Magnet System Definition

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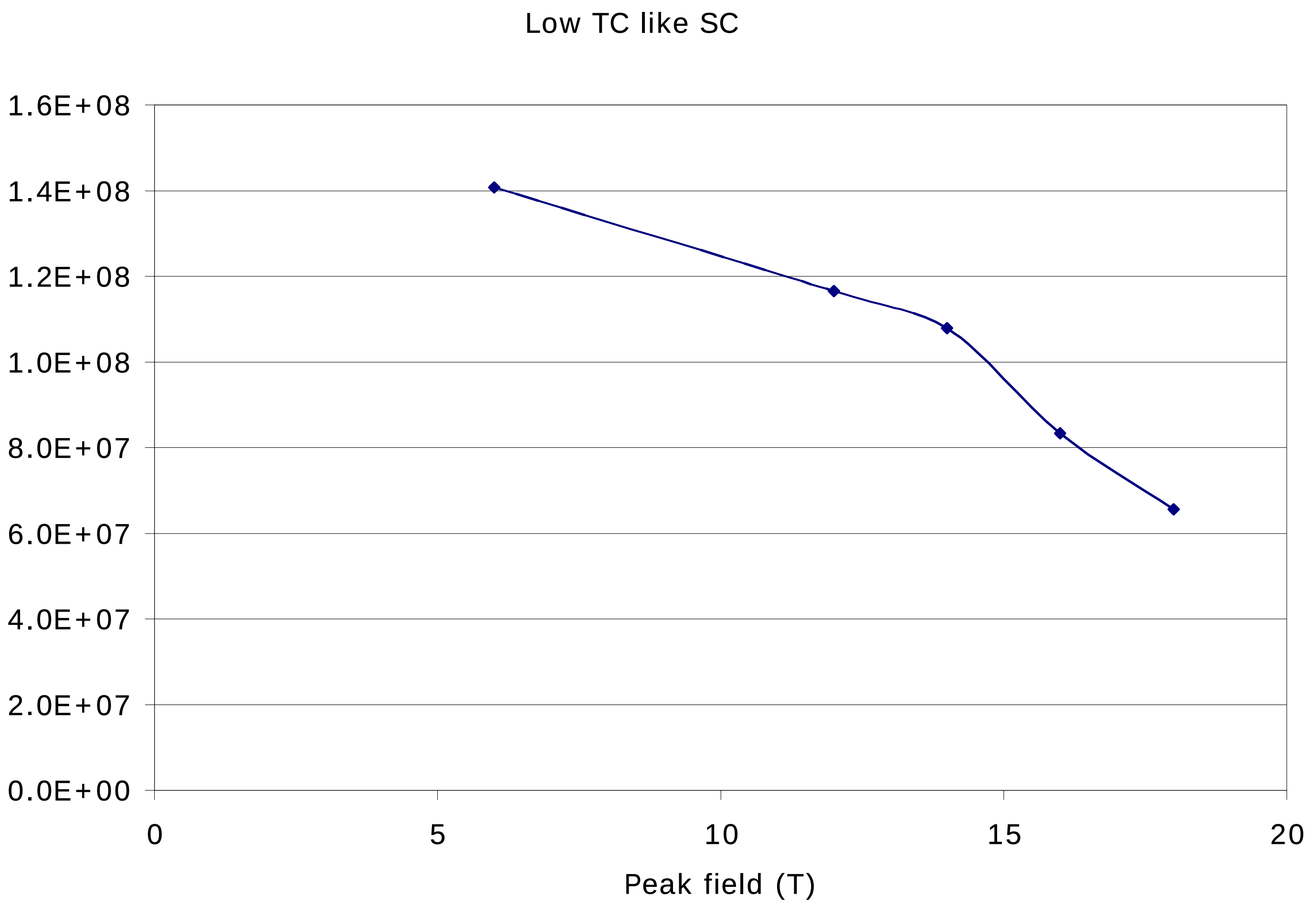
Action items from ORNL meeting

- System code:
  - Evaluate for constant fusion power/wall loading to determine the coil load line, and then decide using a conductor curve, calculate the coil-shield gap for that design.
  - System code uses square conductor cross section, which limits scaling options
    - Need additional input from PPPL
  - Repeat by varying the wall loading until the gap vanishes (or is equal to the dimension needed for assembly and maintenance.
- At MIT:
  - Need to obtain additional results for coil flux surfaces closer to the plasma, so that system code can be used to interpolate coil designs.
  - Develop coil design criteria to be used in system code (load line) to determine smallest coil.
  - Comparison poloidal cases vs a toroidal case

System code magnet module

- Superconductor current density
  - Load line
- Stellarator calculations limited database
  - Need additional cases from PPPL
- Structure
  - Bending vs hoop
  - Implications of deformations on magnet structure

SC design "load line"



Magnet issues

- Meeting SC load line by decreasing cross section of magnet and varying the shape-factor k of the winding pack
  - make the superconductor as wide in the toroidal direction as possible, and decrease the thickness of the conductor to meet SC load line

