Quench Simulation for CEA Magnet with Bruker Cable

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Motivation

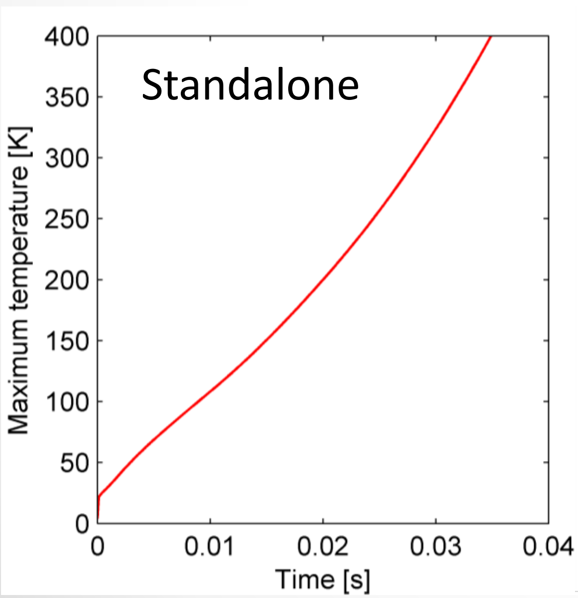
- Update cos-θ quench simulation results to match Bruker tape properties (Cu/Non-Cu = 0.4)
- Model hot spot temperature evolution
- Estimate the needed detection threshold and maximum delays in the protection system application

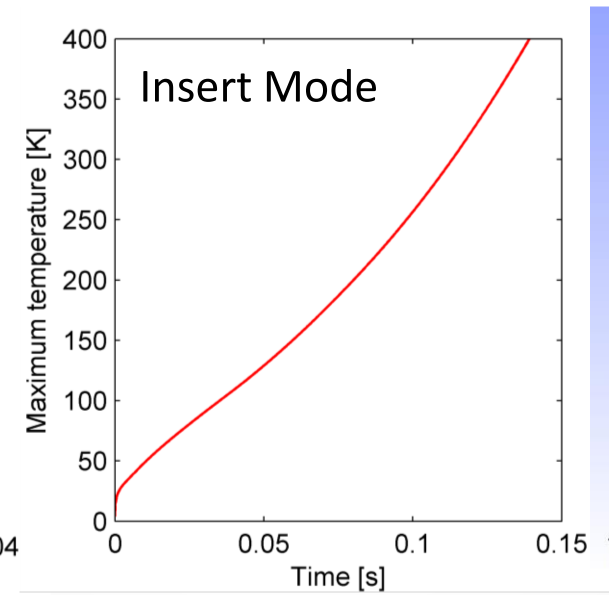
Simulation parameters

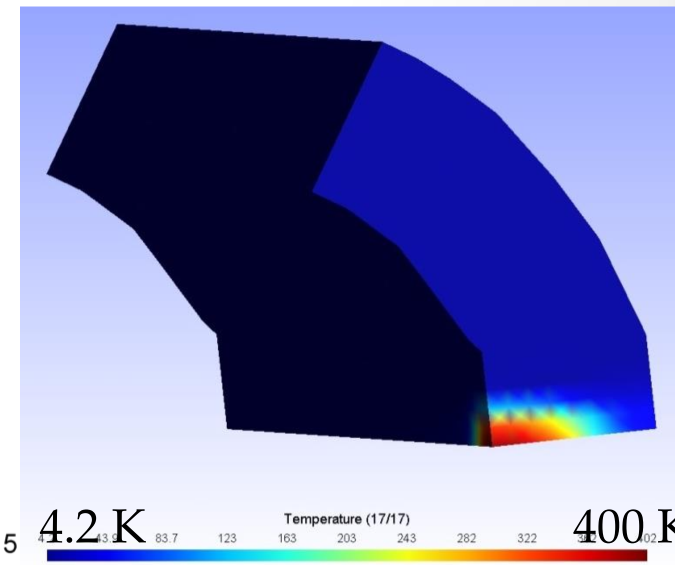
- Operation temperature 4.2 K
- Ic computed using Fujikura fit with C. Lorin modification where α = 3.48 MAT/mm^2
  - Field and its direction accounted at each location to compute min Ic
  - **Standalone**: 14.6 kA -> 20 % Margin leads to **operation current of 11680 A**
  - Cable J_{op} = 810 A/mm^2, Coil J_e = 680 A/mm^2, Copper J = 4100 A/mm^2
  - **Insert mode**: 7.5 kA -> 20% Margin leads to **operation current of 6020 kA**
  - Cable J_{op} = 420 A/mm^2, Coil J_e = 350 A/mm^2, Copper J = 2100 A/mm^2
- L = 0.35 mH
- Cable cross-section: 14.4 mm^2 (bare) 17.08 mm^2 (insulated)
  - Unit Cell with homogenized mat. props.: 17 % Copper, 42 % Hastelloy, rest insulation / impregnation

Hot Spot Temperature

- FEM computation using QueST (Härö et al, IEEE TAS 25(2) 2015)
  - Quench initiated by setting Ic to 0 A at 2.5 cm long hot spot
- Hot spot temperature increases rapidly
  - Standalone: 400 K in **35 ms** (!!)
  - Insert mode: 400 K in 139 ms
    - (How high hot spot temperatures can be tolerated?)

