Mon-Af-Po1.01-10

Quench Protection of the 11 T Nb_3Sn Dipole for the High Luminosity LHC

S. Izquierdo Bermudez, G. Willering, H. Bajas, M. Bajko, B. Bordini, L. Bottura, J. C. Perez, G. de Rijk, F. Savary

Abstract

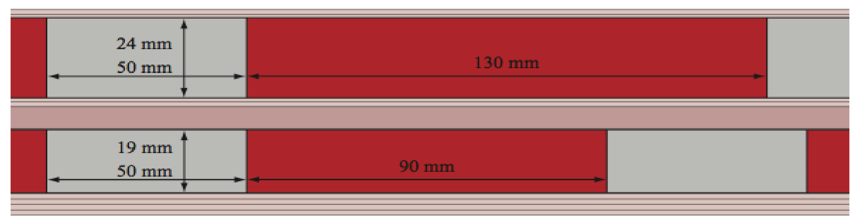
The upgrade of the LHC collimation system requires the installation of 11T Nb_3Sn dipole magnets. Due to the large stored energy density and the low copper stabilizer section, the quench protection of these magnets is particularly challenging. This paper reports on the test results of the model program and presents a parametric analysis on the impact of conductor parameters on the peak temperature. Coil voltage to ground and turn-to-turn voltages are also evaluated under nominal and failure case scenarios.

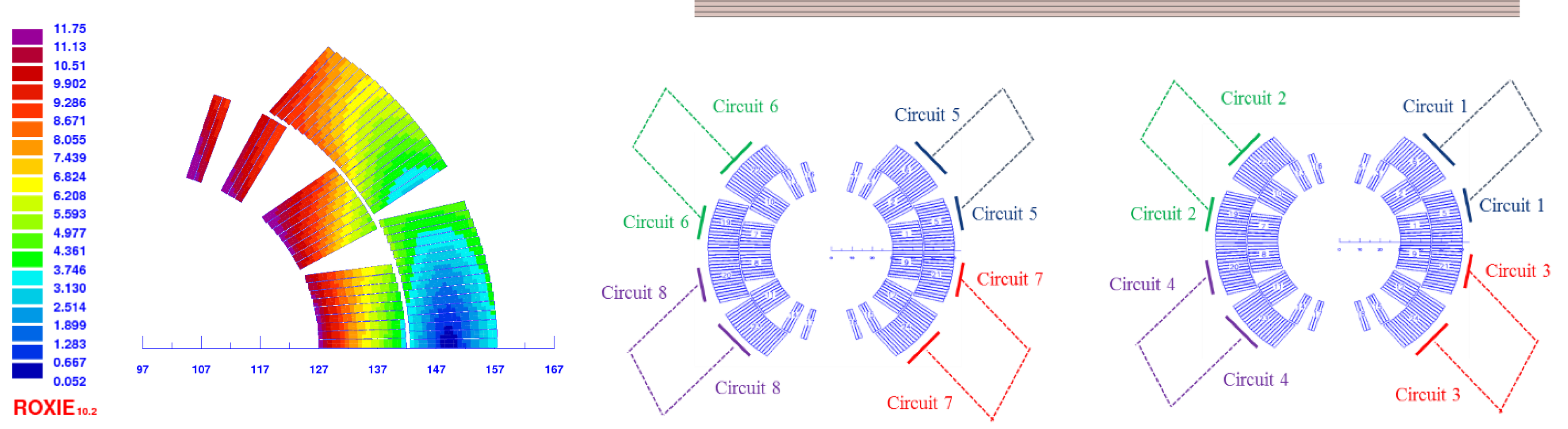
Conclusions

The expected hot spot temperature in the 11 T magnet at nominal operation conditions is 320 K ± 20 K. Among the parameters that affect the quench protection performance, the amount of copper is the most important one. RRR and critical current density parameters have a small impact for the expected range of variability. Varying conductor parameters between coils will significantly increase the hot spot temperature and the peak voltage to ground. The fact of having two cryo-assemblies connected in series and protected by one diode increases the redundancy of the system. On the negative side, in case of heater failure, the peak voltages to ground are larger than if each cryo-assembly was protected with a single diode.