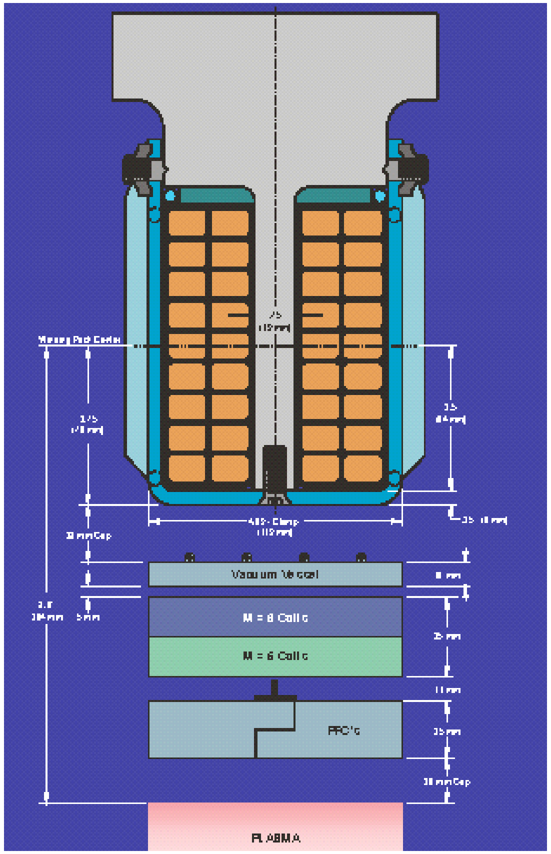
Magnet Structure

- An algorithm has been provided for evaluating the required structure, on the basis of stress constrain
- Slight differences on the thickness of the structure cross section on the outboard side remains between the drawings/assumptions and the algorithm.
- It is relevant because the outer region of the magnet determines to 0^{th} order the weight of the magnets and cost of the structure.
- As opposed to tokamaks, the space in the inboard region is not critical

Wound conductor

- In the case of wound conductor, means of transferring loads to structure are needed
- In NCSX, ribs are placed within conductor
- For ARIES-Stellerator, large loads required stiff ribs.
- Distance between coils need to be adjusted for non-radial load transfer
- Need to determine loads to determine thickness of reinforcement ribs

Modular coil construction of NCSX



Coil structure and costing

- Case analyzed is 8.1.31

Ku's coil set, pwall = 2.5

Δ = 1.07 +6.24ln(P/4) m, side case = 1 cm

1.07 case = blanket everywhere, 0.87 no blanket

	beta = 6%			8/1/03 configuration		
B axis	5.80	5.80	5.80	5.80	5.80	5.80
R axis (m)	7.20	7.20	7.20	7.20	7.20	7.20
Plasma A	4.50	4.50	4.50	4.50	4.50	4.50
t (m)	1.15	1.14	1.12	1.08	1.04	0.98
treq (m)	1.070	1.070	1.070	1.070	1.070	1.070
Coil height	15.00	15.00	15.00	15.00	15.00	15.00
h(m)	0.043	0.068	0.098	0.173	0.271	0.390
w (m)	0.695	0.695	0.695	0.695	0.695	0.695
d0 (m)	0.2	0.25	0.3	0.4	0.5	0.6
Coil k	16.04	10.26	7.13	4.01	2.57	1.78
<a> (m)	1.60	1.60	1.60	1.60	1.60	1.60
treq (m)	0.870	0.870	0.870	0.870	0.870	0.870
β (%)	6.00	6.00	6.00	6.00	6.00	6.00
Bmax	18.41	15.97	14.09	11.86	10.65	9.88
I coil (MA)	12.79	12.79	12.79	12.79	12.79	12.79
d (m)	0.17	0.22	0.26	0.35	0.43	0.52
j (MA/m2)	424.37	271.60	188.61	106.09	67.90	47.15
c-c min	0.00	0.00	0.00	0.00	0.00	0.00
area	639.42	639.42	639.42	639.42	639.42	639.42
pn,wall	2.50	2.50	2.50	2.50	2.50	2.50
PE max	1.60	1.60	1.60	1.60	1.60	1.60

Bo	T	5.80487436
Ro	m	7.20497912
Plasma ASPECT ratio		4.5
INBOARD gap/blanket/shield thicknes	m	1.08448001
OUTBOARD gap/blanket/shield/gap	m	1.07005693
Coil height	m	15
Outer radius of inner leg, Rin		6.69
Inner radius of outer leg, Rout		13.29
A		2.50E+09
S1		1.42E+08
S2		5.71E+07
sigma membrane allowable	Pa	6.00E+08
sigma bending allowable		9.00E+08
Total thickness of inner leg	m	0.55
Thickness of inner leg (hoop compression)	m	0.31
Thickness of inner leg (tension)	m	0.24
Thickness of outer leg, tout	m	0.10
Thickness of top/bottom	m	0.35

