Study of the HTS Insert Quench Protection

M. Sorbi and A. Stenvall

INFN Istituto Nazionale di Fisica Nucleare

UNIVERSITAS STUDIORUM MEDIOLANENSIS

TAMPERE UNIVERSITY OF TECHNOLOGY

HFM-EuCARD, ESAC meeting, WP 7.4.1

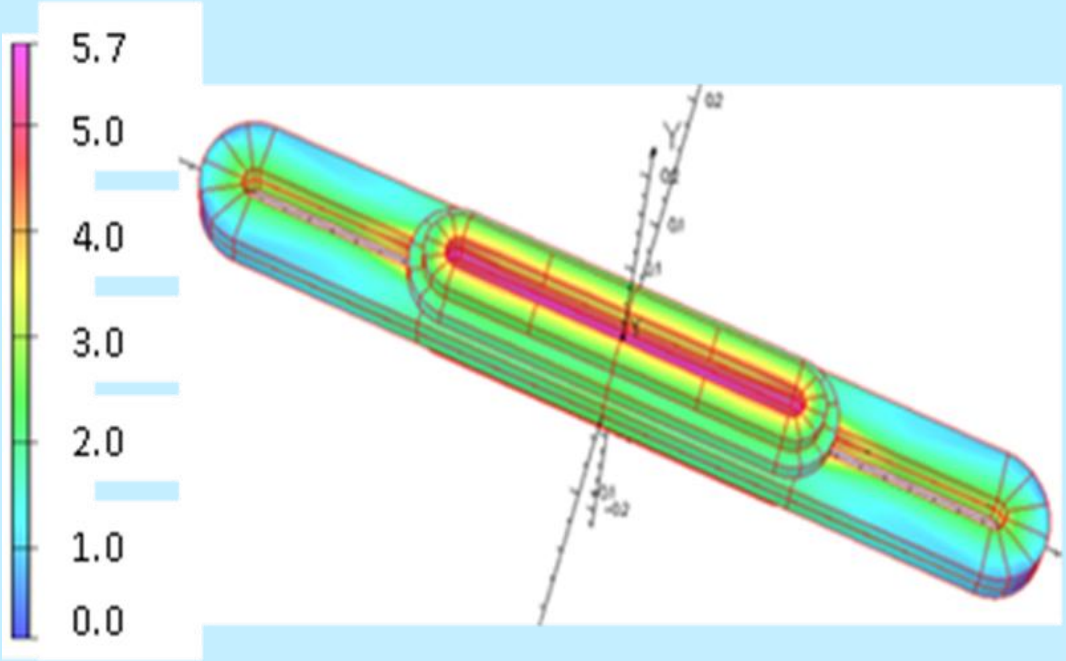
CEA Saclay 28 feb. 2013,

-The study has been executed in parallel with a classical analytical code (LASA-INFN) and a F.E. code (Tampere University)

- Different scenario have been analysed:

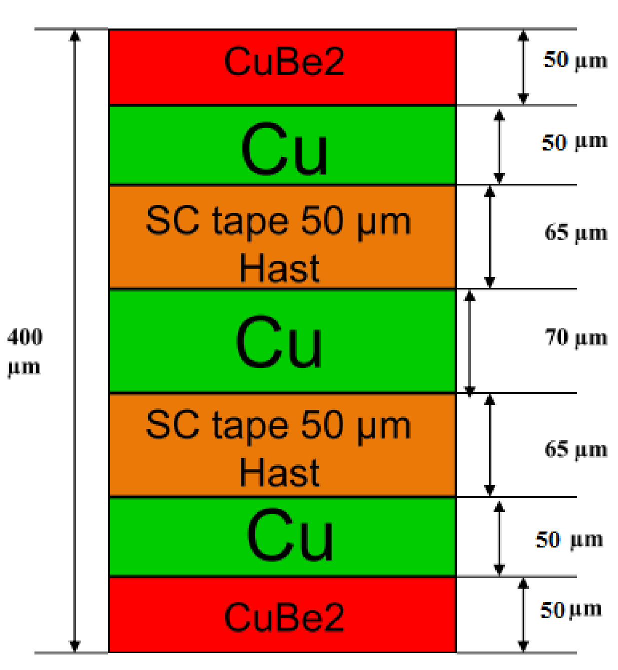
  - Insert tested alone
  - Insert tested inside Fresca (with different options for the sequence of discharge of the two magnets)

