Impact of Medium Temperature Heat Treatments on the Magnetic Flux Expulsion Behavior of SRF Cavities

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Experimental Goal

1. Investigate magnetic flux expulsion behavior as a function of:

- **cool down velocity v_c**
- **spatial temperature gradient ∇T**

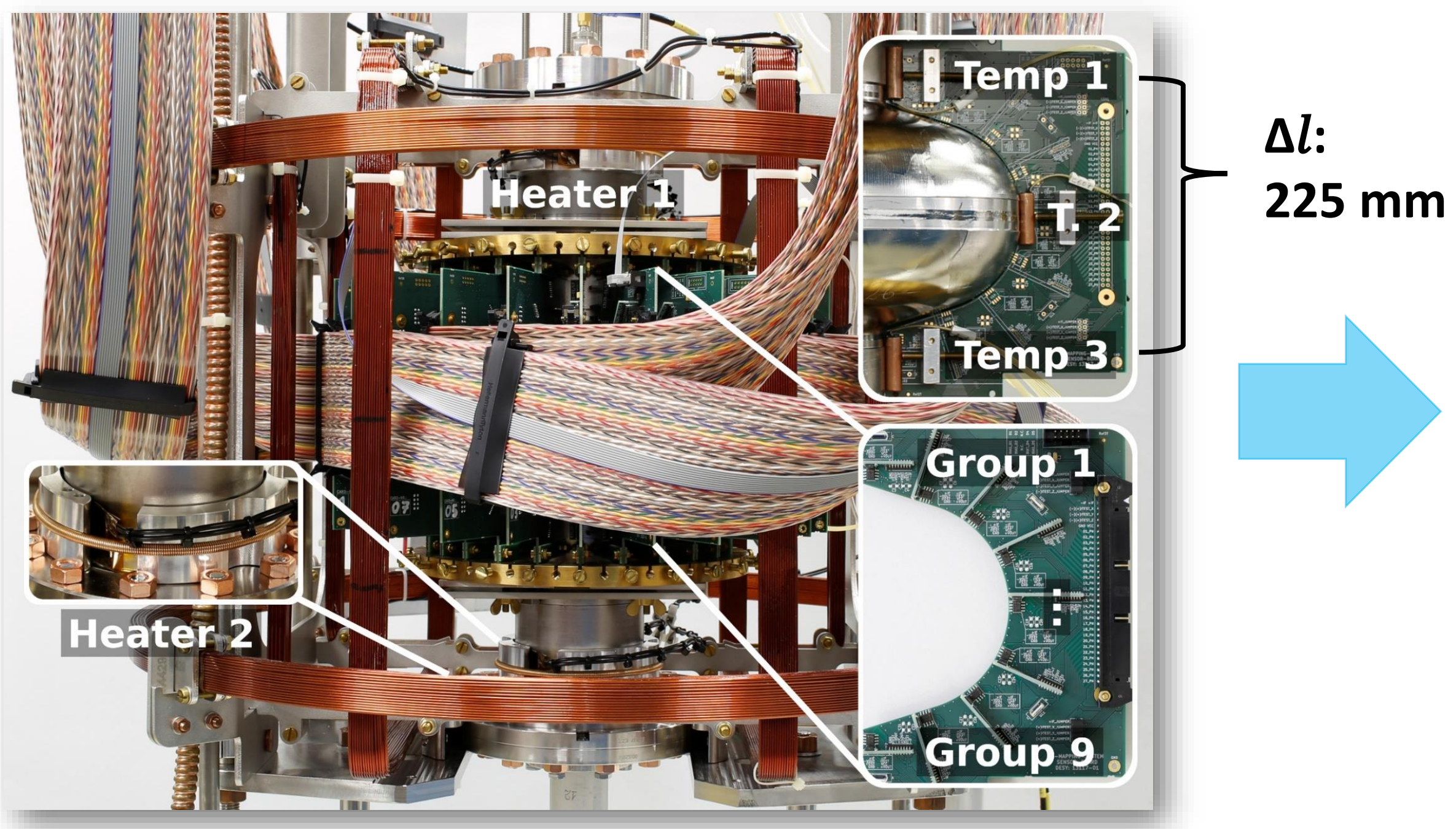
for the **large-grain** test cavity **1DE26** before- and after mid-T heat treatment for assumed technical extrema of:

- **-5 K/h and -20 K/h for v_c**
- **0 ΔK/Δl and 4 ΔK/Δl for ∇T**

to maximize likelihood of significant measurement results (Δl represents the distance between used reference thermocouples located at the upper and lower iris of 225 mm)

