Magnet Protection Considerations

Spectrometer Solenoid Review

October 25, 2010

Soren Prestemon
Lawrence Berkeley National Lab

Outline

MICE Spectrometer Quench Protection Scheme

- Introductor comments
- Coil layout
- Protection system

Analysis Model

- Circuit model
- Design parameters
- Quench code overview

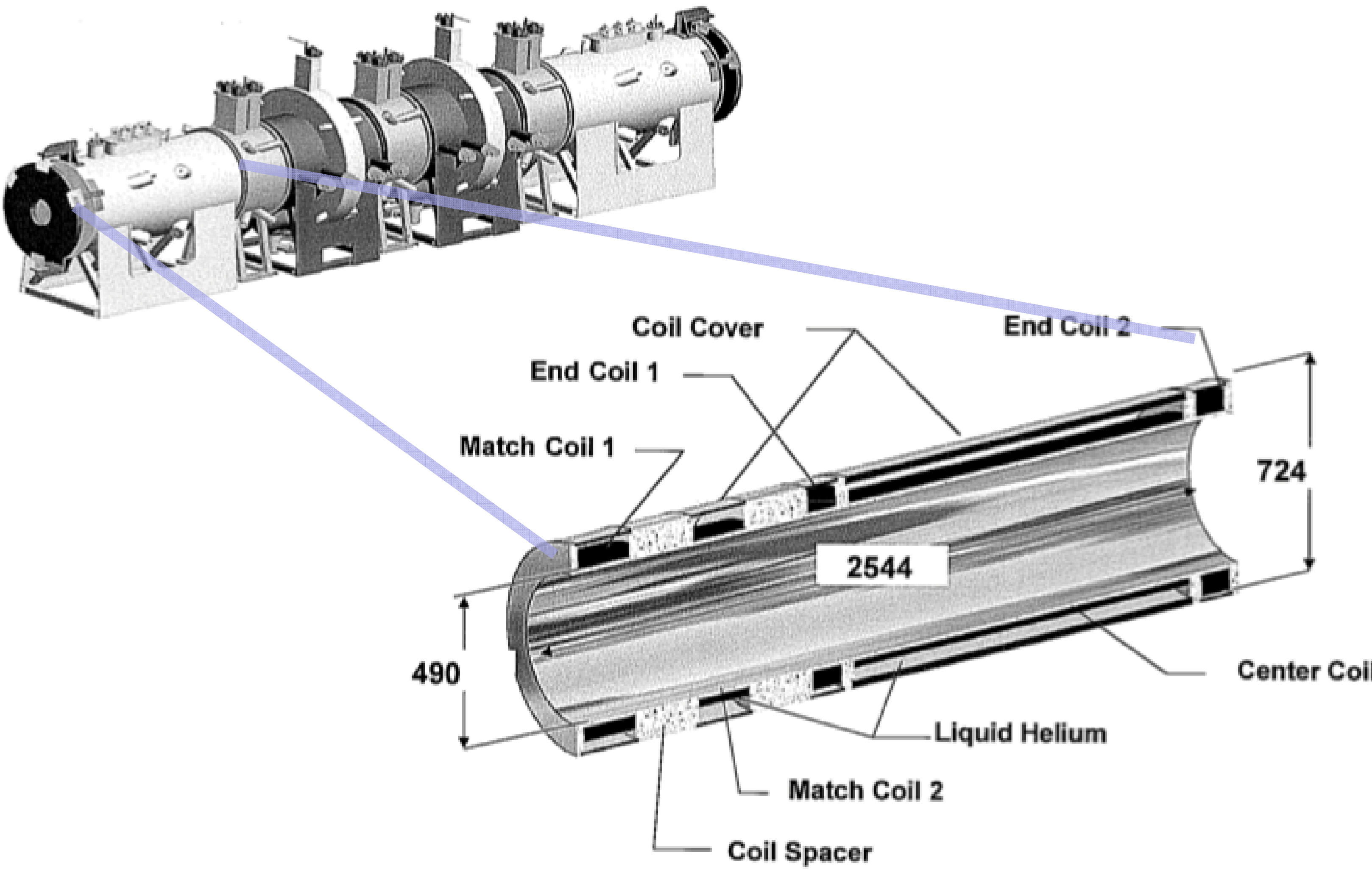
Analysis Results

- Case studies
- Summary

MICE Protection Scheme

- Based on a simple, passive approach
  - Conductor designed to yield reasonable hot-spot temperature
  - Fairly high internal voltage anticipated
    - Mitigated by robust insulation scheme
    - Hi-pot tested as part of specification
- Some design considerations:
