MMI^2T limits for magnets, what are they and how where they developed.

A. Siemko

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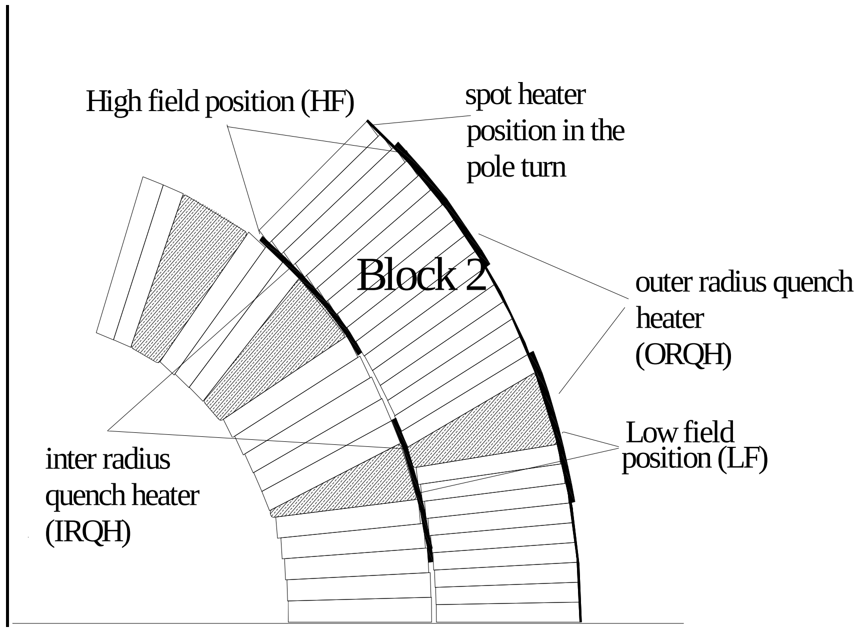
26 February 2009

Quench Heater Position Variants



- the positions of quench heaters were in the <u>outer layer</u> of the coil either at
  - <u>outer radius</u> - so-called outer radius quench heaters (ORQH) or
  - between the inner and the outer layer - inter radius quench heaters (IRQH)

- two insulation foils 75 and 200 μm thick placed between the heater strip and the magnet coil were tested.

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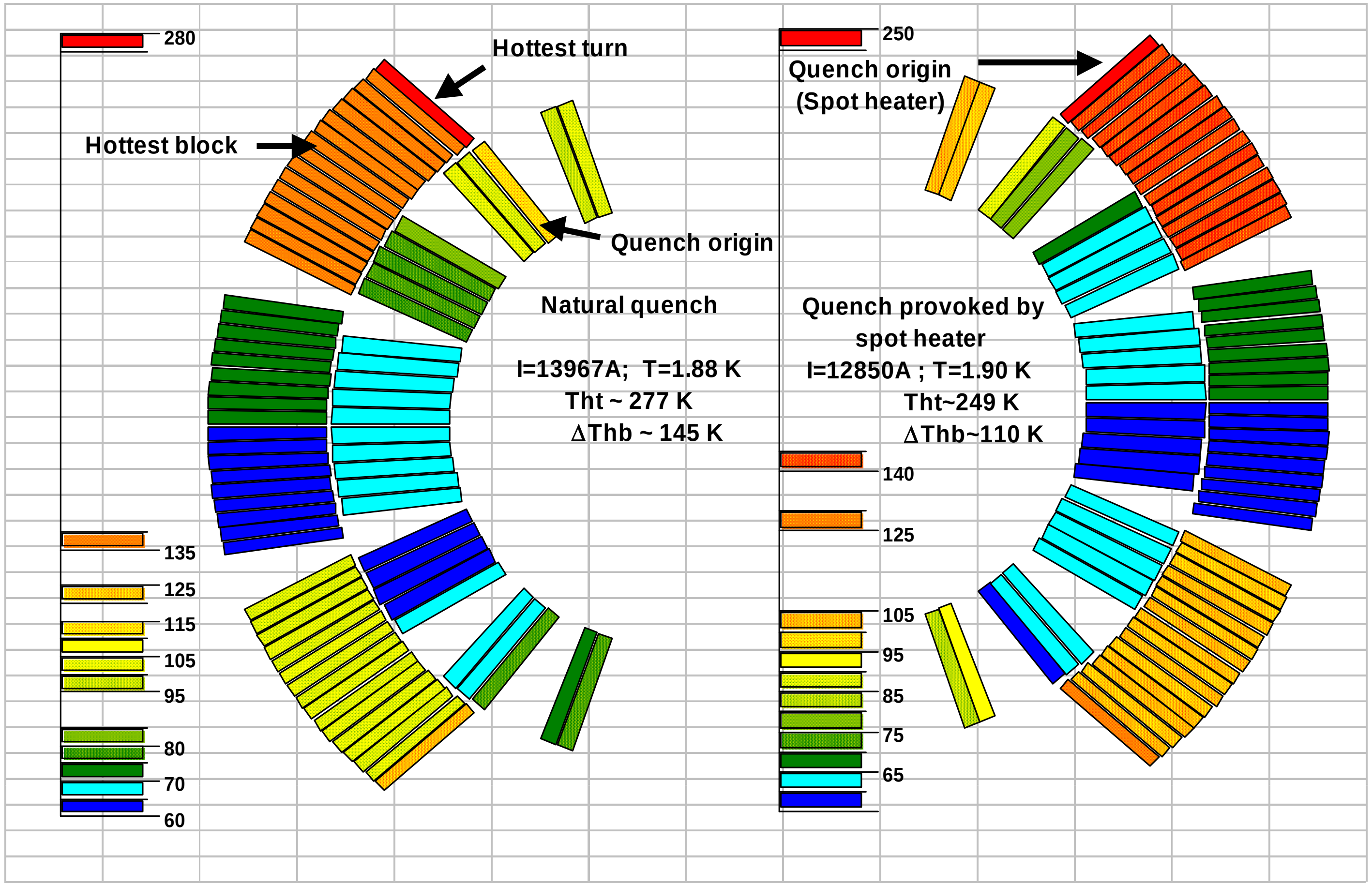
Temperature profiles