2. Study the impact of **mid-T heat treatment** on **sensitivity to trapped magnetic flux**

Experimental Setup

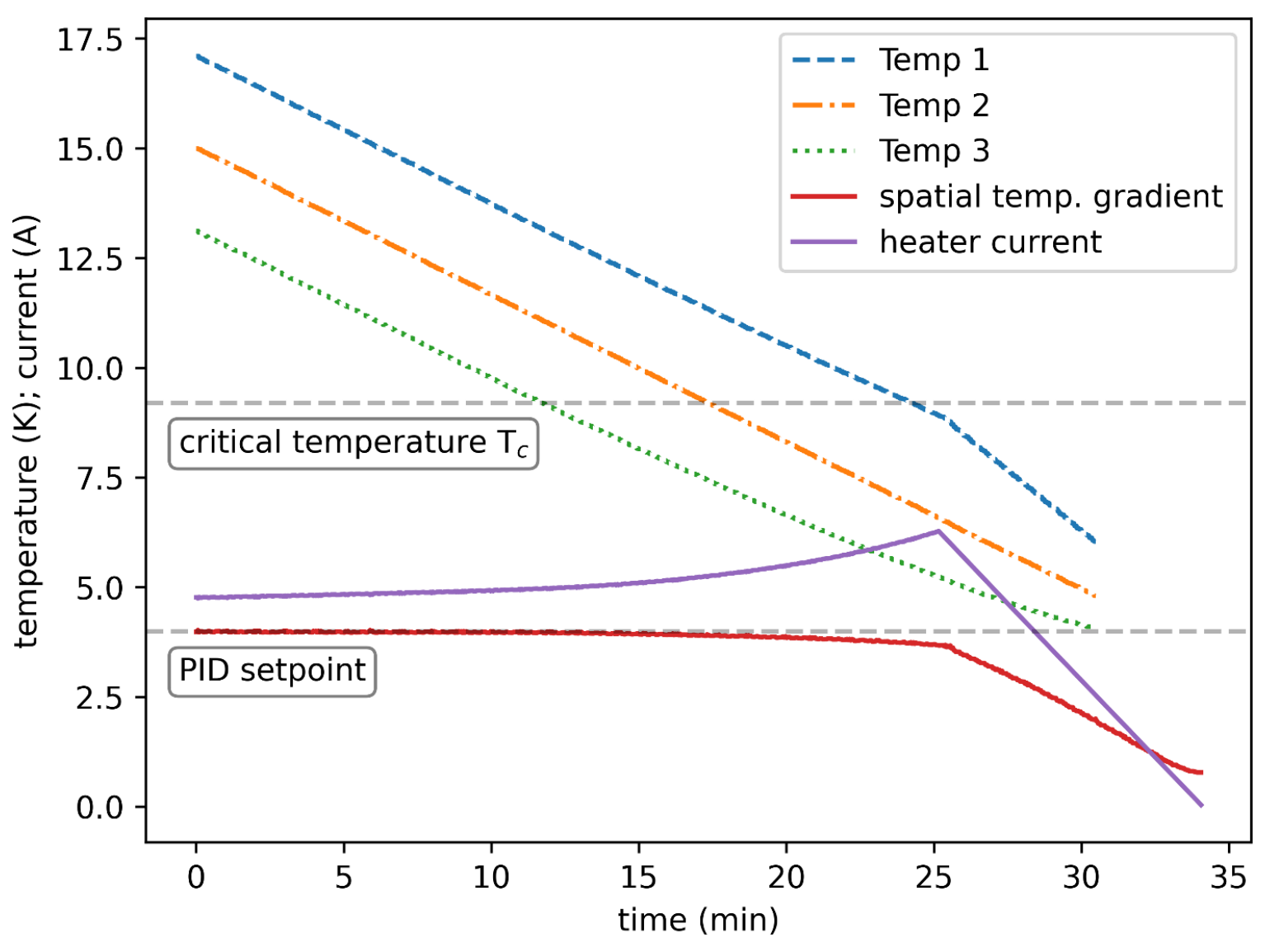


Cavity surrounded by 23 sensor boards and one board for the thermocouples to control the cool down velocity (Temp 2) and the temperature gradient defined as (Temp 1 – Temp 3)/Δ*l*

