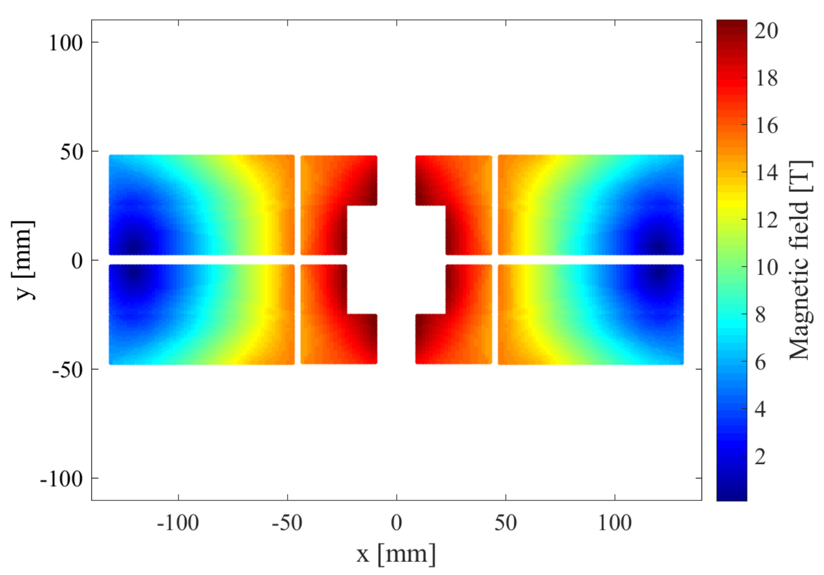
Quench Protection of a 20 T Dipole Magnet with HTS Insert

E. Ravaioli, M. Maciejewski, G. Sabbi, T. Shen, X. Wang
Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, California, 94720

FCC week
Rome
13 April 2016

20 T block-coil dipole magnet

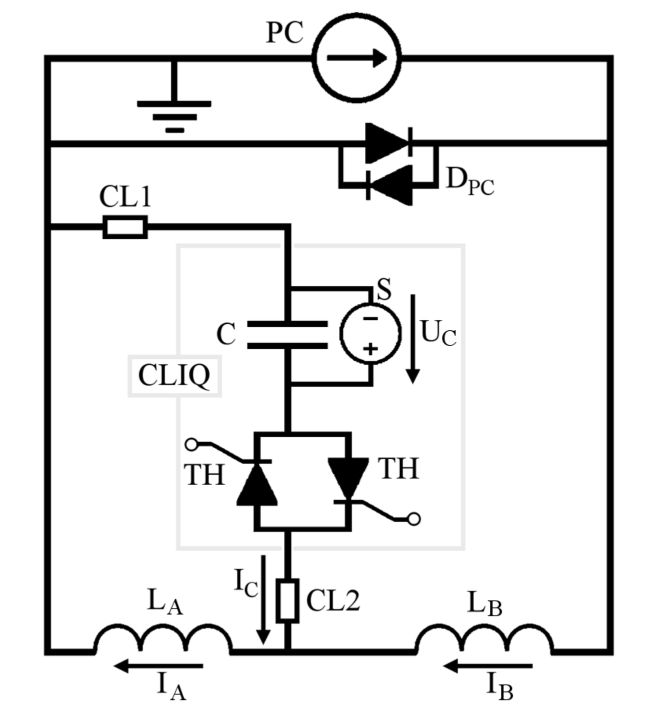
The design of a 20 T dipole magnet constituted by an LTS outer coil and a HTS insert is analyzed from a quench protection standpoint. Protection of such a magnet in the case of a quench brings several challenges. The very high stored energy density requires an effective mean to quickly discharge the transport current and homogeneously distribute the magnet's energy in the winding pack after a quench. Goal of the design study is the development of an effective quench protection scheme which allows maintaining the coil's hot-spot temperature within acceptable limits.