-The insert is supposed 0.7 m long, with a total stored energy of 16 kJ (when alone)



-The conductor is composed by 2 YBCO-SC tape, 12 mm wide, soldered with pure Cu and with CuBe2. The insulation is 0.03 mm thick (kapton).

-Actually the current (2800 A), is shared between 2 of this insulated conductor, in order to reduce the inductance.



Superconductor+Cu+CuBe2

Protection parameters of insert

Maximum voltage (V_{max})	800 V
Dumping resistance (R_d)	0.286 Ω
Time constant ($\tau_i = L/R_d$)	14 ms
Voltage threshold for QDS (V_{qds})	100 mV
Delay time after $V=V_{qds}$ (t_d)	50 ms
Insert inductance	4 mH
Fresca 2 inductance	98 mH
Mutual inductance	9.3 mH
Insert nominal current	2800 A
Fresca 2 nominal current	10500 A
Insert stored energy (alone)	16 kJ
Fresca 2 stored energy (alone)	5400 kJ
Coupling stored energy	273 kJ

Analysis with QLASA

- The material properties are taken from internal library MATPRO.
- The electrical properties of CuBe2 have been substituted with BRONZE properties (very similar)
- The quench velocities are calculated with the Wilson analytical approach

Material content in the unit cell for quench calculation

	Insulated conductor
Copper	31.9%
Bronze (CuBe2)	26.5%
YBCO	6.5%
Stainless steel	21.6%
Kapton	13.5%

- The uncertainness of the quench calculation with analytical approach for HTC Supercond. is well known.
- Actually any approach has limitations, because also the critical temperature surface is not well known at 4.2 K
- However, the uncertainness affects only the detection time of the quench. Thus FEM simulations were also performed to give more confidence in this.
- After the detection, the rapid discharge of the current assures that most of the energy is extracted
- The coil resistance is negligible respect to the dumping resistance, so the discharge is independent by quench velocity.

First scenario: insert alone

-The threshold resistive voltage is reached after about 220 ms, and the main switch opens after 50 ms

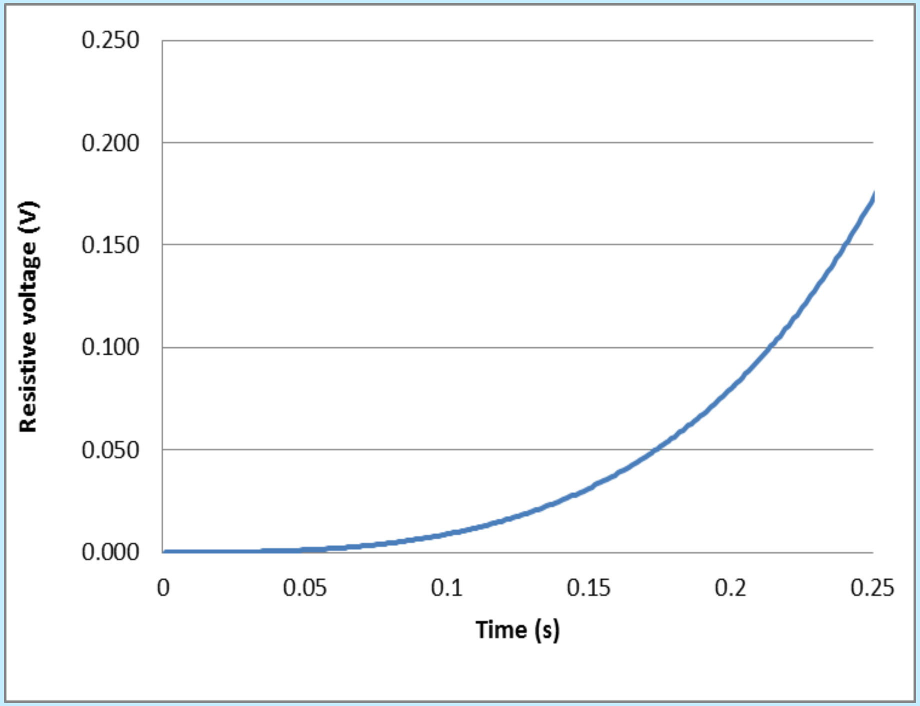
-Most of magnet energy is extracted (30-40 ms after the opening of the power supply switch) because the constant time is very low (τ_i = 14 ms)

