ARIES CS studies

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ARIES meeting
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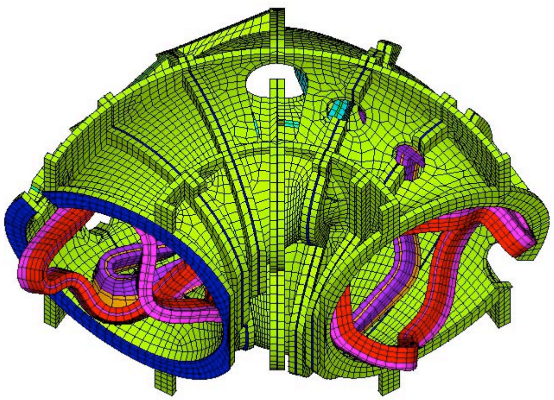
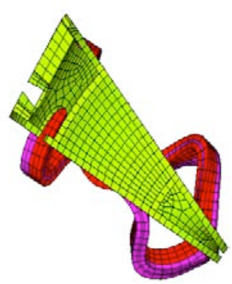
Overview

- What have I learned from the recent Final Design Review (FDR) of NCSX? (May 2004)
- Can we design a magnet using low Tc materials (wound) at 12-16 T? (No NbTi)
- System code tools

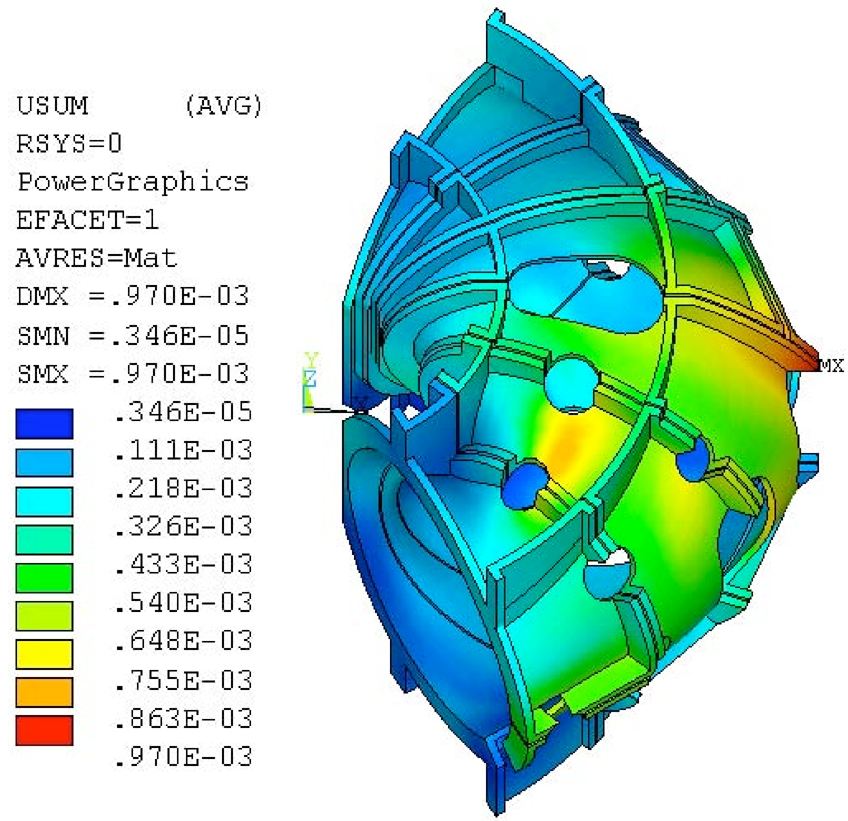
Global Deflection and Stress

- **PDR analysis focused on linear analysis of deflection / stress in the modular coil structure**
- **Assumption: 2-T EM loads, coil winding is continuously supported by shell structure**
- **Results indicate max displacement of 0.038-in, peak Von Mises stress of 26-ksi (181-MPa) in MCWF**





Single Coil Model



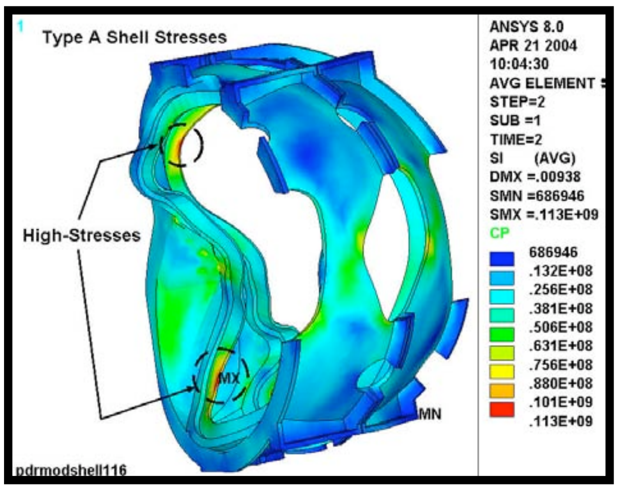
Displacement (m)

