ARIES CS Magnets

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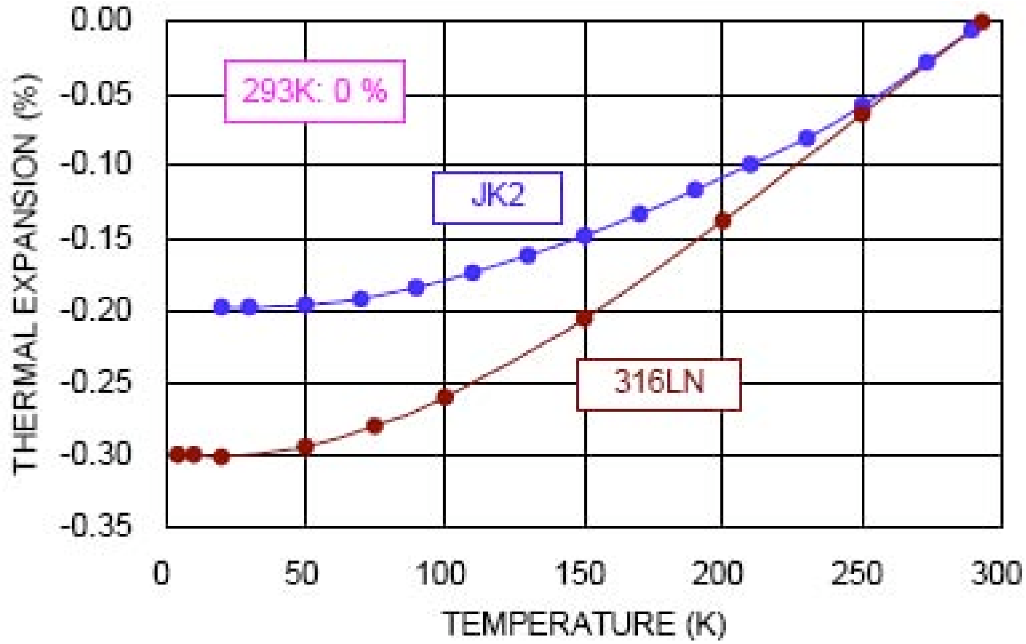
Material for coils

- The material that we have chosen for ARIES-CS magnet structure is JK2
  - For the case of Nb_3Sn wind-and-react
    - JK2LB (for avoiding embrittlement during aging)
  - For the case of Nb_3Sn react-and-wind
    - Use JK2LB (Low C, with Boron)
- These material (similar to Austenitic steels) could be fabricated using rapid prototyping

JK2 class steels

- Substantially less contraction than 316
- Superconductor sensitive to strains of 0.1%
- Note that most contraction in JK2 occurs at > 100 K



Why not Incoloy 908

- US team (led by MIT) developed Incoloy 908 for magnets, and demonstrated the material and manufacturing with the DPC and ITER CSMC (Central-Solenoid Model Coil)
- Material has problem with stress corrosion if there is substantial oxygen in the atmosphere while with stress and at high temperature
  - Annealing for stress relieve coupled with elimination of O2 in environment during heat treatment (solved by use of vacuum furnace)
  - Material has good fatigue life
  - Demonstrated in the CSMC
- The Japanese have been developed an austenitic-like steel, JK2, for cryogenic applications
  - But, to date, there is little fatigue data/weld characterization, and no large coil has been made from this material
  - The Japanese will provide the conductor for ITER Central Solenoid

Average Properties of Candidate Alloys

Property	T(K)	Incoloy 908	316ELN	JK2LB	HA242
		Base metal, no treatment			
Young's modulus (GPa)	295	188	196		221[b]
	4	191[a]	207		238[b]
density (g/cc)	295	8.1	8.0		~9.5
magnetic state	4	ferromagnetic	diamagnetic		?
		Base metal, after cold work and aging			
Young's modulus (GPa)	295	179	(c)	(c)	(c)
	4	182	(c)	(c)	(c)
tensile yield strength (MPa)	295	1260	370	490	1100
	4	1460	1170	1420	1340
tensile ultimate strength (MPa)	295	1450	710	750	1530
	4	1890	1600	1690	1970
tensile elongation (%)	295	20	51	44	34
	4	26	38	25	26
fracture toughness (MPa . $m^{1/2}$)	4	160	(d)	75	(d)
fatigue crack growth rate:					
c (10^{-15}m/cycle)	4	70	5000[d]	1.4	40[d]
n	4	3.8	2,7[d]	5.1	4.0[d]
thermal contraction (%)	295-4	0.17	0.33	0.19	0.23
	1000-4	1.15	1.63	(c)	1.28

(a) estimated; (b) communication from R.P.Walsh, preliminary; (c) not measured
(d) only plane stress values (not applicable to ITER conduit) have been measured

Benefits of JK2

- Lower activation

- Lower cost
  - Austenitic steel with removed carbon and nitrogen

  - We had estimated \$60/kg magnet for Incoloy
  - Should be cheaper for JK2, with main difference a decrease in the cost of the material
  - Use \$55/kg for costing the structure.

