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Quench Modelling of HTS magnets in EuCARD^2

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Outline

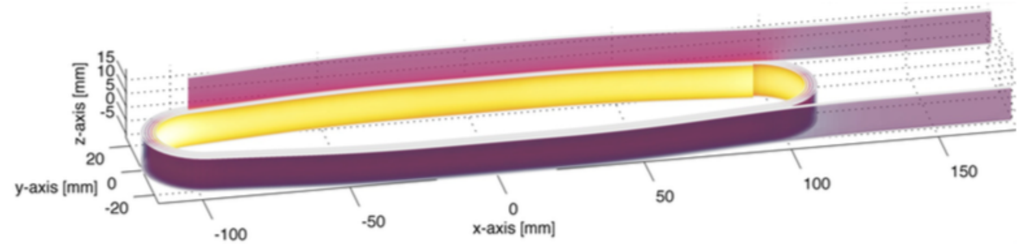
- Introduction
- Feather-M0 quench onset heater design for experimental characterization
- Feather-M2 quench modelling
- Quench in a Cos-θ design in insert use
- Conclusions

- So, we consider three different magnets
  - Feather-M0: for quench detection experiments
  - Feather-M2: for studying HTS technology in acc. magn.
  - Cos-θ: alternative design of Feather-M2

Introduction

- Stability of HTS magnets, cables and tapes is widely documented around 77 K
- Some quench experiments at 4.2 K are available
- Literature lacks information of **high-field low-temperature** stability experiments, especially detection studies, of HTS magnets
- EuCARD^2 project aims to deliver this information aot while keeping eye on future accelerator magnets that are enabled by HTS

Quench onset heater design for Feather-M0



- Max field ~1.5 T
- 5 m (and 5 turns) of 15 tape Roebel Cable

- Inductance 8.16 μH
- Current sharing temperature range within magnet volume 23 K - 52 K at 8.2 kA (73% of SSL at 4.2 K)

- Goal: study quench detection by terminal voltage, ae, pick-up coils, hall probes
- Task: design artificial quench initiation

Quench heater design

- Because of the widespread spectrum of the current sharing temperature, spot heater is not a possibility, **we need strip heaters**

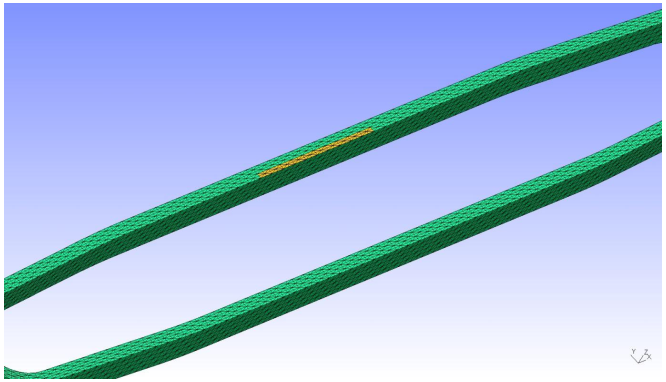
- Three different designs were made based on finite element modelling of quench

- Coil manufacturing is currently ongoing

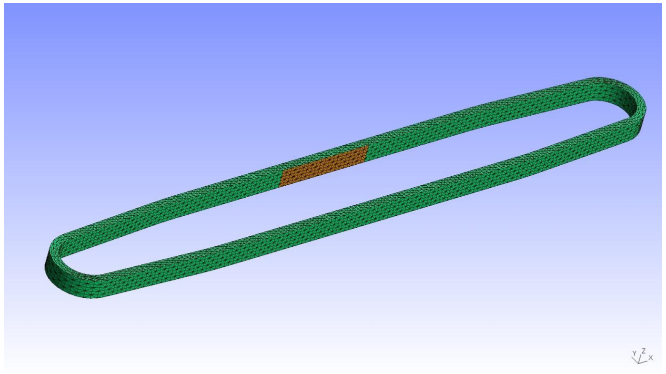
Heater is 100 μm thick ss strip, insulation 50 μm between the heater and the coil, 200 μm between the heater and helium, about 60% of the inserted power have diffused to the coil when the heater is powered off