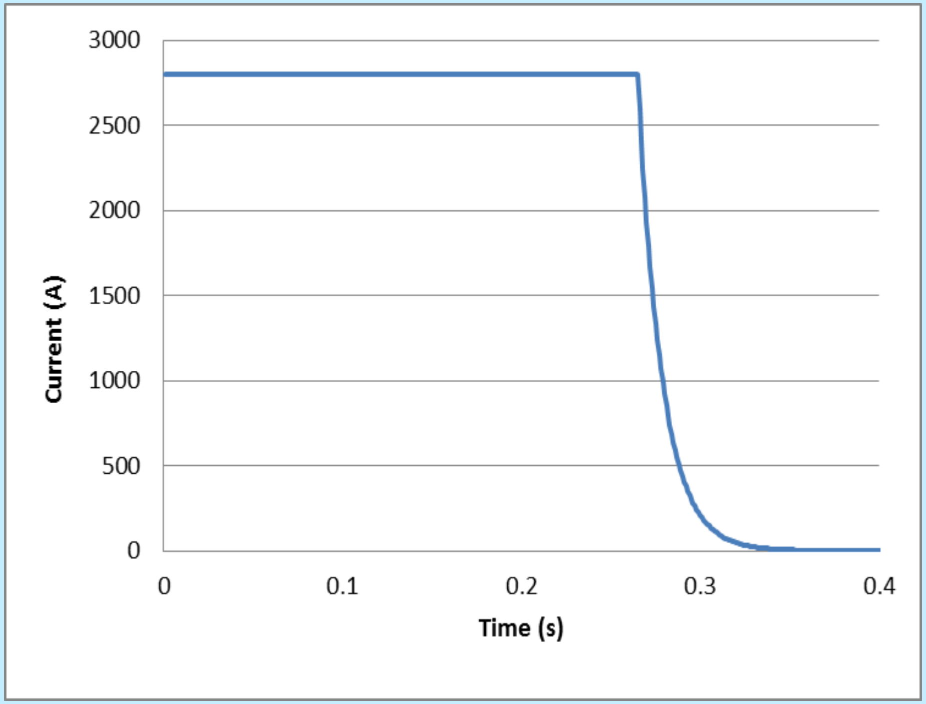
-The quench propagation velocity calculated with "Wilson" analytical formula is not so critical, because almost all the energy is extracted

-The hot spot temperature is about 95 K

-Conclusion: the discharge is "safe"!

First scenario: insert alone





Resistive voltage and current decay of the insert “alone” during a fast discharge for quench

Initial longitudinal quench speed (v_l)	21 cm/s
Initial “radial” quench speed (v_r)	1.6 cm/s
Initial “axial” quench speed (v_h)	4.6 cm/s

Second scenario: insert inside FRESCA 2

-The dumping resistance of Fresca is supposed 76.2 mΩ, corresponding to a maximum voltage of 800 V during the discharge.

-The insert quench velocity results higher respect to the previous case, because of the increased value of the magneto-resistivity (Bpeak=19 T).