  - Coils interact via mutual inductance
    - Can transfer energy
  - Some coils in series, some independent PS:
    - Depends on operating regime
    - Impacts voltage and hot-spot temperature analysis

MICE Coil layout

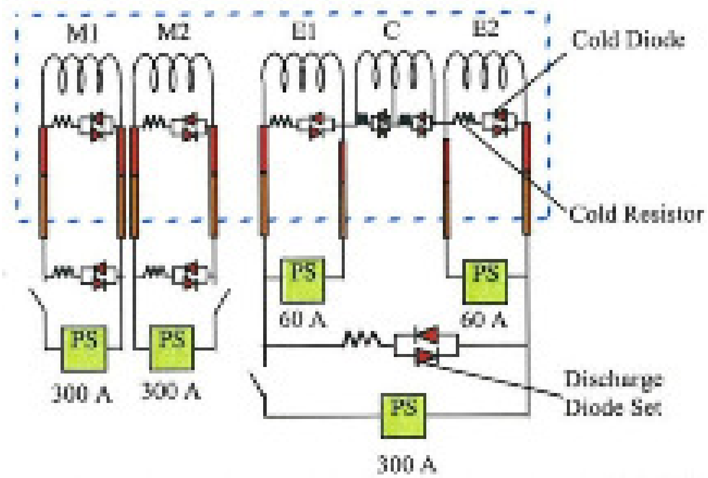


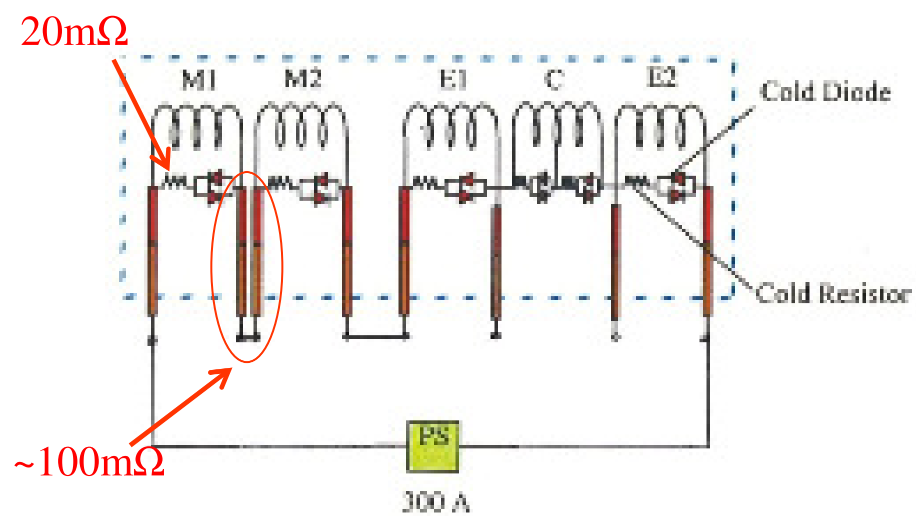
ign”

WangNMR, Inc.

MICE Protection System

- Nominal operation has numerous individual power supplies
  - A quenched coil may or may not induce other coils to quench
  - Some energy transfer, but not all will be deposited in one coil
- Powering during training:
  - All coils in series
  - A quenched coil may or may not induce other coils to quench
  - Worst case all of the stored energy can be deposited in one coil