Current 8960 A at 4.2 K, 900 A at 77 K, 80% of the short-sample I_c

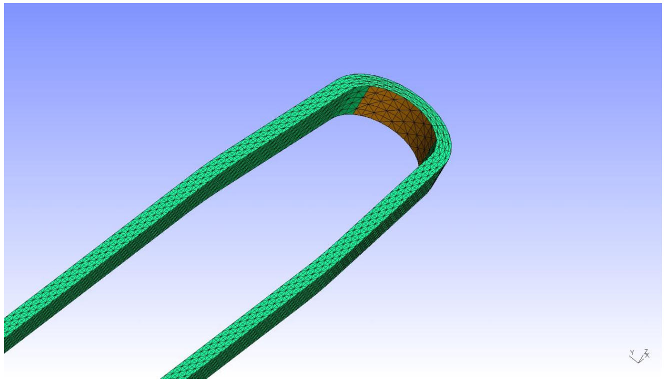
Design 1: two cable thicknesses * 60 mm
@4.2 K: 27 W for 0.5 s, max temperature **88 K**
@77 K: 45 W for 0.5 s, max temperature **143 K**



Design 2: cable width * 60 mm
@4.2 K: 14 W for 0.5 s, max temperature **25 K**
@77 K: 20 W for 0.5 s, max temperature **85 K**

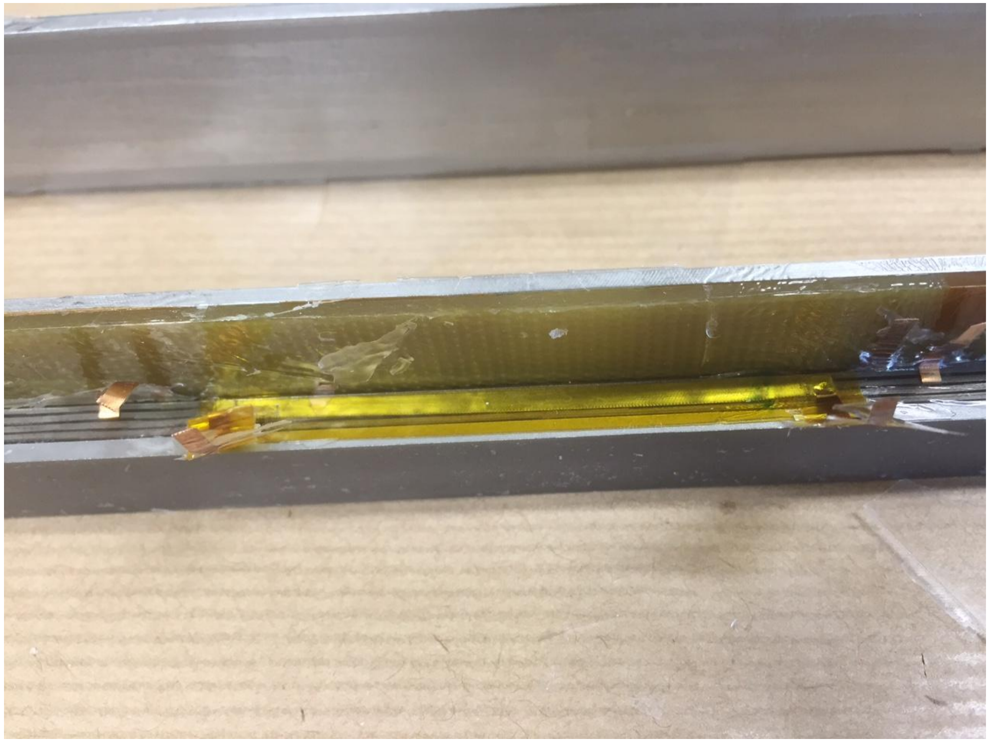


Design 3: cable width * 35 mm
@4.2 K: 24 W for 0.5 s, max temperature **44 K**
@77 K: 17 W for 0.5 s, max temperature **86 K**