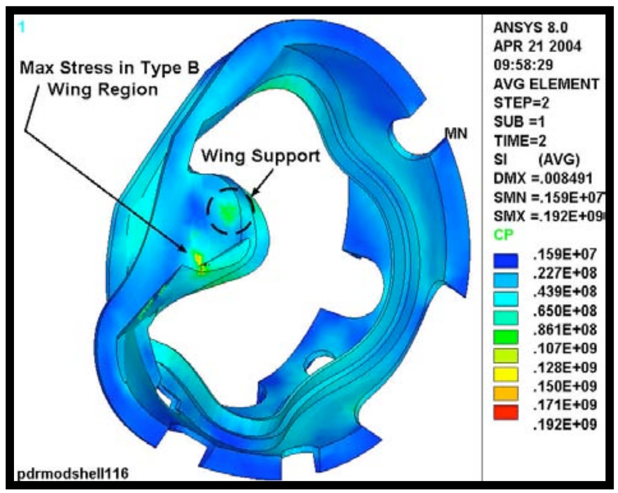
Full Model (120-deg Sector)

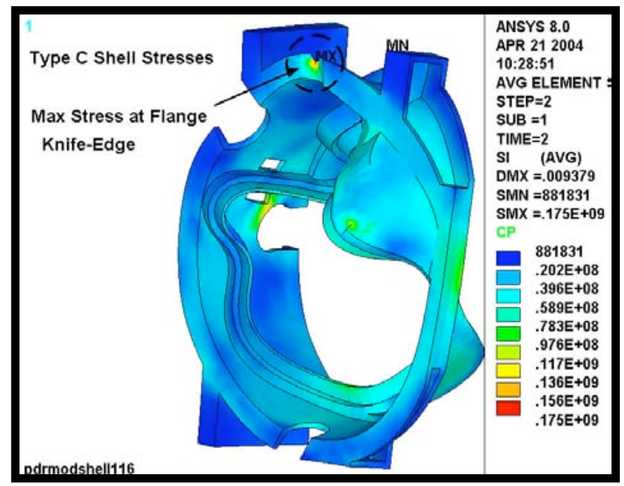
All Models Show Margin on MCWF Stress

- **Stress concentrations around modeling discontinuities, constraints**
- **Allowables based on minimum specified, expect much better properties in real parts**
- **MCWFs show no stress problems**

	Linear analyses			Non-linear analyses		
	membrane stress (ksi)	membrane + bending (ksi)	peak stress (ksi)	membrane stress (ksi)	membrane + bending (ksi)	peak stress (ksi)
Allowable stress	35	52	104	35	52	104
Coil type A	7	11	36		13	25
Coil type B	11	28	43		25	39
Coil type C	15	25	39		19	32
minimum factor of safety	2.3	1.9	2.4		2.1	2.7







Figures per Len Myatt

Design review implications for ARIES-Stellarator

- Stresses ~ 180 MPa for 4 T at the coil.
- We want to go to 16 T
  - Much more structure, specially at the outside
  - Better design
- Strains:
  - ~1 mm in for NCSX
  - Assuming 16 T, but only 600 MPa
  - Strains proportional to forces, inversely to stresses

  - 5 cm for ARIES-Stellarator

Magnet differences

- No thermal loads!
- Better use of space where coil lies can be achieved if experimental requirements are eliminated (continuous winding)
- No TF coils
- Coils can be smaller (on a relative sense)

Existence proof of LTS solution for high field ARIES Stellarators

- Work being carried out on Nb_3Sn, Nb_3Al, MgB_2

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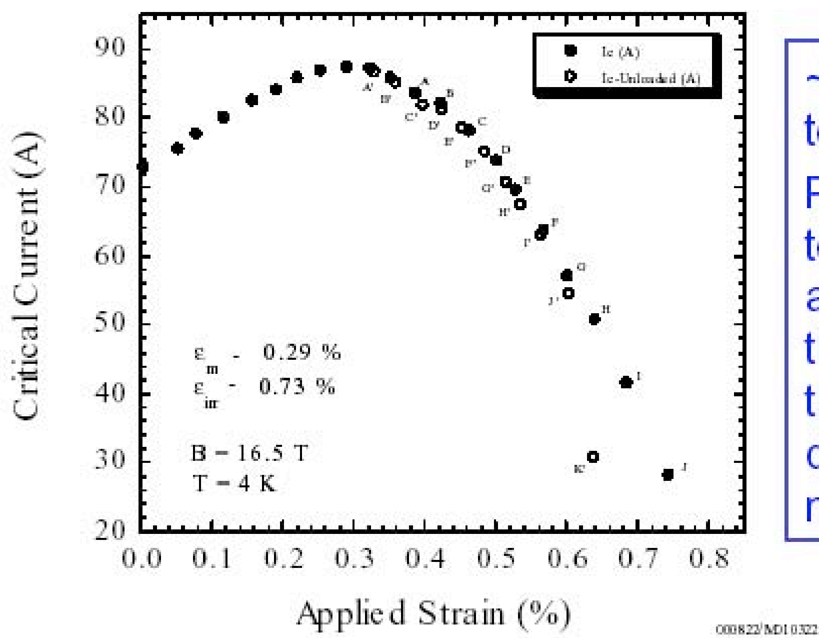
Superconducting
Magnet Division

Axial Strain Studies

High niobium density (50% nca) Nb_3Sn (Oxford)

J. Ekin, N. Cheggor, et al, NIST, LTSW '01



~0.3 % axial strain seems to be acceptable.