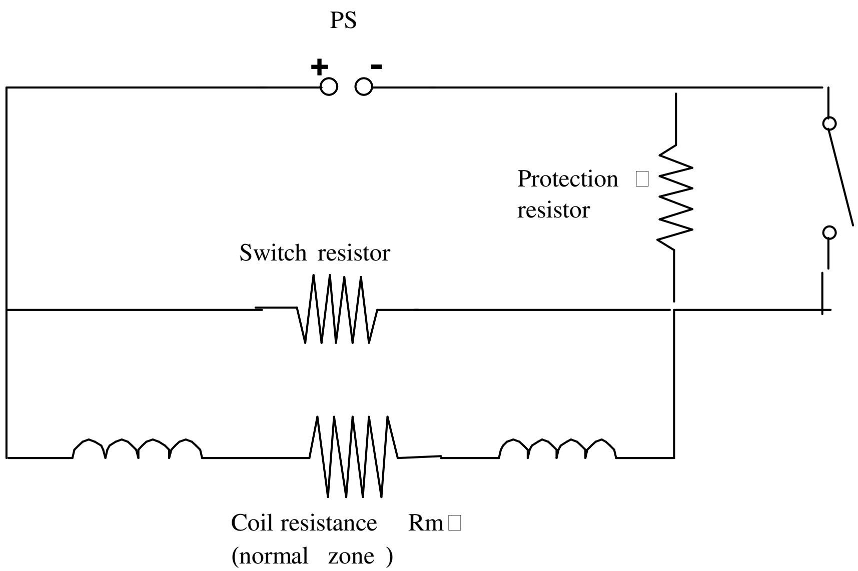


From V. Kashikhin, MICE review report, July 19, 2010

Analysis model

- Circuit model

$$IR_m(I,\theta,t) + I\frac{R_{switch}R_{prot}}{(R_{switch}+R_{prot})} + L\frac{dI}{dt} = 0$$



- Inductance matrix and conductor/coilpack characteristics

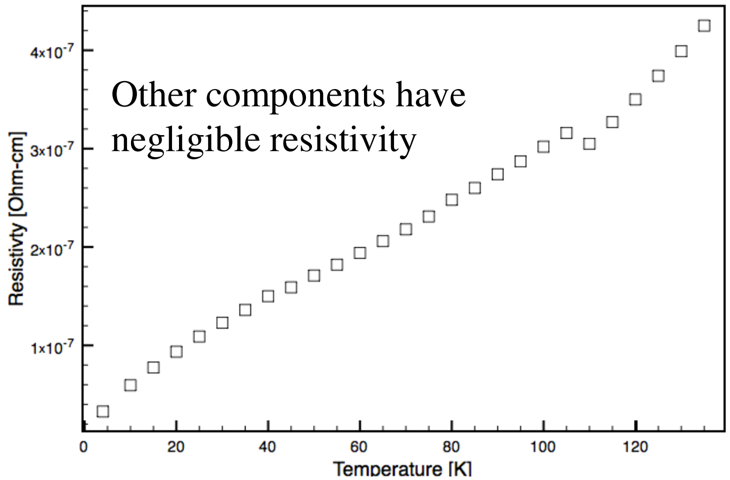
Inductance matrix [H]

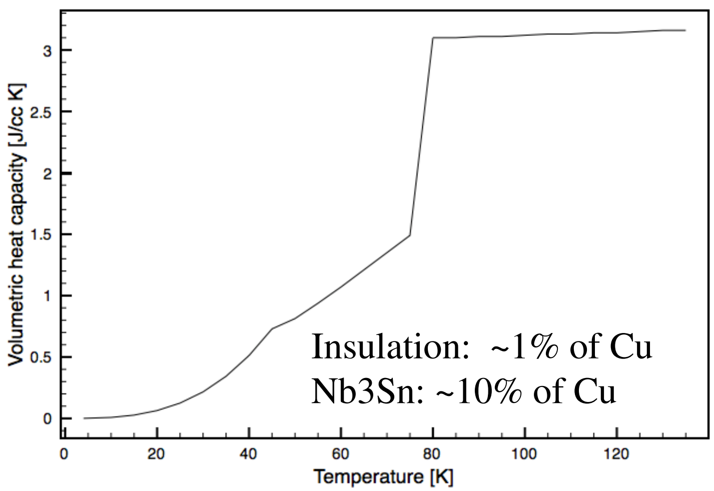
	M1	M2	E1	C	E2
M1	15.68	1.14	0.31	0.28	0.02
M2	1.14	6.84	0.28	0.57	0.02
E1	0.31	1.01	10.48	3.50	0.05
C	0.28	0.57	3.50	43.77	3.79
E2	0.02	0.02	0.05	3.79	12.01