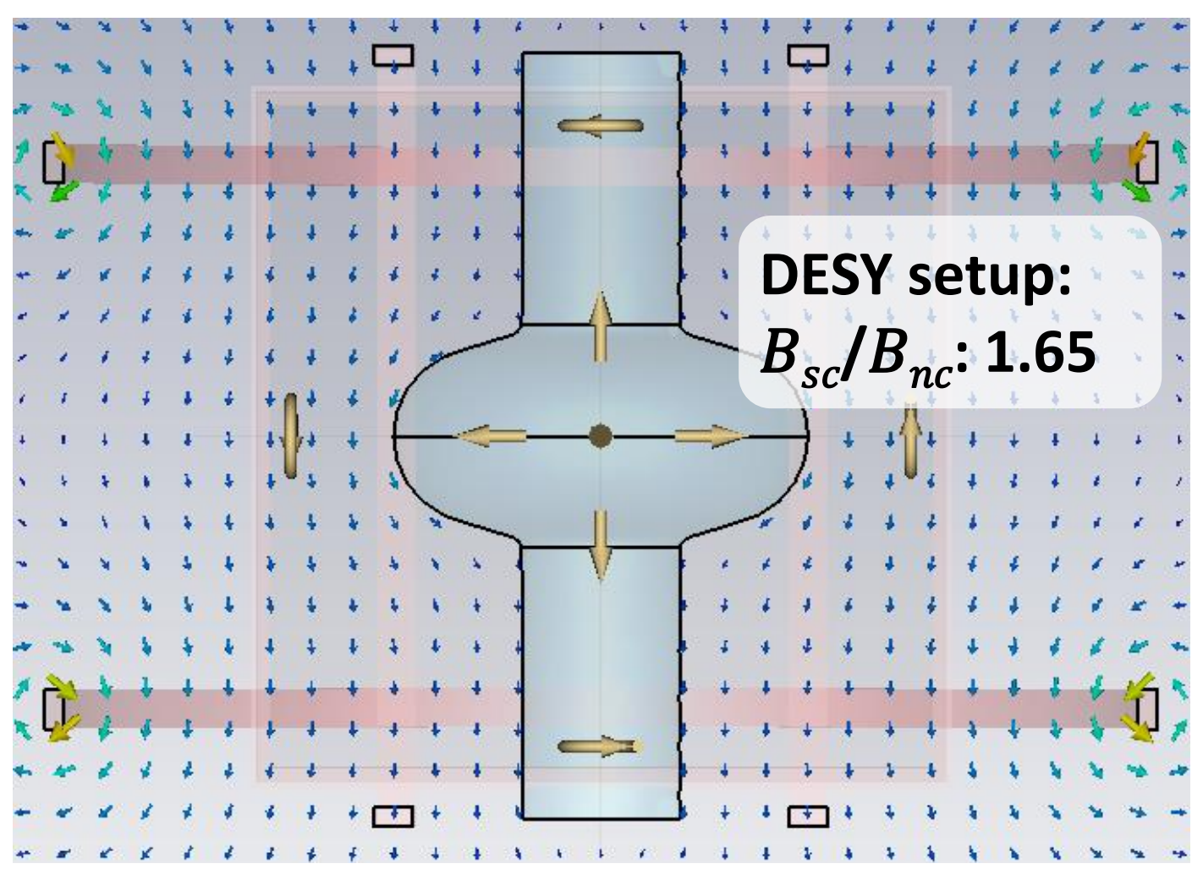
Sensor signals digitized inside of cryostat by custom-build evaluation boards to: extensively reduce number of feed-throughs, shorten analog signal lines and reduce thermal noise

Setup Characteristics

- Ensure consistent test conditions
- Setup operated in an ambient field of **10 µT**
- Spatial mapping of magnetic flux density by 621 AMR-sensors
- Based on HZB approach [1,2]