- the temperature of the hottest turn and the temperature difference between the hottest turn and the average temperature of the related block ΔT_{hb} were considered.

Principles of the method

- Magnet equivalent electrical circuit during a quench

- At the beginning of the quench, a pure inductive voltage is measured by most of the voltage taps
- For the cable length between two voltage taps

$$L_n = \frac{V_{inductive}^{taps}}{V_{inductive}^{magnet}} L_E(I = 0)$$

- Joule heat released during the quenches

$$Q(t) = \int_{t_o}^{t} V(t')I(t')dt' + \frac{L_n}{L_E(0)}\frac{1}{2}\left(L_E[I(t_0)]I(t_0)^2 - L_E[I(t)]I(t)^2\right)$$

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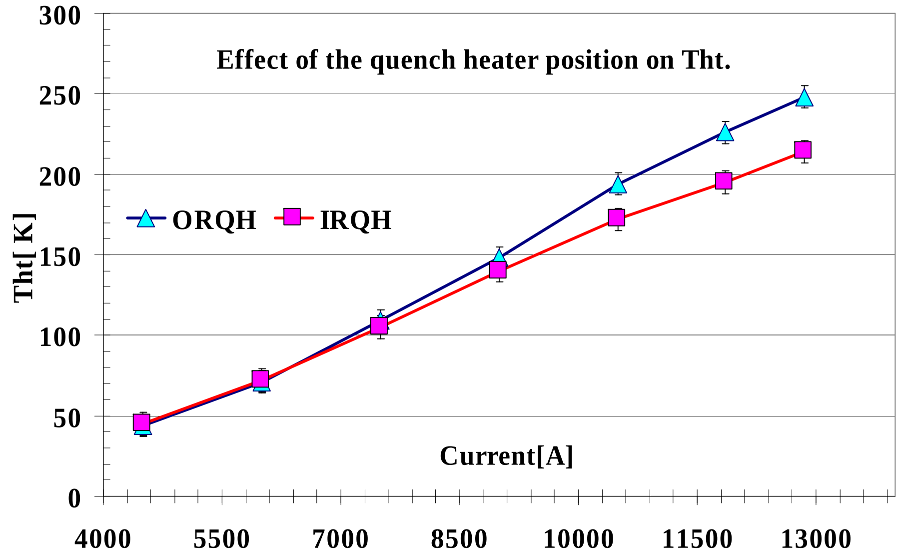
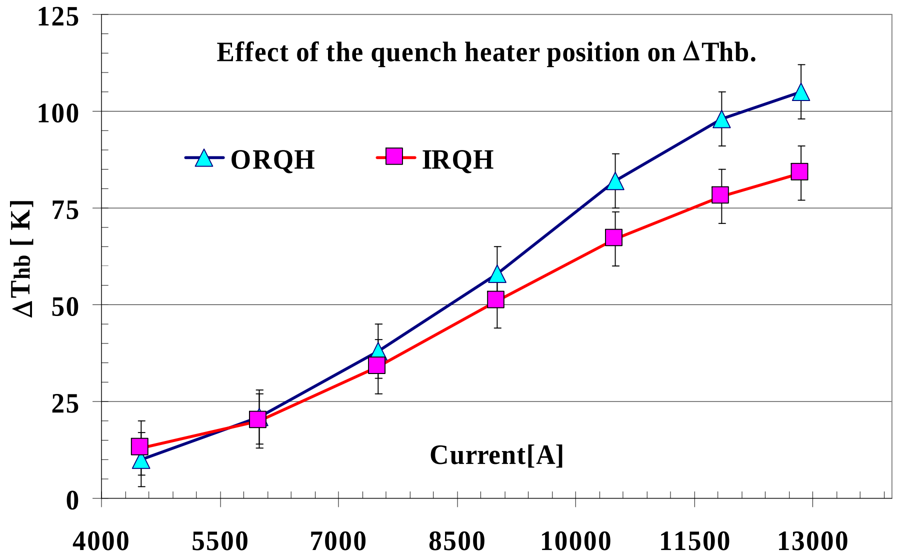
Effect of the quench heater position





- Quenches were provoked by firing a spot heater in the outer layer.
- At low currents the protection by IRQH and ORQH was equivalent.
- At I = 12850A reduction of 35 K and 20 K was measured for T_{ht} and ΔT_{hb} when the magnet was protected by the IRQH and ORQH respectively.