Heaters in dummy winding

From Glyn Kirby 00:15 this Wed



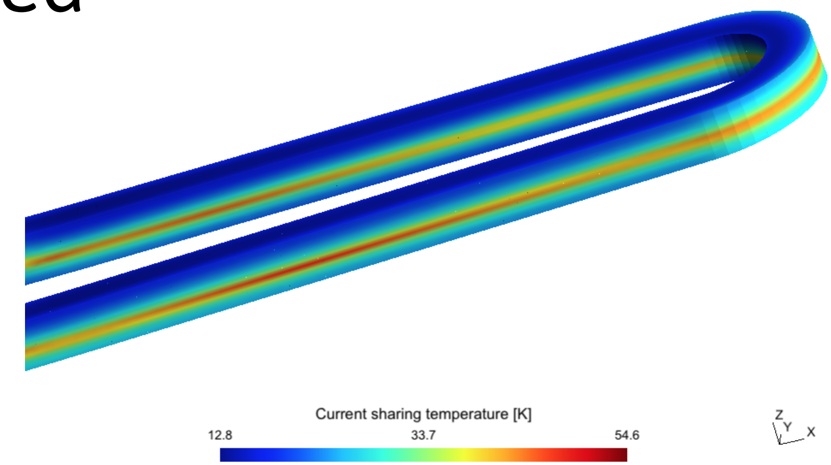
Feather-M2 - Some parameters

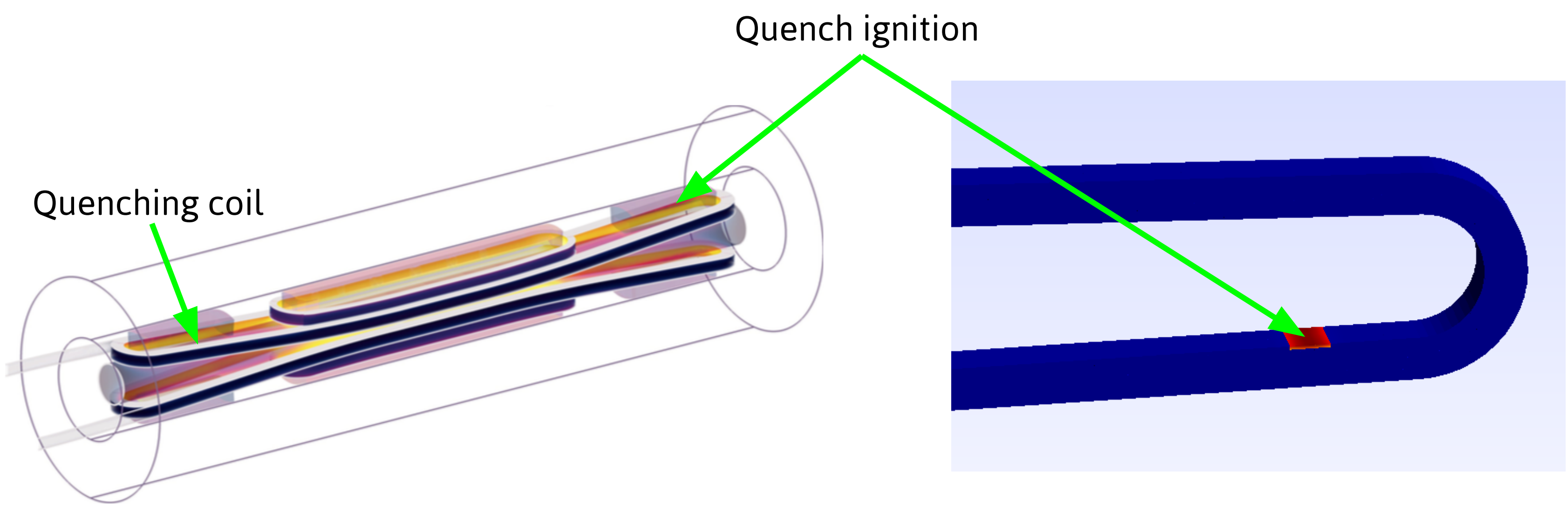
Cable	15 Tape Roebel (Fujikura, Cu 32% of coil unit cell, 44% of cable)
Coil filling factor (inc. cable void)	30 %
Cable length	45 m
Inductance	0.127 mH
Short-sample limit 4.2 K	8900 A
Short-sample limit 30 K	5500 A
Short-sample limit 77 K	870 A
Considered currents	0.8 SSL (1800 A/mm^2 in copper at 4.2 K)
Terminal voltage limit	1 kV
B max at 4.2 K and 0.8 SSL	5 T
Dump resistor resistance	112 mΩ
Current decay time to 10%	2.6 ms

It is enough to study the time before the current starts to decay

Feather-M2 - Quench simulation

- Ignite quench with reduced critical current
- Thermally isolate other coils
- Stop simulation at 400 K
- Homogenized mat. prop.

