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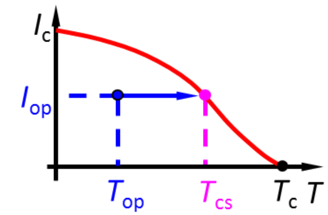
Quench Protection of CCT-Type High-Field Magnets for Accelerators

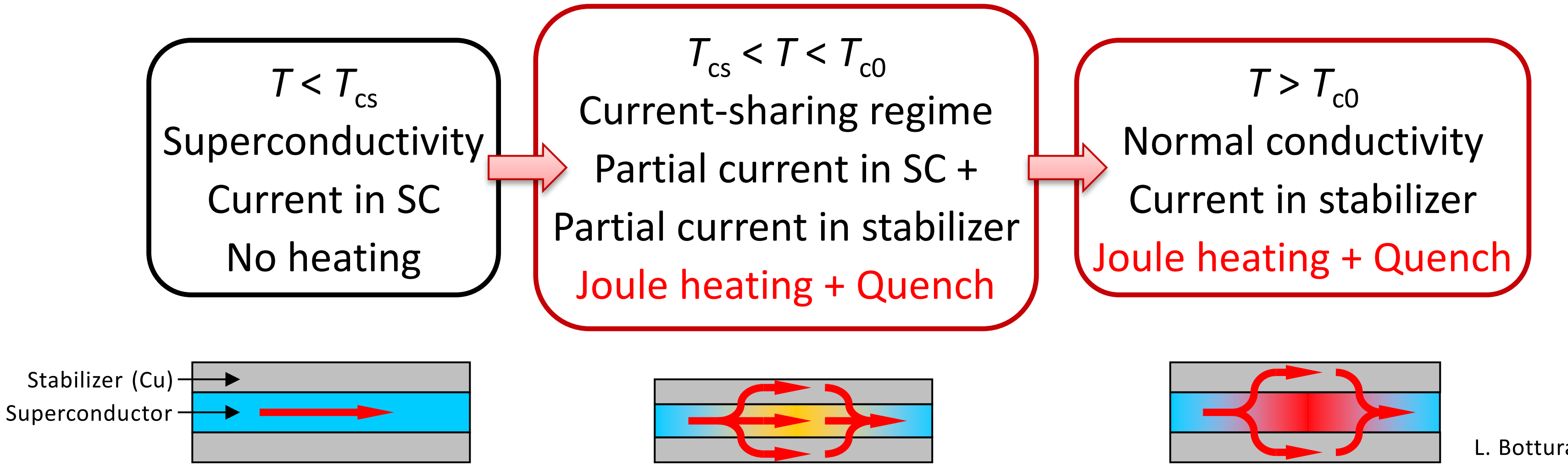
Work supported by the Swiss State Secretariat for Education, Research and Innovation SERI
Annual Meeting of the Swiss Physical Society, 28-31 August 2018, EPFL

Contents

Quench Protection



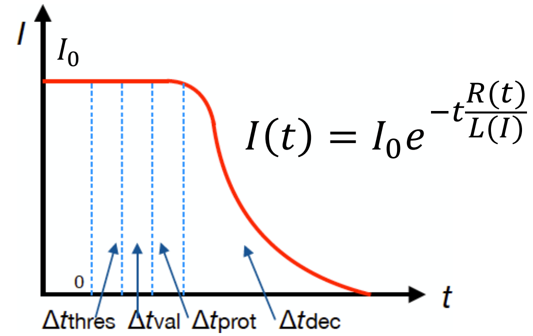
- Quench: transition from superconducting to normal-conducting state
  R_{quench} ↗ Joule heating in Cu, causing T ↗ in normal zone



Quench Protection

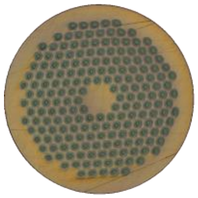
- Protection: dissipate magnetic energy as heat or quench entire coil to limit T_{peak} and avoid damage in coil

- Different phases in a quench:
  - I constant, heat propagation:
    - 1a. Detection $\Delta t_{\mathrm{thres}}$ 1b. Validation Δt_{val}
  - I decreases, energy dissipation by Joule heating:
    - 2a. Protection Δt_{prot} 2b. Discharge Δt_{dec}



Time in ms!

