Design decision on MQXF protection

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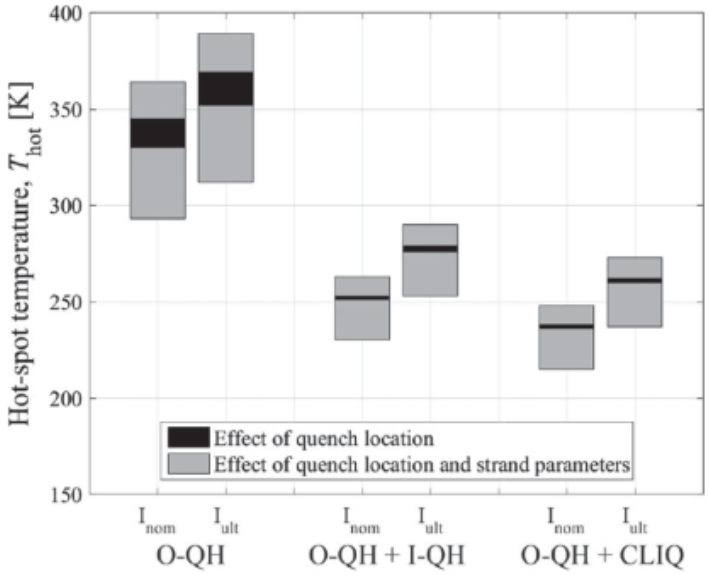
MQXF PROTECTION

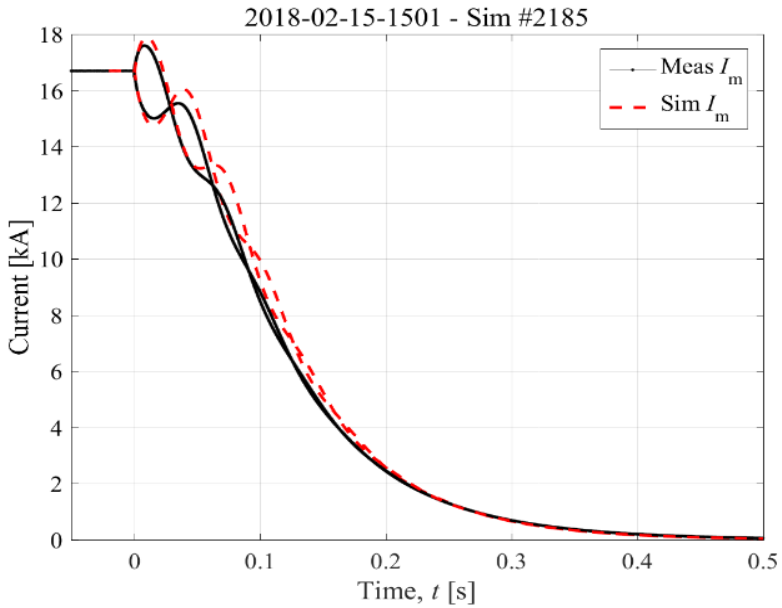
- Since the beginning of the project, MQXF protection considered OL heaters, and CLIQ or IL heaters, with the idea of selecting one of them
  - Outer layer quench heaters – well established, giving a hotspot temperature at the limit of our specification of 350 K
    - Note that 11 T has 10 K more hotspot but goes with OL only – but for MQXF we want more margin
  - To give more margin (100 K) we implemented in the short model program
    - Inner layer quench heaters (issues with delamination)
    - CLIQ (novel system, contrary to heaters its physics is not independent of the magnet length)