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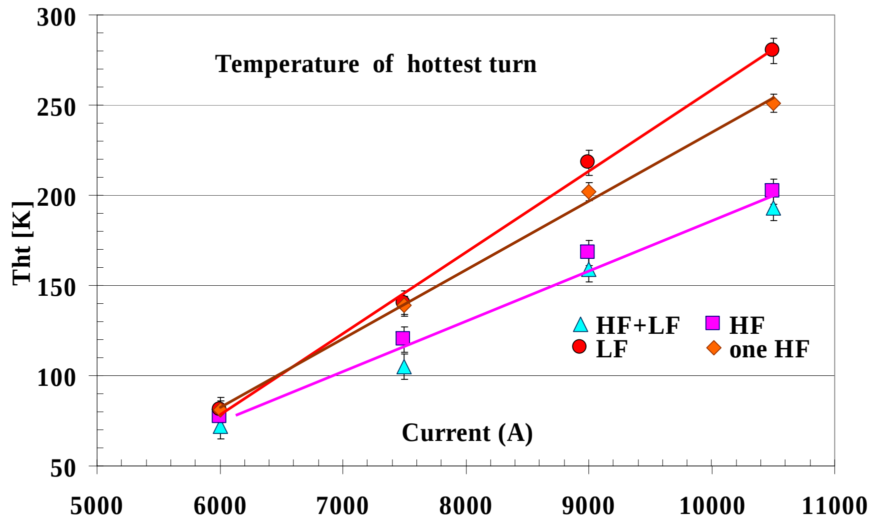
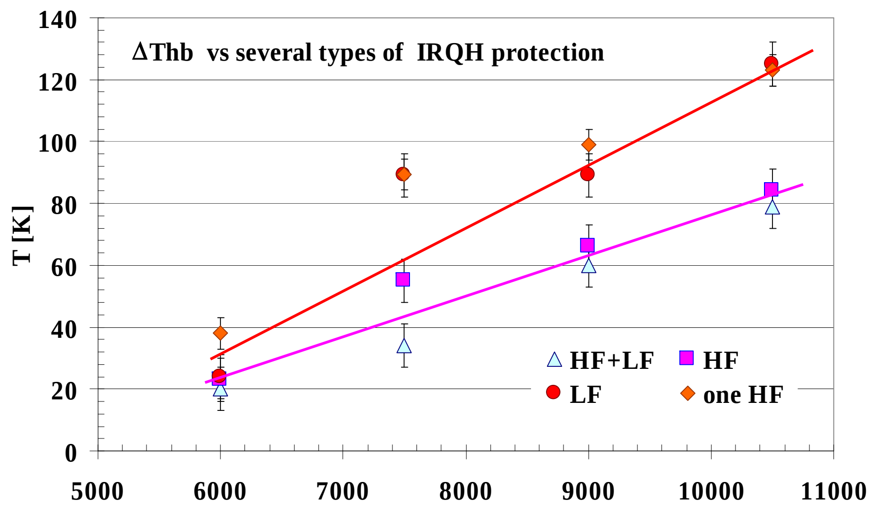
Protection by different sets of IRQH





- Protection by all IRQH heaters (HF+LF) or by HF only is equivalent.
- Protection by only half HF IRQH assured temperatures within the design specification limit.
- For adequate redundancy protection by one full set of HF IRQH is fully sufficient.

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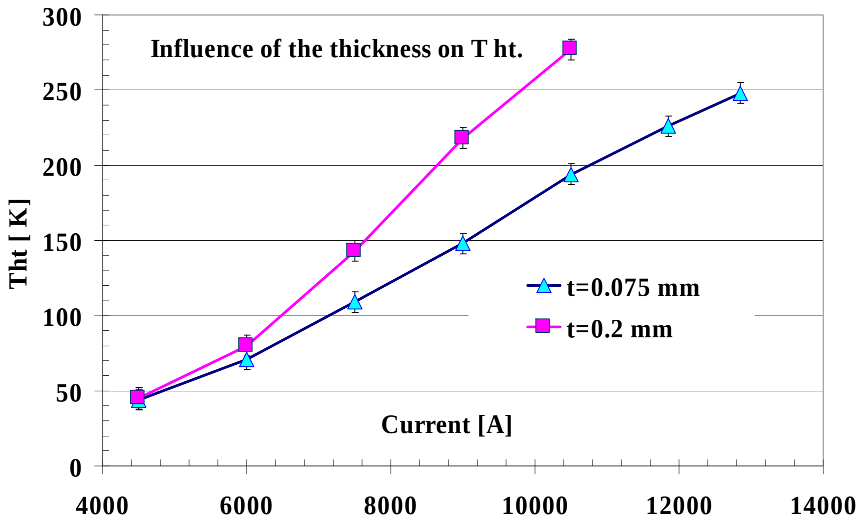
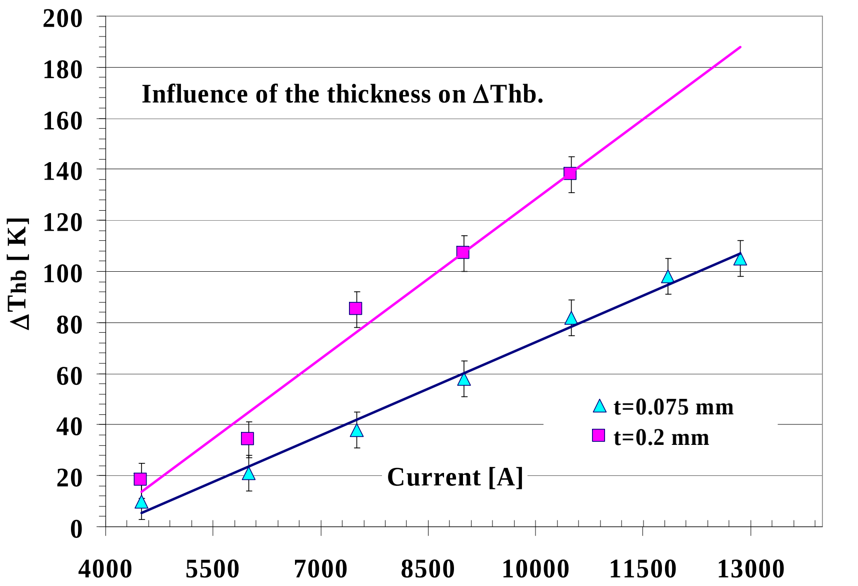
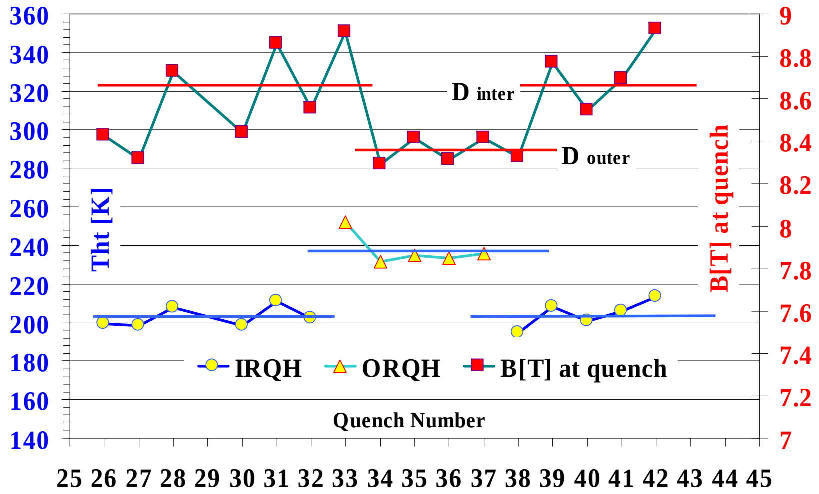
Effect of the insulation thickness