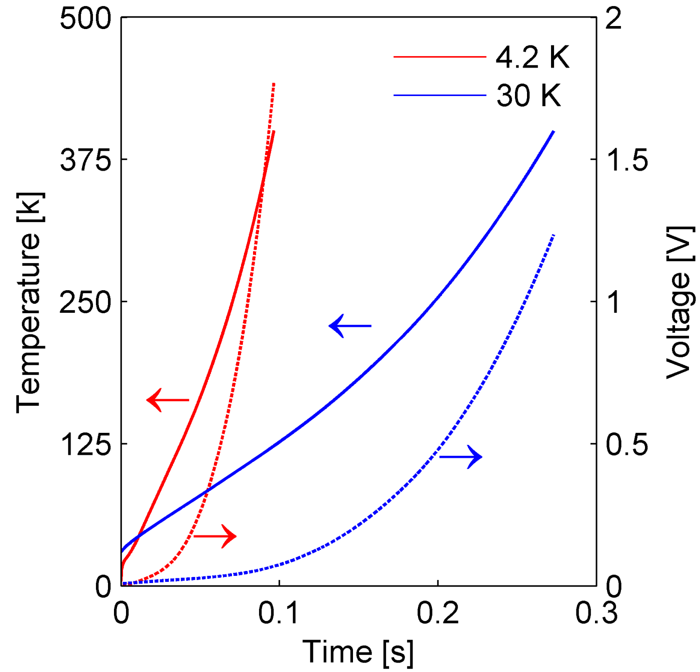




Feather-M2 - Quench simulation results

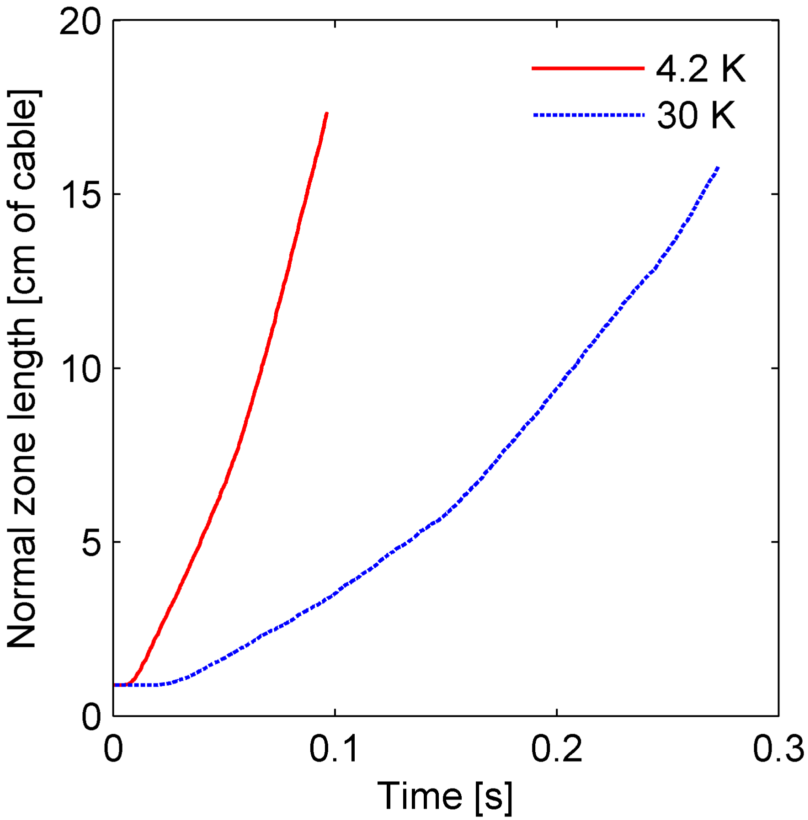
- Max dT/dt very high: 65 000 K/s at 4.2 K, 2400 K/s at 30 K