Thickness of outer leg

- For 8.1.31 case, required thickness of outer leg is 0.1 m
- However, structure in the outside looks like Swiss cheese due to presence of large ports
- Assuming that ports take ~ 30% of cross section, thickness of coil needs to increase by a factor of 2
- Numbers provided for neutronics/drawings include this effect
- However, for costing assume the thin homogeneous cross section

Costing of magnet structure

Volume:		
large ellipsoid	m^3	5956
Small ellipsoid	m^3	4881
Total	m^3	1075
Weight	ktonnes	8.6
Assume $50/kg		51
cost of structure	M$	438

Deformation

- As opposed to axisymmetric configurations, deformation of coils results in substantial field errors
- Local deformation can be dealt by designing locally strengthened structures
- Global deformations can be incorporated in the design or can be supported

Simplified impact of forces on deformations

- Coils in stellerators have forces that:
  - Tend to inflate the coils
  - Straigthen the kink
  - Net radially inward force
- Deformation of the coils follow (in an integrated sense) these loads

Load behavior in Stellerator geometries

HSR4/18: Net coil forces.

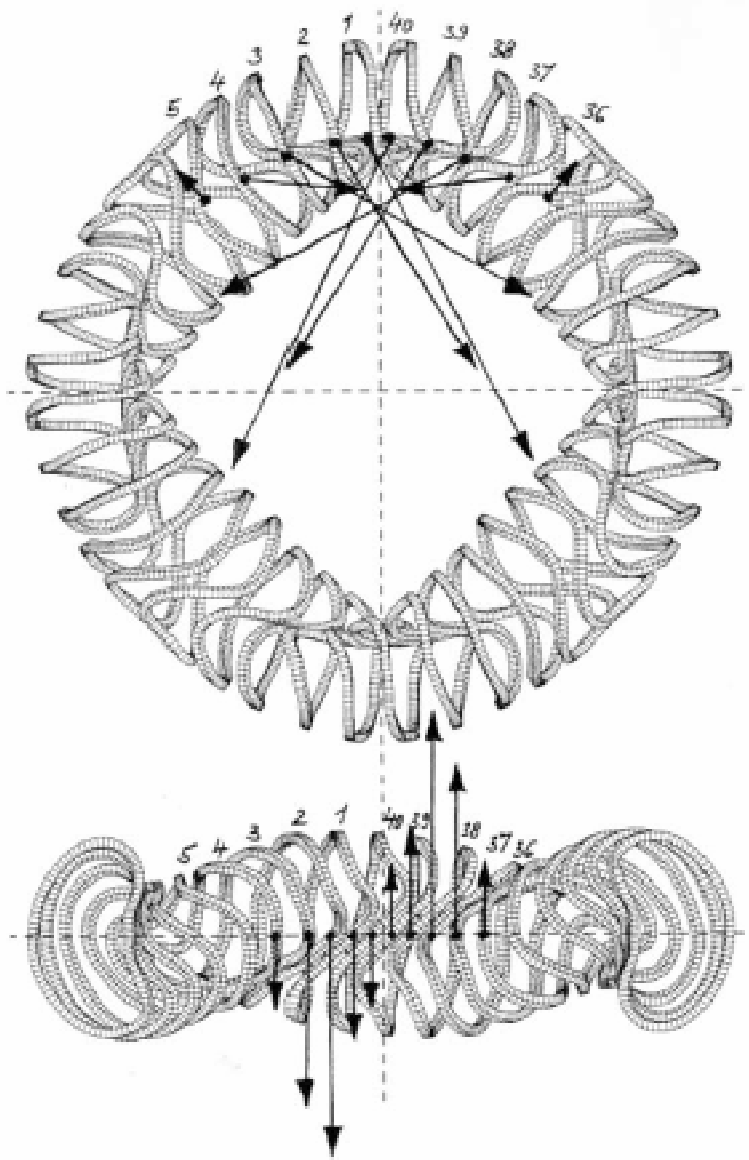


Fig. 1. Net coil forces of the HSR4/18 configuration.

Improved support concept for the Helias reactor coil system

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Deformation

- Coil case is insufficient to provide sufficient stiffness to coils to prevent large deformations
- If exclusively toroidal fields, coil wants to take D-shape, resulting in very tall coils
- Shell structure is much more efficient

Coil global deformations

- For structural efficiency
  - Deformation ~ 0.2% strain (determined by the superconductor)
  - Assume typical dimension ~ 12 m
  - Maximum global deformation ~ 2 cm
  - Non-symmetries can place substantial strains that need to be balanced by rib-like structure
- Design coil so that when loaded conductor is at desired location
  - Global deformation does not add to constrain
  - Local deformation needs to be handled by point design

Conductor support

- As opposed to NCSX, there are no large thermal differentials (from conductor heating)
- Conductor (in the case of wound) can be impregnated into structure, simplifying load transfer from conductor to structure
- In the case of HTS material, conductor is directly supported by structure

Future work

- Need to verify that the maximum field as a function of coil-shape k for a set of coils
- Need to prepare for calculations of loads and structure for a case
- Determination of structure deformation from loads, including openings