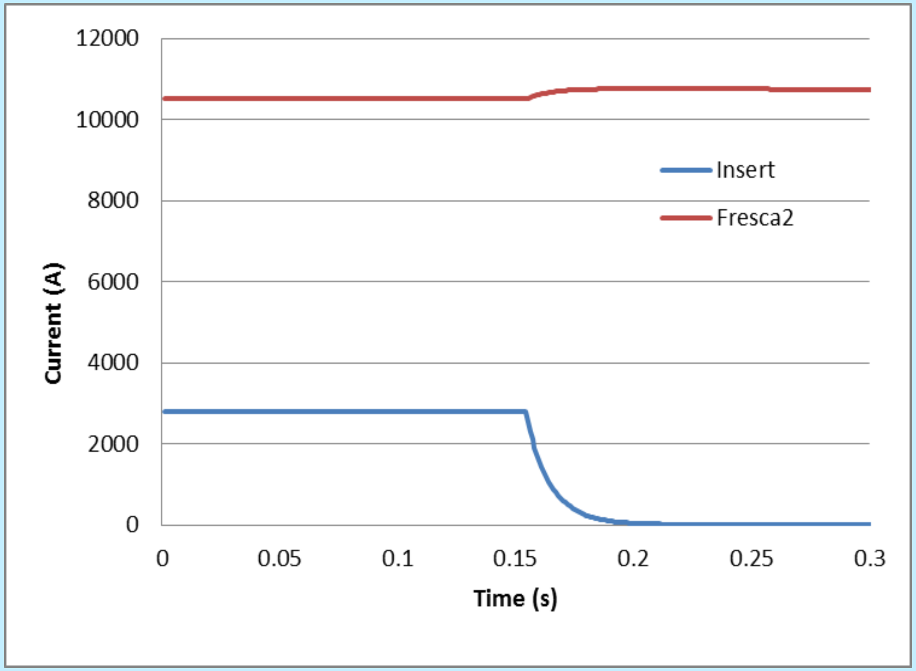
-The results depends by the following situations:

1. A quench with fast discharge for the insert without a discharge for the Fresca dipole

2. A quench with fast discharge for the insert with a fast discharge also for the Fresca dipole

1 - Quench with fast discharge for the insert without a discharge for the Fresca dipole

- Some extra current is induced in the Fresca dipole
- The peak reverse voltage across the Fresca power supply is about -19 V (maybe dangerous for power supply).
- The peak of the current in Fresca is 10755 A, i.e. 255 A above the nominal value of 10500 A.



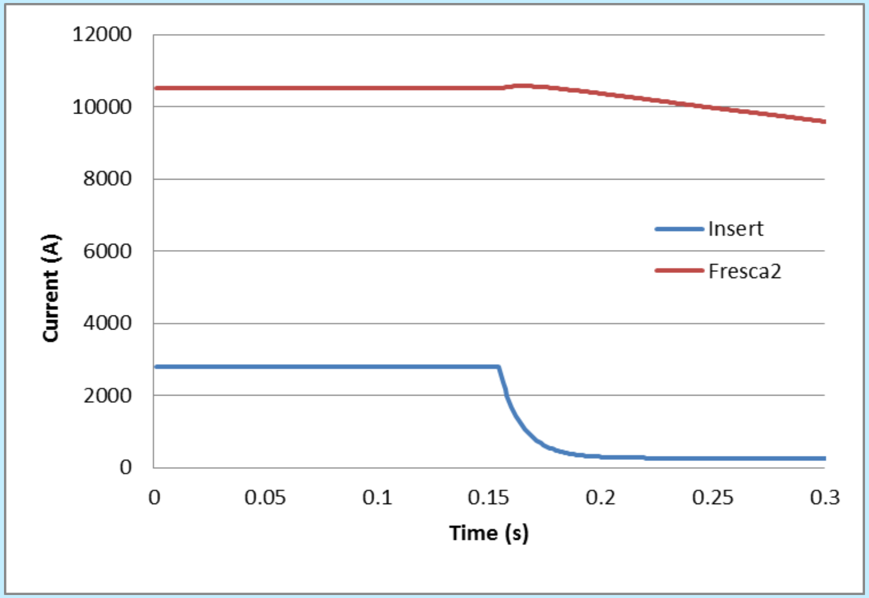
If Fresca does not quench for the current bump, the current decay follows Fresca constant time $\tau = 1.3$ s