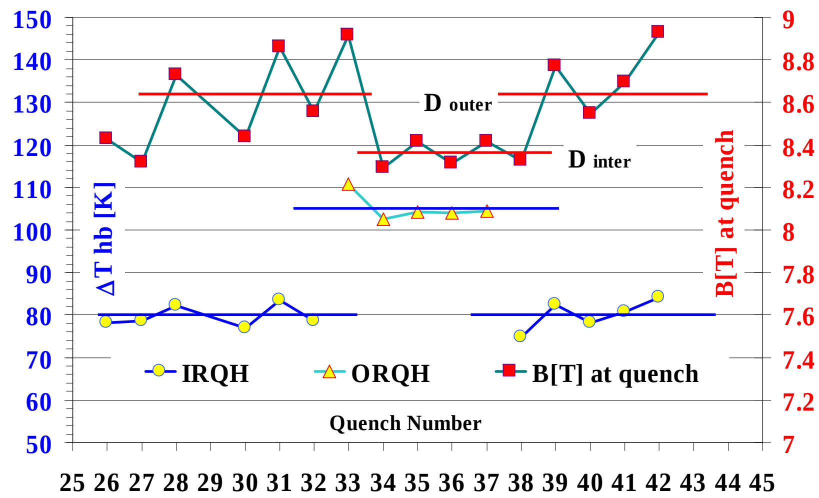




- As expected T_{ht} and ΔT_{hb} increase with the insulation thickness.
- At high currents the increase was important and equal to about 80 K for T_{ht} and 54 K for ΔT_{hb} .
- At the nominal current (11850 A) an insulation thickness of 200 μm between the heater and the coils results in peak temperatures and gradients exceeding "good engineering" practice.

De-training and Temperature





- Quench field drops down to two different levels D_{inter} and D_{outer} , depending on heaters.
- Protection by ORQH caused a decrease of quench level to 8.4 T in average (D_{outer}).
- Protection by IRQH limited the drop to an average value of 8.7T (D_{inter}).
- Drop to a lower level appeared after an increase of T_{ht} and ΔT_{hb} of 35 K and 26 K respectively.

