Validation of protection strategy for WP3 magnets

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Contents

- Questions
  - Magnet by magnet, we give an overview of the protection aspects including the following questions:
  - Did we already test the final configuration for protection ?
  - Did we already test the failure scenarios ?

- We start with easy cases
  - MCBXF, D2 corrector and skew quadrupole (dump)
  - Higer order correctors (self protected)

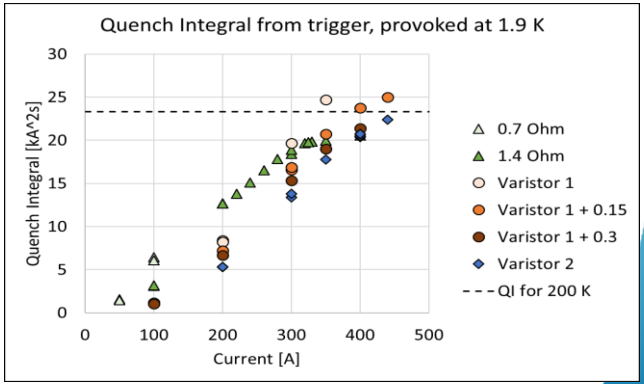
- Then we go for the more critical cases
  - The separation and recombination dipoles
  - The quadrupoles (already discussed in detail by E. Ravaioli talk)

Easy cases

- MCBXFA/B
  - They are protected with a dump resistor (initially 0.3 Ω, on MCBXFA only, then reduced to 0.15 Ω and installed also in MCBXFB, see EDMS 2360296)
  - After the decision of installing energy extraction also in MCBXFB, the protection of the nested correctors is removed from the critical path
  - The final configuration was tested in MCBXFBP2 and MCBXFB01 (two magnets) with 0.15 Ω
    - The first prototype was protected with 0.22 and 0.30 Ω
  - Protection based on energy extraction depends on the lenght - still to be tested in the long nested corrector MCBXFA, but no issues foreseen

Easy cases

- MCBRD
  - They are protected with a 1.4 Ω dump resistor
  - Tested in MCBRDP1, P2, P3, at CERN and in IMP with 1.4 Ω dump resistor (and also metrosil, plus 0.7 Ω … etc)
  - No issues foreseen – initial value of 0.7 Ω was increased to 1.4 Ω since the energy extraction was much less effective then expected (studied on MCBRDP1, see test report EDMS 2046092)
  - RRR of the former should be carefully monitored since it is a driving parameter for protection



Quench integral versus current for MCBRDP1 (F. Mangiarotti, G. Kirby, et al)