1 - Quench with fast discharge for the insert without a discharge for the Fresca dipole (continued)

- The quench detection time is shorter because the field in the insert is higher
- In principle the insert could benefit from the energy trasfert to Fresca 2
- The hot spot temperature is about 75 K
- However the situation is to be considered two dangerous for the Fresca circuit

2 - Quench with fast discharge for the insert with a discharge for the Fresca dipole

- When a quench is detected in the insert, a fast discharged is triggered both to the insert and to the Fresca dipole, with the same delay time t_d=50 ms.
- A small bump of current is induced in Fresca 2 (ΔI=67 A)
- At the end of insert rapid discharge, some small current remain in the insert

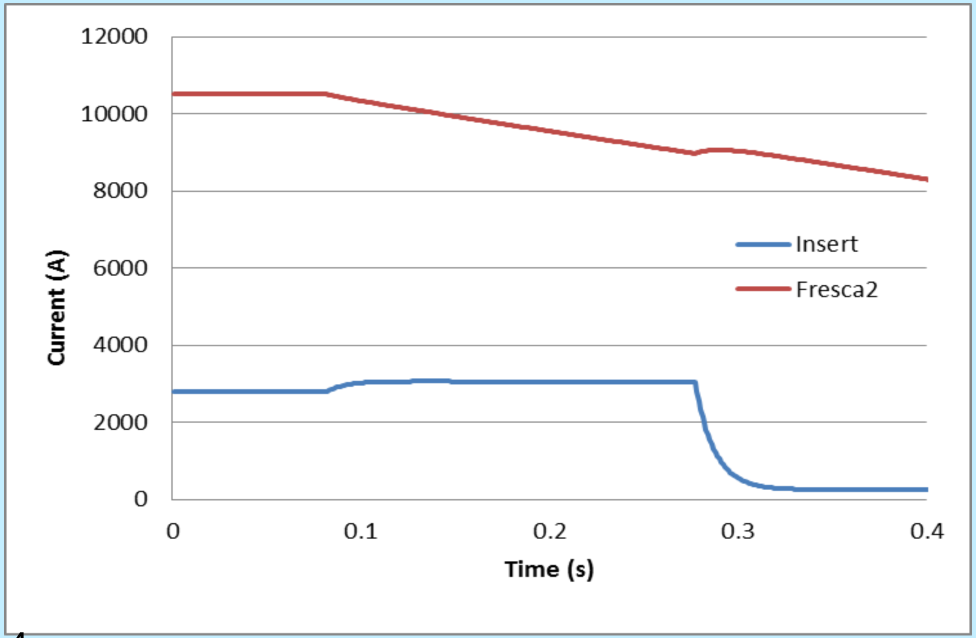


- The insert hot spot temperature is 75 K

Third scenario: quench of FRESCA 2

-In this scenario we suppose a rapid discharge of FRESCA 2 without a dump of the insert

- A current bump of 260 A is induced in the insert: likely the insert would quench (as in the simulation).



