Quench in high field YBCO insert dipole

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Outline

- Overview of the case: Nb_3Sn-YBCO hybrid dipole magnet in EuCARD project
- Starting points
- Insert quench simulations
- Considerations on insert protection scheme
- Uncertaintities / difficulties / future work
- Conclusions

Overview of the case

- YBCO magnet producing 6 T will be inserted into the bore of FRESCA II (previous presentation), maximum field will be 19 T at 4.2 K
- Insert consists of six racetrack coils (3 double pancakes)

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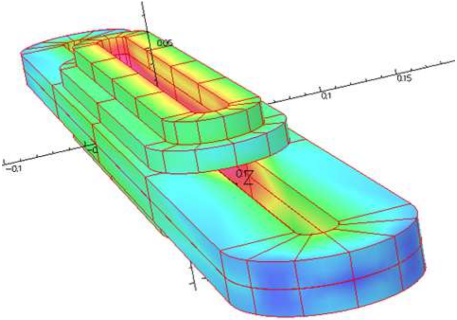

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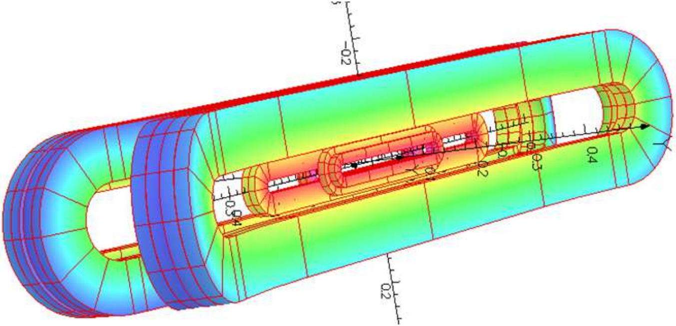

Old design of FRESCA II

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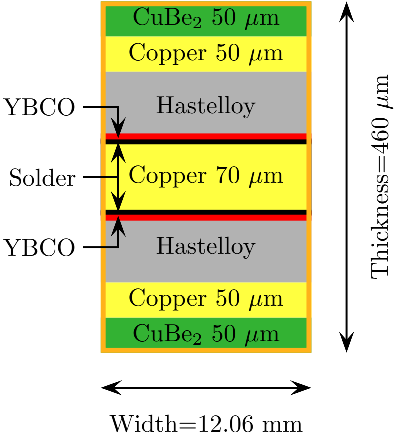

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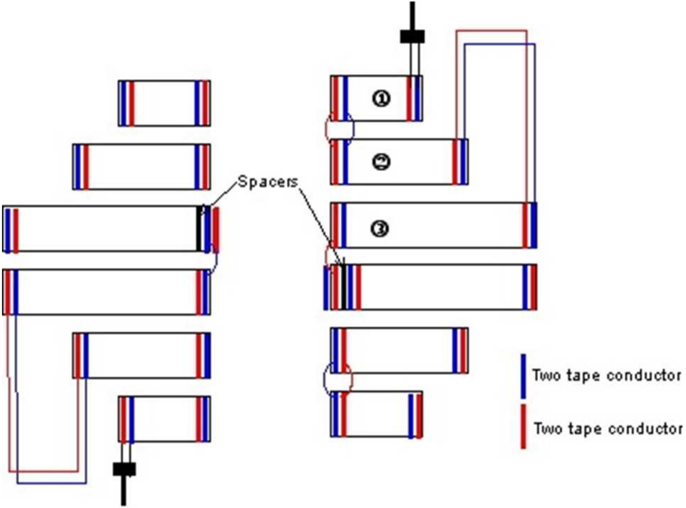

Overview of the case

- Insert
  - inductance: 4 mH
  - operation current: 2800 A
  - self-energy: 15.7 kJ
- FRESCA II
  - inductance: 64 mH
  - operation current: 10500 A
  - self-energy: 3.53 MJ (225 × that of insert)
- Mutual inductance 9.3 mH
  - total energy 3.68 MJ
  - mutual energy 8.7 × that of insert
- Maximum insert terminal voltage 800-1000 V
  → maximum dump resistor 0.29 Ω