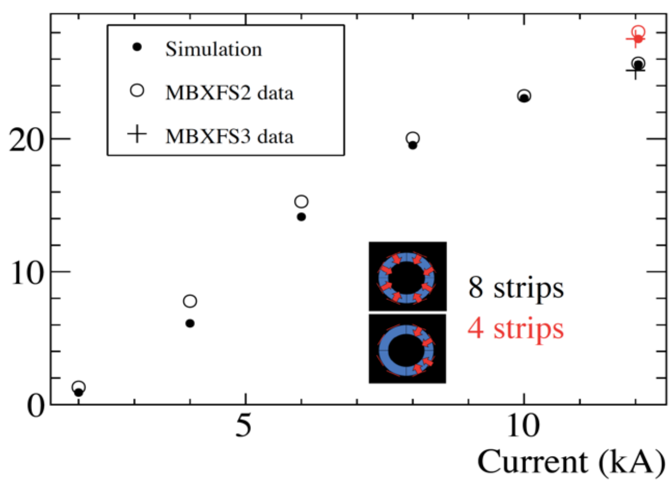
HO correctors

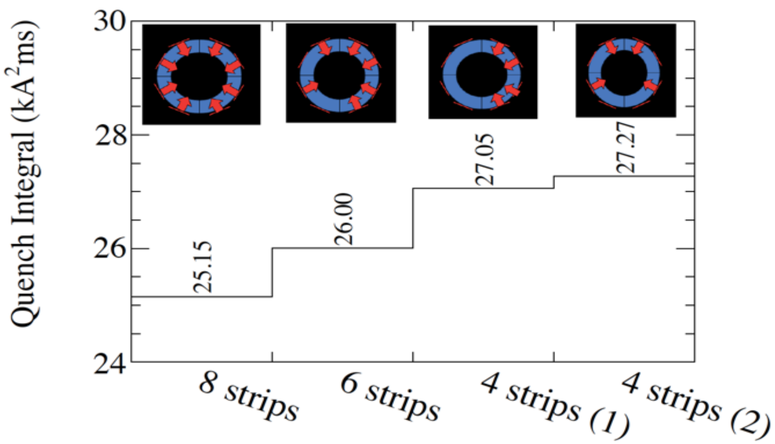
- Skew quadrupole
  - Protected with energy extraction
  - Tested with 1.5 Ω dump resistor

- Other magnets
  - Self protected
  - Tested with 1.5 Ω dump resistor in LASA vertical test station
  - To be tested without dump resistor in the corrector package cold mass, horizontal position

D1

- D1
  - D1 is protected via quench heaters (four circuits)
  - Iteration has been done on the quench heater shape after the first model MBXFS1
  - Tested on short models MBXFS2 and MBXFS3 (always with dump) up to ultimate current, and with failure scenario (see test report MBXFS3, EDMS 1856621)