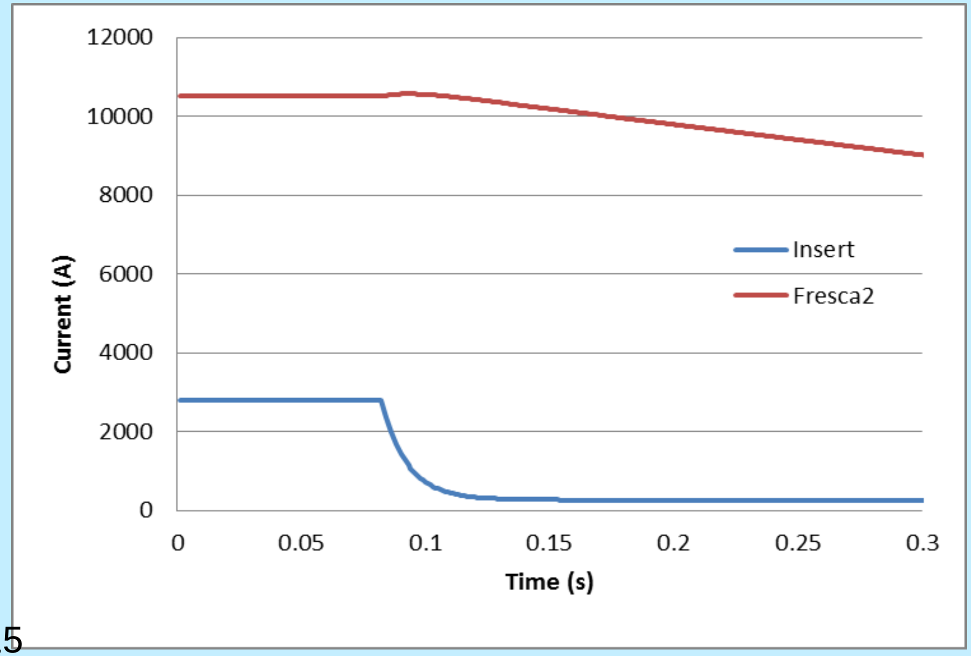
- The insert hot spot temperature is 85 K

- The peak reverse voltage in the insert power supply would be -78 V

Third scenario: quench of FRESCA 2 (continued)

-In case of a rapid discharge of FRESCA 2 <u>with</u> a dump of the insert

- A small current bump of 66 A is induced in Fresca.



- The insert could quench for the rapid discharge.
- Any case the insert hot spot temperature would be very low

Summary of interaction with Nb_3Sn dipole

Scenario	Insert $T_{hot\ spot}$ (K)	Remark
Insert quench **No** Fresca discharge	77 K	$V_{fresca\ p.s.}$ = - 19 V **ΔI_{fresca} = + 255A**
Insert quench Fresca discharge	77 K	ΔI_{fresca} = + 67 A
Quench Fresca No insert discharge	85 K	**$V_{insert\ p.s.}$ = - 78 V** **ΔI_{Insert} = + 260 A**
Quench Fresca Insert discharge	< 70 K	ΔI_{fresca} = + 67 A

FEM simulations

• Purpose: verify that hot spot temperature isn't too high at the time of detection like the QLASA simulations predict.

•Due to the low inductance and energy, discharge can be performed rapidly to the external circuit. Thus, no protection circuit was used, but only quench onset was studied.

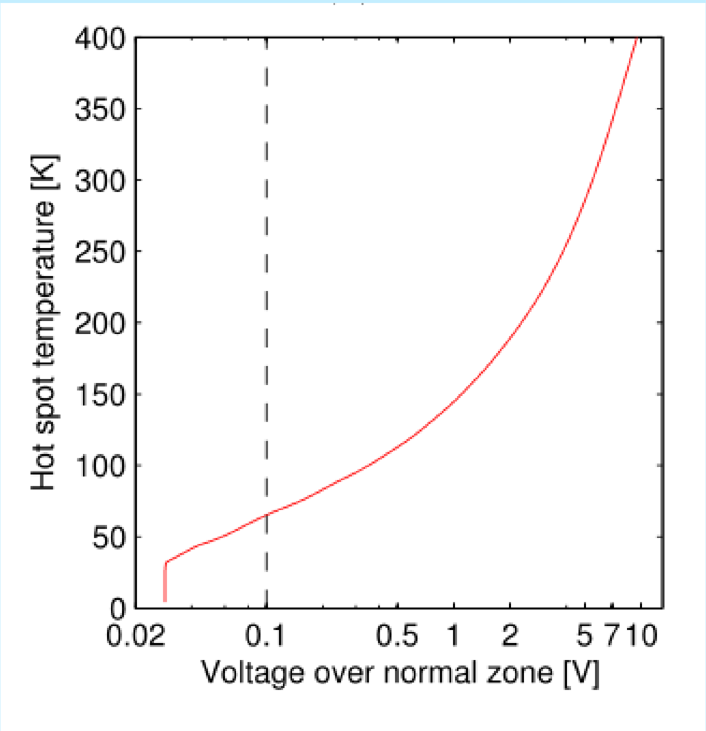
•Current was kept constant and simulations were terminated when the hot spot temperature reached 400 K.