Performance at 20 T	Outsert	Insert
Operating current	13.5 kA	
Peak field in the conductor	15.4 T	20.4 T
Current density in the sc	970 A/mm^2	1980 A/mm^2
Operating temperature	4.2 K	
Self-inductance at 20 T	33.8 mH/m	
Self-inductance at 1 T	68.5 mH/m	
Magnet length	14 m	

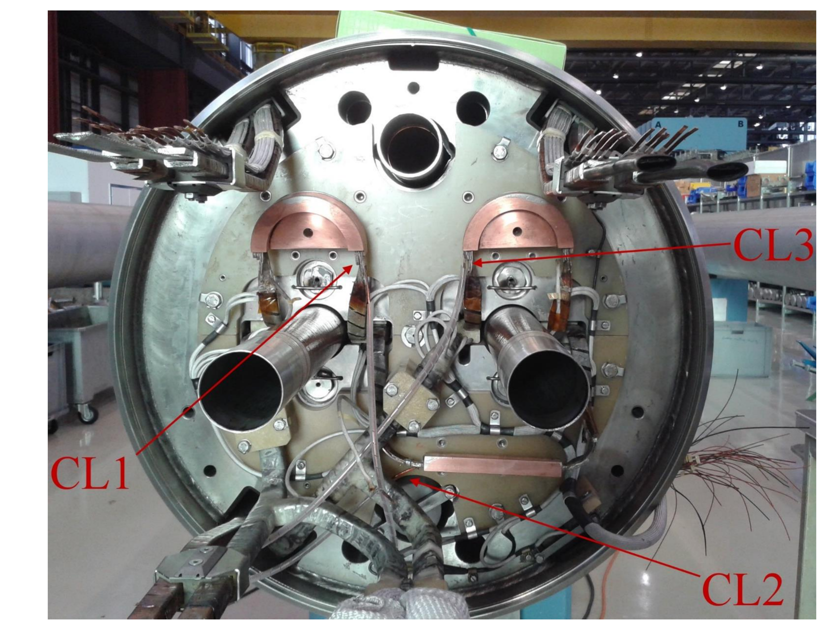
Conductor	Outsert	Insert
Superconductor	Nb_3Sn	Bi-2212
Stabilizer	Cu	Ag / AgMg
Number of strands	51	48
Strand diameter	0.80 mm	0.85 mm
Fraction of non-stabilizer	54%	25%
Cable width	22 mm	22 mm
Cable thickness	1.40 mm	1.49 mm

CLIQ (Coupling-Loss Induced Quench method)

