•Structural Assessments of Magnets for the Next Generation Spherical Tokamaks

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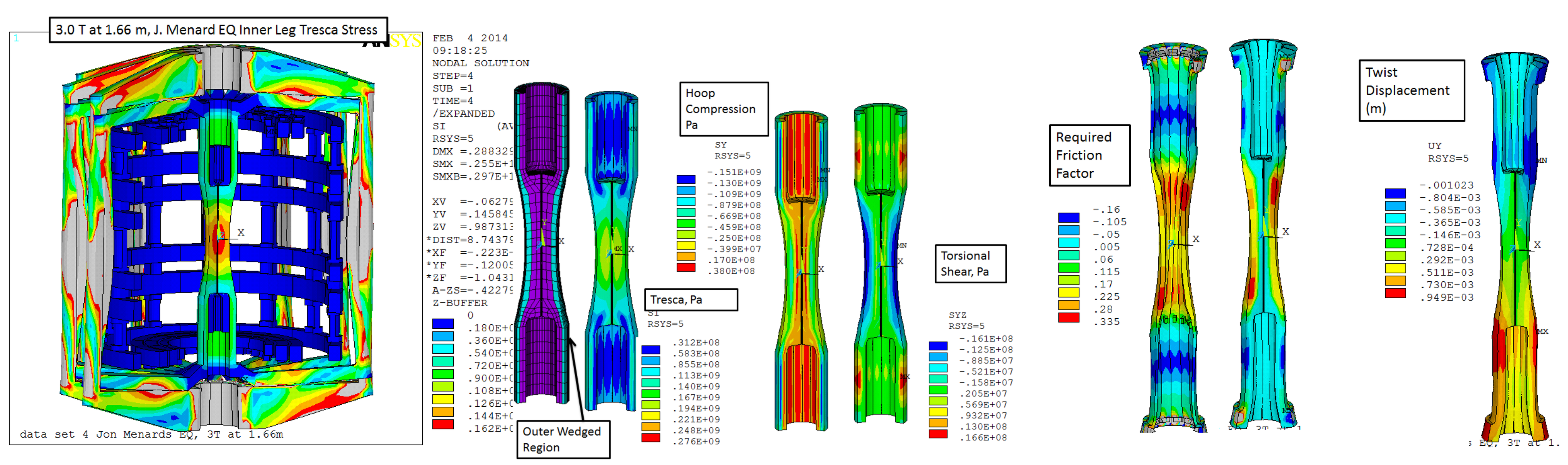
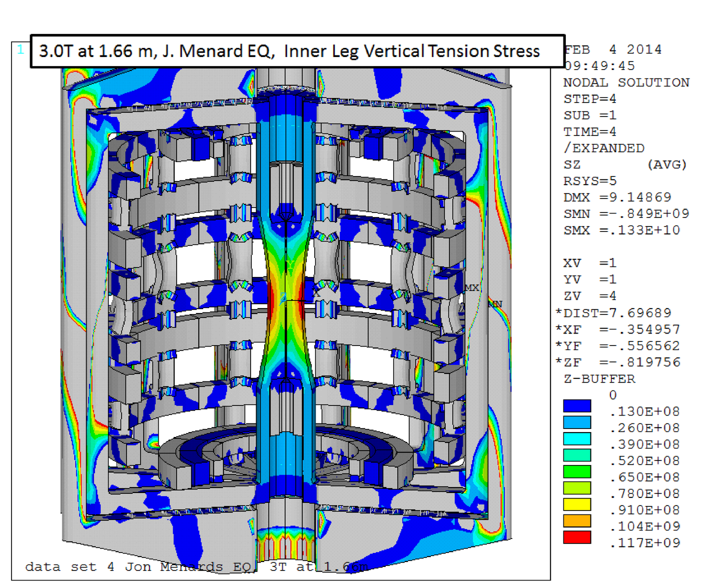
PRINCETON PLASMA PHYSICS LABORATORY