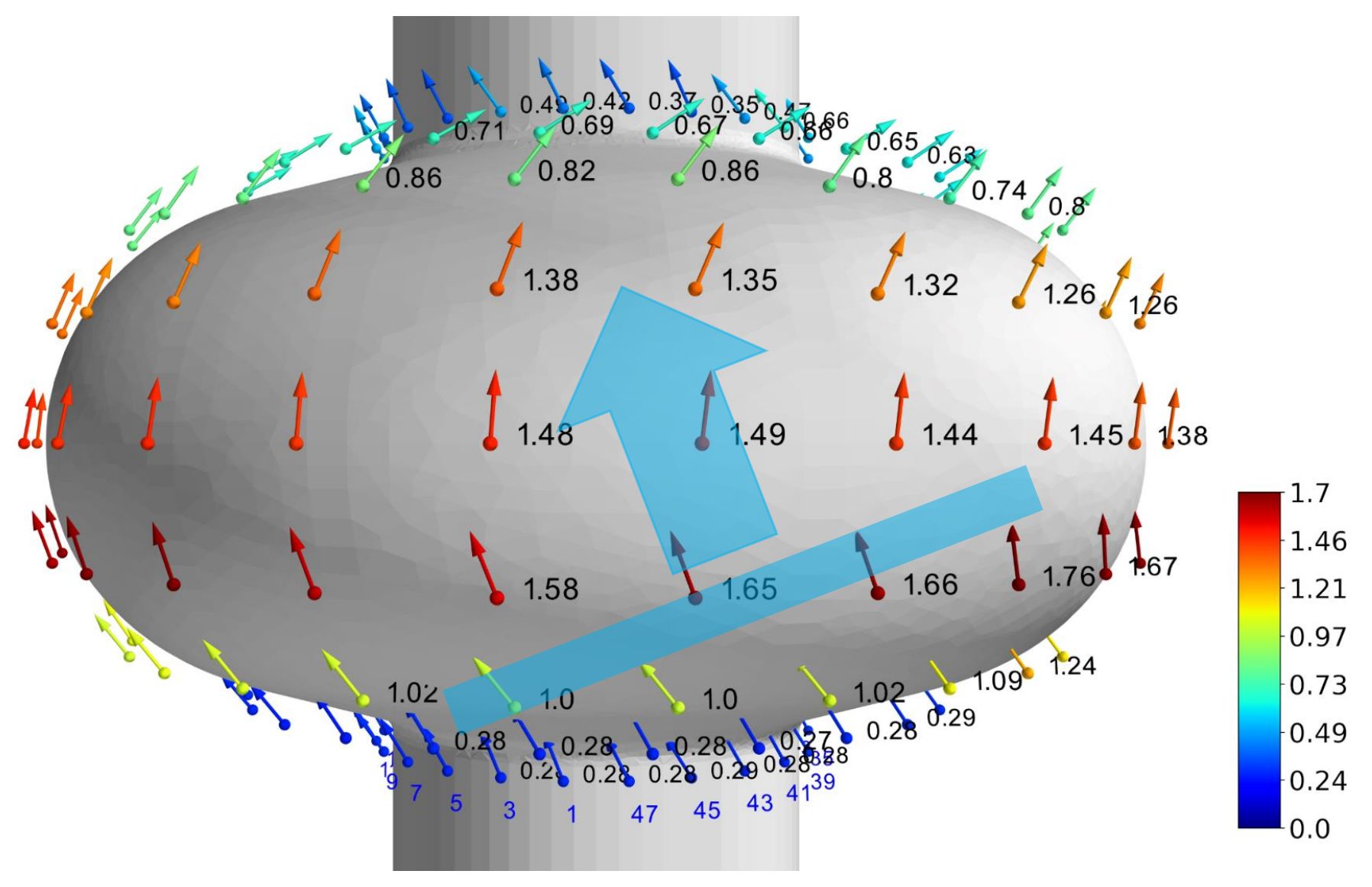
- PID controlled cool down velocity v_c
- PID controlled spatial temperature gradient ∇T