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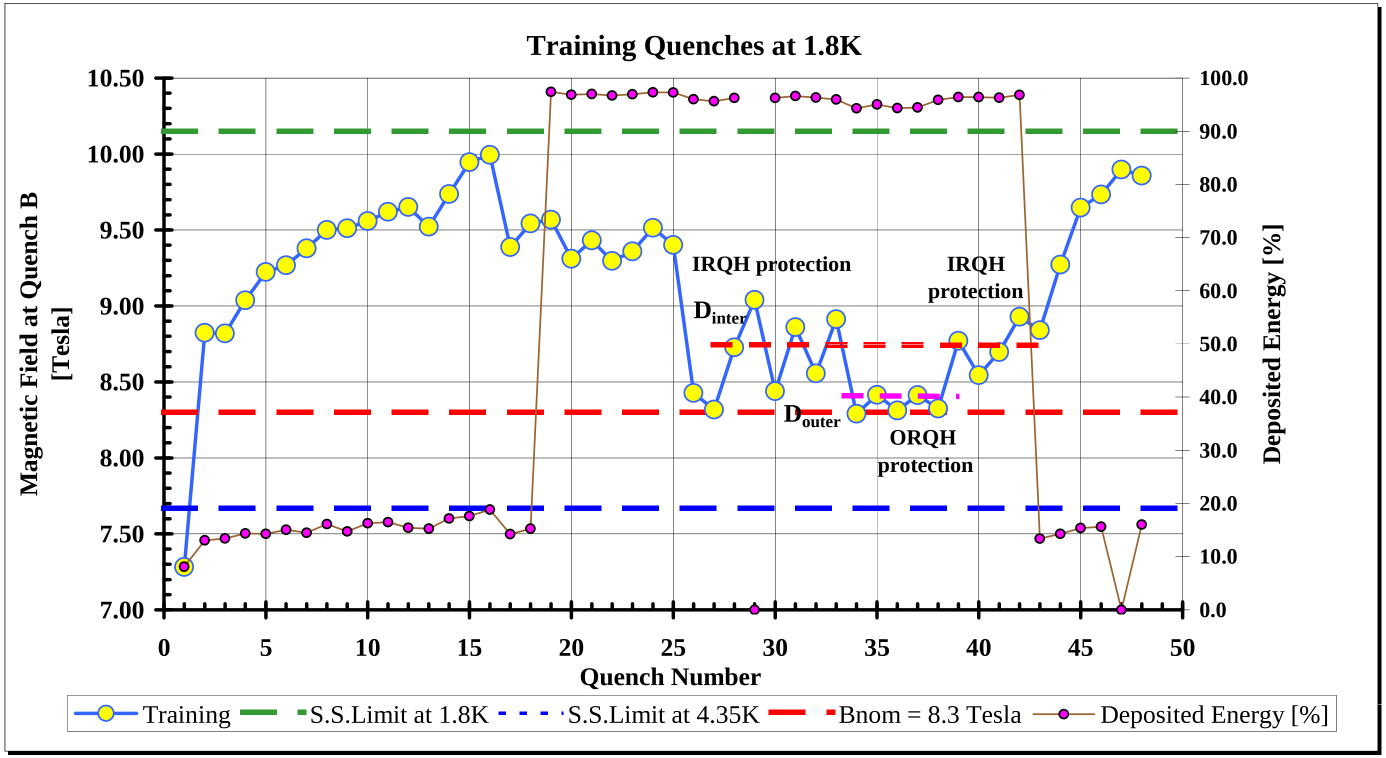
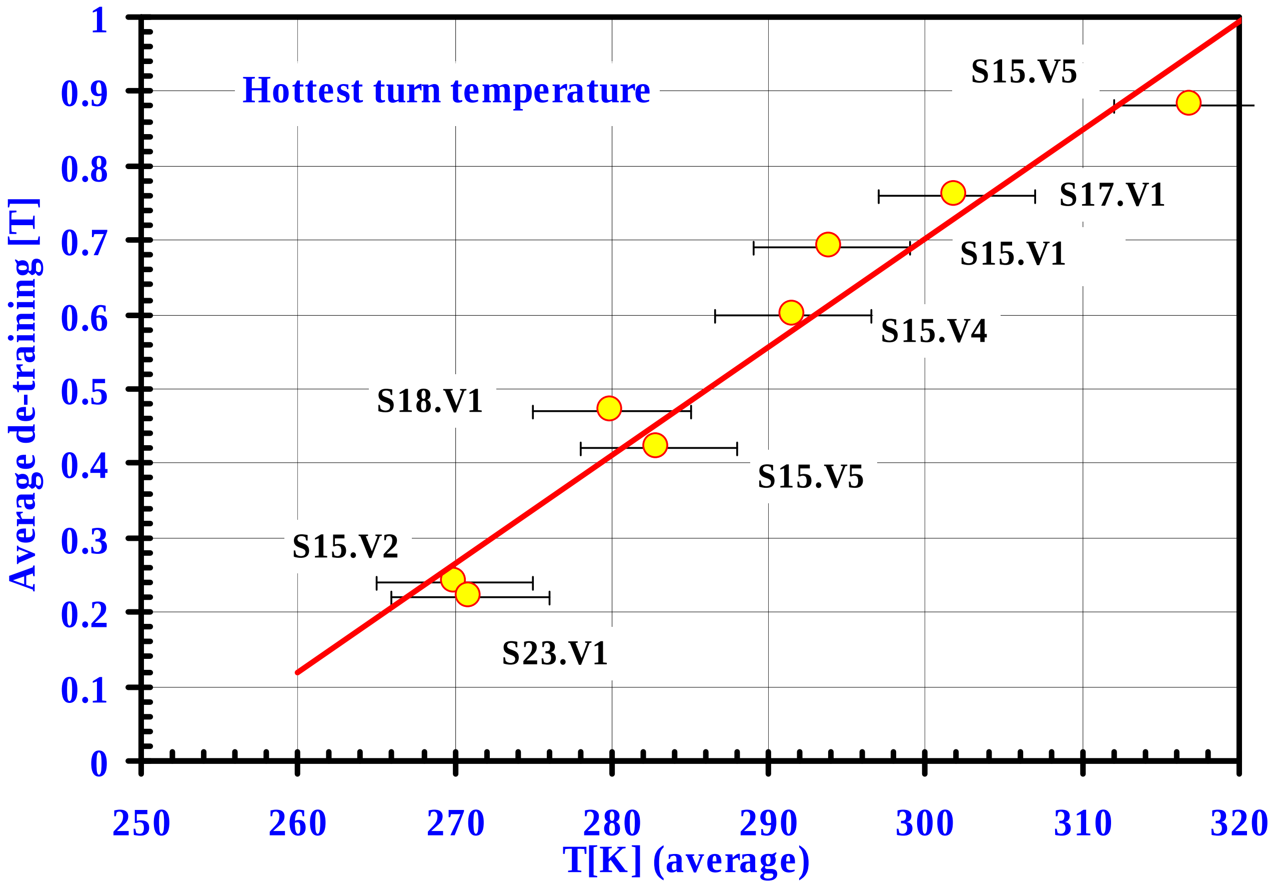
Influence on the quench training



