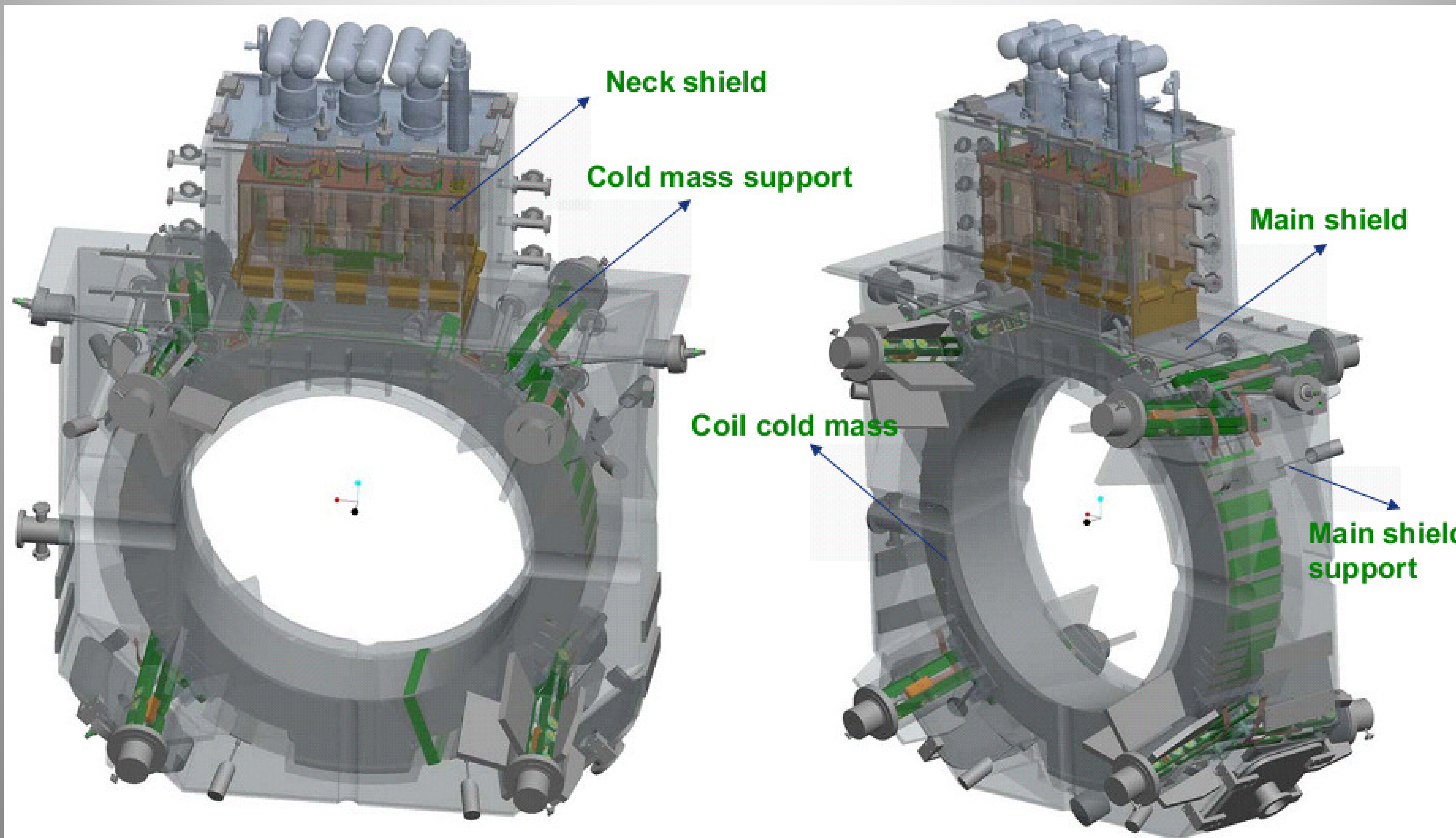
Thermal analysis for the MICE coupling magnet