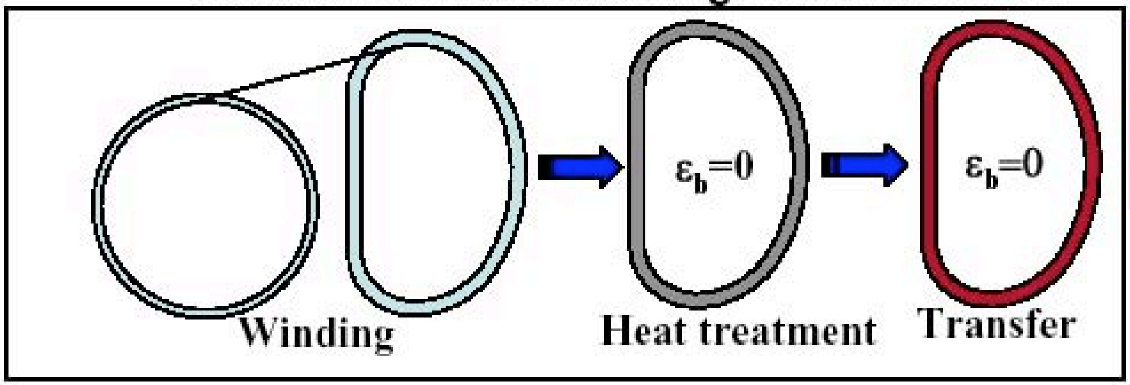
Perhaps ~0.5% may be tolerable, if "high strain" and "high field" are not at the same location (as is the case in the most designs of accelerator magnets).

A direct bend strain study is, however, more relevant for accelerator magnets.

5. Comparison between W&R and R&W method

1. Wind-and-React (W&R) method

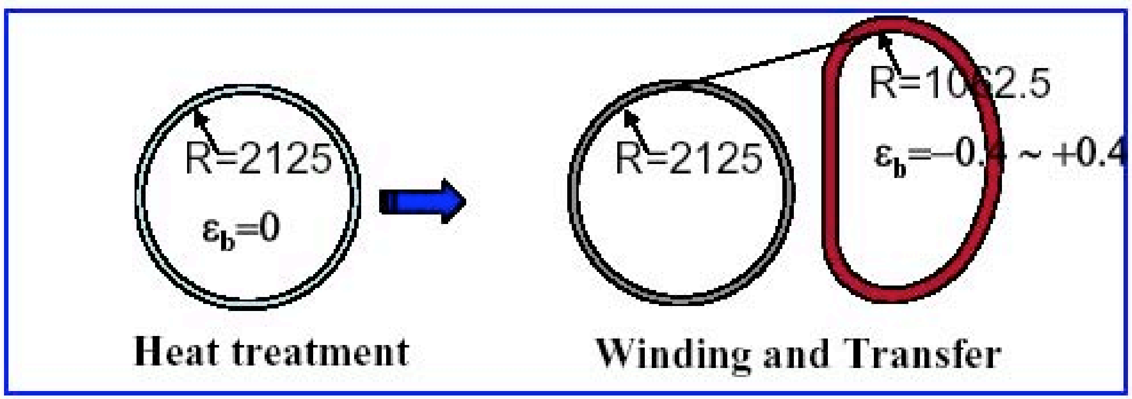
Furnace size has to be larger than coil size.