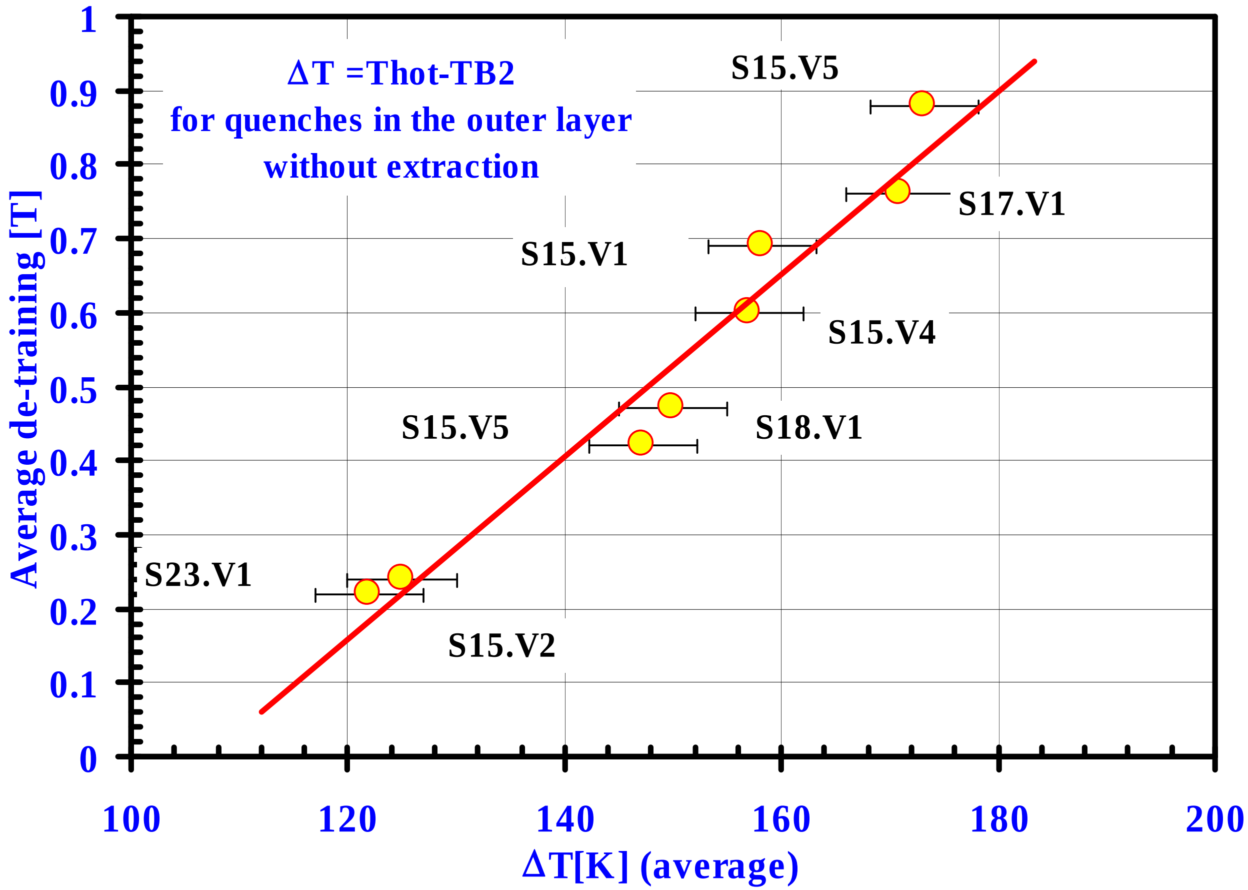
- de-training effect, observed in LHC dipole model magnets is of a thermo-mechanical origin.
- it is induced by the coexistence of a mechanical weak region and a thermal contraction which is due to the temperature rise when all the stored energy is dissipated in the magnet.