E. Ravaioli et al., IEEE TAS, (2017) 27 4702107.

RESULTS OF MQXFP1

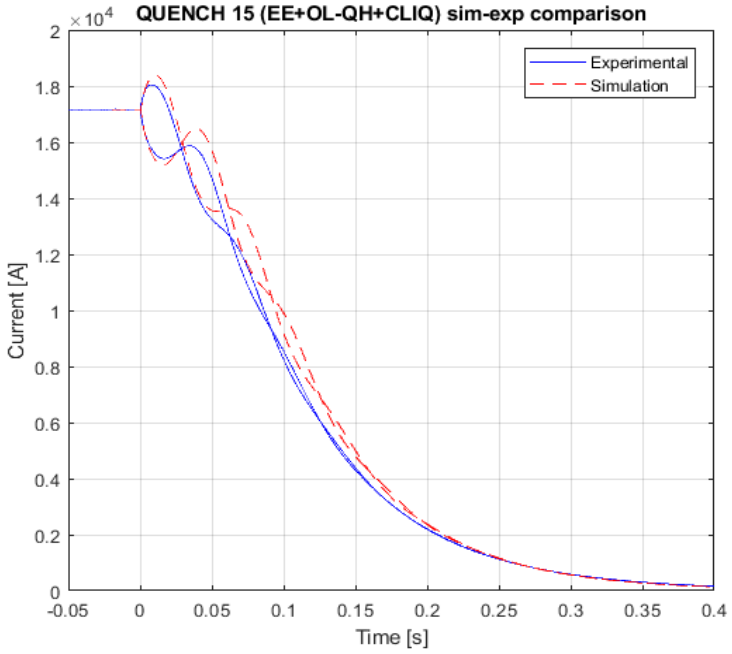
- CLIQ was already tested on long magnets (LHC dipole)
  - We planned to decide between IL heaters/CLIQ after a test on MQXF prototype
  - First test on 4-m-long prototype (MQXFAP1) took place in BNL in August 2017
  - Nominal configuration of CLIQ (500 V, 40 mF)
  - Quench 14 with outer layer heater, inner layer heaters, CLIQ, and dump resistor
  - Quench 15, 16, 17 with outer layer heater, CLIQ, and dump resistor
- Measured 25.2 MIITs instead of 27.1 MIITs foreseen (reality a bit better than simulation)



Simulation versus measured quench protected with dump, IL heaters, OL heaters, and CLIQ in MQXFAP1, quench 14 [E. Ravaioli, J. Muratore, et al.]

RESULTS OF MQXFP1

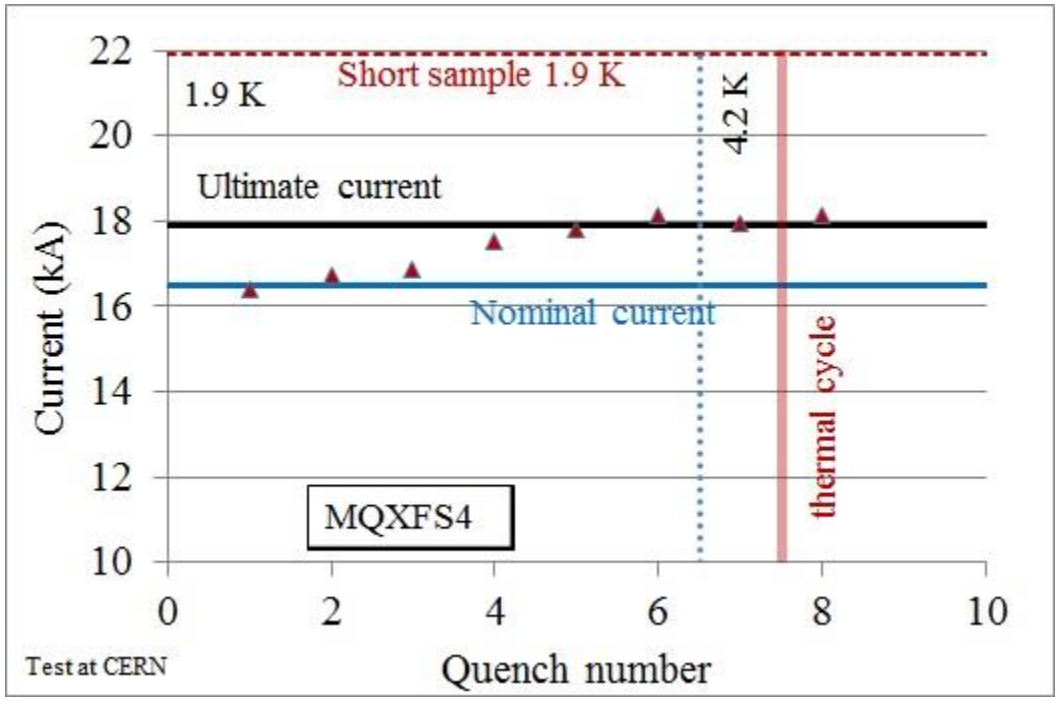
- Initial plan to have a test in nominal configuration (no dump resistor) jeopardized by magnet short that interrupted the test
  - No evidence of any relation of the short to CLIQ – mechanism is a double short to outer layer heaters