Magnet Parameters & Protection

Relying on outer layer heaters



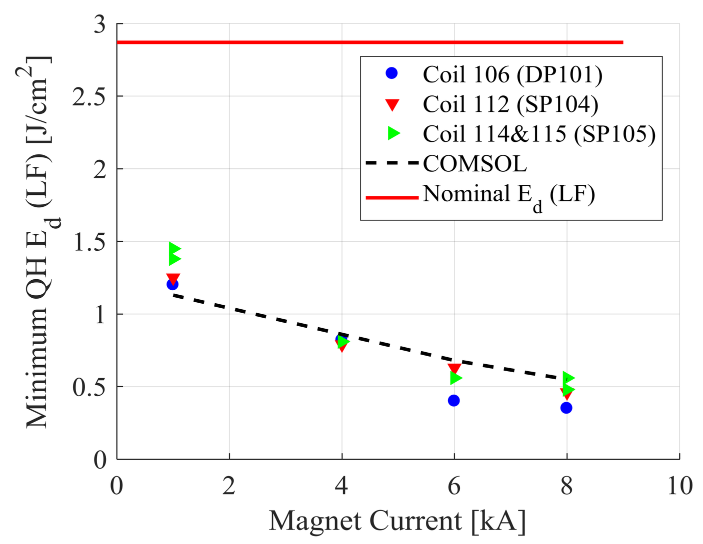


Main Magnet And Conductor Parameters At Nominal Current (I_{NOM} = 11.85 kA)

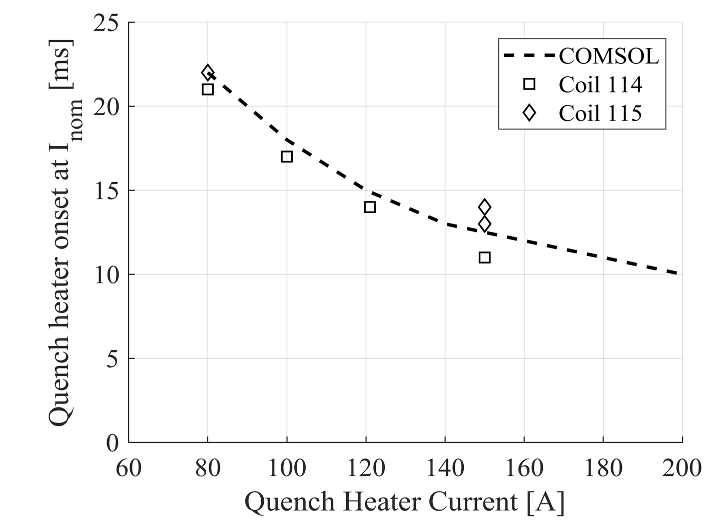
Parameter	Unit	
Strand diameter	mm	0.700±0.003
Number of strands	--	40
Copper to superconductor ratio (cu/SC)	--	1.15±0.10
Conductor peak field	T	11.6
Differential inductance	mH/m	11.7
Stored energy density in conductor volume	MJ/m³	130
Non-insulated conductor current density	A/mm²	790
Magnetic length	M	2 x 5.3

Quench Heater Performance

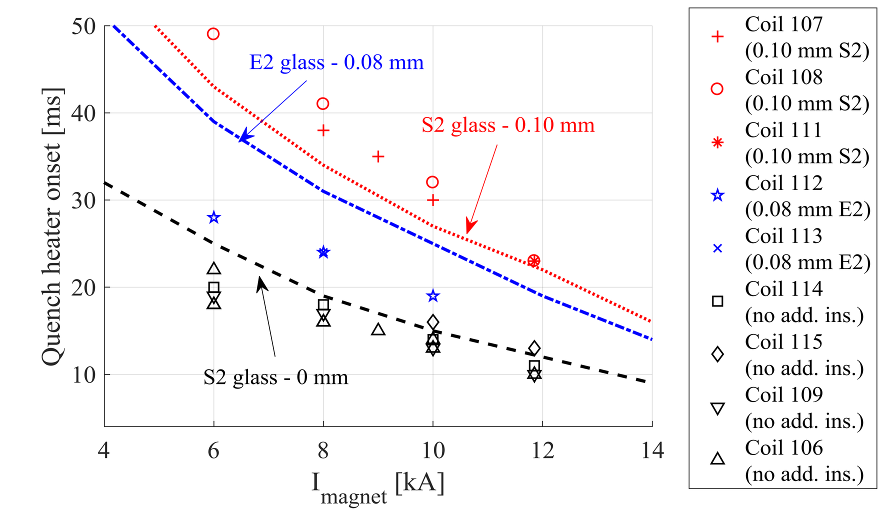
Quench heaters are able to quench the magnet at all current levels.



