Symmetric quenches in IPQ circuits with a single MQY cold mass

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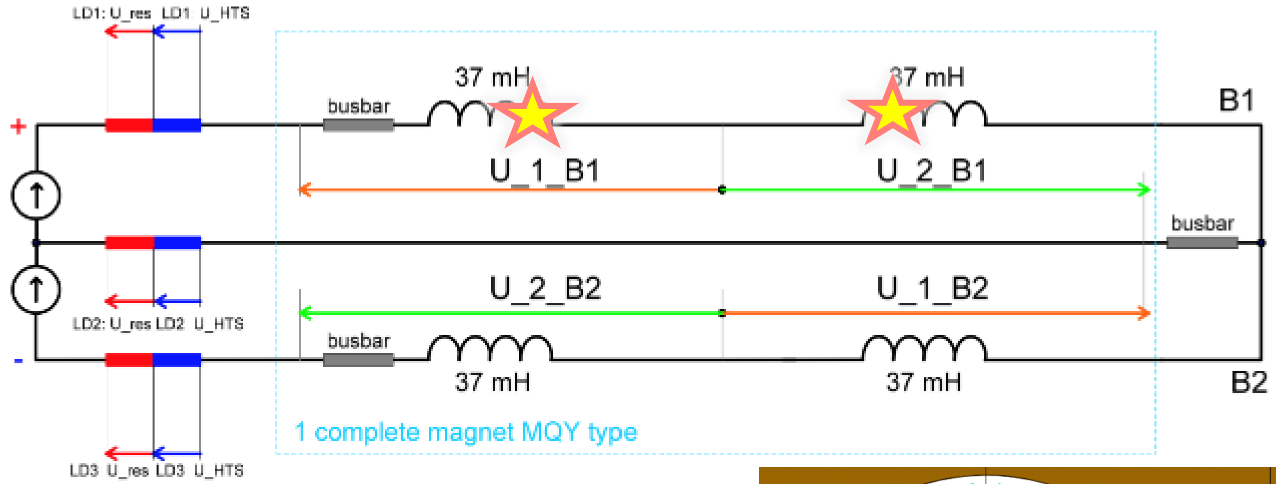
Quench detection

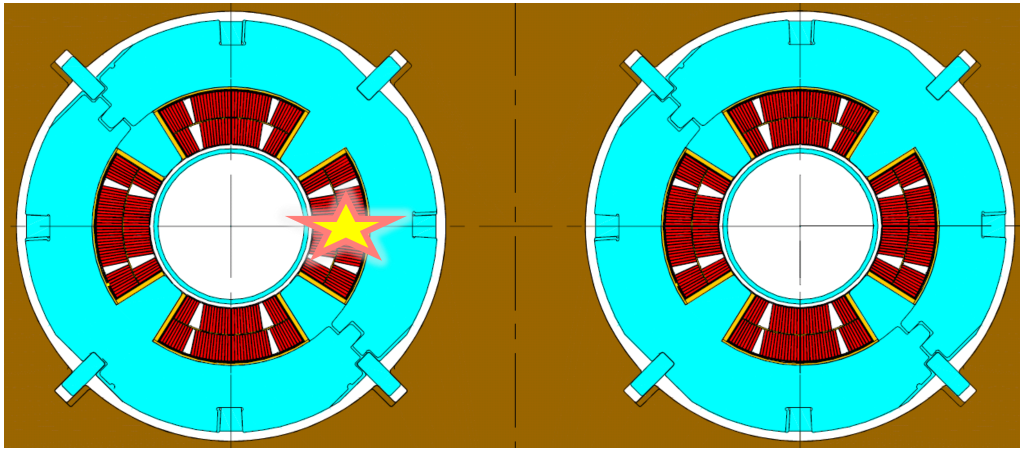
- Most of our protection strategy is based on detection of asymmetric quenches with differential comparison of two parts in the circuit to eliminate inductive components.
  - Between two apertures
  - Between two magnets in the same aperture
  - Between two cold masses

- Symmetric quenches are assumed only to occur between two magnet parts in the same aperture of the same cold mass.

- Other strategies are based on direct voltage measurements, including inductive components
  - Inductive components can be subtracted when measuring dI/dt.
  - Final redundancy to symmetric quenches, but in many cases with a very high threshold.