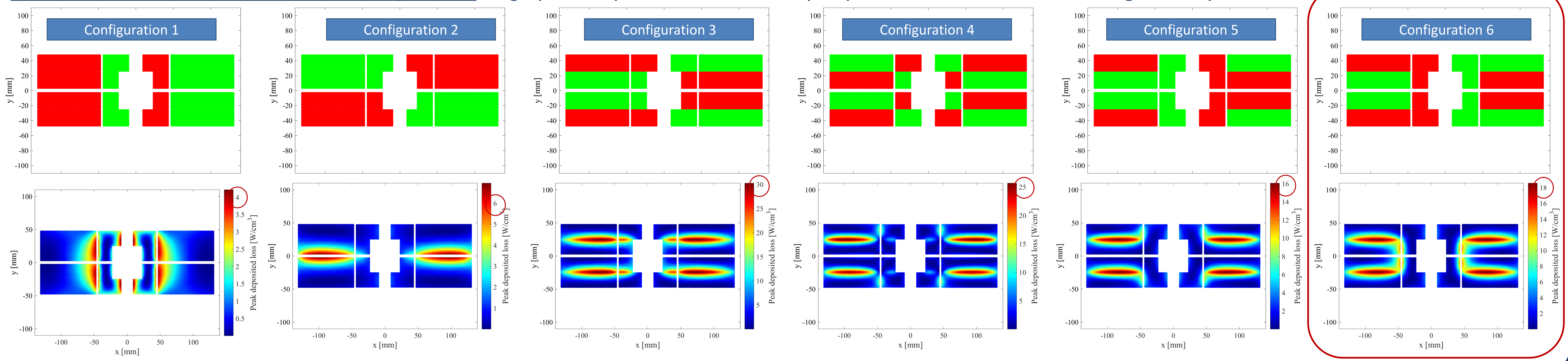


CERN Patent
EP13174323.9, June 2013

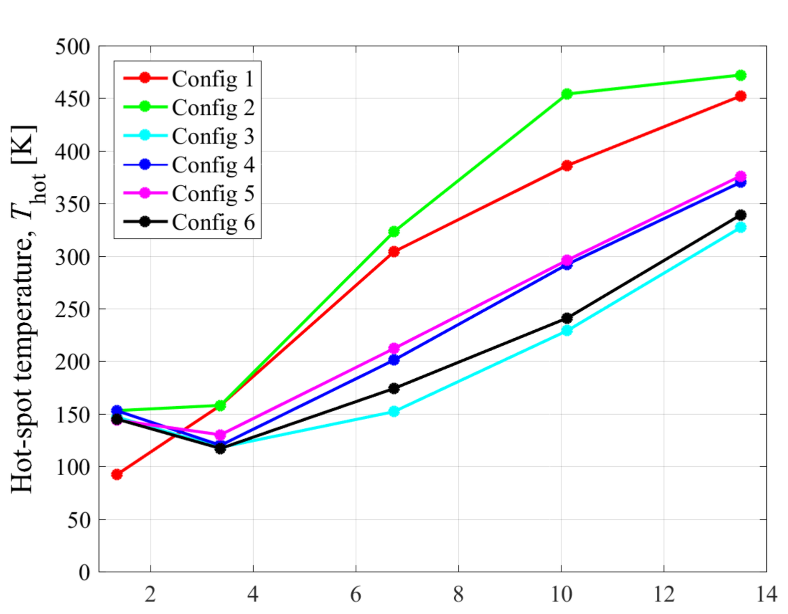
The oscillating current quickly changes the local magnetic field, which in turn generates inter-filament coupling loss
→ **Effective** and electrically **robust** system



Choice of the most effective CLIQ configuration: High peak deposited loss and easy implementation on a block-coil geometry