Usual method for Nb_3Sn coil like the ITER TF model coil

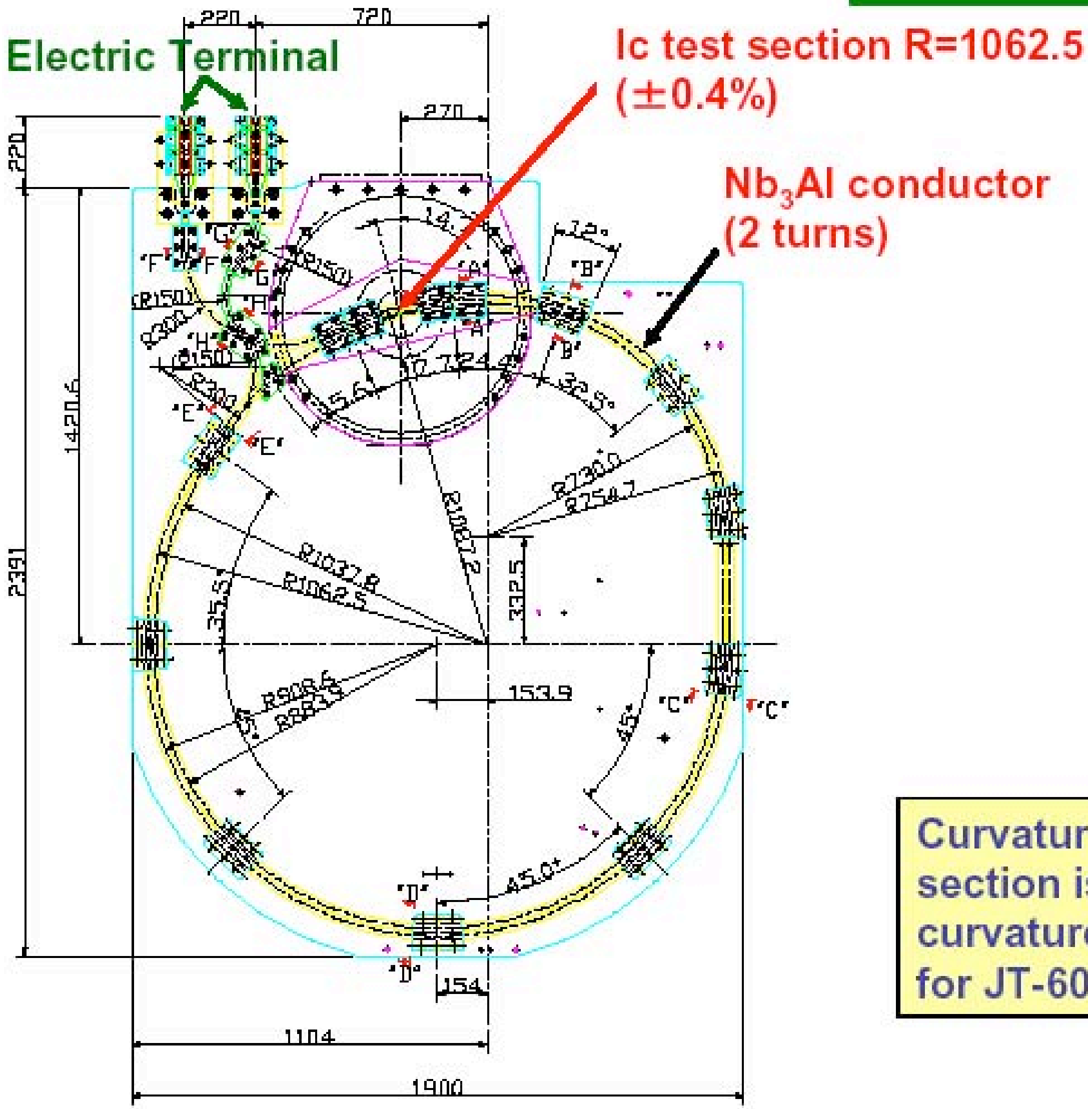
2. React-and-Wind (R&W) method

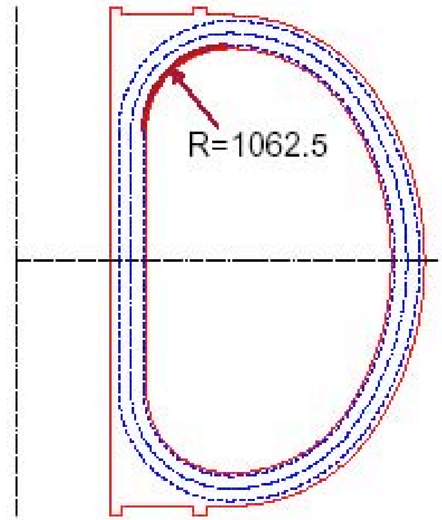
Furnace with drum size is sufficient.



Advantage for large coil like the ITER TFC

6. Design of D-shaped test coil





TFC of JT-60SC

Curvature radius of Ic test section is same as the minimum curvature radius of real TF coil for JT-60SC

11. Ic test section (R1062.5) was successfully bent within the 0.8% of bending strain.

Limitation for winding

>0.8% of axial strain for Nb_3Al strand

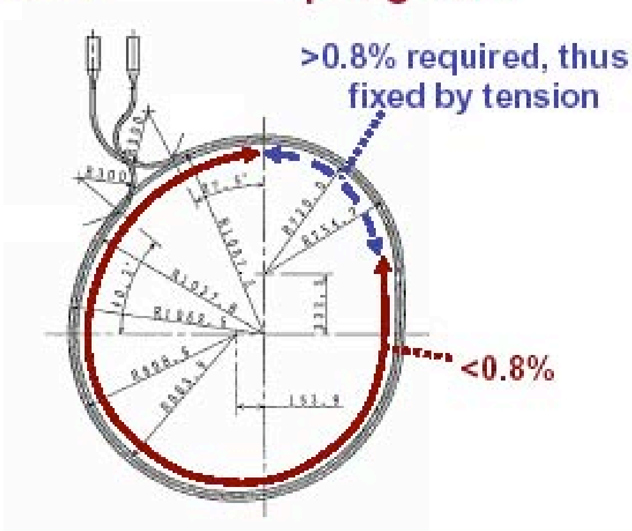
→ Irreversible Ic degradation

(by Specking and Ando in 1996)

In this work, We performed all bending less than 0.8% in bending strain including the over bending.