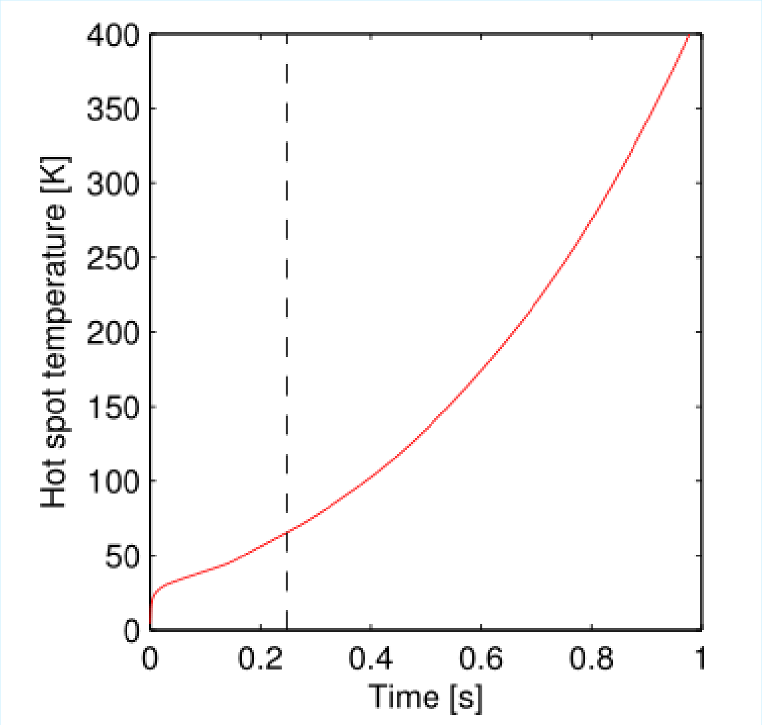
•Quench was ignited by reducing the Ic in a short conductor length (the induction of a quench with an energy deposition, i.e. MQE, would result in large temperature increase and rapid resistive voltage).

FEM simulations results

•Detection time depends greatly on the length of conductor with reduced Ic, but hot spot temperature at the detection time doesn’t (ASC2012 paper).

•Hot spot T is about 60 K at the time of detection (Vth=100 mv)





FEM simulations conclusions

- FEM simulations leads to similar conclusions as the QLASA simulations:
    - 100 mV threshold voltage is enough to detect the quench early, and is reached after about 220 ms.
    - The time delays used in the QLASA code give reasonable margin to quench the coil safely.
    - However, the hot spot is very localized, which might lead to thermal stresses.
- To revise the quench simulations, Ic data of the actual cable at actual operation conditions (and at higher temperatures) is needed

Conclusions

- Insert self protected alone (T_{max} ≈ 95 K)
- Insert inside FRESCA 2:
  - Fast discharge of both magnets is recommendable when any quench is detected: extra care has to be paid in the construction of the coupled quench triggering system
  - Insert hot spot temperature T_{max} **≈ 80 K.**
- It is necessary to assures particular care for the quench detection, like dedicated voltage drop in any sub-coil, in order to remove inductive voltage.
- Each of these voltages should be monitored and when any of these goes above 100 mV, QDS should be triggered