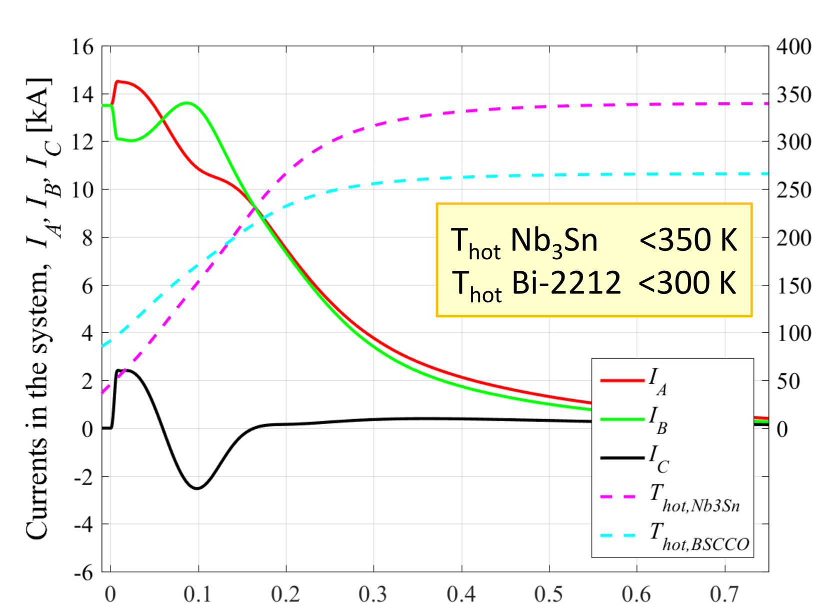


Hot-spot temperature

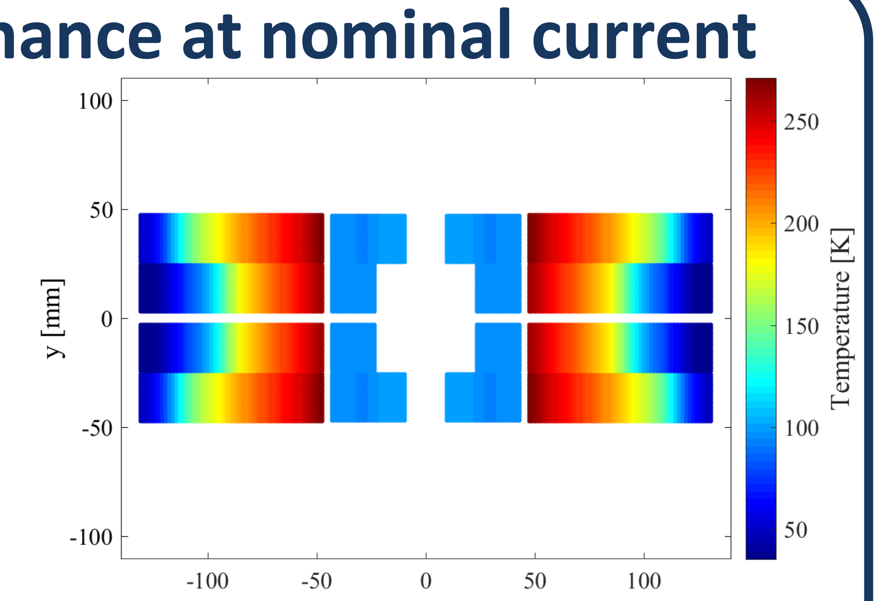


Comparison between six configurations
Charging voltage: 1 kV; Capacitance: 150 mF

Configuration 6 – Performance at nominal current



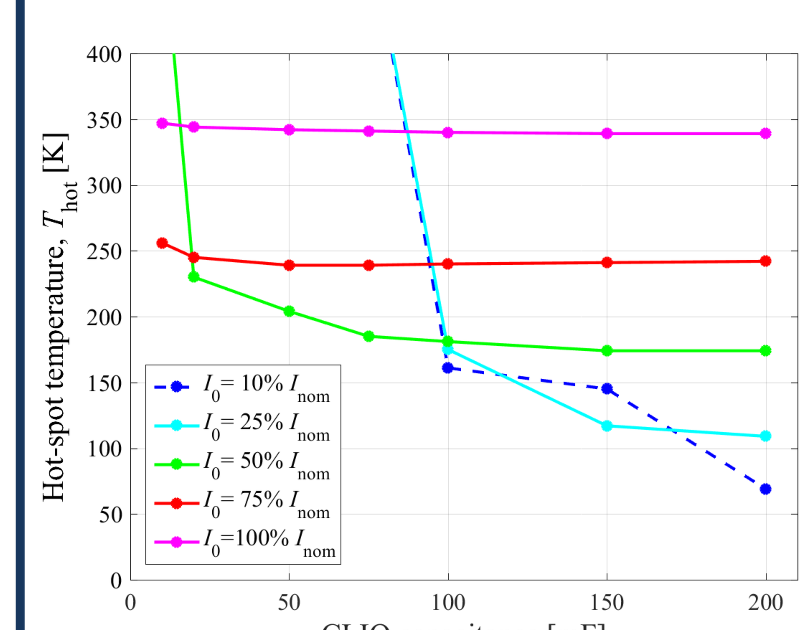
Assumed detection + validation time
For Nb_3Sn: 15 ms For BSCCO: 110 ms



The hot-spot is in the Nb_3Sn outsert where the current density in the stabilizer is higher

Simulations performed with a LEDET model (Lumped-Element Dynamic Electro-Thermal)

Optimum capacitance



High current performance independent of the value of the CLIQ capacitance

DISCUSSION

- 20 T block-coil dipole magnet protected at any current level
- Longer detection time in the HTS (assumed 100 ms vs 5 ms) is not critical since the current density in the stabilizer is lower in the HTS conductor
- At low current, the HTS insert remains sc and is discharged by the resistance developed in the series-connected LTS outsert
- The design of the magnet can be further optimized for improving the performance of the protection system
  - Thicker cable, Less turns → Lower self-inductance
  - Nb-Ti outsert → Easier to quench at low current
- Further studies: Double-aperture design, Optimization of strand parameters, Updated material properties