Ic test section (R1062.5) was successfully bent within the 0.8% of bending strain.

R2125 ε_b=0% → (over bend) R829.2 ε_b=0.621% → (spring back) R1062.5 ε_b=0.4%



Three point bending system

Roller bender

Conductor requirements for React-and-Wind Nb_3Sn magnets

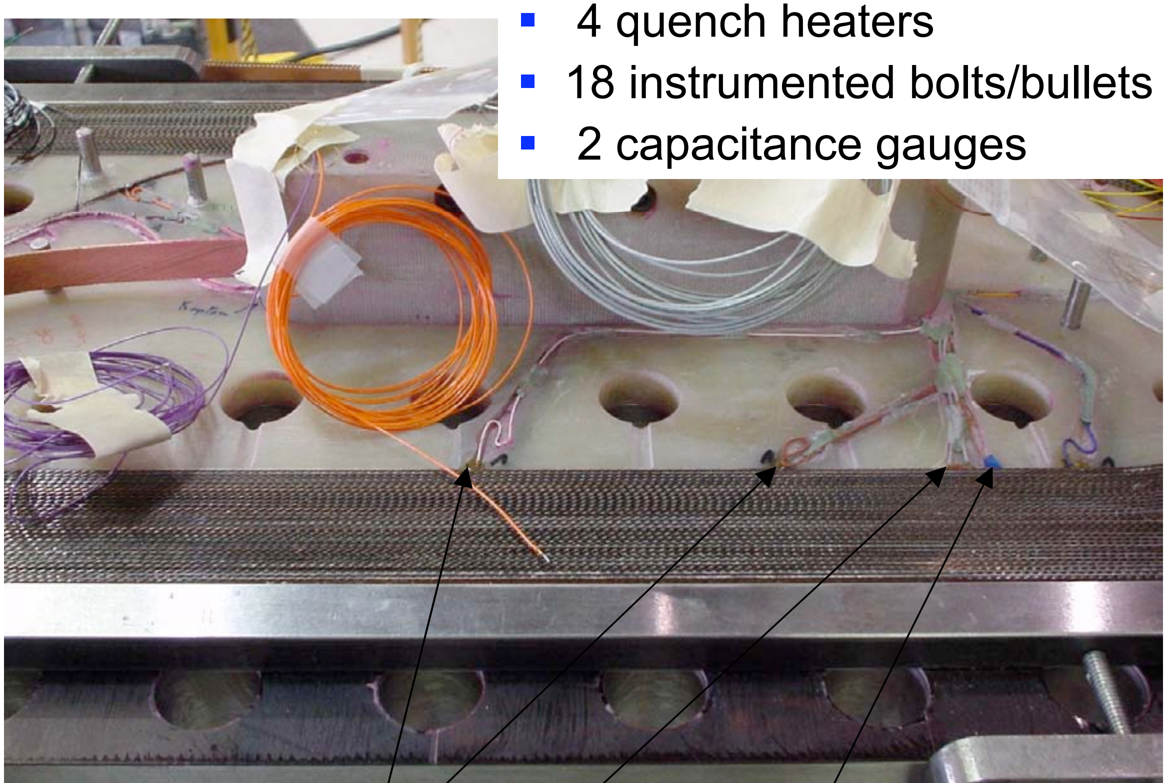
- Bending degradation:
  - Low degradation in the operation range:
    - 0.2% FNAL – 0.27% BNL
  - Sufficient margin before permanent degradation

- High Jc is very good for React-and-Wind wires
  - because we are going to loose some Jc due to bending
    - Cu/non_Cu = 1 Jc = 3000 A/mm^2 PROTECTION ???
    - ➔ Cu/non_Cu = 1 Jc = 2400 A/mm^2 USABLE