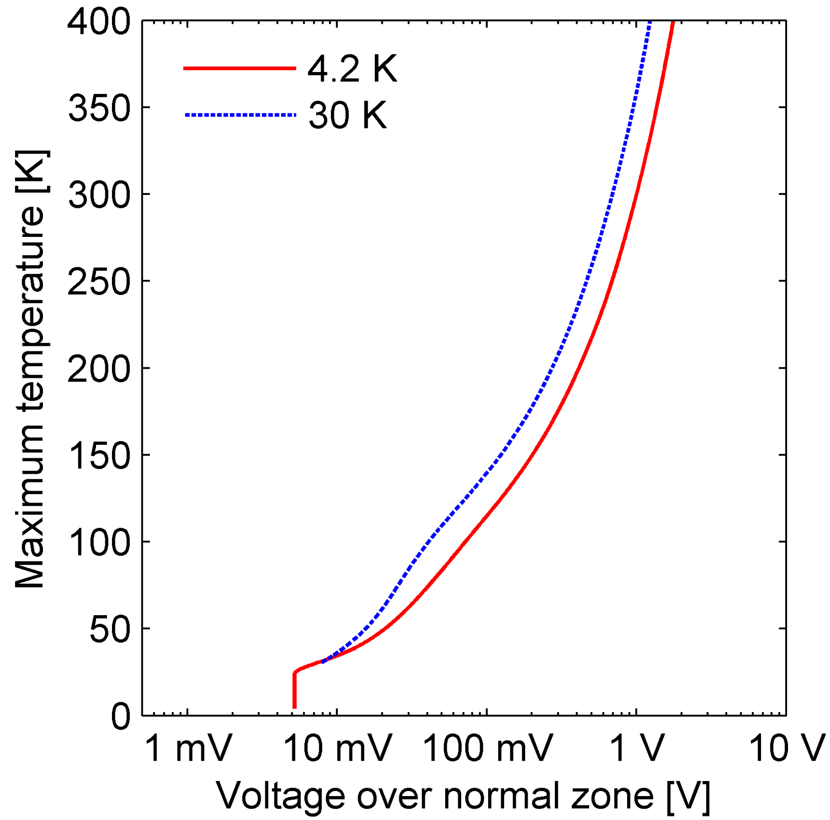
Threshold voltage	Time to operate (4.2 K)	Time to operate (30 K)
10 mV	72 ms	222 ms
30 mV	63 ms	170 ms
50 mV	56 ms	140 ms
100 mV	46 ms	110 ms



Time to operate corresponds to time it takes from the given voltage to 300 K, and thus does not mean the actual time that can be spent before doing anything. Key point: current decay time - 2.6 ms - is negligible.