Heng Pan

Lawrence Berkeley National Laboratory

March 6,2012


Neck shield
Cold mass support
Main shield
Coil cold mass
Main shield support

Outline

- Heat Load
  - Heat load to 60 K
  - Heat load to 4.2 K
- Steady State Thermal Analysis
  - Steady state temperature distribution in the cold mass
  - Temperature margin calculation

Heat leaks calculation

- Radiation heat load---heat leaks through MLI blankets
- Conduction heat load
  - Heat leak from supports (cold mass supports, shields' supports, 1ts stage copper plate supports)
  - Heat leak from cooling pipes (304 stainless steel)
  - Heat leak from current leads (Binary current leads)
  - Heat leak from instrumentation wires (mainly are phosphor bronze)
- Joule heat of superconducting joints

Uncertainties in calculation

- Radiation heat
  - the quality of MLI blankets
  - the gap between blankets layers
  - vacuum degrees
- Conduction heat
  - the temperature of the intercept and the conductivity of materials
  - the quality of the intercept connection
- Joule heat of superconducting joints
  - the quality of actual coil joints compared to the samples
- Assembly errors (20%~40% of nominal heat)
  - thermal shorts
  - thermal-acoustic oscillation
  - other errors

Radiation heat load

- The heat flux density through MLI blankets is a function of temperatures on warm and cold surfaces, vacuum and MLI layers:

$$q_r = \frac{\varsigma \cdot 10^4}{n}[1.22\times10^{-2} P(T_H^{\frac{1}{4}} - T_L^{\frac{1}{4}}) + 3.22\times10^{-14}(T_H^{\frac{17}{4}} - T_L^{\frac{17}{4}})]$$

ζ is empirical factor, usually is 4; *n* is the layers of MLI blanket.

- The shields will be wrapped 50 layers, the cold mass will be wrapped 20 layers.
- For the 1st stage and the cold mass, the nominal heat flus densities are 0.88 W/m^2 and 0.03 W/m^2;
- Considering the uncertainties, the high range will be the nominal heat plus the effects of uncertainties. For shields and cold mass, the high range will be 1.32W/m^2 and 0.2 W/m^2

Conduction heat load

- Conduction heat load can be obtained by Fourier equation:

For solid rod: $Q = \frac{A}{L}\int_{T_L}^{T_H} \lambda(t)dt$ For hollow tube: $Q = \frac{\pi r^2 - \pi(r-\delta)^2}{L}\int_{T_L}^{T_H} \lambda(t)dt$

- A pair of binary current leads (conventional copper leads + HTS leads) connect the coupling coil with the power supply. The optimization of conventional conduction-cooled copper leads was carried out.
- For the 1st stage heat load, the high range will be 50% higher than nominal heat;
- For the 2nd stage heat load, the high range will be set as the heat at a higher intercept temperature (85 K) and 30% higher thermal conductivity;

Heat Load Summary (1^{st} stage)

