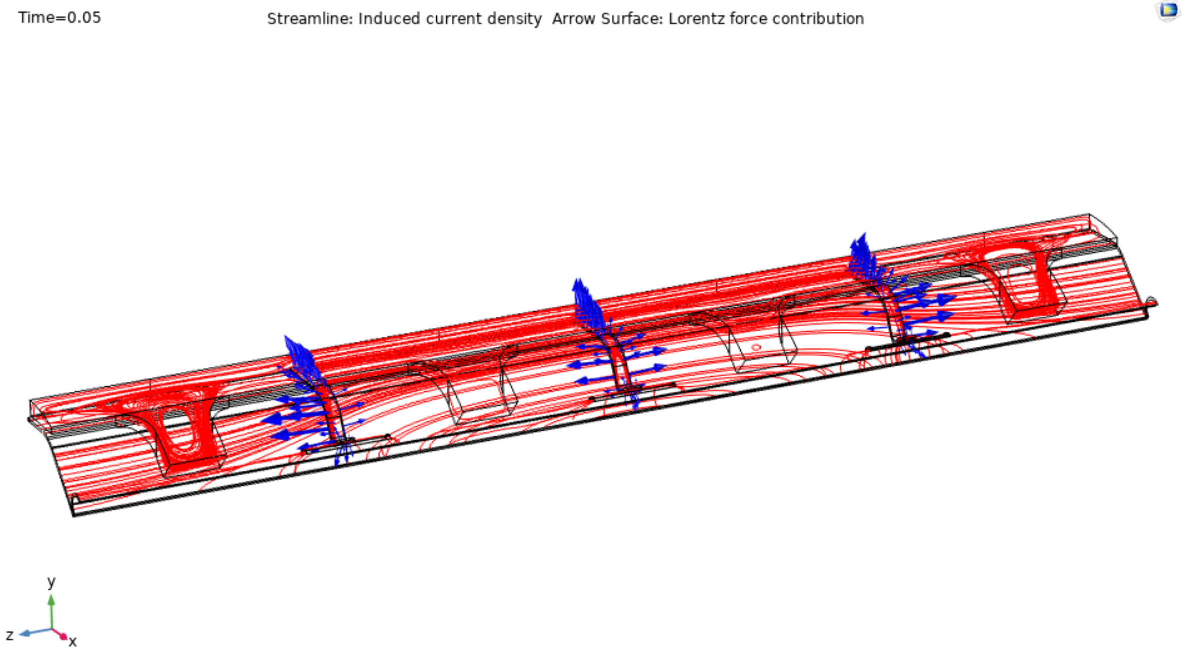


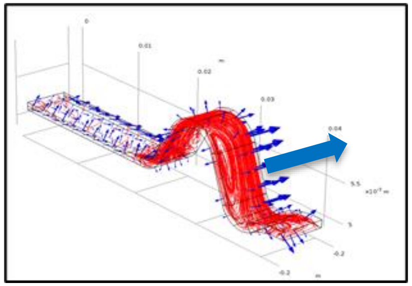

External thermal link

The Lorentz forces induced in the external t.l. point outwards
→ <u>The forces are not balanced</u>

The Lorentz forces induced in the central t.l. have opposite directions
→ <u>The forces are balanced</u>

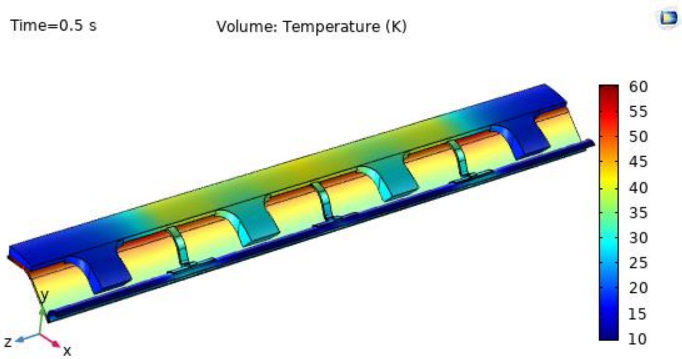
# Simulation study:
## Force and temperature of the thermal links during a magnet quench (Q2 BS)