Normal zone propagated less than 20 cm before 400 K was reached



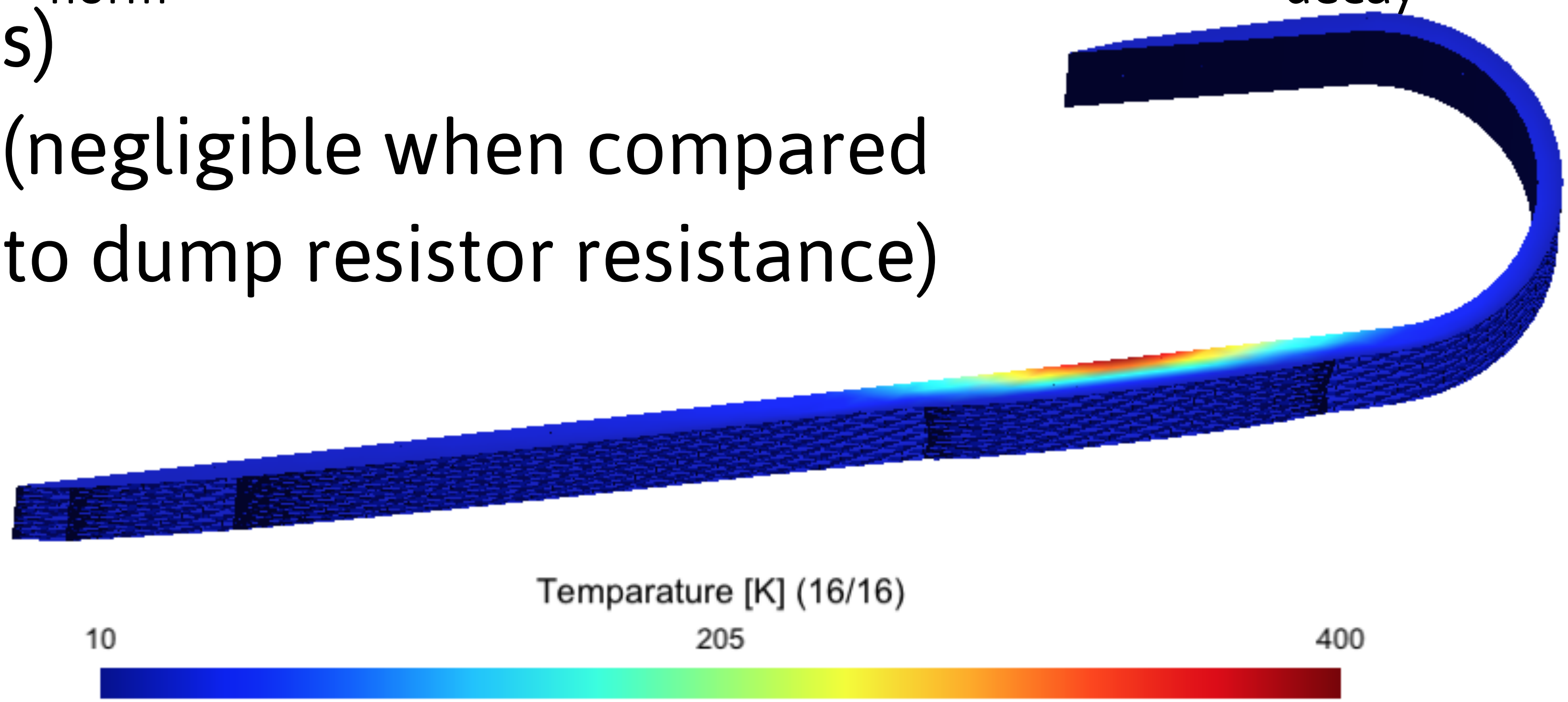


Temperature increase was very localized

Only volume where *T*>10 K is shown

R_{norm} reaches about 0.2 mΩ at 400 K (t_{decay}=1.5 s)

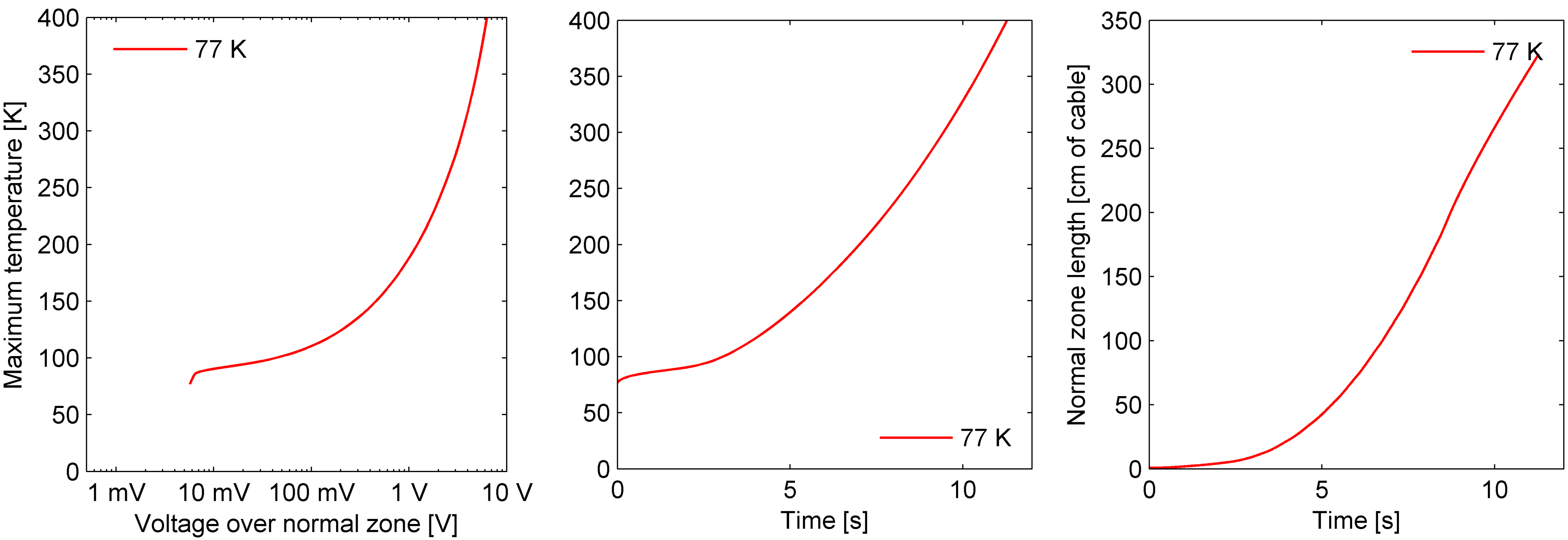
(negligible when compared to dump resistor resistance)