Correlation between T_{ht} and de-training



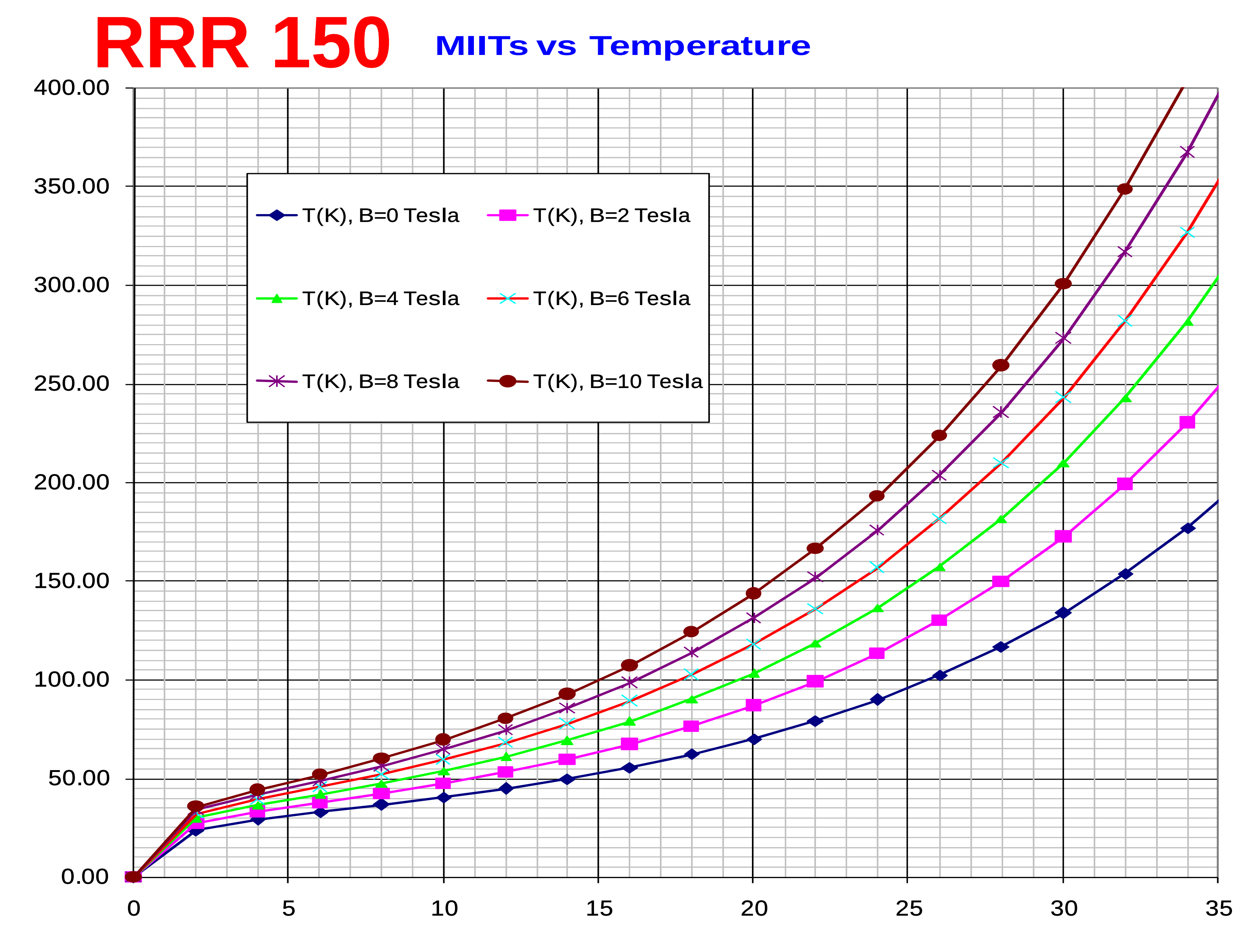
- magnets with similar mechanical features exhibit a strong correlation between the de-training effect and the hot spot temperature

Correlation between ΔT_{ht} and de-training



- magnets with similar mechanical features exhibit a strong correlation between the de-training effect and the temperature gradients

RRR 150



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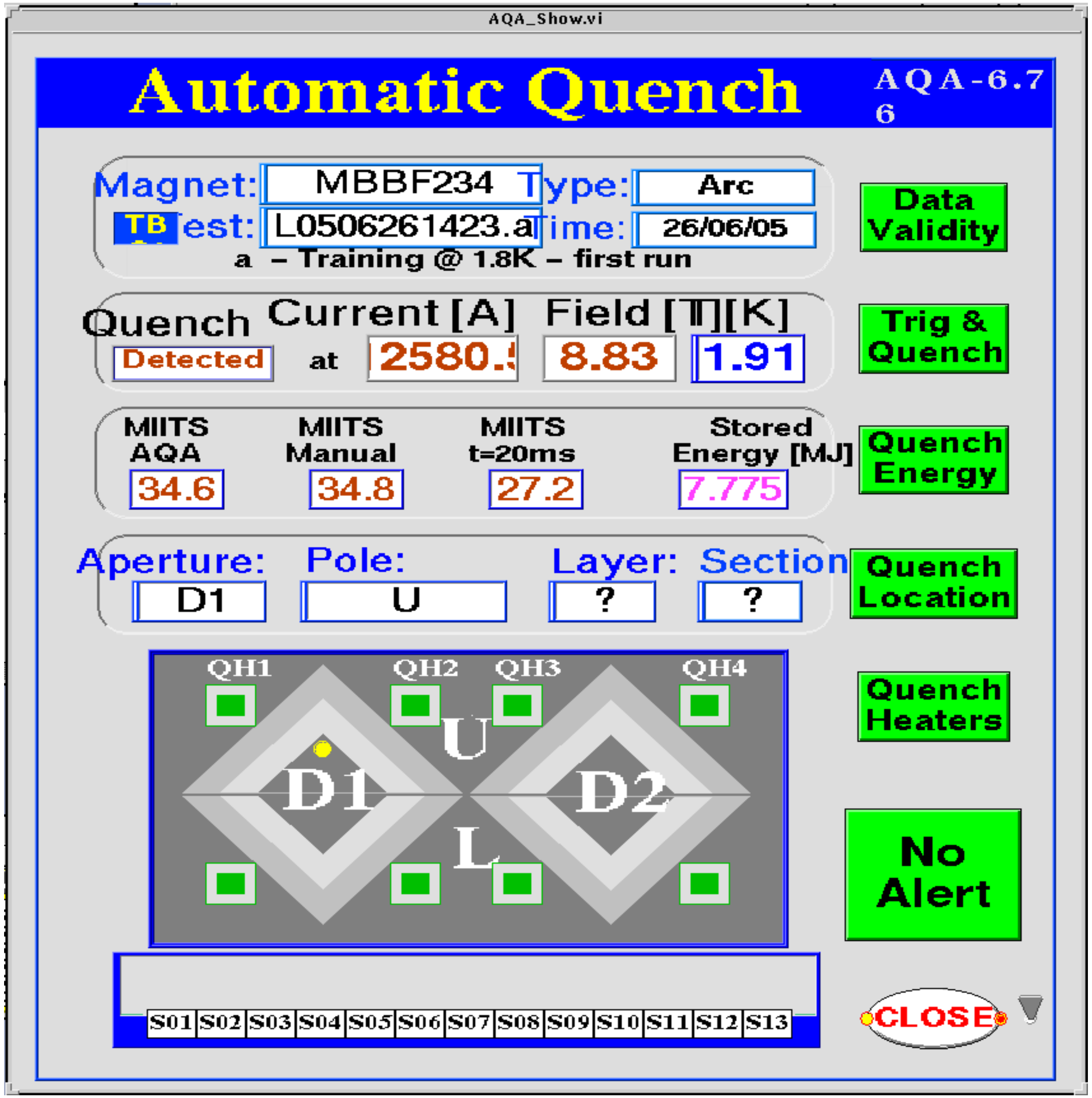
Automatic quench analysis and MIITs monitoring