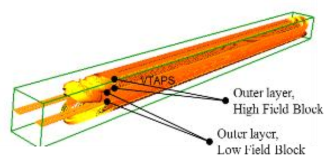
Further increase of the heater power will not significantly reduce the heater delay.

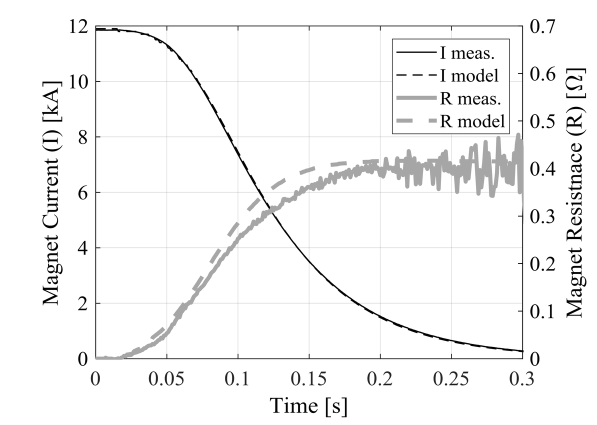


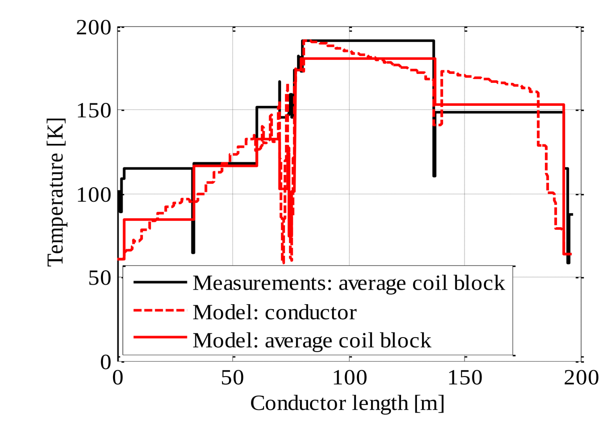
Time needed to provoke a quench is in agreement with expectations



Model vs Measured current decay and resistance growth is typically within 3 %.





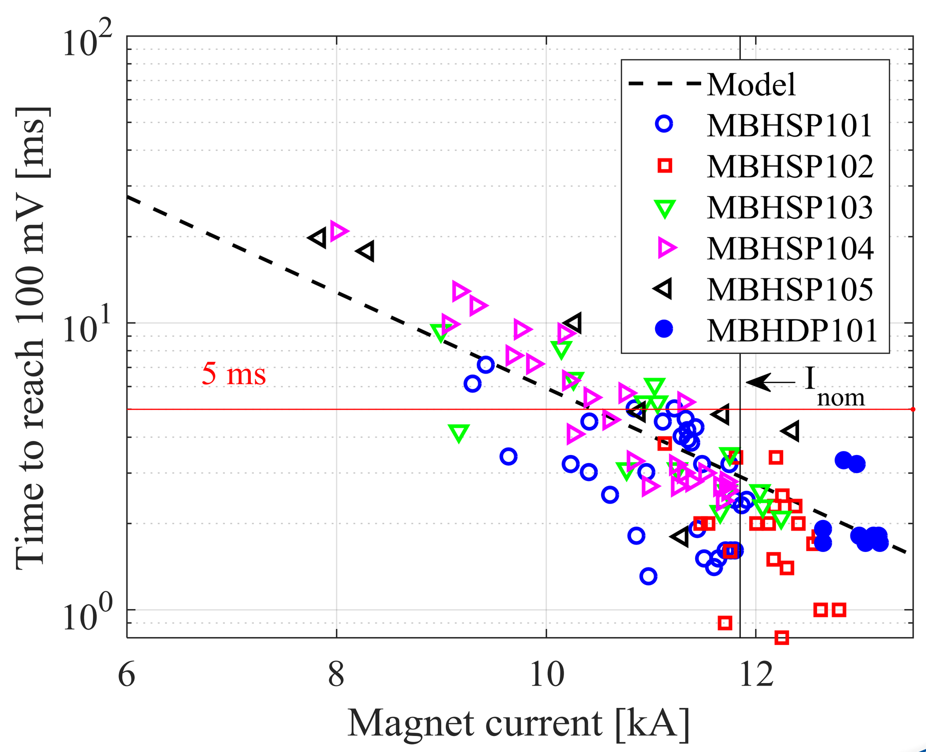


Detection

Assumption for detection:

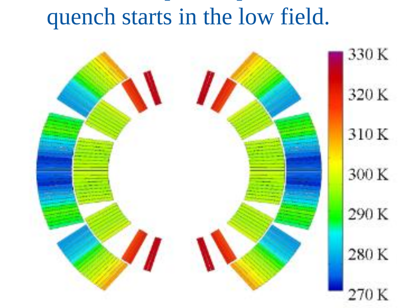
- 5 ms to detect at nominal current.
- 10 ms to validate the quench.