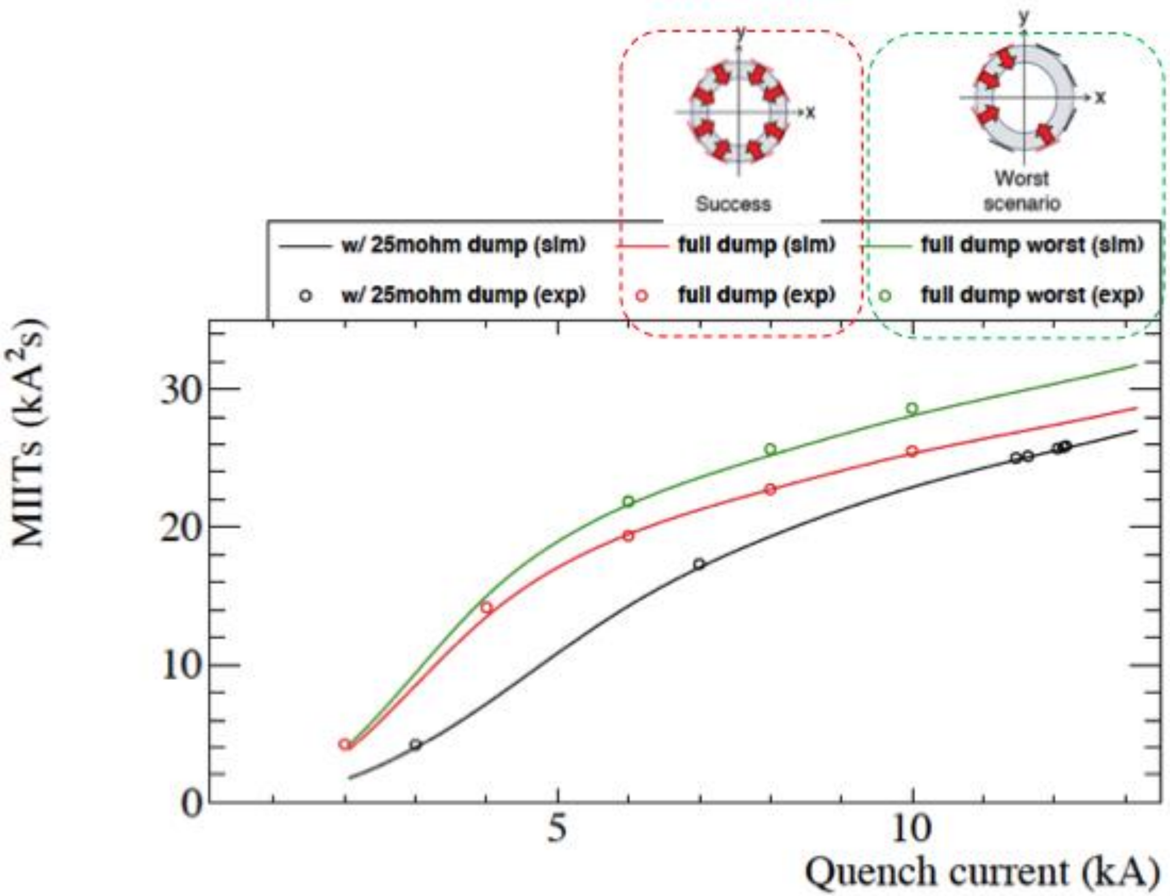




Quench integral versus current for MBXFS3 (M. Sugano, T. Nakamoto, et al)

D1

- D1 prototype tested vertical, with 25 mΩ e.e. in KEK
  - Without dump resistor test carried out up to 10 kA (test station limitations)



Quench integral versus current for MBXFP1 (M. Sugano, T. Nakamoto, et al)

D1

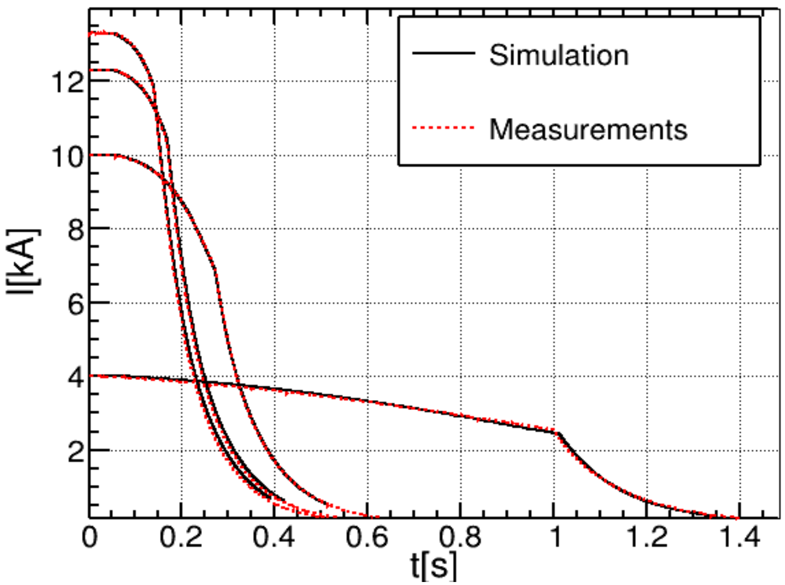
- Failure scenario checked up to 10 kA
  - Warning on high values of expected hot spot temperature, to be further analysed

	Expected MIITs and T_{peak} at 12.110 kA		
	Counted from t=0	HF quench (5 T)	LF quench (1 T)
Success	27.7	30.5 / 247 K	35.0 / 217 K
Worst	28.9	33.5 / 311 K	38.0 / 273 K

	Expected MIITs and T_{peak} at 13.231 kA		
	Counted from t=0	HF quench (5 T)	LF quench (1 T)
Success	30.7	32.1 / 279 K	37.6 / 265 K
Worst	32.0	35.2 / 354 K	40.7 / 336 K

D2

- D2
  - D2 is protected via quench heaters (four circuits)
  - Tested on short models MBRDS1 up to ultimate, with energy extraction on 25 mΩ, see EDMS 2386341)
  - Special test were done delaying the dump to verify the nominal configuration, and the failure cases



Quench integral versus current for MBRDS1 (B. Caiffi, P. Fabbricatore, et al)

D2

- D2
  - Worst case with two failures also brings the temperature around 300 K – ultimate will be proably around 350 K as for D1
  - The prototype will be tested in April 2022, horizontal position, in final configuration (no energy extraction)