Cu:SC	3.9
A_{cu}/A_{tot}	0.69
A_{sc}/A_{tot}	.177
A_{ins}/A_{tot}	.133

Quench code input

- Material properties: Cu





- Coil parameters

Coil	Z1 (m)	Z2-Z1 (m)	R1 (m)	R2-R1 (m)
M1	3.510	0.201	0.258	0.045
M2	3.951	0.200	0.258	0.030
E1	4.396	0.111	0.258	0.060
C	4.544	1.314	0.258	0.021
E2	5.896	0.111	0.258	0.066

- Other input parameters:
  - Transverse propagation velocities:
    - Decay rate of current highly sensitive to transverse propagation
    - Use measured ~5s decay seen during training to determine V_{trans}/V_{long}~0.01
  - Protection resistance does not play critical role

Case studies

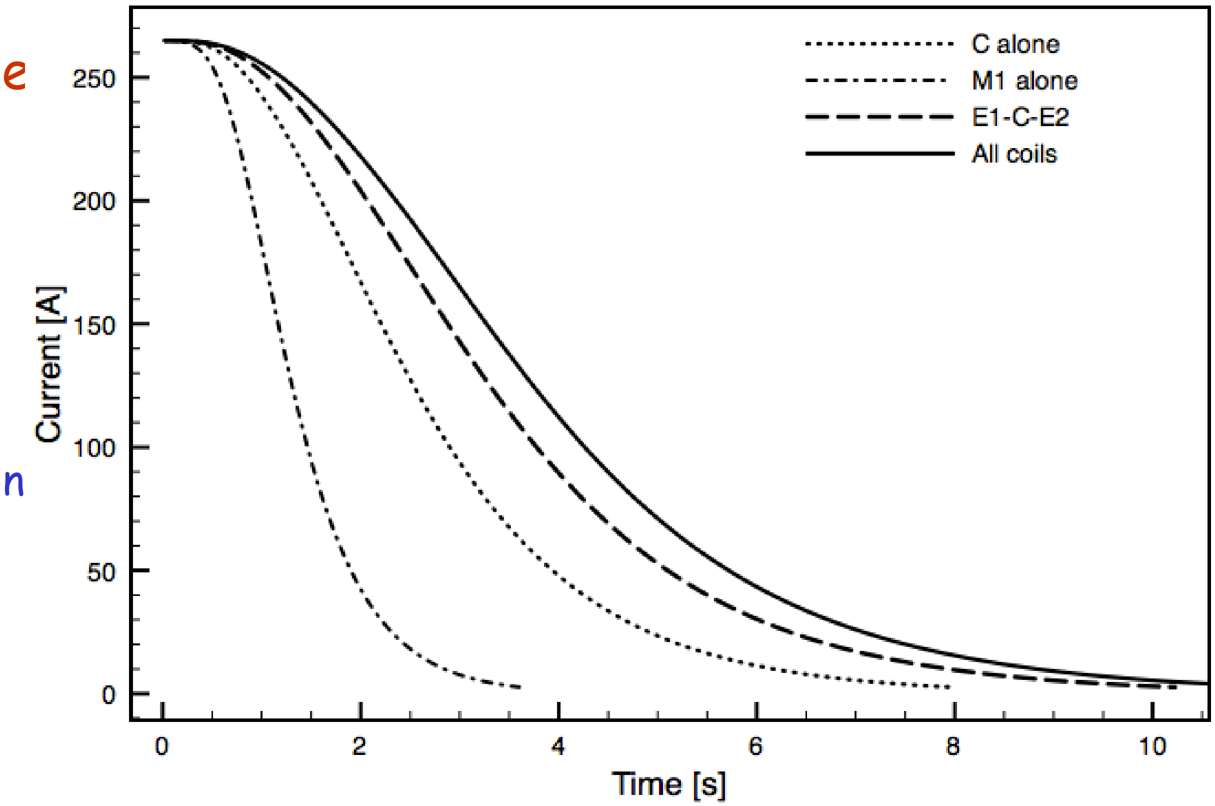
- Four cases:
  1. All coils in series
  2. Coils E1-C-E2 in series
  3. Coil C alone
  4. Coil M1 alone