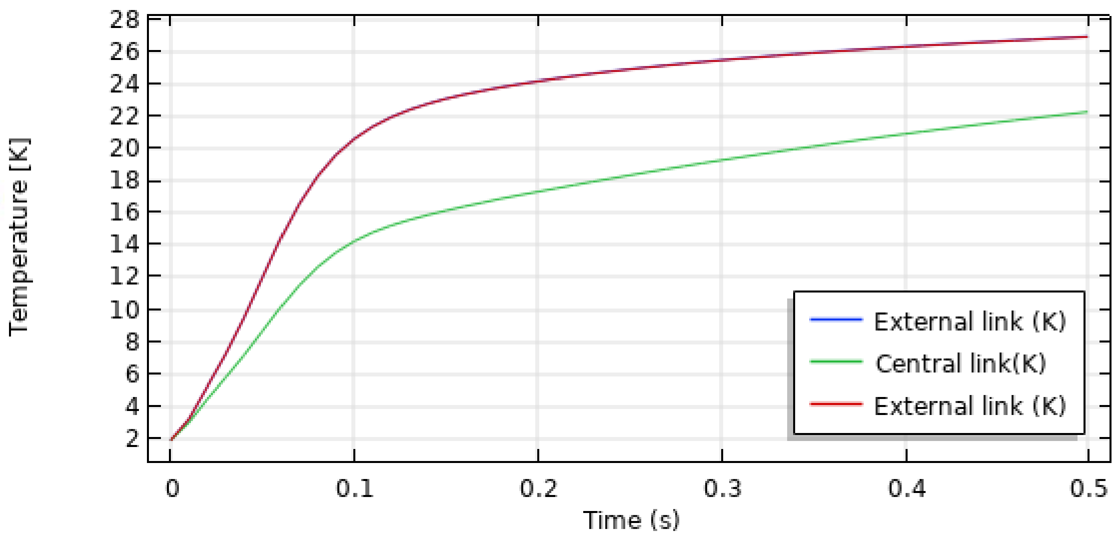


The total Lorentz forces induced in the external thermal link varies between 177 N and 255 N at 16.5 kA (1.9 K).

The temperature of the thermal link reaches 28 K at nominal current (16.5 kA).



# Visual inspection

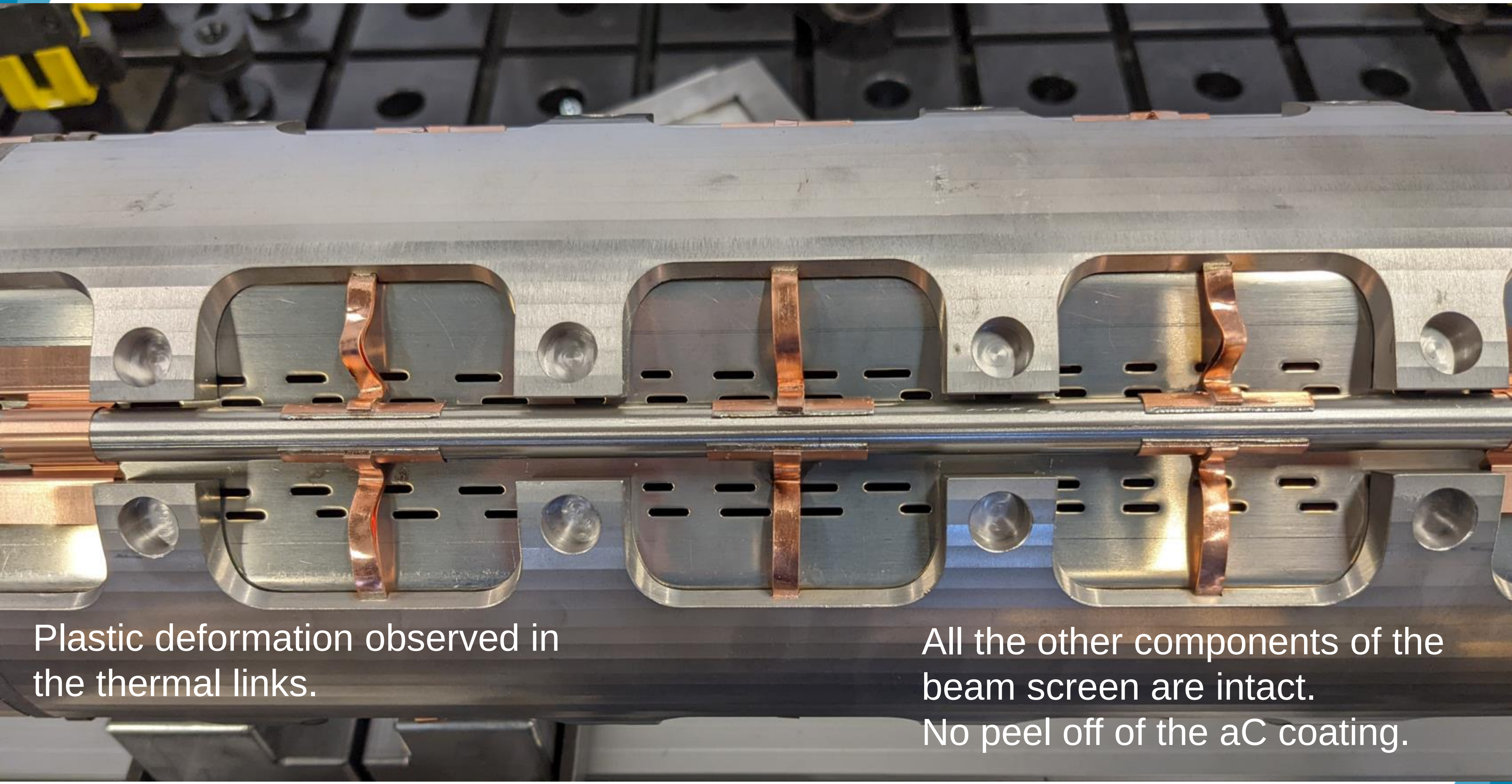
## Quench @ 8.1 kA → Equivalent to nominal forces

No plastic deformation observed in the thermal links.