OK based on training data from short model magnets.

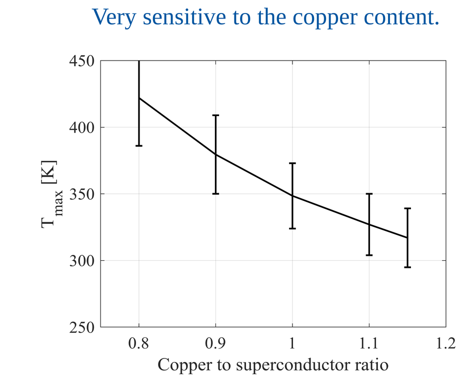


Sensitivity Analysis

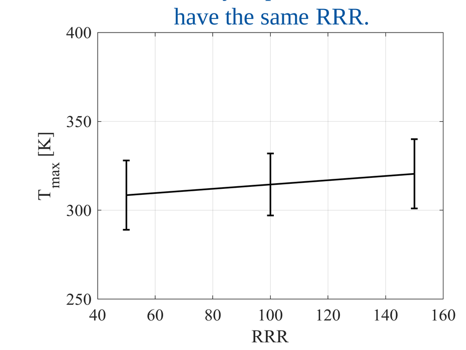
50 K lower hot spot temperature if the quench starts in the low field.



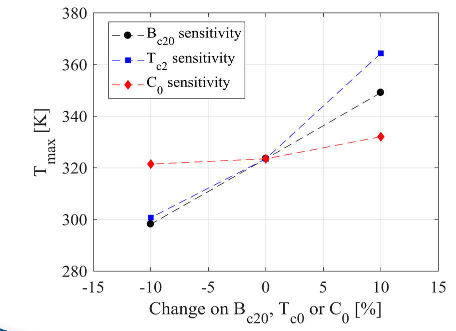
Very sensitive to the copper content.



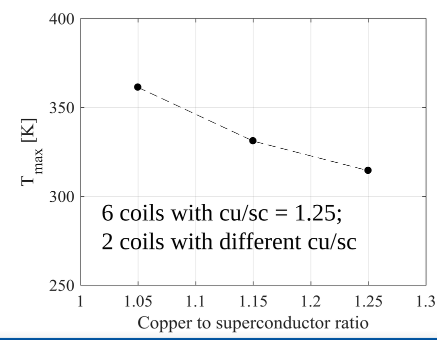
RRR not very important, if all coils have the same RRR.



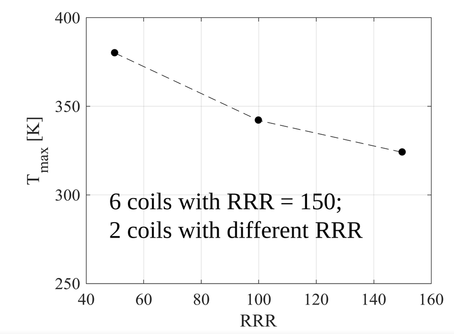
T_{c0} and B_{c2} are not expected to change more 2 % within the production, so weak impact on the hot spot temperature.



Not uniform cu/sc in the different coils in the same assembly becomes important!



Not uniform RRR in the different coils in the same assembly becomes critical!



Expected Performance "Accelerator Conditions"

Strategy:

- If one quench heater power supply fails, the heater power supply will be replaced during the next access.
- If two quench heater power supplies fail, the beam is dumped and the heater power supply is replaced.
- If one out of the sixteen heater circuits fail, during next long shut down the magnet will be replaced.
- If more than two circuits fail the individual case needs to be studied.

		Nominal		1 circuit failure		2 circuits failure	
		I_{nom}	I_{ult}	I_{nom}	I_{ult}	I_{nom}	I_{ult}
Current	kA	11.85	12.80	11.85	12.80	11.85	12.8
Quench Integral	MA²s	15.8	16.2	16.1	16.4	16.2	16.5
T_{max}	K	320	342	327	349	333	356
U_{ground}	V	245	340	570	680	950	1070
$U_{turn-turn}$	V	75	80	80	90	90	95