- Powering during training:
  - All coils in series
  - A quenched coil may or may not induce other coils to quench
  - Worst case: only one coil quenches

- Assumptions:
  - No mutual inductance coupling with other coils
  - Quench starts somewhere inside a coil, but does not propagate to other coils in the series
    - In coil C for cases 1-3
  - Other coils in series do not quench
  - No quench-back taken into account

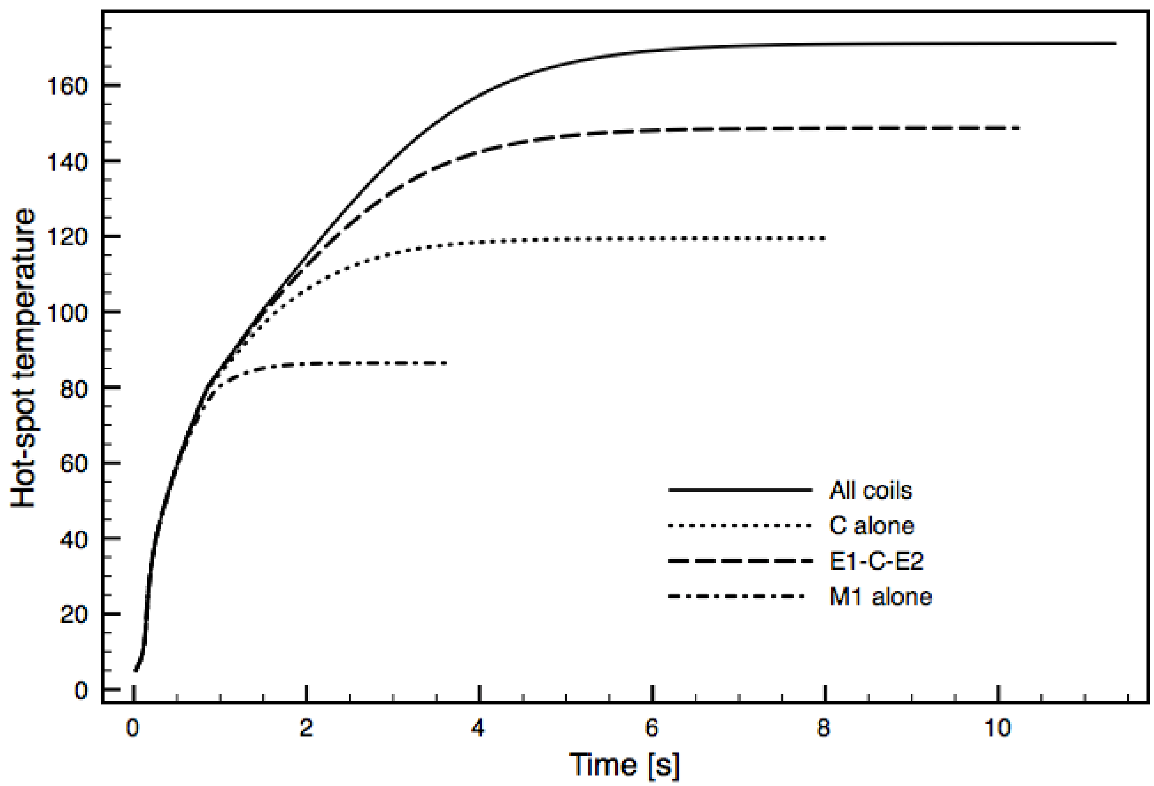
Results: Current decay

- Decay rate depends strongly on normal zone growth rate
  - Should be monitored during training
  - Provides crude insight into quench process
  - Should be faster if multiple quench initiation sites exist
- Majority (>2/3) of stored energy in main triplet E1-C-E2