All the other components of the beam screen are intact.
No peel off of the aC coating.

# Visual inspection

## Quench @ 16.2 kA → 3 x nominal forces

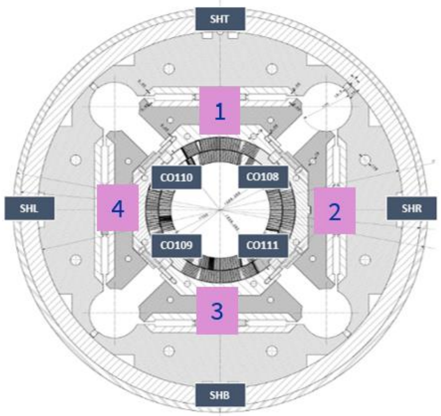


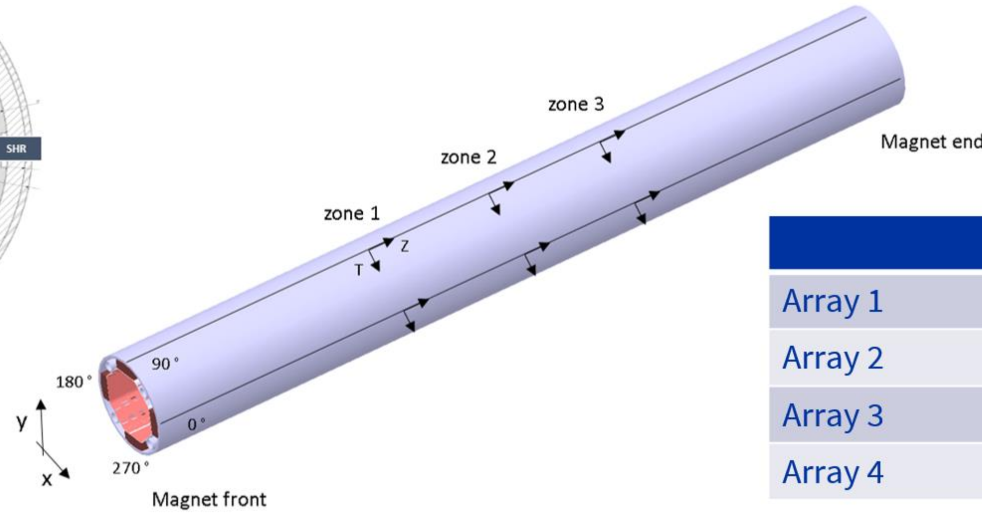
Plastic deformation observed in the thermal links.

All the other components of the beam screen are intact.
No peel off of the aC coating.

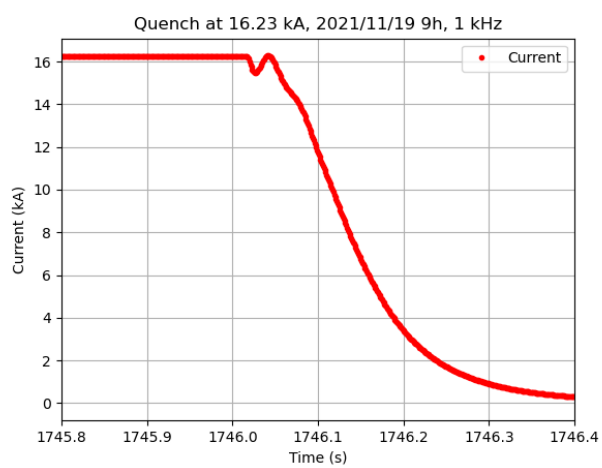
# Cold bore strain measurement
## Quench @ 16.2 kA

MQXFS4d cold bore insertion



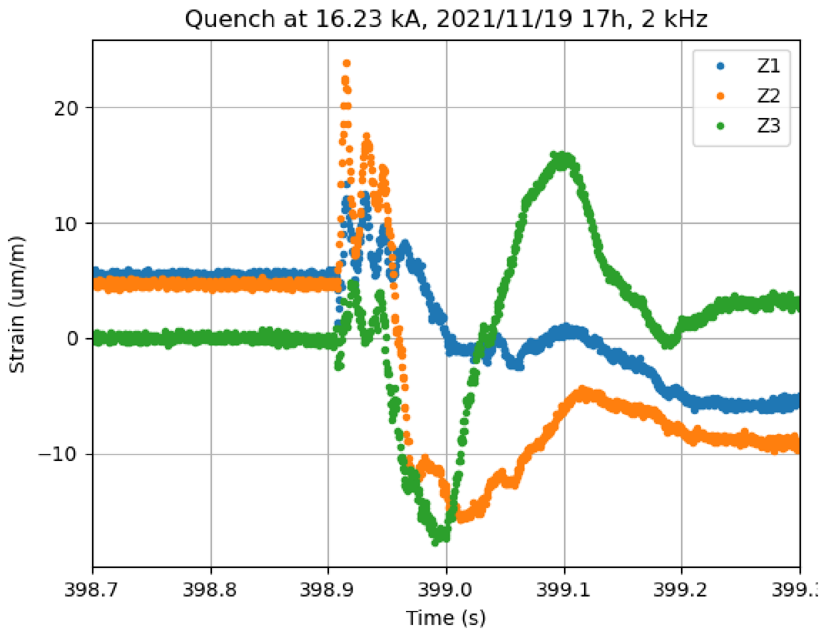

| | |
|---|---|
| Array 1 | 90 ° |
| Array 2 | 0 ° |
| Array 3 | 270 ° |
| Array 4 | 180 ° |