Quench at 4.2 K

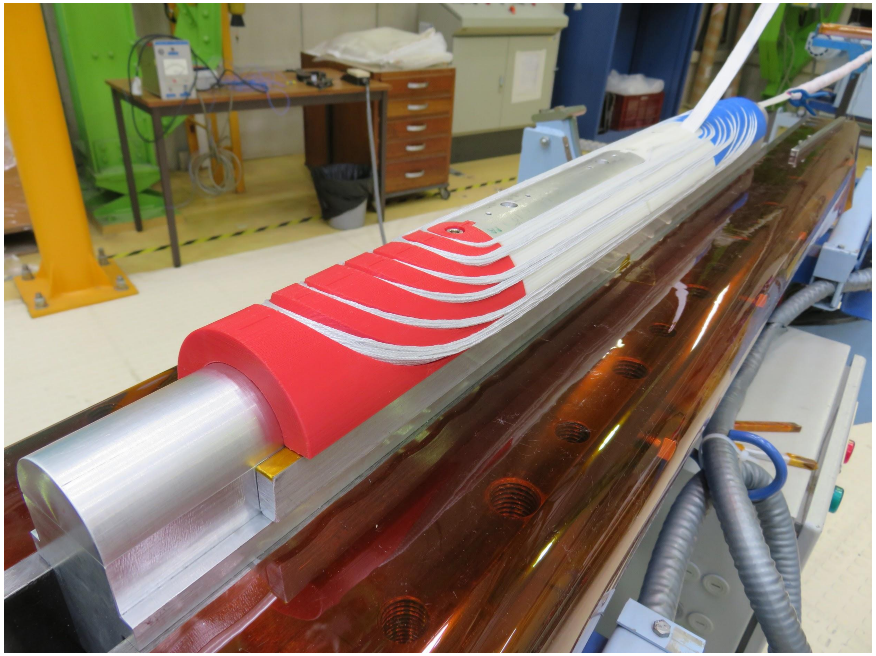
Feather M2 - A quench at 77 K

- Quench at 690 A (< 10 % of I_{op} at 4.2 K)
- Lot of time to react, but can we learn anything about quench? Yes: proceed step by step towards lower *T*

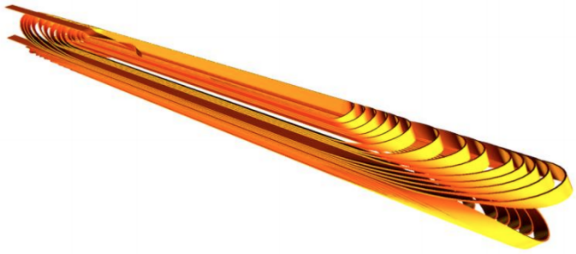


Quench modelling of a Cos-θ magnet

- We considered quench only in the straight part of the magnet when the magnet operates inside FRESCA-II at 4.2 K and 13 T
- Aim: Fully discharge insert before FRESCA-II



Dummy winding of the coil (Maria Durante, CEA)