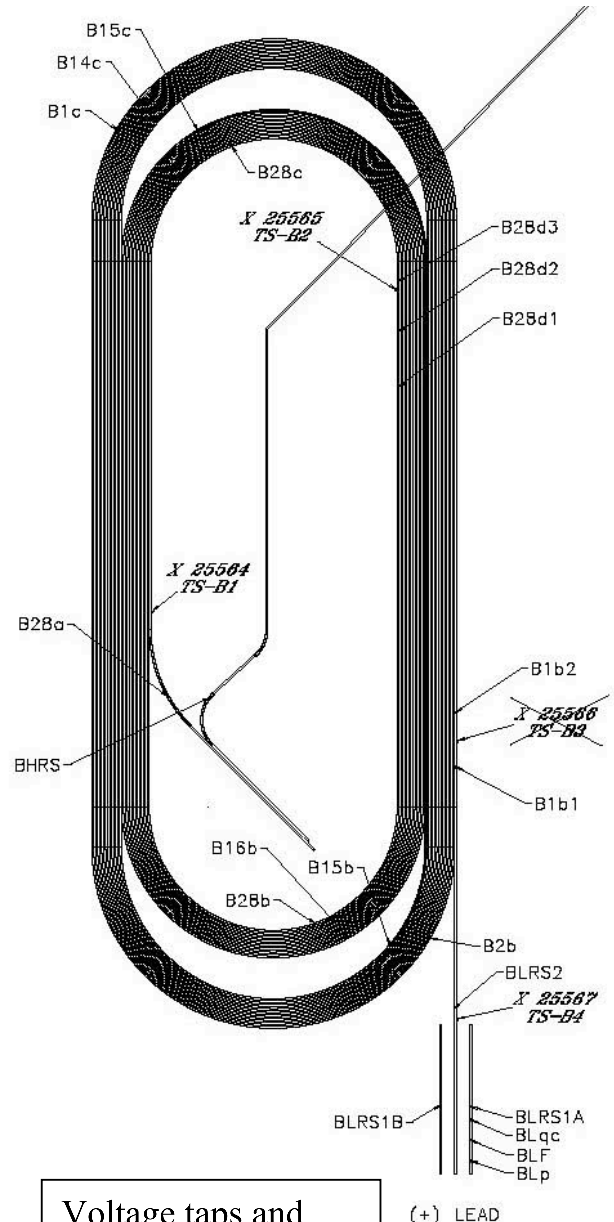
- If cable stability is a problem:
  - More stable strands
  - Control of the inter-strand resistance:
    - Cleaning residues of synthetic oil
    - Alternative solutions at "reasonable" costs

Instrumentation

- 44 voltage taps
- 7 temperature sensors
- 3 spot heaters
- 4 quench heaters
- 18 instrumented bolts/bullets
- 2 capacitance gauges



Voltage taps, Spot heater, Temperature sensor



Voltage taps and Temperature sensors

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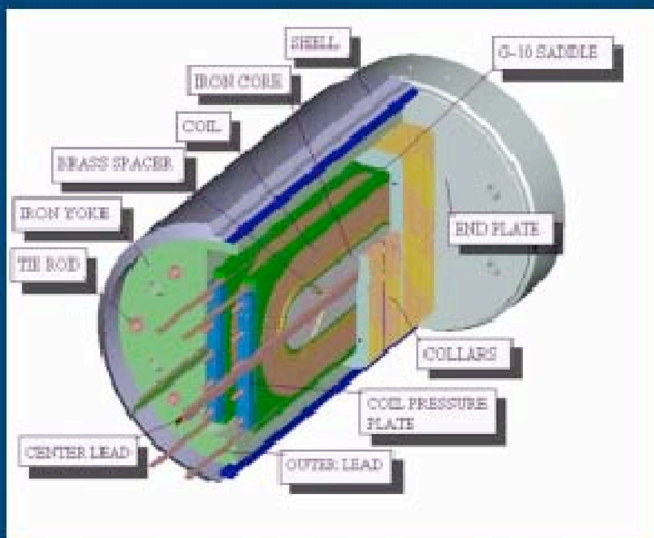
BNL Plans

High Field R&D: Nb_3Sn and HTS flat coil fabrication and testing.



- Goal of 12 T react and wind magnet next year
- Background magnet for cable testing

Existence proof with "near term" technology

- By decreasing the thickness of the wires, larger strains can be tolerated
  - True for both Nb_3Sn and for Nb_3Al.
- For Nb_3Sn, with filament sizes less than 0.5 μm, Hitachi has made coils with 1.5 % strain (irreversible strain)
- Strain in ARIES Reactor:
  - For NCSX, strain ~ 2 cm / (2x20 cm) ~ 5%
  - For the reactor: If conductor remains about 2 cm, then strain scales inversely with machine size:
    - Strain ~ 0.5%