IPQ case





- Assymetric protection: 100 mV, 10 ms detection time, 20 ms moving average.
- In the circuits with a **single cold mass**, 2 poles are compared to the other 2 poles

Direct voltage protection at 5 V, reduced to 250 mV during quench tests with beam, but only manual after start of PC.

Circuits concerned

Individually Powered Quadrupoles MQY

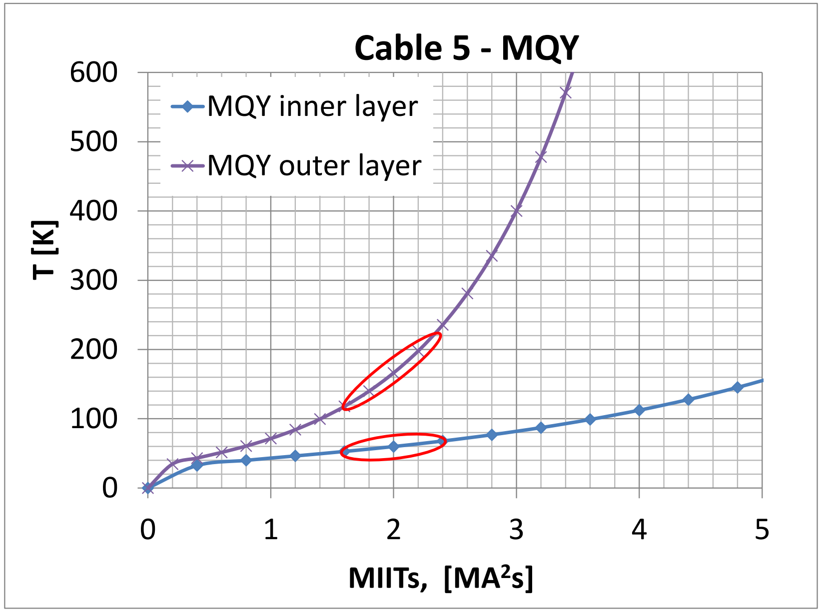
Magnets in the Circuit	Temperature	Position	General information
2*2 MQY	4.5K	RQ4.L2, RQ5.L2 RQ4.R2 RQ4.L8 RQ4.R8, RQ5.R8	I Nominal : 3610A I Ultimate : 3900A L tot : 2*2* 74mH L per aperture : 74mH Max(di/dt) : 10.8A/s
2 MQY	4.5K	RQ4.L1 RQ4.R1 RQ4.L2, RQ5.L2 RQ4.R2 RQ5.L4, RQ6.L4 RQ5.R4, RQ6.R4 RQ4.L5 RQ4.R5 RQ4.L6, RQ5.L6 RQ4.R6, RQ5.R6	I Nominal : 3610A I Ultimate : 3900A L tot : 2* 74mH L per aperture : 74mH Max(di/dt) : 10.8A/s

- Only the circuits with a single cold mass are concerned.
- They are sometimes called 2MQY circuits, since they have a power converter for each aperture.

Hotspot temperatures in the magnets

Hotspot calculation always based on conservative adiabatic conditions

Magnet	$I_{nominal}$ [K]	$T_{operation}$ [K]	Range of MIIts during SM18 tests [MA^2s]	Expected adiabatic hotspot temperature (K)
MQY	3610	4.5	1.8-2.2	60 to 190