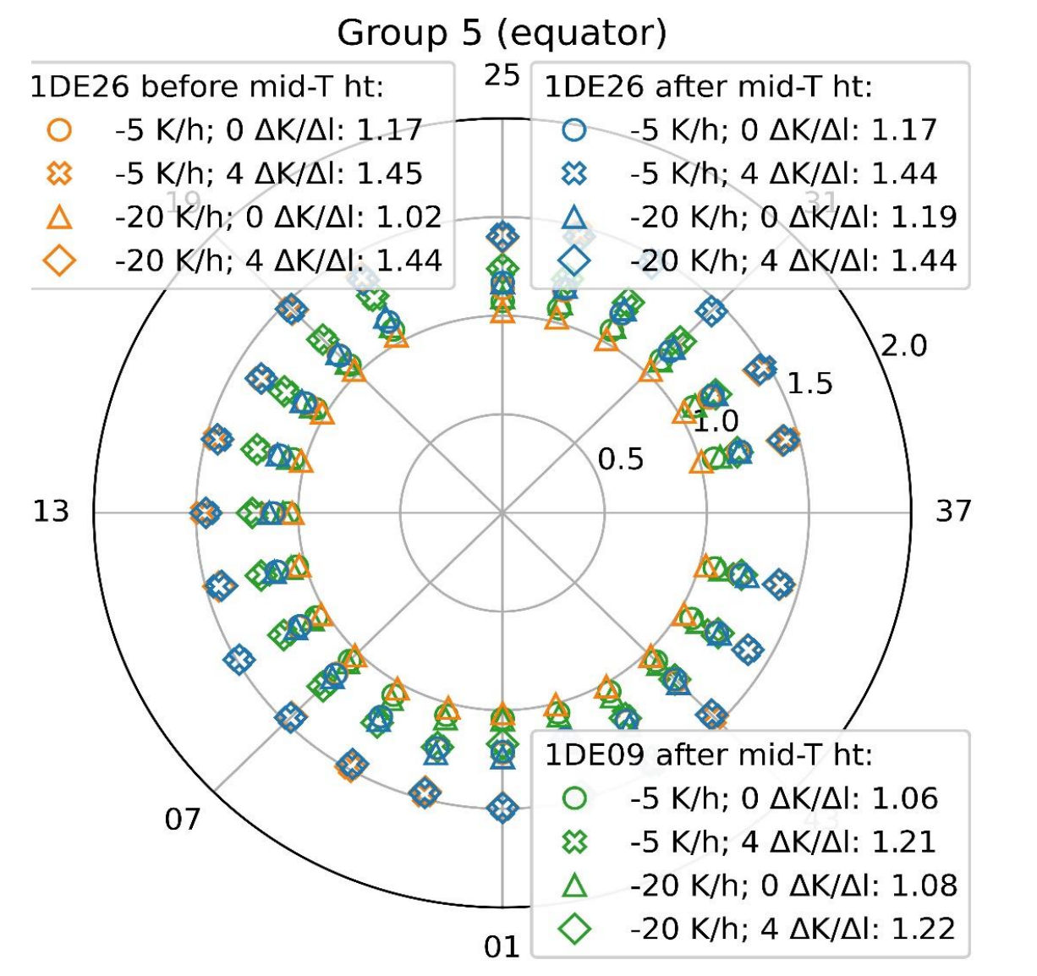
Increase of magnetic flux density for ideal Meissner state obtained by simulation model to derive fraction of flux trapped

Setup Limitations

- Inclined T_c transition due to an asymmetrical helium flow
- Asymmetrical expulsion of magnetic flux



Magnetic flux distribution snapshot. The given numbers indicate the expulsion ratio $|B_{sc}/B_{nc}|$. An inclined T_c transition led to an asymmetrical magnetic flux expulsion.



Polar distribution of the ratio $|B_{sc}/B_{nc}|$ of the fine-grain cavity 1DE09 to distinguish between asymmetries related to the large-grain material and potential anomalies caused by an inhomog. He flow