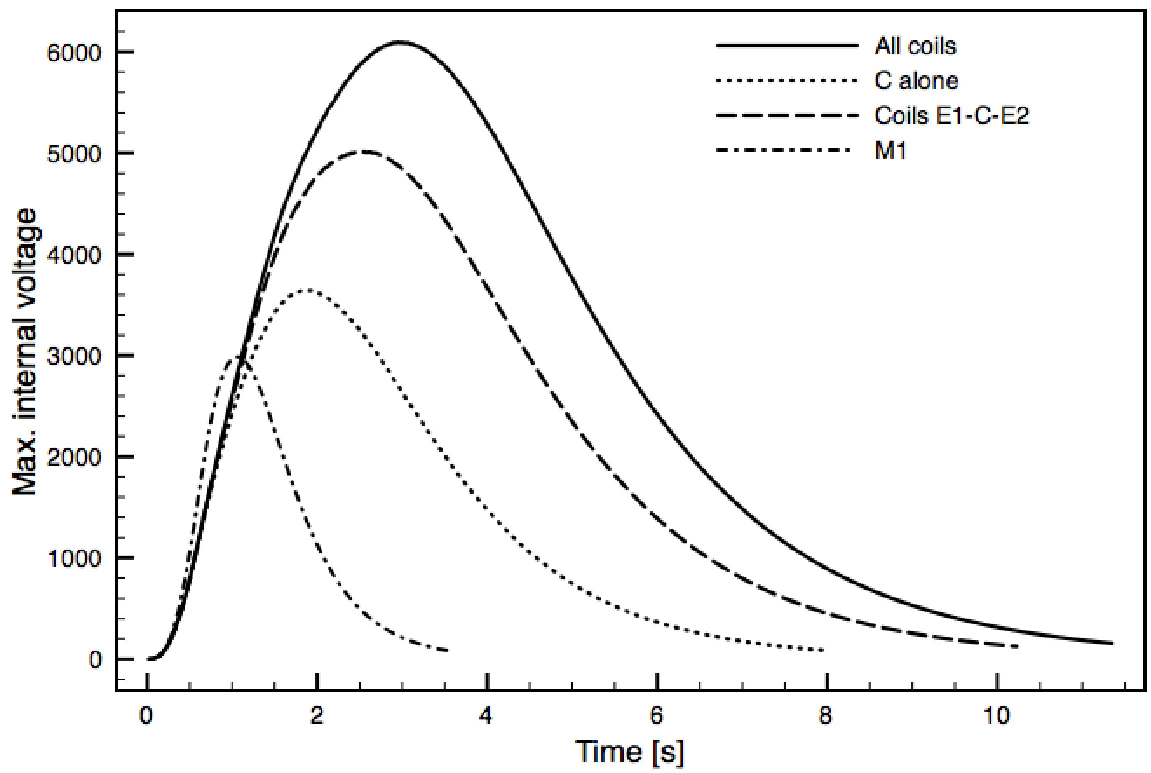
Results: Hot-spot temperature

- Hot-spot temperatures are reasonable
  - 150K is a common design point
  - Will be somewhat reduced if multiple coils quench



Results: Internal voltage

- High internal voltages may occur
  - Coilpack design tries to accommodate
    - Good insulation scheme
    - Hi-pot to 5kV
  - Depends on 3D propagation velocity
    - Faster propagation results in higher peak voltage
    - **Impact of quenchback remains to be studied**
  - Quenches in multiple coils would reduce peak voltage



Summary

- Analysis considered major cases
  - Provide insight into coil protection issues
  - Numerous simplifying assumptions:
    - No quenchback
    - Simple mutual coupling
    - Crude empirical determination of V_{trans}
  - "Full system" case corresponds to training run scenario
  - E1-C-E2 is most relevant for normal operation

- Summary of main results:
  - Hot-spot temperature appears acceptable in all cases
  - Decay rates are "reasonable", but need to be checked against experimental data
  - Peak voltages are high
    - Single coil cases are well within specification
    - E1-C-E2 case is at limit of design
    - "Full system" case exceeds design voltage by ~20%
- Conclusions:
  - Limit current to 240A during "full-system" training runs
  - Then restrict to E1-C-E2 set