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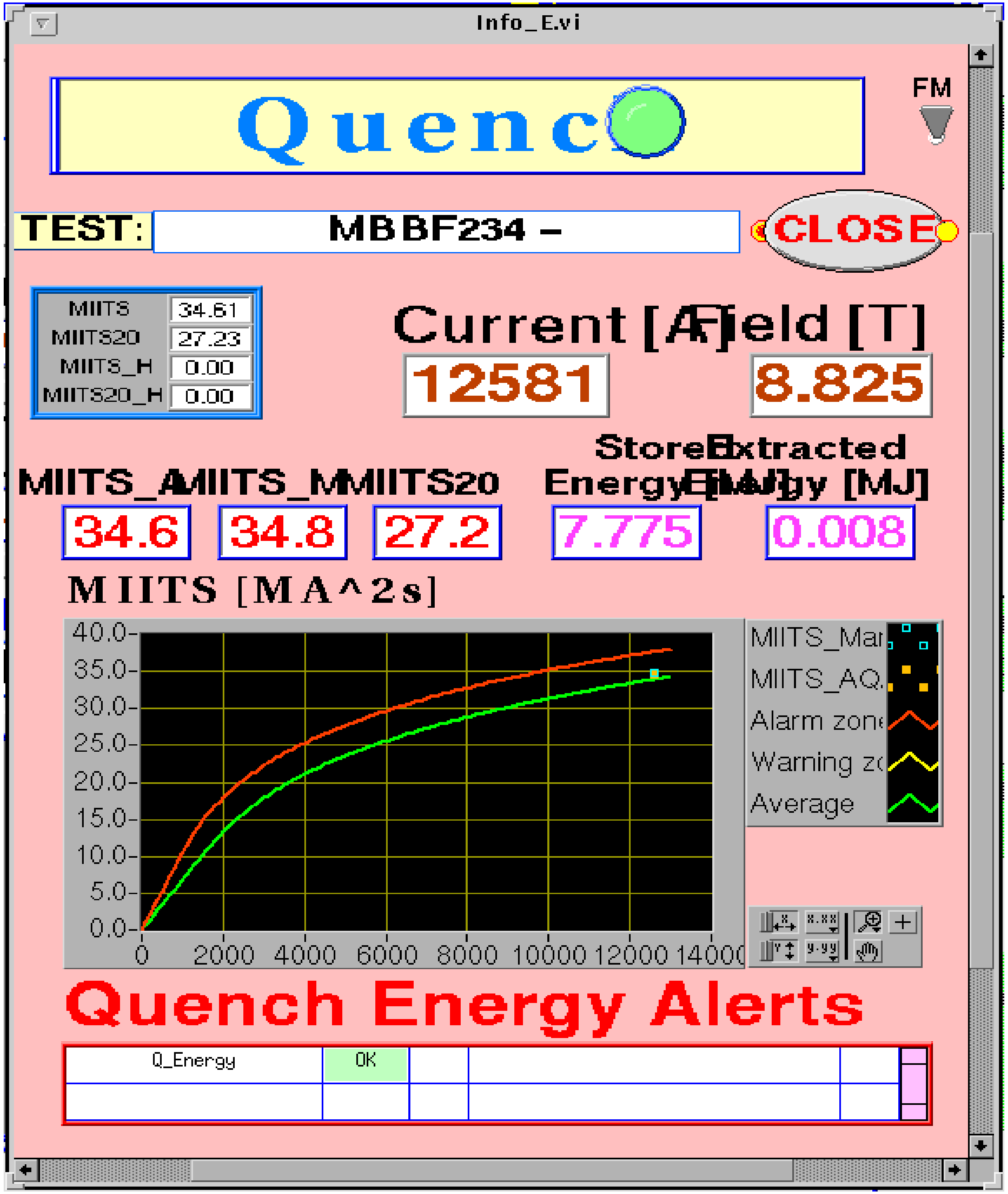

MIITs monitoring

Reference

- **V.Maroussov and A.Siemko**
- **" A Method to Evaluate the Temperature Profile in a Superconducting Magnet During a Quench"**
- IEEE Trans. Applied. Superconductivity **9**, pp. 1153-1156 (1998).