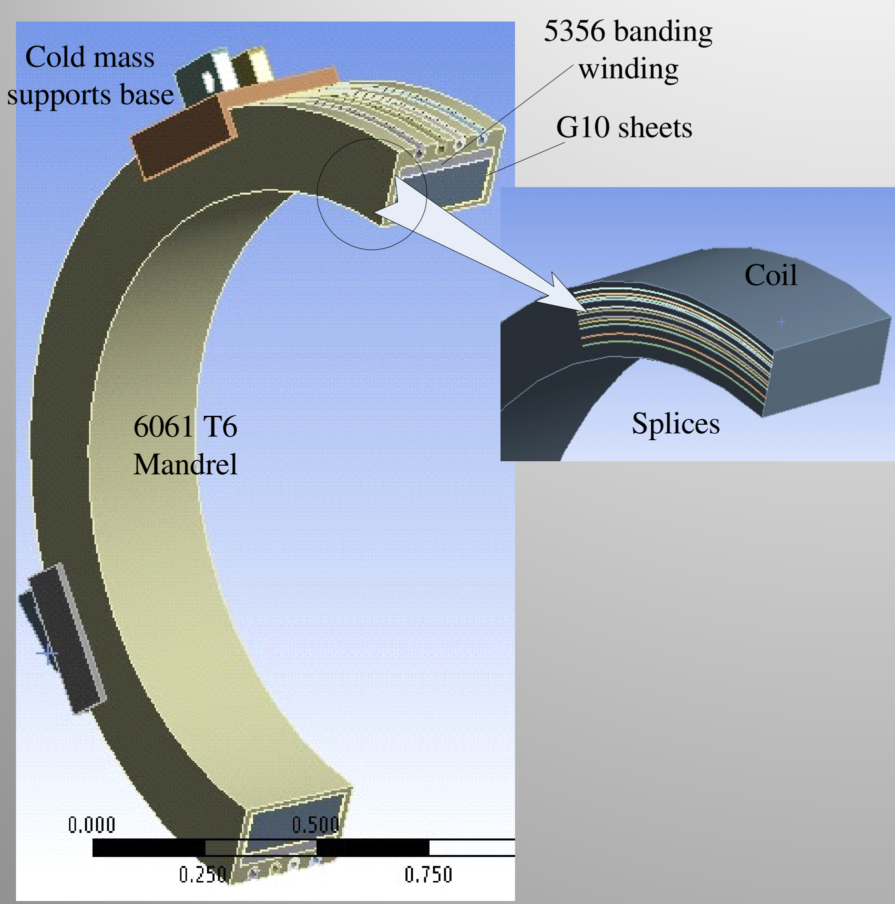
Heat loads items	Nominal heat (W)	High range (W)
Current leads	19.30	28.90
Cold mass supports	11.68	17.52
Radiation Heat	7.75	11.75
Instrumentation wires	0.06	0.09
He Cooling Tubes	4.63	6.95
Cooler SS sleeves	8.90	13.35
Neck shield supports	0.88	1.32
Heat shield supports	0.69	1.04
Assembly error	10.7	21.6
Sub-total	64.59	102.52

Heat Load Summary (2nd stage)

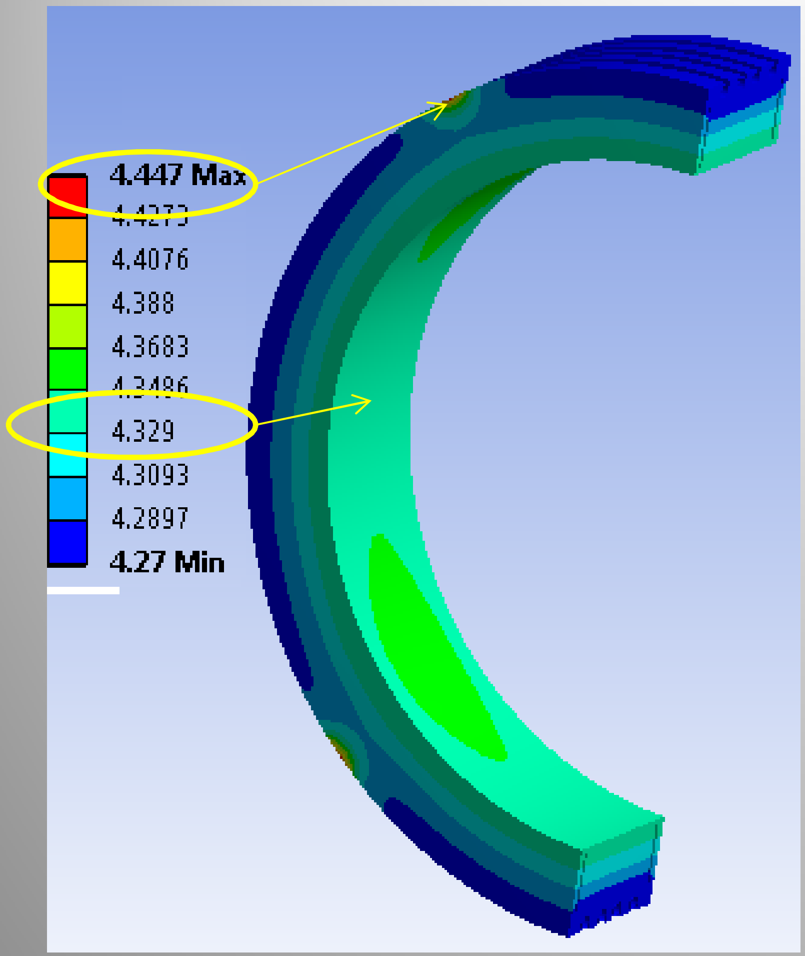
Heat loads items	Nominal heat (W)	High range (W)
Current leads	0.150	0.210
Cold mass supports	0.478	0.750
Radiation Heat	0.3	1.12
Instrumentation wires	0.002	0.004
He Cooling Tubes	0.09	0.18
Cooler SS sleeves	0.6*	0.9
SC joints	0.006	0.012
Assembly error	0.325	0.78
Sub-total	1.95	3.956