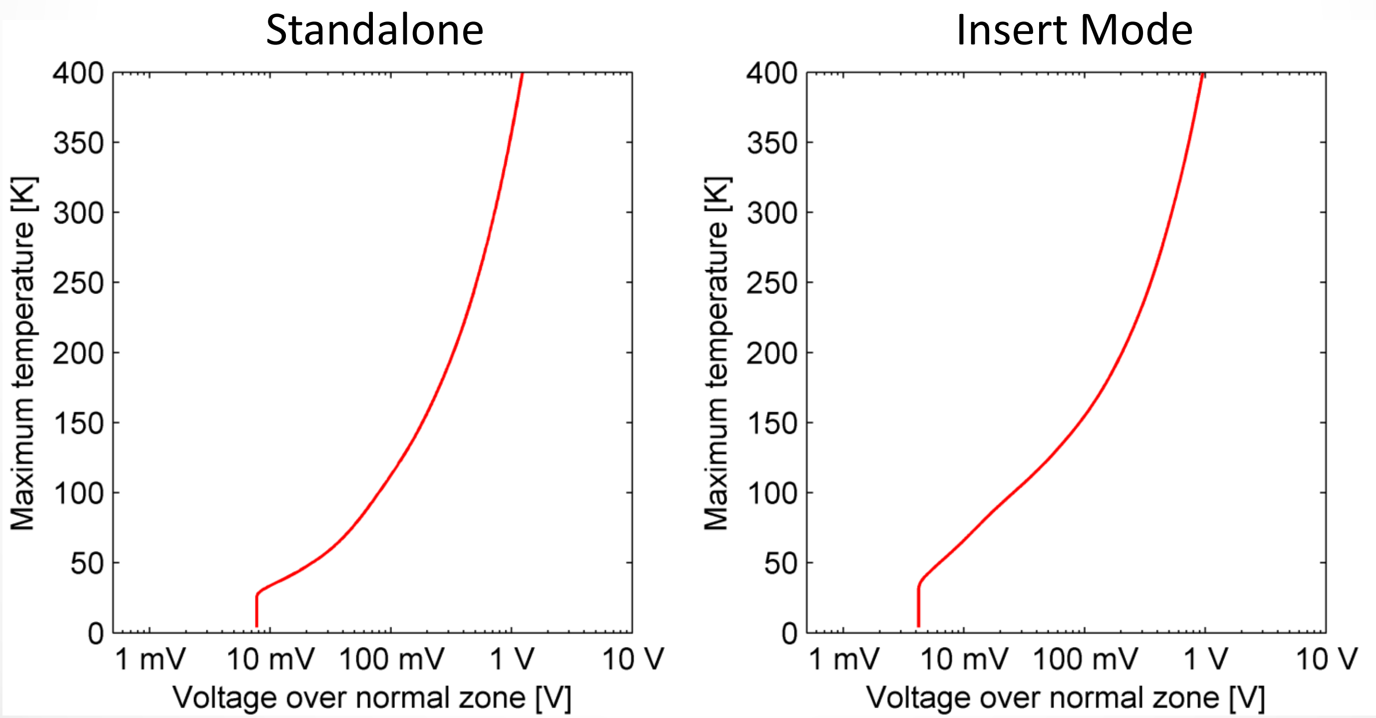






Hot Spot Temperature Related to Voltage

- Quench detection from resistive voltage
  - Standalone: 100 mV at 112 K
  - Insert mode: 100 mV at 155 K
  - Temperature rise is very fast…