Starting points

- FRESCA II is the big guy, we focus only on the quench simulations of the insert and how to protect it and the influence of protection on FRESCA II
- We need to know how quench evolves in insert → simulate quench
- We need to know how fast we can discharge the insert and what is its influence on the FRESCA II → do simple circuit simulations

FEM quench simulations of HTS magnets

Simulating quench in an HTS magnet

- HTS magnets don't want to quench easily, at least in simulations. Options for triggering quench
    1. Quench the coil with a heater → unrealistic temperatures in the hot spot in the beginning
    2. Force critical current to some value below I_c in some region → if region is too small, there are several seconds to quench → long simulation times

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- Quench doesn't propagate to the whole coil → don't simulate the whole coil (quench can also be difficult to detect, especially at low currents)
- How to get critical current characteristic for such a cable? Did anyone ever measure $I_c(B, T, \theta)$ over a wide range of parameters? If you buy new batch of tape, has it similar properties than the samples? → we used certain approximation for I_c.

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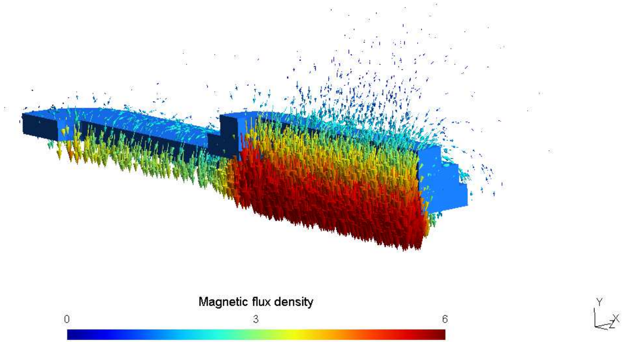
  - All solvers (including matrix assemblers) are built by us in C++ with help from many GNU licensed libraries.
  - We can separate the magnetic problem from the thermal (at least the meshes), and also combine if needed. We are free to build in FEM software what ever we need – within the limits of time (and money).

Simulation results

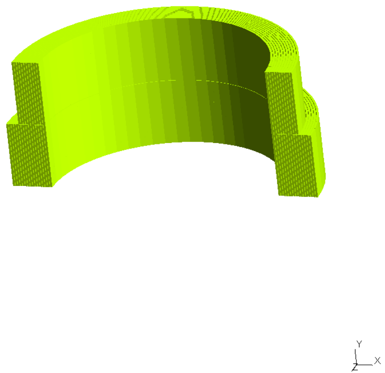
Step 1: compute field distribution (for I_c computations add the contribution from FRESCA II)



Simulation results

Step 2: simulate quench without any detection, terminate when $T_{hot\ spot} = 400$ K, now circuit simulator wasn't included due to low inductance

- Mesh



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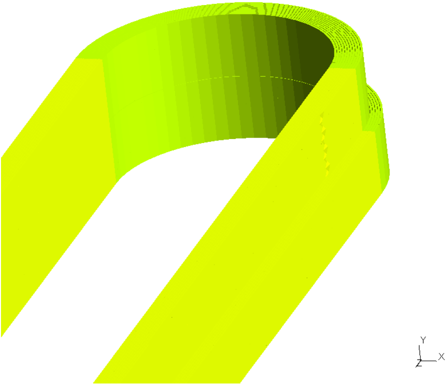

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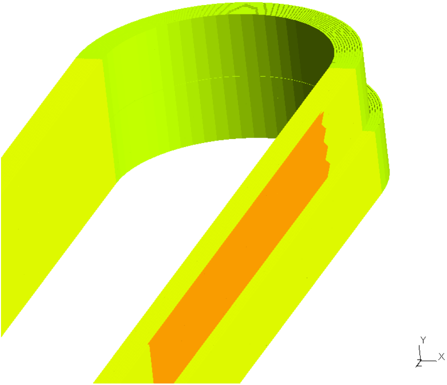