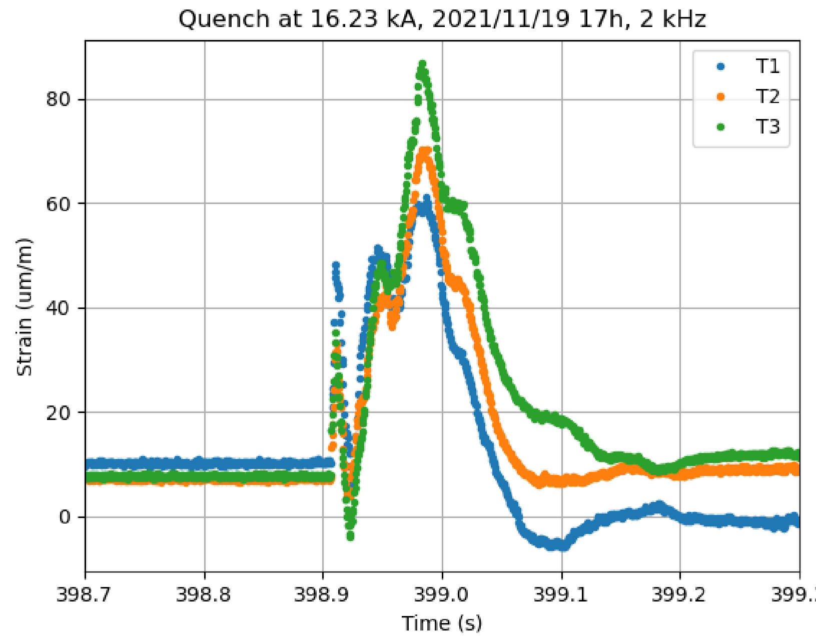



Courtesy of K. Kandemir, M. Guinchard

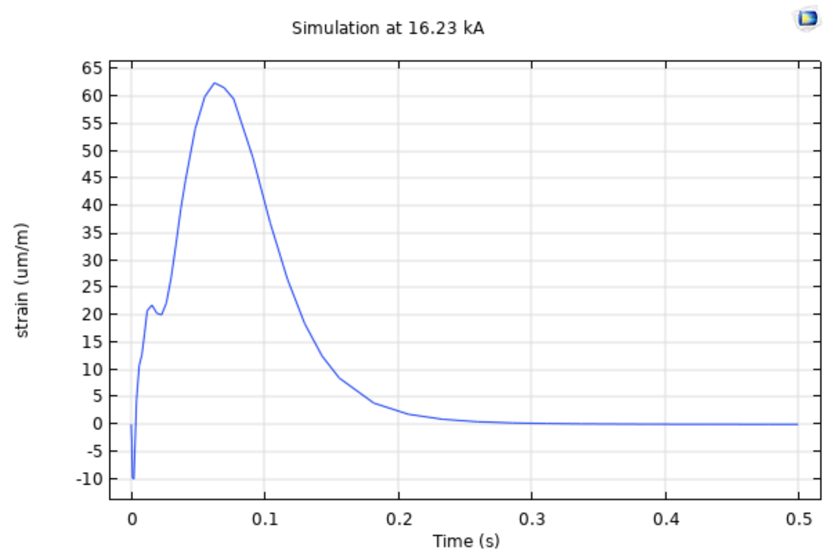
# Cold bore strain measurement

## Quench @ 16.2 kA




Courtesy of K. Kandemir, M. Guinchard




The strain measurements are as expected.
Good agreement between simulation and measurement.