- Magnet design efficiency: less time – less Cu fraction – smaller coil



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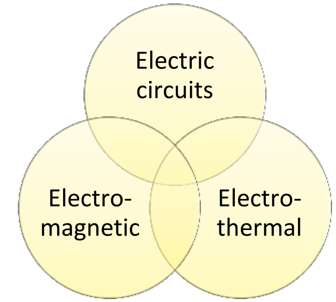
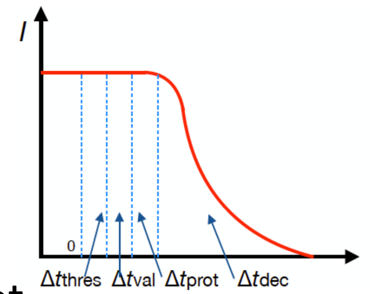
Simulation Methods

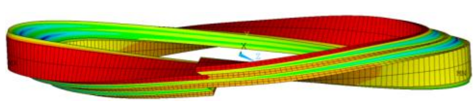


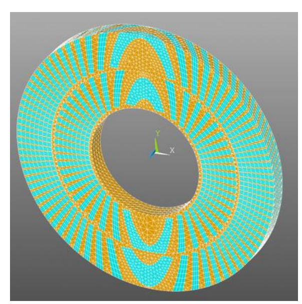
- Study quench phenomenon in two-/four-layer CCT geometry
  - Use of ANSYS User-Defined Elements (UDEs) developed at LBNL
    - Thermal: multi-dependency material properties
    - Electromagnetic: effects of cable-eddy currents

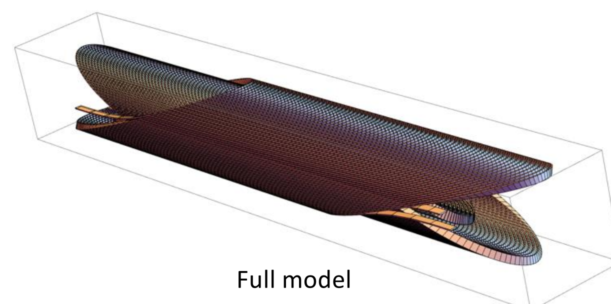


- Coupled quench simulation in a hierarchical approach

1. MIITs adiabatic calculation (Joule heat source) → time budget
2. ✔ MATLAB adiabatic integrator (update on $R(t)$) → current decay
3. Magnetostatic & Electrothermal model → quench propagation
4. ⇨ Electrothermal & Electromagnetic model (UDEs) → protection methods
5. Electromagnetic-thermal full model of model magnets

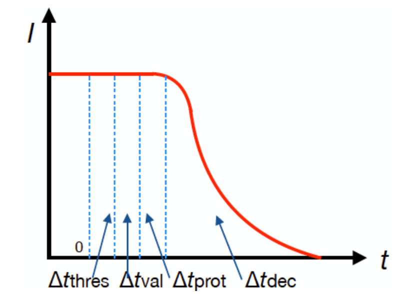

Helical model


Periodic model

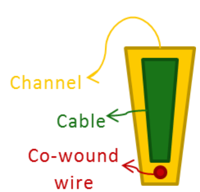

Full model

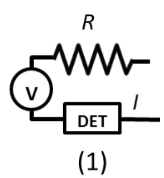
Detection Concepts

- Study different detection & protection concepts and design a fast and efficient protection system for CCT

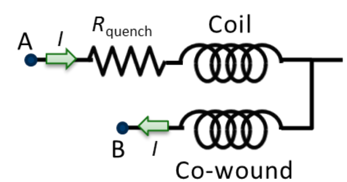


1. Voltage detection using co-wound Cu wires: V ↗ (I cst)
   – Low-risk but Δt_{val} obligatory
2. Current detection using co-wound SC wires: I ↘ (V cst)
   – Expect to eliminate Δt_{val}; can be studied in detail
3. Co-wound optical fibers: temperature and strain data from analysis of spectral shift (Rayleigh backscattering spectra)
   – High-risk but shorter delay time; collaboration with Penn State Univ.





Current det.



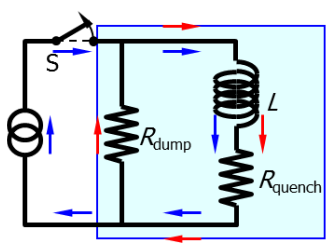
Co-wound principle

L. Bottura. Superconductors. Presentation, 2012.

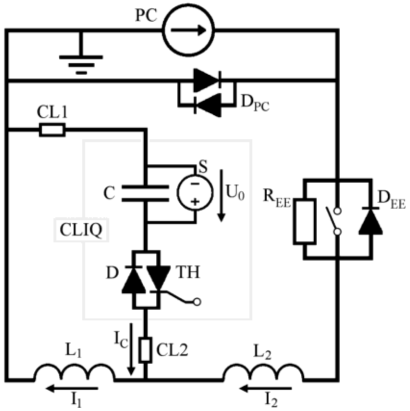
M. Marchevsky. Protection of superconducting magnet circuits. Lecture notes of USPAS, 2017.