Simulation versus measured quench protected with dump, OL heaters, and CLIQ in MQXFAP1, quench 15 [E. Ravaioli, J. Muratore et al.]

RESULTS OF MQXFS4

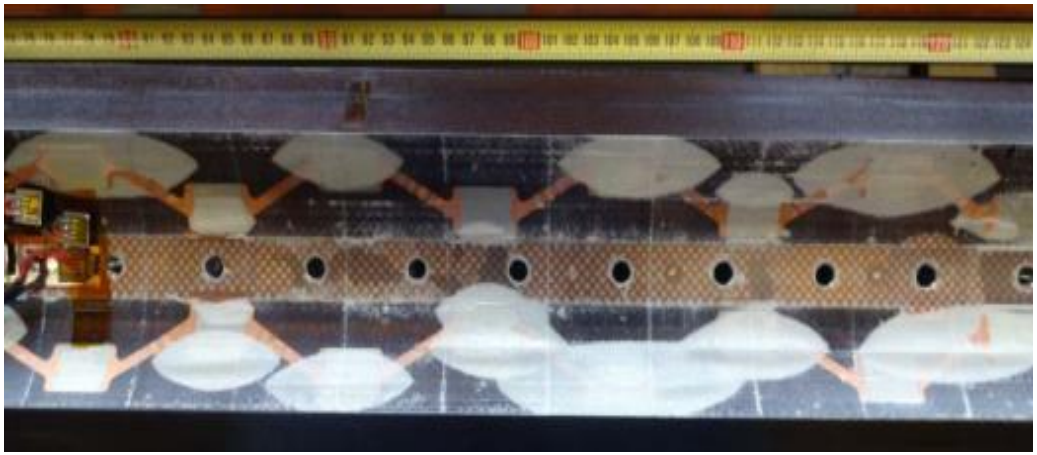
- MQXSF4 was the first magnet to have a full training in nominal configuration
  - No dump, outer layer heaters and CLIQ
  - 8 quenches done, no issues (and good performance)



Training of MQXFS4

INNER LAYER HEATERS

- Inner layer heaters shown significant issues of delamination: we found so far
  - Delamination present also without inner layer heaters powering
  - Delamination between stations and inner part of the aperture
  - Voltage breakdown below the specified valie of 3 kV on a relevant fraction of the coils (50%)
  - No short coil to ground induced by this issue in the whole short model program



- Decision to remove the inner layer heaters

SUMMARY

- New data give us further confidence on selecting CLIQ as a baseline (with IL heaters)
  - Four quenches on the 4.0-m-long prototype using CLIQ
  - Full training on a short model with nominal configuration
- Inner layer heater delamination
  - Considerable progress in the phenomenology of the problem
  - No solution ready, as a risk reduction we remove them from the baseline
    - From coil 107 in MQXFA (first coil of MQXFA03)
    - From coil 104 of MQXFB (First coil of MQXFBP1)