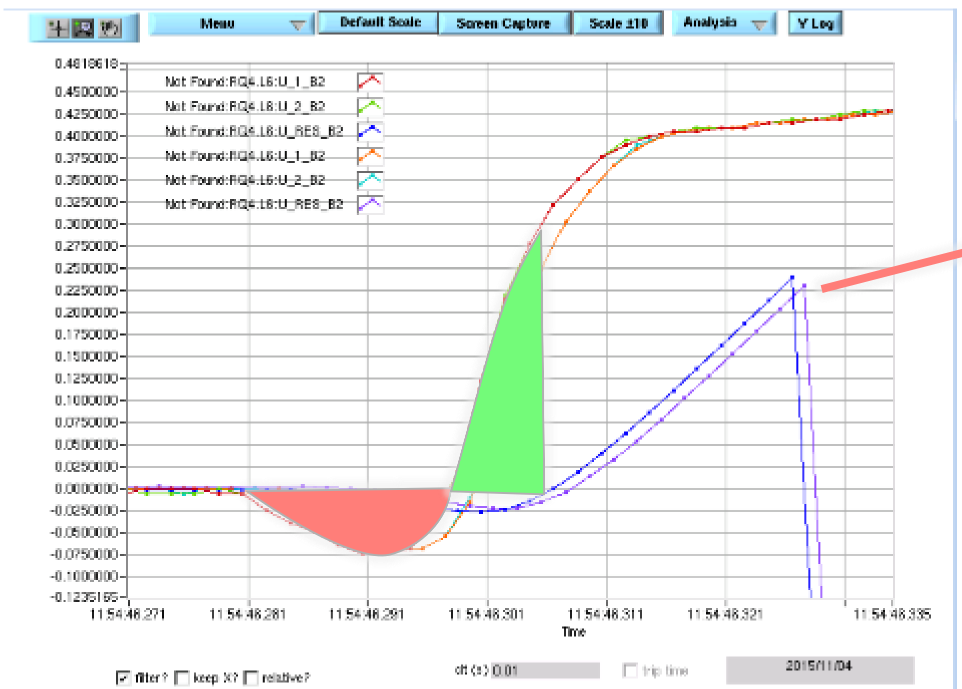


- Delays due to symmetric quenches are quite unpredictable.
- A delay of 80 ms at nominal current will add 1 MA^2s.
- Beam loss induced quenches are unlikely on the outer layer.

Source for T vs MIIts data:
https://twiki.cern.ch/twiki/pub/MP3/CircuitInfoGeneral/150219_Andrzej_Siemko_MIITs4All.xlsm

Actual beam induced quench,

B2, BIQ, signature of asymmetric part of quench. U1 = U2!
U_RES lags due to 20 ms mov. avg.



Small U_Res

- NB: PM time scale x10 too long due to special high-resolution mode.

Solutions

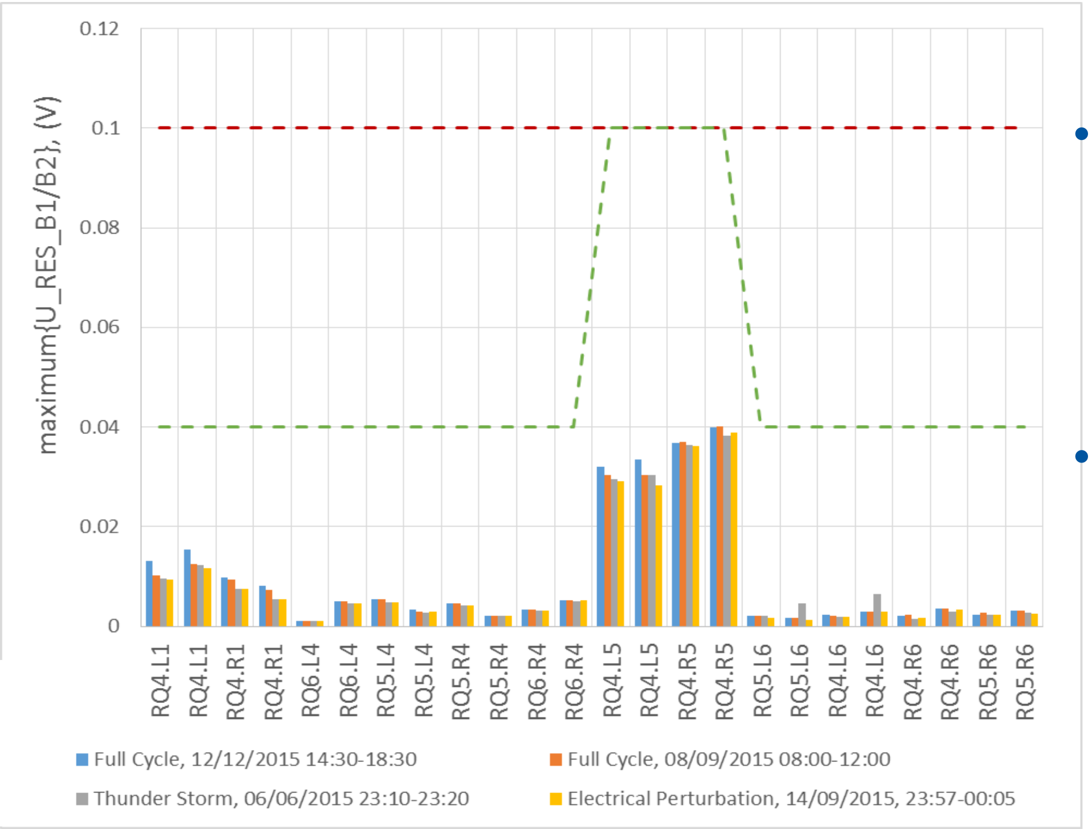
- Real solution: Measure U1+U2 and subtract inductive voltage for symmetric quench detection. This needs a long term development.