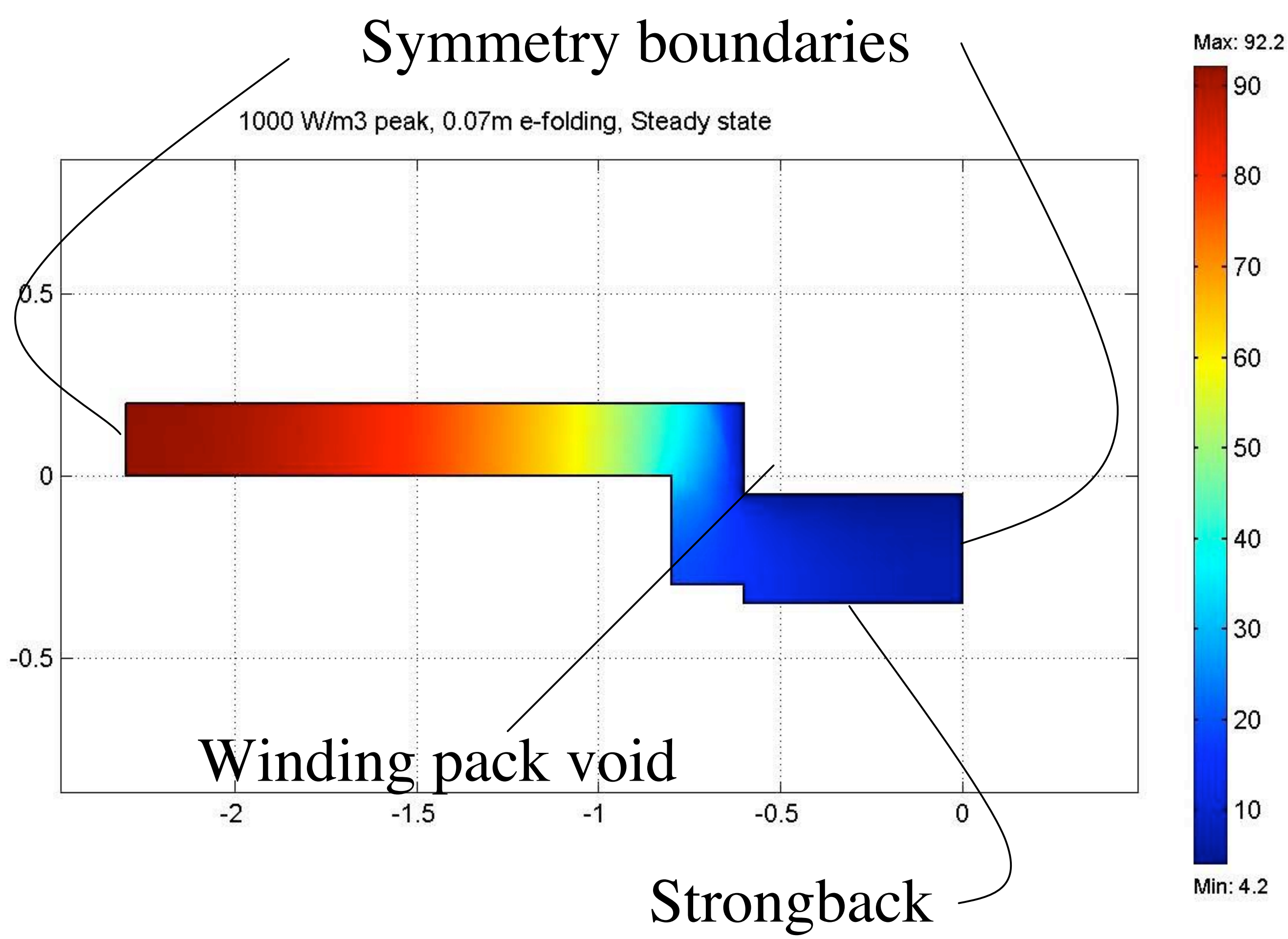
Cooling

- Calculations for the cooling of the structure were presented in January meeting
- Low heat load allowed the use of minimal cooling
- However, thermal loads were assumed lower than recently calculated by Res. Prof. El-Guebaly
- Heating and heating profiles were used to repeat the calculations

Modeling

- Steel thermal conductivity
- Modeling with heating density ~ 1 mW/cm^3, decaying with a 0.07 m scale length
  - Newer numbers from Res. Prof. El-Guebaly
  - Heating of ~10^{15} (what units?), with a decay length of 0.04 m
  - Not much of a difference, as most heat absorbed in coil structure

Steady state temperature profile (K)