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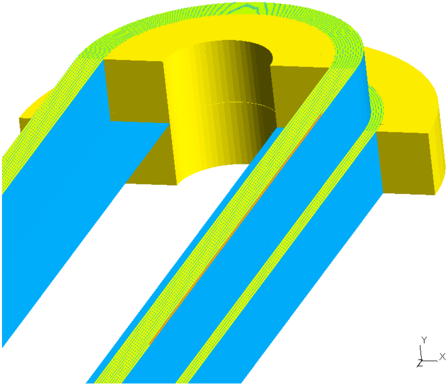

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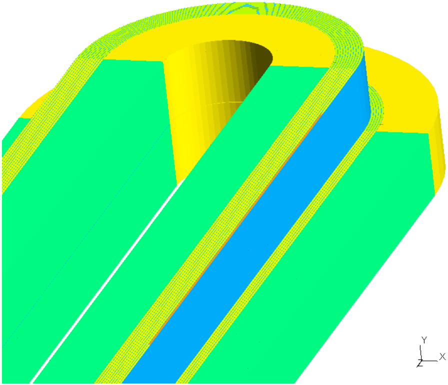

Simulation results

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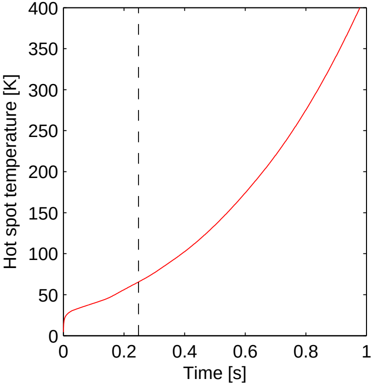
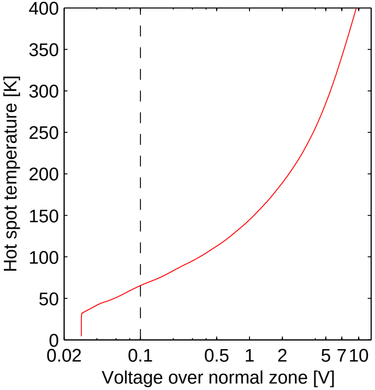
Step 3: determine when detection threshold voltage (100 mV) is reached, how normal zone propagetes etc