# Conclusions

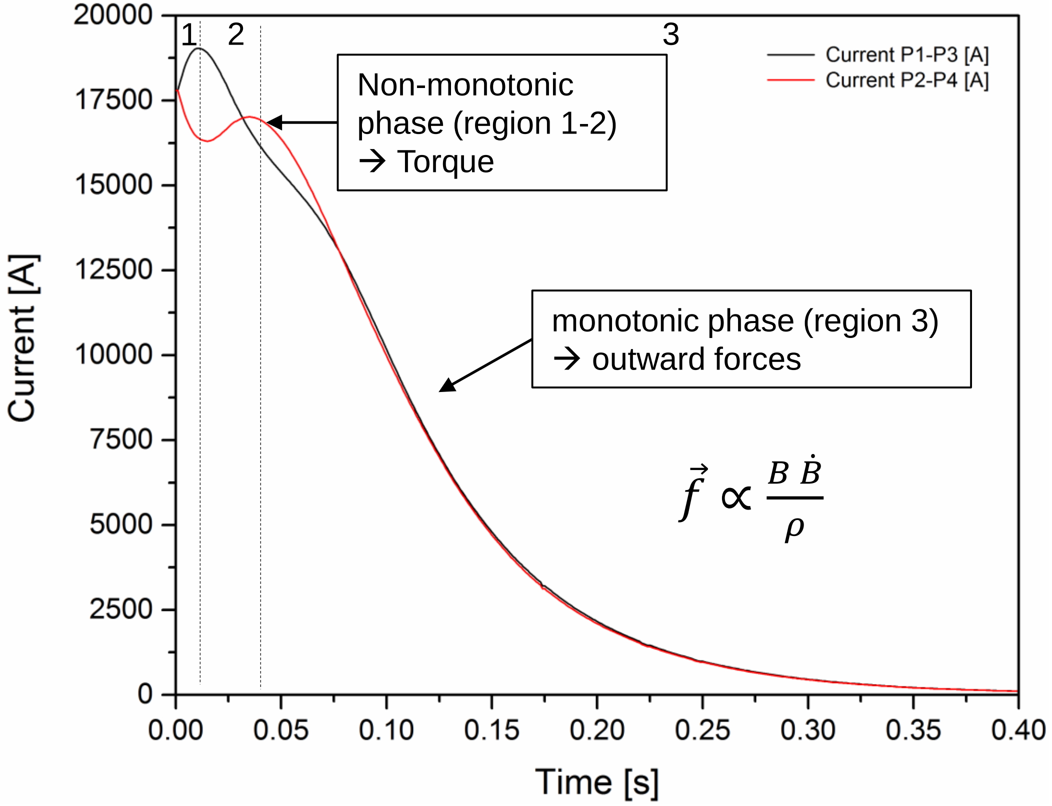
- A Q2-type beam screen was manufactured to assess the impact on the magnetic field quality;
- The same beam screen underwent magnet quenches to assess its mechanical integrity at 8.1 kA (equivalent to nominal forces) and 16.2 kA (equivalent to forces around 3 times higher);
- No plastic deformations were observed within the assembly nor for the new design of the thermal links at 8.1 kA;
- No plastic deformations were observed within the assembly. Some plastic deformations were observed for the thermal links at 16.2 kA. However, these do not pose any concern as the forces are around 3 higher than expected and despite such deformations, the thermal links remain fully functional.
- Therefore, the mechanical design of the Q2-type beam screen is validated.

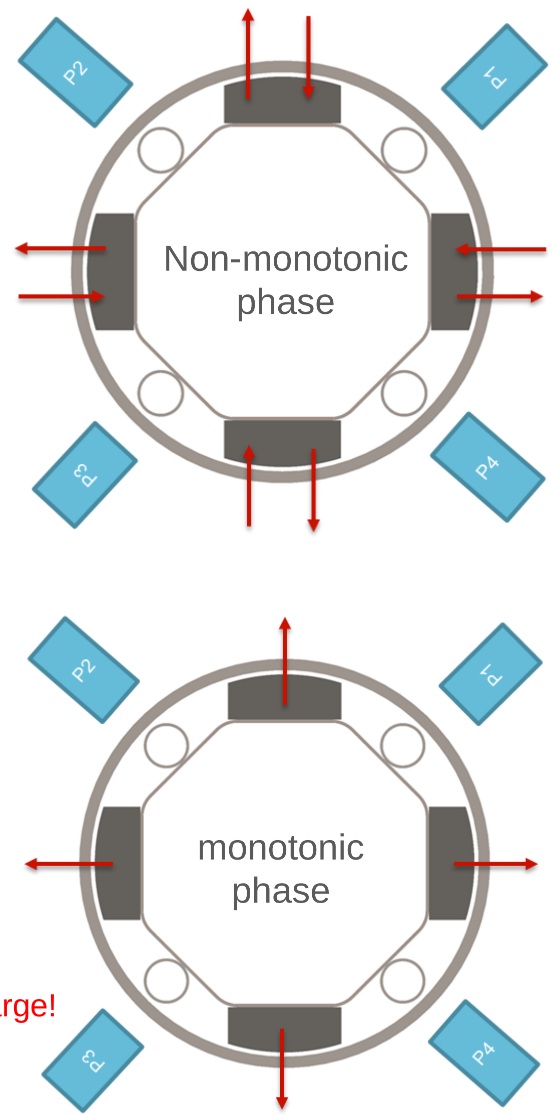
**A big thank you to the WP3 colleagues and the SM18 team for the great collaboration.**

**Thank you for your attention**

# Extra slides

# Physics of the problem




$\dot{B}B$ ($\dot{B}$ 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.