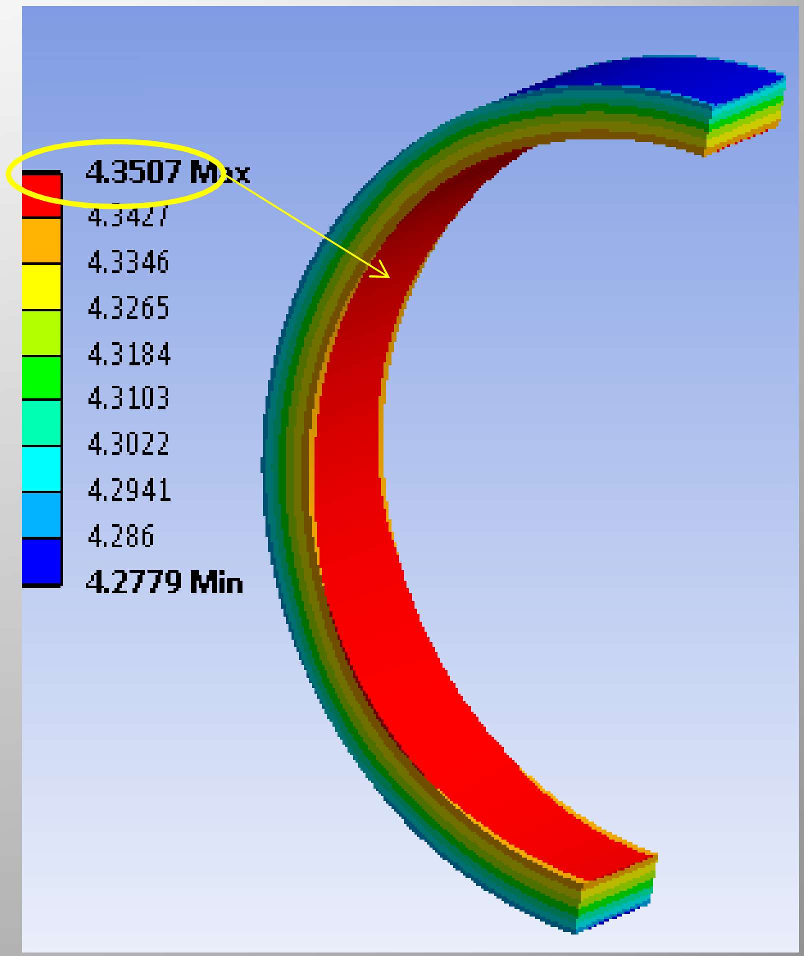
* test results by Mike Green

Steady thermal analysis

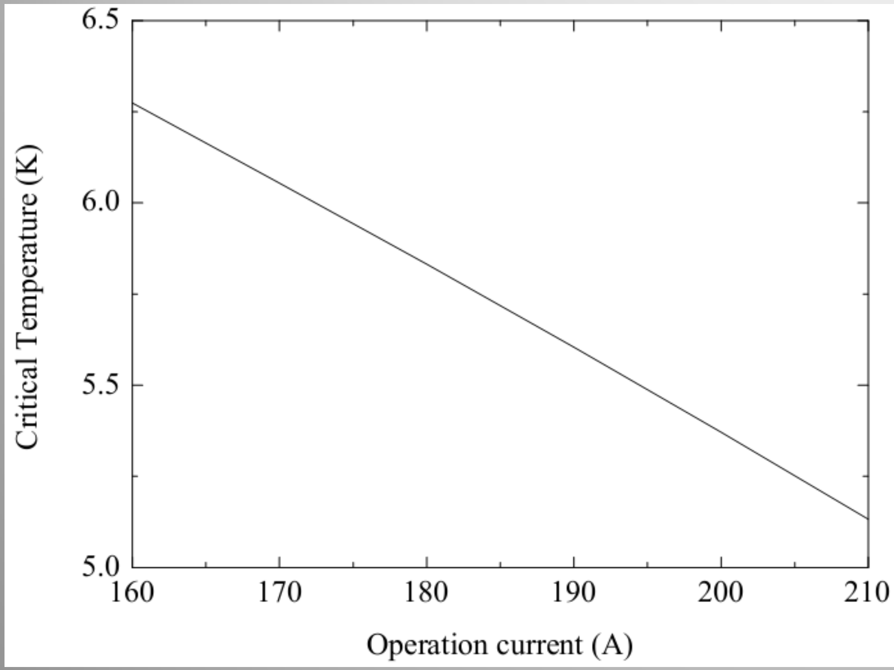


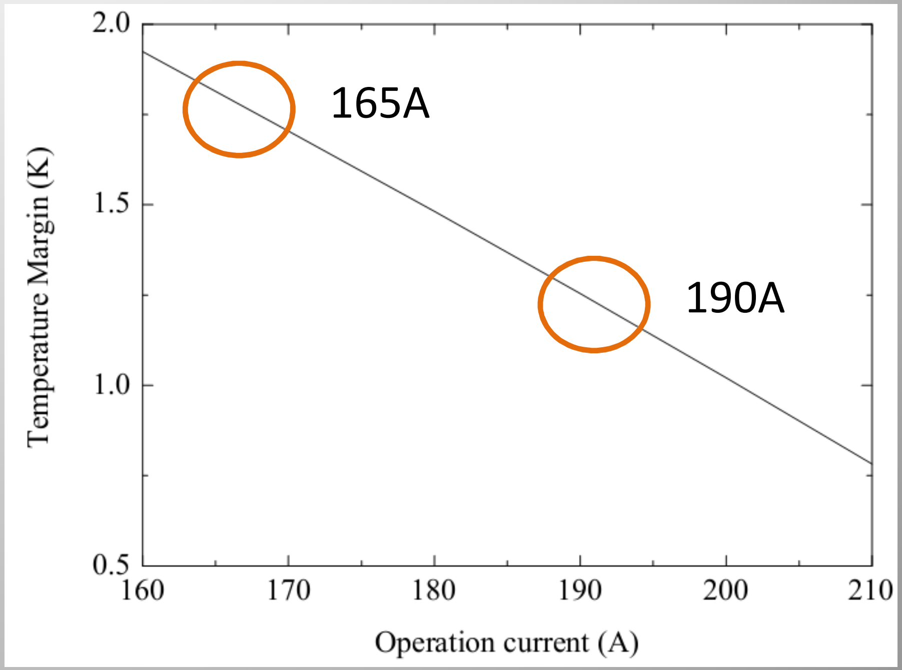
- The temperatures on the inner walls of the cooling tubes are set at 4.27 K.
- Radiation heat flux on cold surfaces.
- Heat conduction through the cold mass supports from 60K to 4.2K is applied on the curved surfaces of the support brackets.
- Heat conduction through cooling tubes imposed on the outer surfaces of cold mass.
- Heat leaks from the HTS leads imposed on the coil as volumetric load.
- Joule heat of SC joints imposed on the joints as volumetric load.


4.447 Max
4.4273
4.4076
4.388
4.3683
4.3486
4.329
4.3093
4.2897
4.27 Min


4.3507 Max
4.3427
4.3346
4.3265
4.3184
4.3103
4.3022
4.2941
4.286
4.2779 Min

Temperature margin





Ongoing tasks and plan

- Steady thermal and structural analysis for shields already done, the results need to be organized.
- The fluid dynamic simulation for cooling down process (for test) is undergoing.
- The analysis for eddy current effect on the shields during the magnet quench is undergoing.
- The stress behavior of the cold mass during quench will be done in the next 2 weeks.
- The structural analysis for the cryostat of the coupling magnet will be verified in the next 2 weeks.