Field Scaling

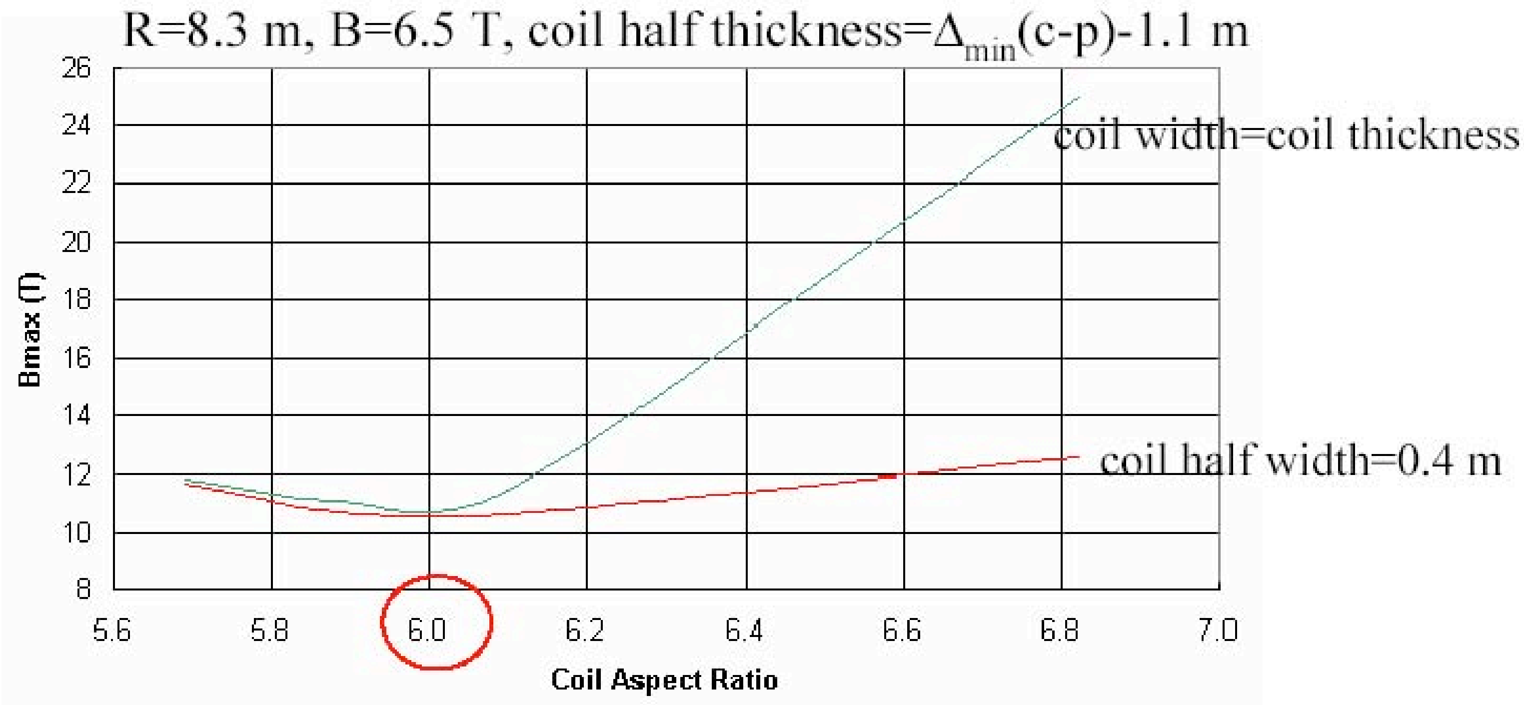
- For a torus, the maximum field is independent on the thickness of the winding pack.
- For a solenoid (assuming that the coil current in only flowing in the toroidal direction), again the maximum field is independent on the winding pack.
- Only for the “saddle” regions in the coil may the peak field depend substantially on the winding pack thickness.
- But even then, by properly lining the surface of the winding surface (making current distributed instead of peaked) it should be possible to decrease the peaking.
- Where does the peak field occur????