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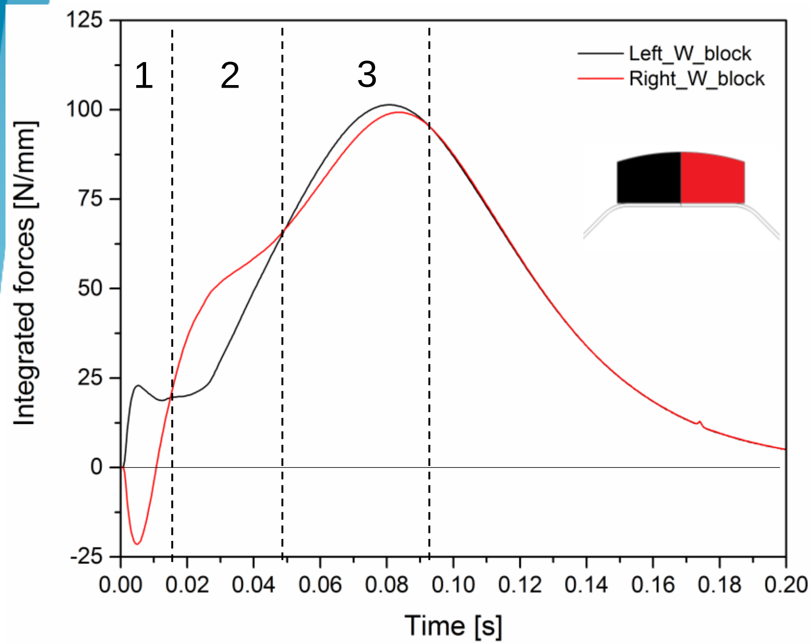
# Numerical results at 17.8 kA

Integrated forces induced in the W block




Region 1: Most critical!!

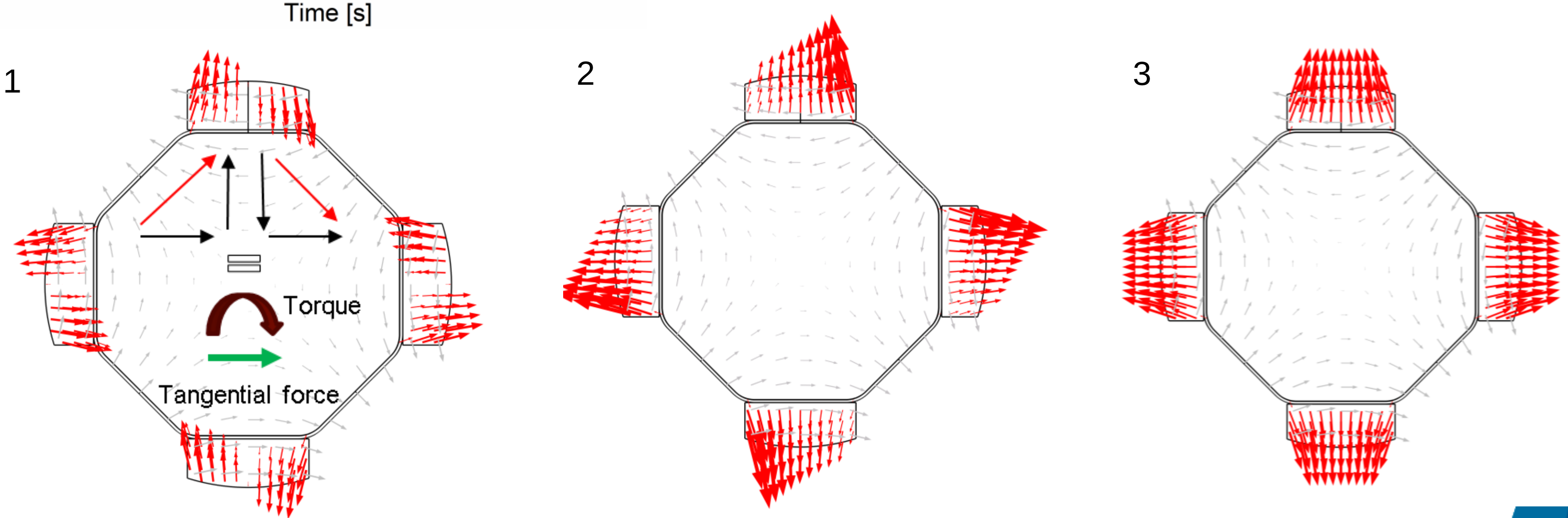
| component | Q1 | |
|---|---|---|
| | Torque [N m/W block] | Tangential force [N/W block] |
| Cold bore | 253 | 3400 |
| Heat absorber | 280 | 4200 |
| Octagonal pipe | 81.5 | 1600 |

Region 2: Less severe than phase 1

Region 3: Less severe than without CLIQ

E.g. Fy for the tungsten block:

$Q1_{NO\ CLIQ}$ ~233.5 [N/mm] > $Q1_{CLIQ}$ ~200.5 [N/mm]