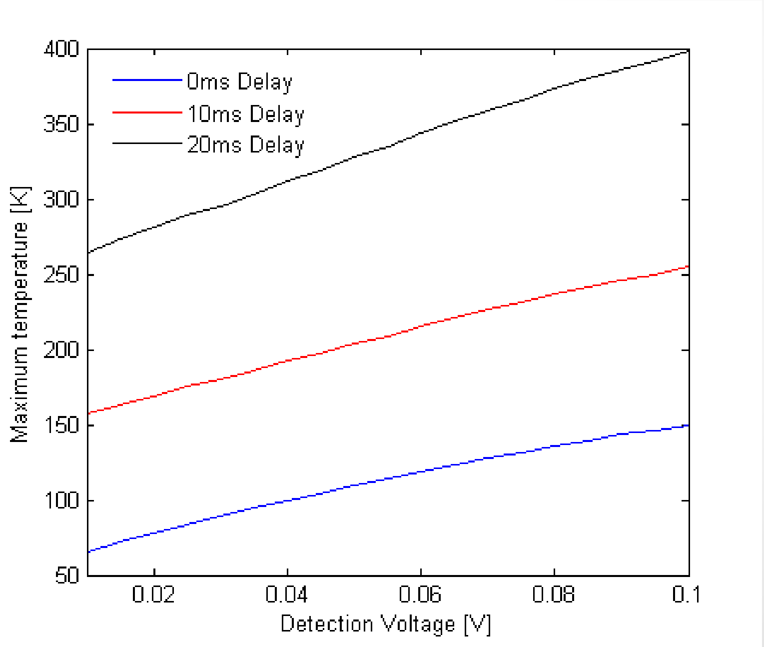
Protection considerations

- What is the maximum **validation+switches delay** between quench detection and dump activation?
- Hotspot temperature at detection depends only on v_{det} (Härö et al., IEEE TAS 23(3), 2013)
  - Quench due to locally degraded Jc, short initial normal zone length
- We computed temperature at V_{det} and the temperature increase during the **validation+switches delay**
  - FEM simulation with QueST
  - Finally, we add the T increase based on the MIITs during the current decay
- Dump resistor sized for 1 kV (@ I_{op})

Standalone

- In standalone I = 11.68 kA -> R_d = 85.6 mΩ
  - Current decay takes ~4 ms (MIITs 0.3, T_{max} increase ~30 K)
- With 0 ms delay: T_{max} is 60 – 150 K
- With 20 ms delay:

  T_{max} range 260 K- 400 K



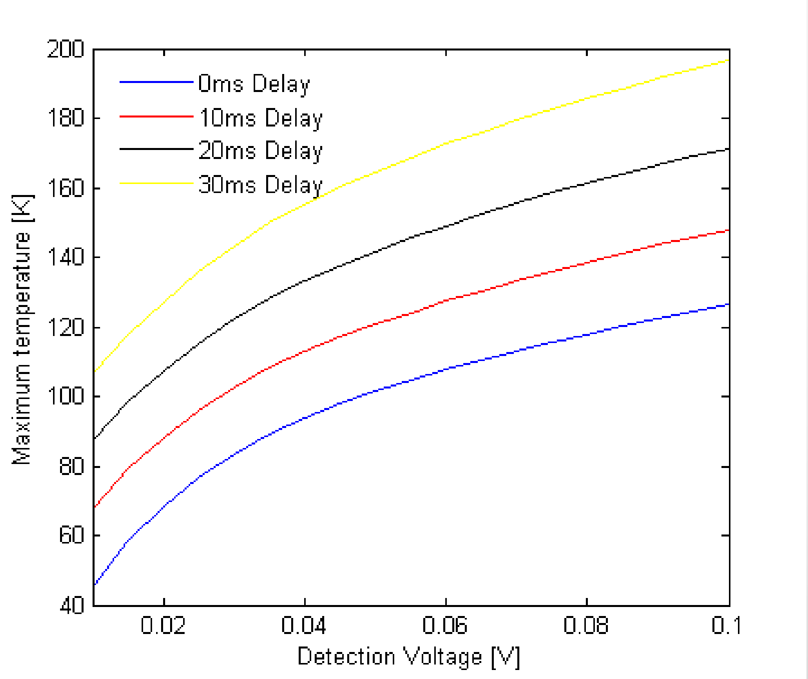
Insert Mode

- In insert mode I = 6020 A -> R_d = 166.1 mΩ
  - Current decay takes ~2 ms (MIITs 0.04, T_{max} increase ~3 K)

- Insert mode operation safer due to lower current density

- T_{max} range 120 K – 200 K when v_{det} = 100 mV

- Below 200 K even with 30 ms delay



Conclusions

- Current decay time is fast with low inductance and large dump
- To stay below 300 K with Bruker cable:
  - Detection at 20 mV + 20 ms delay before dump
  - Detection at 100 mV + 10 ms delay before dump
- Reason to fast temperature increase is high copper current density
  - More copper and less hastelloy would be better
- Insert mode operation safer due to lower J_{op}
- Based on simulations, margins very small… Uncertainties can be critical
  - Need experimental validation for simulated temperatures
- More research needed for longer magnets
  - Current decay will be slower because external extraction not as efficient