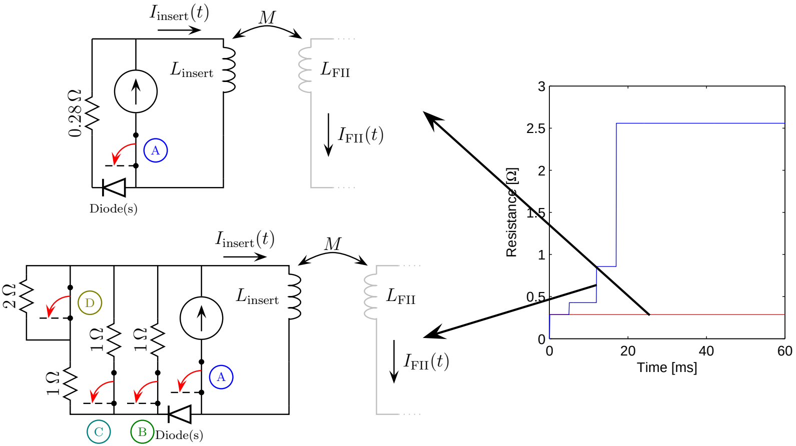




Simulation results

Step 4: Circuit simulations

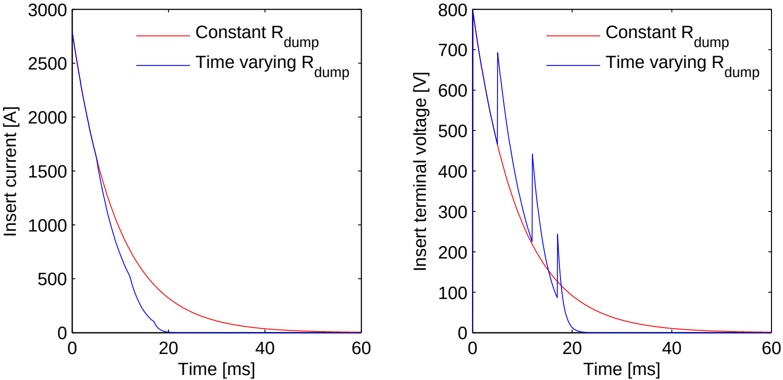
- Possible protection circuits



Simulation results

Step 4: Circuit simulations

- Insert fast discharge



Simulation results

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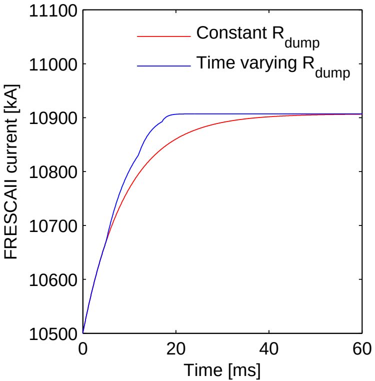
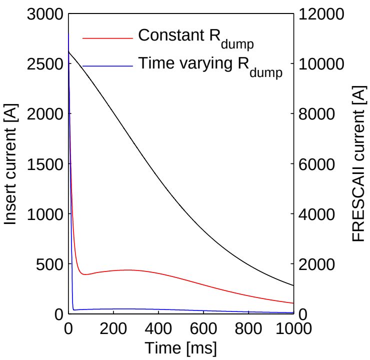
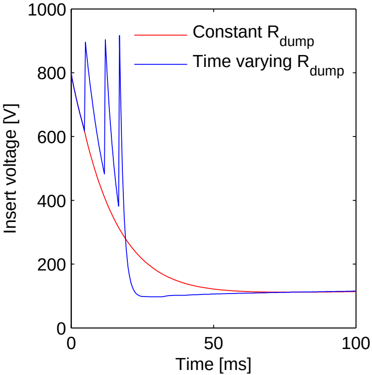


Simulation results

Step 4: Circuit simulations

- FRESCA II quench and insert dischange

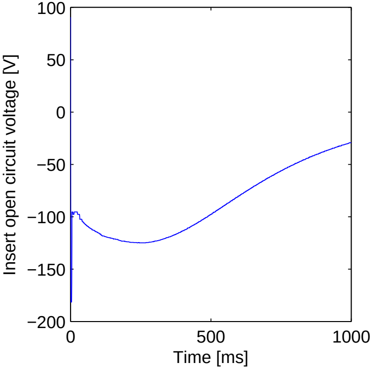




Simulation results

Step 4: Circuit simulations

- FRESCA II quench while insert in open circuit



Simulation results

Step 5: conclusion (not a new one): this small coil can be protected with only a dump resistor BUT

- How could we discharge the magnet as fast as possible and what is the influence of this to the PSU of FRESCA II?
- Option to consider: if FRESCA II quenches, could we first discharge insert and then activate the quench protection of FRESCA II? How to include the PSU of FRESCA II to simulations?
- Protection of very large HTS magnets is much more difficult: margin to T_{cs} is high → effective quench heaters cause problems

Discussion - open questions

- How to get reliable scaling law for $I_c(B, T, \theta)$?
- How difficult is it to protect HTS magnets having large stored energies?
- What is the influence of AC-losses during quench in such a wide coated conductor?

Summary

- YBCO insert magnet in EuCARD project was introduced
- Quench in the magnet was studied
- Possible protection schemes for the insert were considered
- Open questions were presented

Thank you for your attention

You can find this presentation and summarizing paper also from my home page
`http://antti.stenvall.fi`