Nominal current	Vpeak [V]	Tpeak [K]	MIITS [MAAs]
Standard	112	212	26
Failure 1	475	246	28
Failure 2	439	304	31
Failure 3	701	304	31

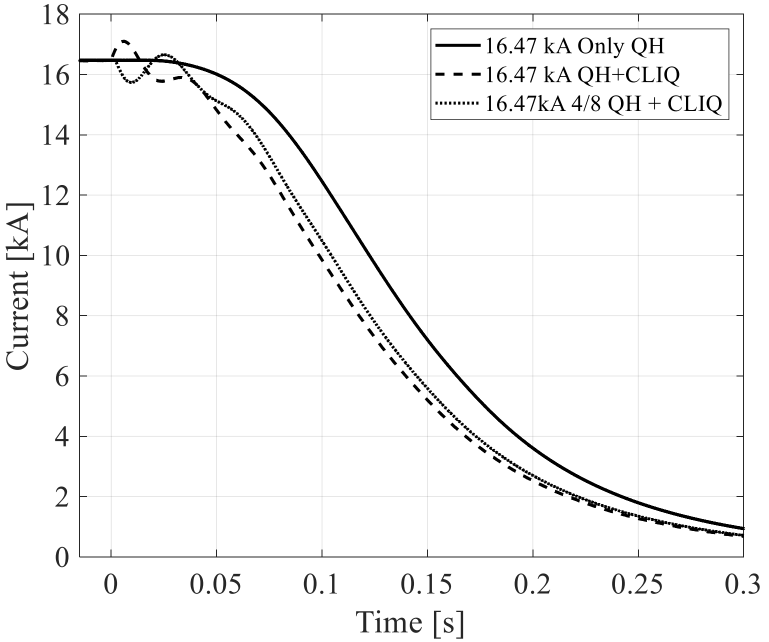
MQXF

- Protection strategy: QH and CLIQ
- Failures: two QH (easier for hotspot, more difficult for voltage) or one QH and CLIQ (viceversa)

- What did we test?
  - MQXFS (short models): special cases without dump (and failures)
  - MQXFA: always tested with energy extraction (7 magnets) – no failures cases analysed
  - MQXFB: no energy extraction (2 magnets) – no failures cases analysed

MQXFS

- Failure cases were analysed in MQXFS4



Magnet	Case	I_{nom}
MQXFS4b	CLIQ + QH	24.8
MQXFS4c	CLIQ + 4 out of 8 QH	26.2
MQXFS4c	Only QH	30.9

Quench discharge in MQXFS4 (S. Izquierdo Bermudez, et al)

MQXF

- In case of no failure, very safe hotspot below 250 K
  - Verified by all training quenches done on MQXFA and MQXFB
- Failure cases simulations
  - Based on simulations, in the present baseline we have 346 K hotspot and 374 K at ultimate current
  - If the mini-swap is approved, this will bring 30 K more in MQXFB

	No failure, uniform conductor		Failure (CLIQ + 1 QH), non-uniform conductor coil ordering	
	I_{nom}	I_{ult}	I_{nom}	I_{ult}
Impregnated heaters	227	250	346	374
Mini-swap (0.055 mm G10 layer)	231	253	375	404

CONCLUSIONS

- Protection of correctors based on energy extraction, its validation has been completed
- Protection of D1 and D2 have 300 K hotspot for failure cases at nominal current, and will be above this at ultimate current
  - Final validation of the prototypes expected in April and August 2022, horizontal test at CERN
- Triplet protection has been fully validated for the nominal scheme (CLIQ and QH)
  - Tested on short models and MQXFB, with a hotspot temperature with very large margin (250 K)

CONCLUSIONS

- The failure scenarios still have to be validated on the full-lenght magnets
  - The hotspot in the case of CLIQ and one QH failure approaches 350 K at nominal current
  - With the miniswap to be implemented on MQXFB, this will become 30 K higher, but still with an acceptable margin – this option will be tested on a short model including coils with this configuration, test in spring 2022