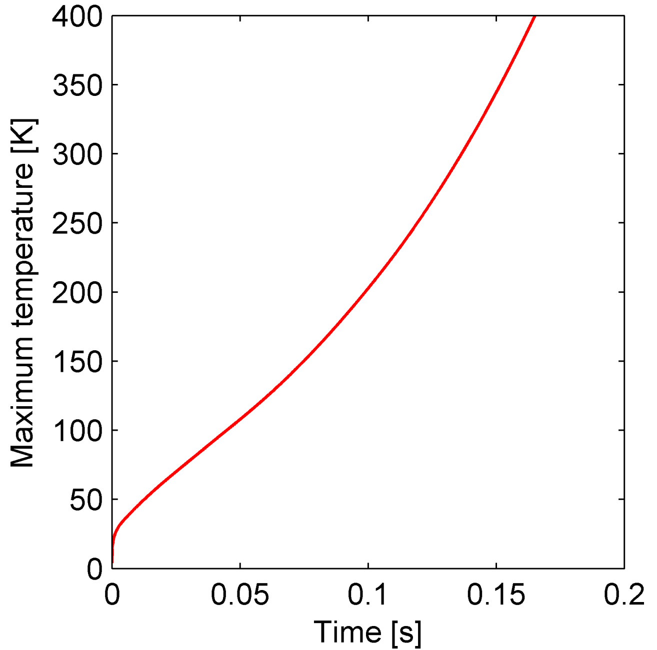
A Quench study of Cos-θ magnet

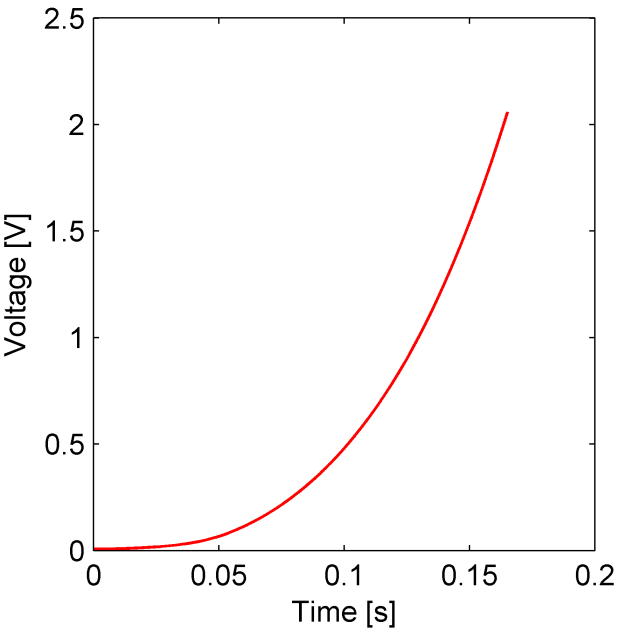
Main coil parameters for the analysis

Cable	15 Tape Roebel (Bruker I_c, but Feather-M2 material proportions)
Inductance	0.35 mH (3 times that of FM-2)
Short-sample limit at 4.2 K and 13 T background field	9400 A
Quench current	7500 A (1320 A/mm^2 in copper)
Terminal voltage limit	1 kV
Dump resistor resistance	106 mΩ
Current decay time to 10%	7.6 ms (3 times that of FM-2)

Quench simulation results

- Quench simulations followed similar procedure as with Feather-M2
- Time to operate 120 ms (10 mV), 100 ms (30 mv), 92 ms (50 mV), 79 ms (100 mV)





Conclusions 1

- In low inductance HTS magnets the most important issue related to the quench is the **detection**
- For quench experiments, strip heater may be wise choice for ignition
- At low temperatures, the current densities are high, cable includes a lot of non-stabilizing material (substrate) and $\mathrm{d}T/\mathrm{d}t$ can be very high → only few tens of ms to operate
- Only small volume of the coil quenches passively before it is too late

Conclusions 2

- When an HTS coil is operated in insert mode, a reasonable protection method to study is to discharge the insert before the outsert and put it open circuit
- In insert mode, the operation of an HTS coil is slightly safer because of the reduced operation current
- 77 K is perhaps not feasible for studying quench experimentally at safer environment, but 30 K could be, still step-by-step to safety

Thank you for your attention

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