Options for cooling structure

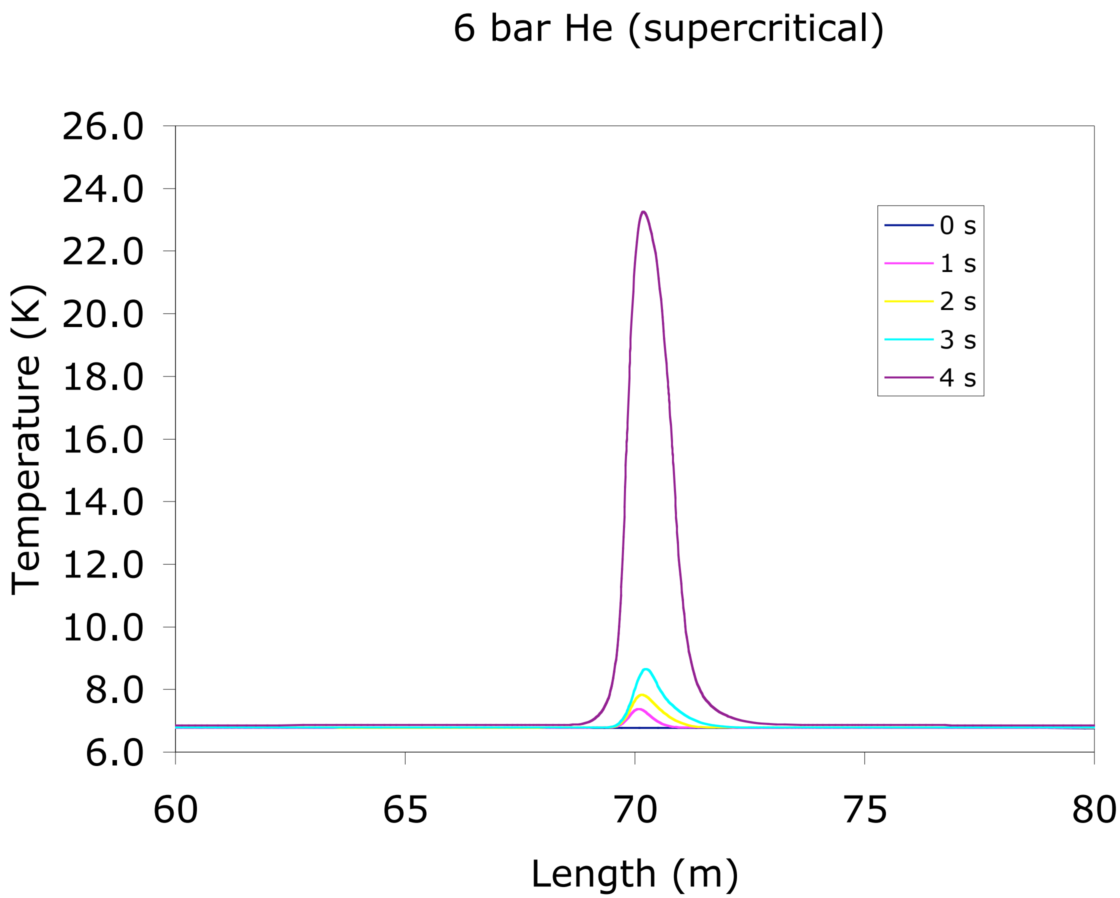
- Large temperature gradients to do result in substantial strains
  - Most contraction at temperatures > 100 K
- Most of the heat can be intercepted at temperatures higher than 4 K
  - 30-40 K
- Decrease power requirement to cool structure by more than an order of magnitude
  - Total power required decreased by about a factor of 4
  - ~ 1 MWe refrigerator

Quench of superconductor

- Attempts to use the quench propagation code developed at MIT failed
- Code meant to handle soft quenches, with or without flow reversal
  - Accompanied with external dump

Modeling soft quench

- 6 m long heater
- 1500 W/m
- 1 K temperature margin, @ 6.8K and 13 T



Periodic internal heaters Quench model

- Difficult with the model lies in the hydrodynamics of the flow
- For the case of multiple discrete internal dumps, there is little or no flow, as the multiple quenches increases the resistance to flow to the point that flow is stopped early in the quench
- New model is being developed, in which there is no coolant flow during the quench
  - Pressure builds in system in constant-volume geometry, with reduced heat capacity (faster heating)

To do

- Off normal events
  - Effect of quench on first wall loading
  - Coil failure on structure

Publications

- *High Performance Superconducting Options for ARIES Compact Stellarator*, L. Bromberg, J.H. Schultz, L. El-Guebaly, L. Waganer and the ARIES Team (TOFE)
- *Implications of quench protection mechanism to modular stellarator winding design and fabrication*, *IEEE Transaction on Superconductivity*, L. Bromberg, J.H. Schultz
- *Quench methods for superconductor protection*, US patent applications, L. Bromberg, J. Schultz, J. Minervini, T. Antaya and L. Myatt