# Cold bore fibers

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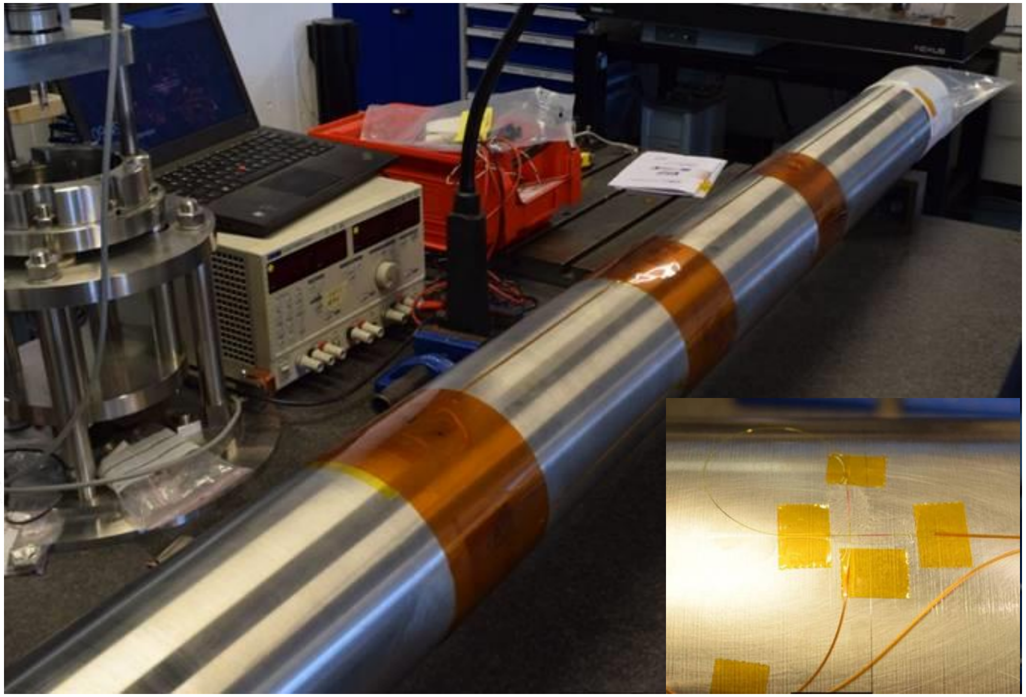
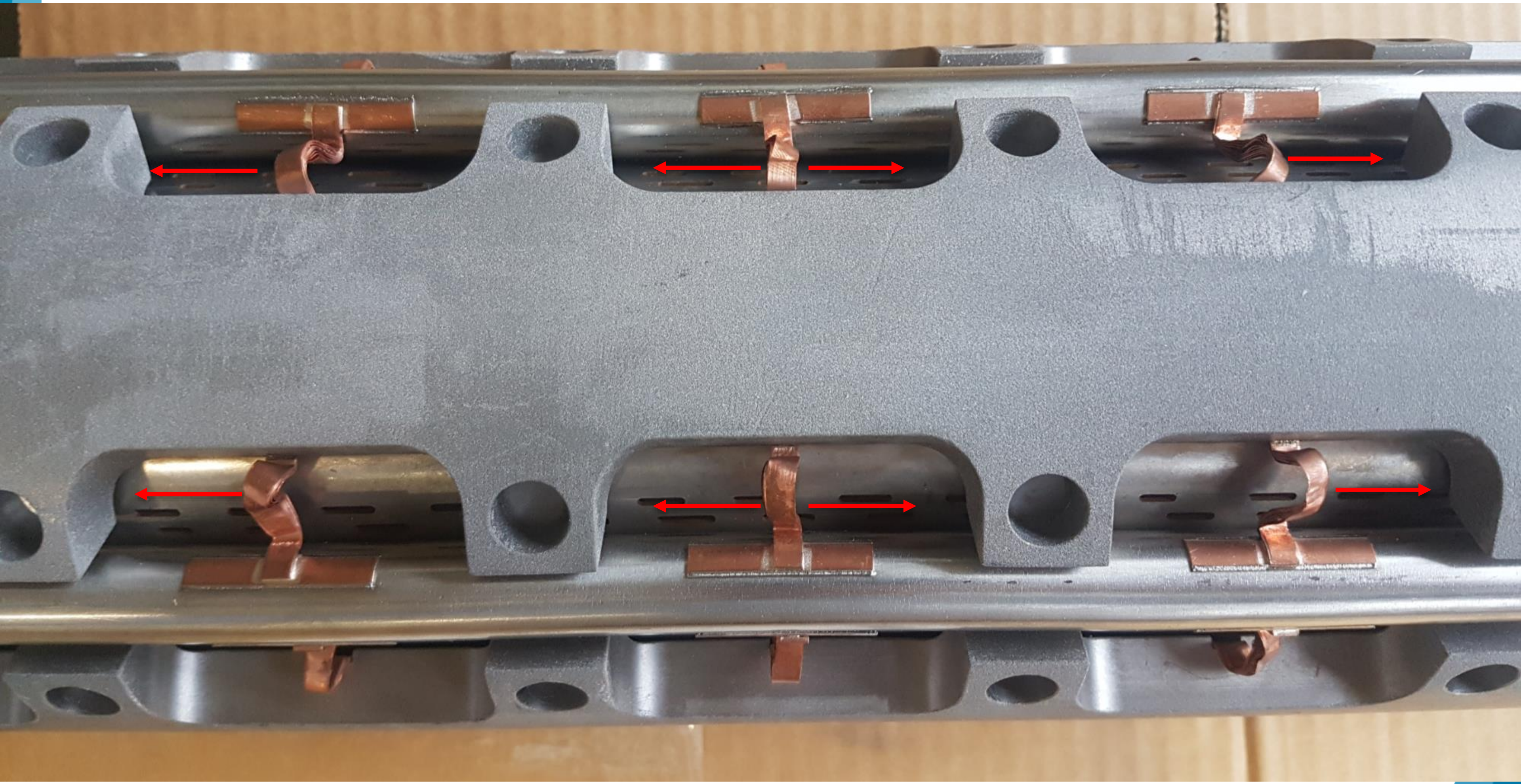
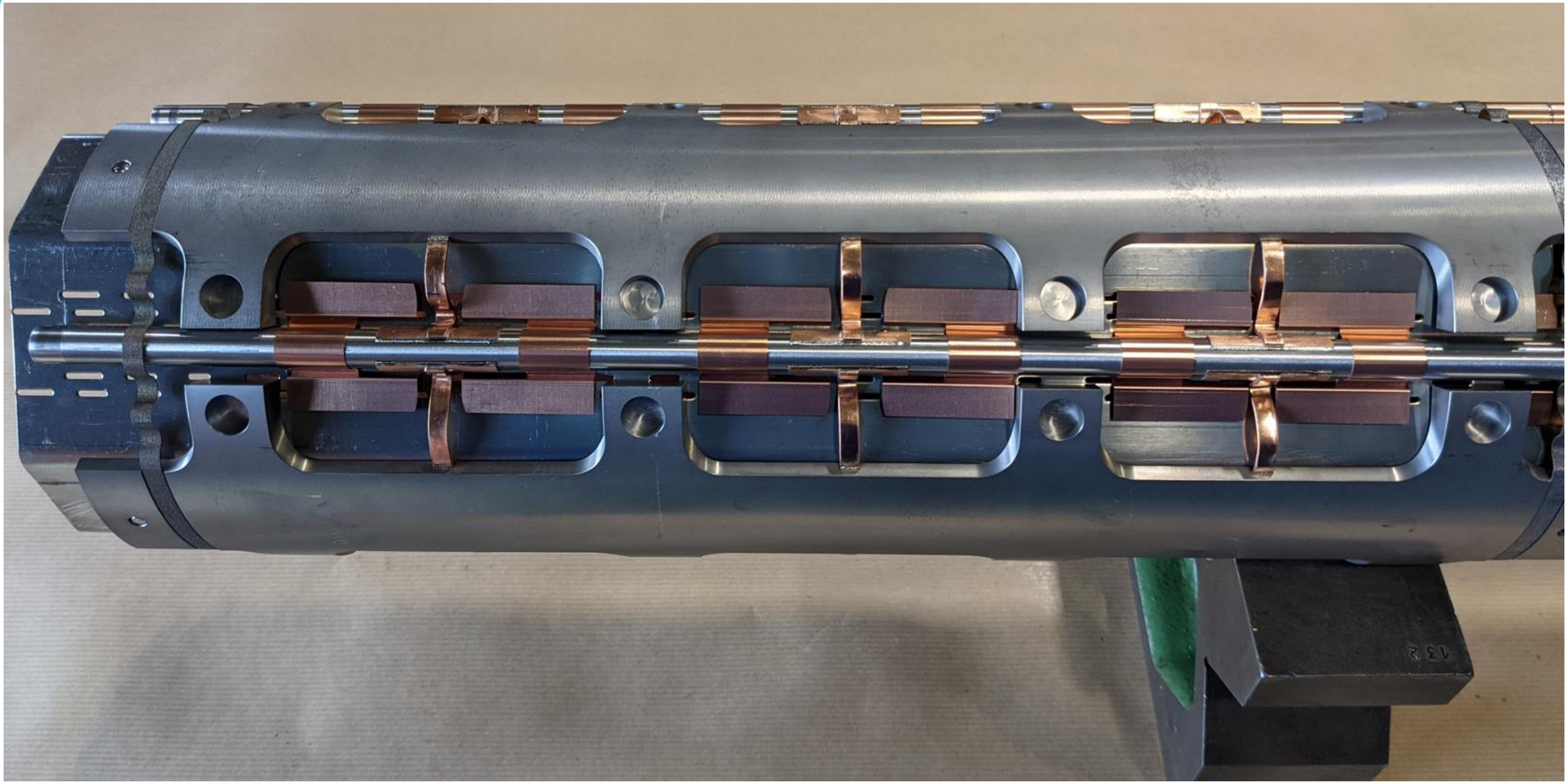
*4 lines of fibers installed in 4 diametrally opposed generatrixes of the cold bore: 12 biaxial strain measurement points.*



# Thermal link Q1 beam screen (Nov 2018)



# Thermal link Q2 beam screen (Nov 2021)



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