Protection Concepts

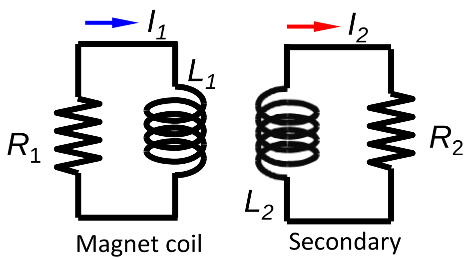
1. Energy extraction: suitable for a single-magnet system; basic method for R&D magnets
2. Coupling-Loss Induced Quench (CLIQ): *I* oscillations → coupling losses (heat) → quench; most promising method
3. Inductive protection using co-wound Cu tapes: quench process enhancement



Energy extraction
Courtesy of L. Bottura



CLIQ
Courtesy of E. Ravaioli



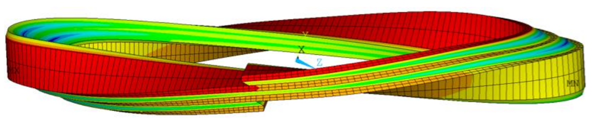
Inductive protection

L. Bottura. Superconductors. Presentation, 2012.

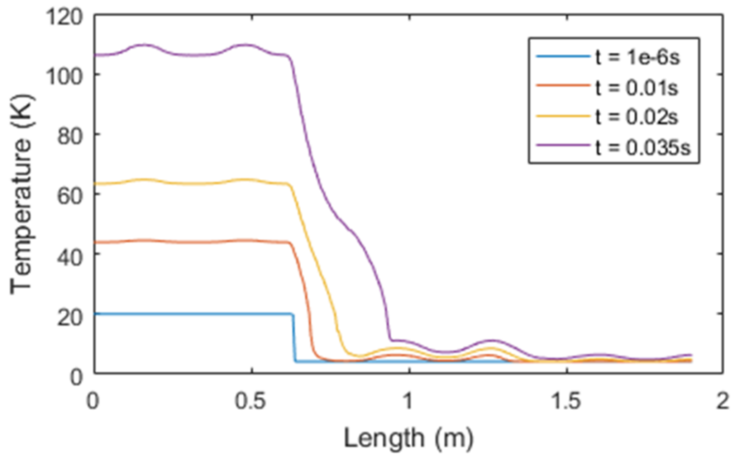
M. Marchevsky. Protection of superconducting magnet circuits. Lecture notes of USPAS, 2017.

Protection of Two-layer Model Magnet CD1 with Energy Extraction (+ Voltage Detection)

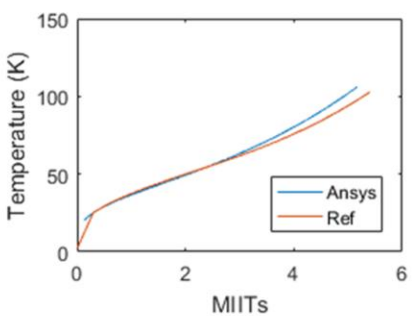
I [kA]	B [T]	$\Delta t_{\mathrm{thres}}^{\mathrm{ref}}$ [ms]	$\Delta t_{\mathrm{thres}}^{\mathrm{ANSYS}}$ [ms]	MIITs [MA^2S]	T_{max} [K]
18	11	23.5	3.8	7.6	199
15.5	9.5	33.5	12	7.5	193
12	7.3	59	26.9	6.8	145



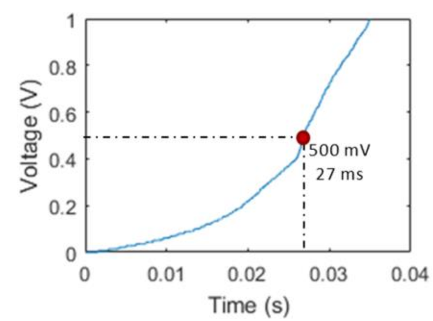
Temperature profiles along the coil at different times



Comparison of MIITs and temperature coherence



Evolution of detectable voltage with time



→ Good time margin and temperature margin

→ CD1 protectable with energy extraction; test-bed for other detection & protection methods

Future Work

- Continue studying different protection concepts, especially CLIQ, via coupled simulations in two-/four-layer CCT magnets

- Implement, test and validate the detection & protection system in two-layer model magnet that will be built at PSI during the thesis

My thanks go to

- Bernhard Auchmann
- Lucas Brouwer
- Giuseppe Montenero
- Gabriella Rolando
- Stephane Sanfilippo
- Federico Scurti