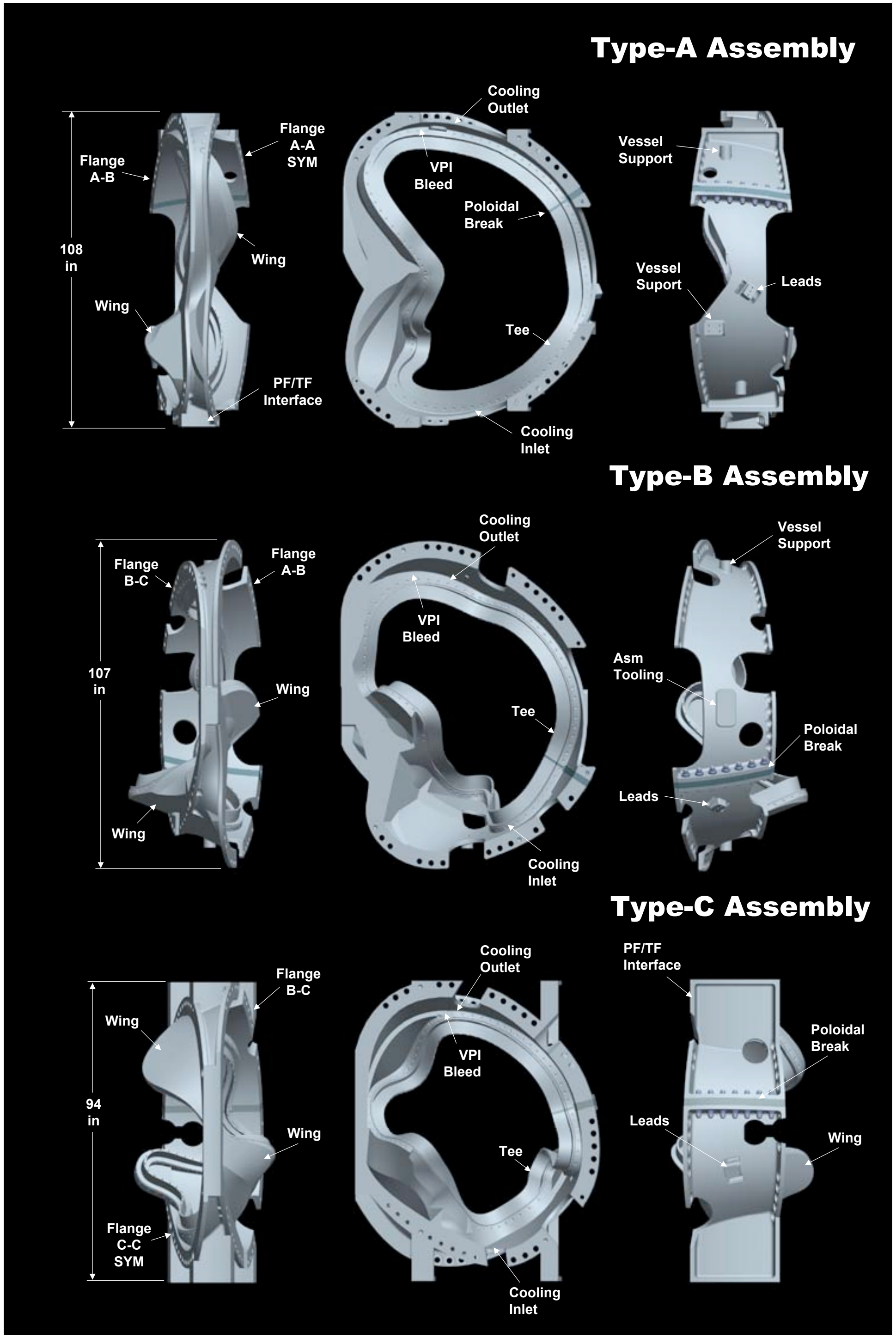
A simple code is assembled to calculate the magnetic field intensity in coils for sizing, finding the maximum field, and estimating body forces.

Conductor current density and maximum field intensity for modular coil #3, Ip=13 MA.

conductor cross section (m × m)	conductor current density (MA/m^2)	B_{max} (T)
0.2 x 0.2	$3.3 \cdot 10^2$	16.1
0.3 x 0.3	$1.4 \cdot 10^2$	11.6
0.4 x 0.4	$8.1 \cdot 10^1$	9.7
0.5 x 0.5	$5.2 \cdot 10^1$	8.8
0.6 x 0.6	$3.6 \cdot 10^1$	8.2

We can take advantage of the increase in Δ_{min}(c-p) as A_c is decreased to increase the coil cross section to reduce J_{max} and B_{max}, but there is a point where further decrease in A_c will no longer be paying off.





Saddle coils

- Tightest radius of curvature in the inboard region is for type-C coil.
- It looks like ~ 12 in radius of curvature.
- For 2 cm conductor in NCSX, the strain is about 5%
- Coil deflects about 2 coil thickness for the Type B and 3 coil thickness for type C
- WHERE IS THE HIGHEST FIELD?

ROUGH ESTIMATE OF POLOIDAL VS TOROIDAL FIELDS

- At plasma edge, iota ~ 0.4 (q ~ 2.5)
  - Therefore, $B_p \sim 1/10\ B_T$
    - Assume B_p is quadrupole like (with minor radius)
    - B_T scales as 1/R
- B_T doubles (halved major radius)
- B_p quadruples (doubled minor radius)

- $B_p/B_T \sim 1/5$

- Need to determine with PPPL engineers and physicists actual dependence of field vs coil thickness

System tools at hand

- If poloidal issues are "secondary" for coil sizing, then tools have already been developed (sizing/overall design/costing).

System code tools

- Meeting with Ku/Heitzenroeder in PPPL to discuss algorithms
- Need the ability to scale the coils
  - Options?
  - System code needs to track numbers like peak fields, dimensions.
  - Need to determine how sensitive calculations are about non-toroidal fields (for magnet sizing)

Work to be done

- Detailed calculations need to be performed for a design point, in order to assure the appropriateness of the algorithms
  - Calculate stresses using actual currents and geometries
    - Structural considerations
    - Deformations and strains of the structure and superconductor
  - Superconductor characteristics
  - Power supplies
  - Cryogenic loads and cooling
- Need one design point to calculate some details
  - NCSX (??)
  - HSR

Costing?

- Scale the size/field until something reasonable comes out (wall loading, power), and then cost it.
- If nothing else, algorithms can be tested…

PRICE OF GASOLINE IN CA