- Short term mitigation: Reduce asymmetric quench thresholds to intercept quasi-symmetric quenches, no solution to fully symmetric quenches.

- Other mitigation: Reduce locally BLM thresholds to reduce chance of beam loss induced quenches

Feasibility of mitigation - MQY

- Need to avoid false trips
- Past Ures-signals checked during 2 full cycles, a thunderstorm and during electrical perturbation



- New threshold of 40 mV already implemented for 10 MQY magnets.
- Not possible for 2 MQY magnets

Other cases to be checked

- Further investigation is needed too for IPQ circuits with a single MQM cold mass, especially at 1.9 K. In total up to 34 magnets affected.

- Tripplets and D1 magnets will be investigated too.

Individually Powered Quadrupoles MQM

Magnets in the Circuit	Temperature	Position	General information
2MQM	1.9K	RQ7.L4, RQ7.R4	I Nominal : 5390A I Ultimate : 5820A L tot : 2x15mH L per aperture : 15mH Max(di/dt) : 12.917 A/s
2x2MQM	1.9K\4.5K*	RQ7.L1, RQ7.R1 RQ7.L2, RQ7.R2 RQ7.L5, RQ7.R5 RQ7.L8, RQ7.R8 RQ5.L8*, RQ5.R2*	I Nominal : 5390A \ 4310A* I Ultimate : 5820A \ 4650A* L tot : 2x2x15mH L per aperture : 15mH Max(di/dt) : 12.917 A/s
2MQML	1.9K\4.5K*	RQ5.L1*, RQ5.R1* RQ5.L5*, RQ5.R5* RQ6.L1*, RQ6.R1* RQ6.L5*, RQ6.R5* RQ8.L1, RQ8.R1 RQ8.L2, RQ8.R2 RQ8.L4, RQ8.R4 RQ8.L5, RQ8.R5 RQ8.L6, RQ8.R6 RQ8.L8, RQ8.R8 RQ10.L1, RQ10.R1 RQ10.L2, RQ10.R2 RQ10.L4, RQ10.R4 RQ10.L5, RQ10.R5 RQ10.L6, RQ10.R6 RQ10.L8, RQ10.R8	I Nominal : 5390A \ 4310A* I Ultimate : 5820A \ 4650A* L tot : 2x21mH L per aperture : 21mH Max(di/dt) : 12.917 A/s
2MQMC	1.9K\4.5K*	Does not exist as an individual power circuit (exists only in combination with 2MQM)	I Nominal : 5390A \ 4310A* I Ultimate : 5820A \ 4650A* L tot : 2x11mH L per aperture : 11mH Max(di/dt) : 12.917 A/s
2MQM+2MQML	4.5K	RQ6.L2, RQ6.R2 RQ6.L8, RQ6.R8	I Nominal : 4310A I Ultimate : 4650A L tot : 2x15mH + 2x21mH Max(di/dt) : 12.917 A/s
2MQM+2MQMC	1.9K	RQ9.L1, RQ9.L1 RQ9.L2, RQ9.R2 RQ9.L4, RQ9.R4 RQ9.L5, RQ9.R5 RQ9.L6, RQ9.R6 RQ9.L8, RQ9.R8	I Nominal : 5390A I Ultimate : 5820A L tot : 2x15mH + 2x11mH Max(di/dt) : 12.917 A/s

Conclusion

- Presentation follows recent developments, a proper investigation needs to be done:
  - The worst case may not be the reality!
  - Symmetric quenches typically start in a larger area than training quenches
  - Beam loss may speed up the quench process.
  - Perfect symmetry may not be very common.

- MP3 recommendation is being written

- Mitigation measures already implemented for 20 MQY circuits.

- Also MQM, D1 and triplets to be investigated.