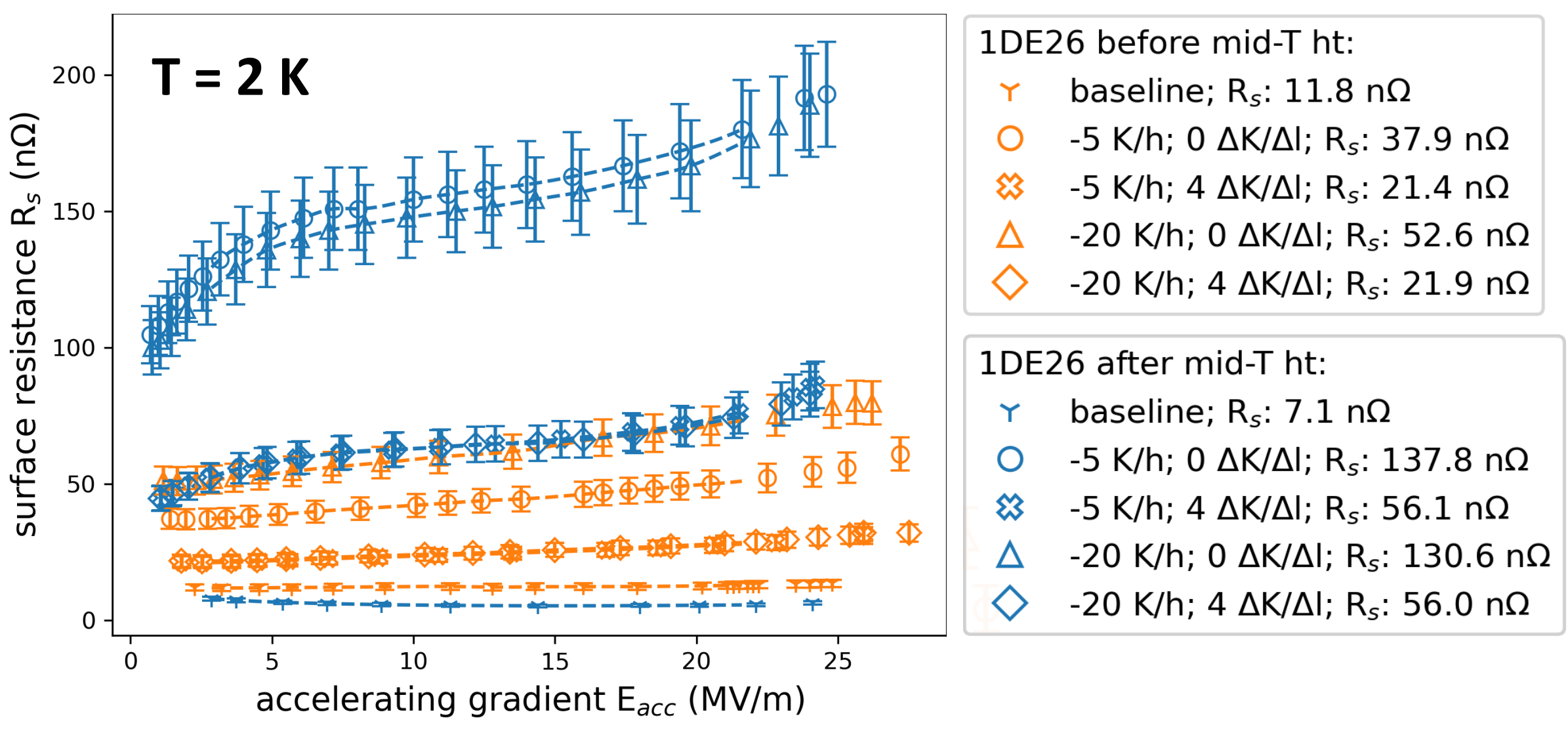
Magnetic Flux Expulsion Behavior (large-grain material)

- No impact of cool down velocity & mid-T heat treatment on expulsion behavior
- Large impact of spatial temperature gradient:
  - 0 ΔK/Δl: 26 % of magnetic flux expelled
  - 4 ΔK/Δl: 69 % of magnetic flux expelled

Polar distribution of the ratio $|B_{sc}/B_{nc}|$ separately for each sensor group as a function of the cool down velocity and the spatial temperature gradient at an ambient field of 10 μT in vertical direction before- and after mid-T heat treatment. The Θ-labels indicate the card identifier of each sensor board (01 – 47).

Sensitivity to Trapped Magnetic Flux S

- Increase of S by a factor of five after mid-T heat treatment:
- 0 ΔK/ Δl: 3.5 nΩ/µT to 17.7 nΩ/µT; 4 ΔK/ Δl: 3.1 nΩ/µT to 15.7 nΩ/µT



The surface resistance R_s given in the legend was obtained by cubic interpolation for an accelerating gradient of 4 MV/m.

$$S = \frac{\Delta R_s}{B_{trap}}$$

ΔR_s: Increase of R_s per unit of trapped mag. flux B_{trap}

Conclusions

- No significant impact of cool down velocity and mid-T heat treatment on flux expulsion behavior of large grain cavity 1DE26 observed
- Large impact of spatial temperature gradient on flux expulsion behavior: 0 ΔK/Δl: 26 % of mag. flux expelled; 4 ΔK/Δl: 69 % of mag. flux expelled
- Only sensitivity to trapped magnetic flux increased by a factor of five due to mid-T heat treatment: 0 ΔK/Δl: 3.5 nΩ/µT(bef. mid-T) to 17.7 nΩ/µT(aft. mid-T); 4 ΔK/Δl: 3.1 nΩ/µT(bef. mid-T) to 15.7 nΩ/µT (aft. mid-T)

References

[1] B. Schmitz et al., “Magnetometric Mapping of Superconducting RF Cavities”, doi: 10.1063/1.5030509
[2] F. Kramer et al., “Impact of geometry on flux trapping and the related surface resistance in a superconducting cavity”, doi: 10.1103/PhysRevAccelBeams.23.123101

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