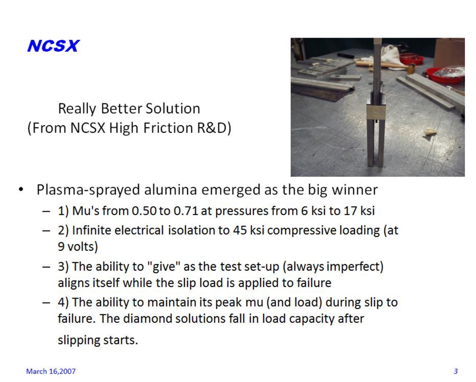
Abstract

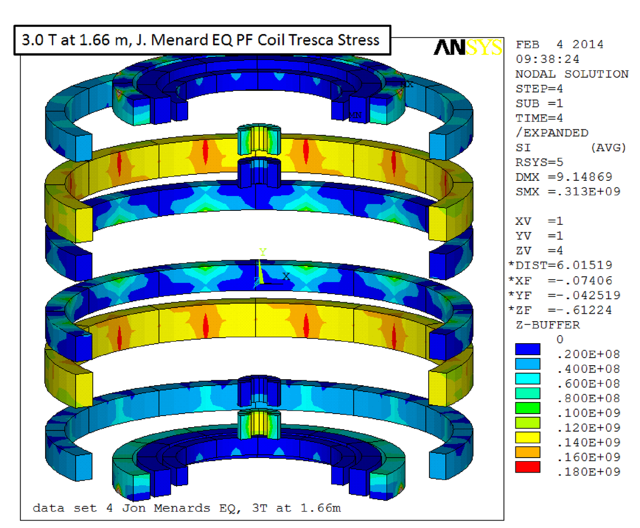
•In one class of spherical tokamaks (ST) studied, the TF field is lower than AT's with similar performance. The lower field reduces the wedging pressures in the TF inner leg. The smaller radial build of the central column also reduces the wedging stress. If a conventional multiple coil case arrangement is chosen rather than the large single central conductor, then the out-of-plane (OOP) load on the TF inner leg must be taken by friction or mechanical keys. With the lower wedge pressure, friction can be a marginal torsional shear support mechanism. Advanced divertors will impose different out of plane loading and may introduce a different regime of OOP loading. ST's offer little space for a solenoid and inner corner shaping coils and will pose new PF coil support challenges. Structural analysis of 2 and 3 meter major radius next generation ST's is presented. The 3 meter design uses a proposed long legged super X configuration. Both TF and PF coils are evaluated. The TF coils are cased coils with HTS superconductor winding packs. Space allocation issues for the TF inner leg are also discussed. Structural contributions from the tape structure of the high temperature superconductor are considered.

In-Plane Support in PPPL Copper Multiturn TF



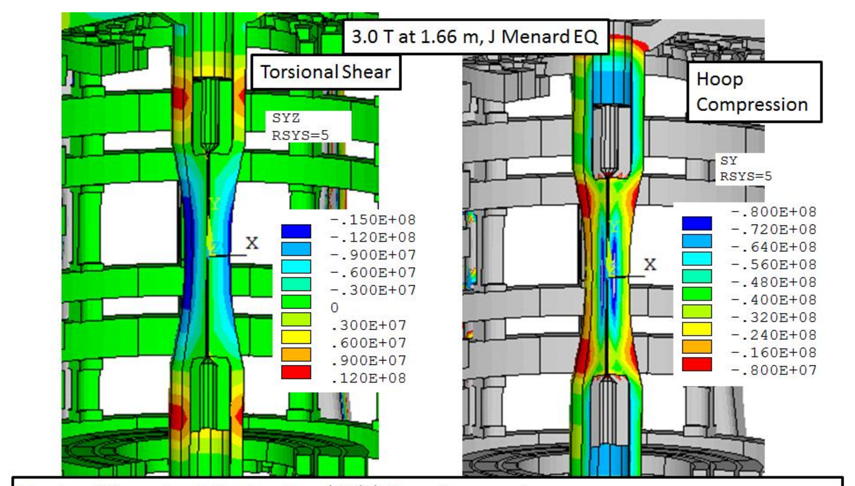






*Work Supported by U.S.D.O.E. Contract No. DE-AC02-09CH11466

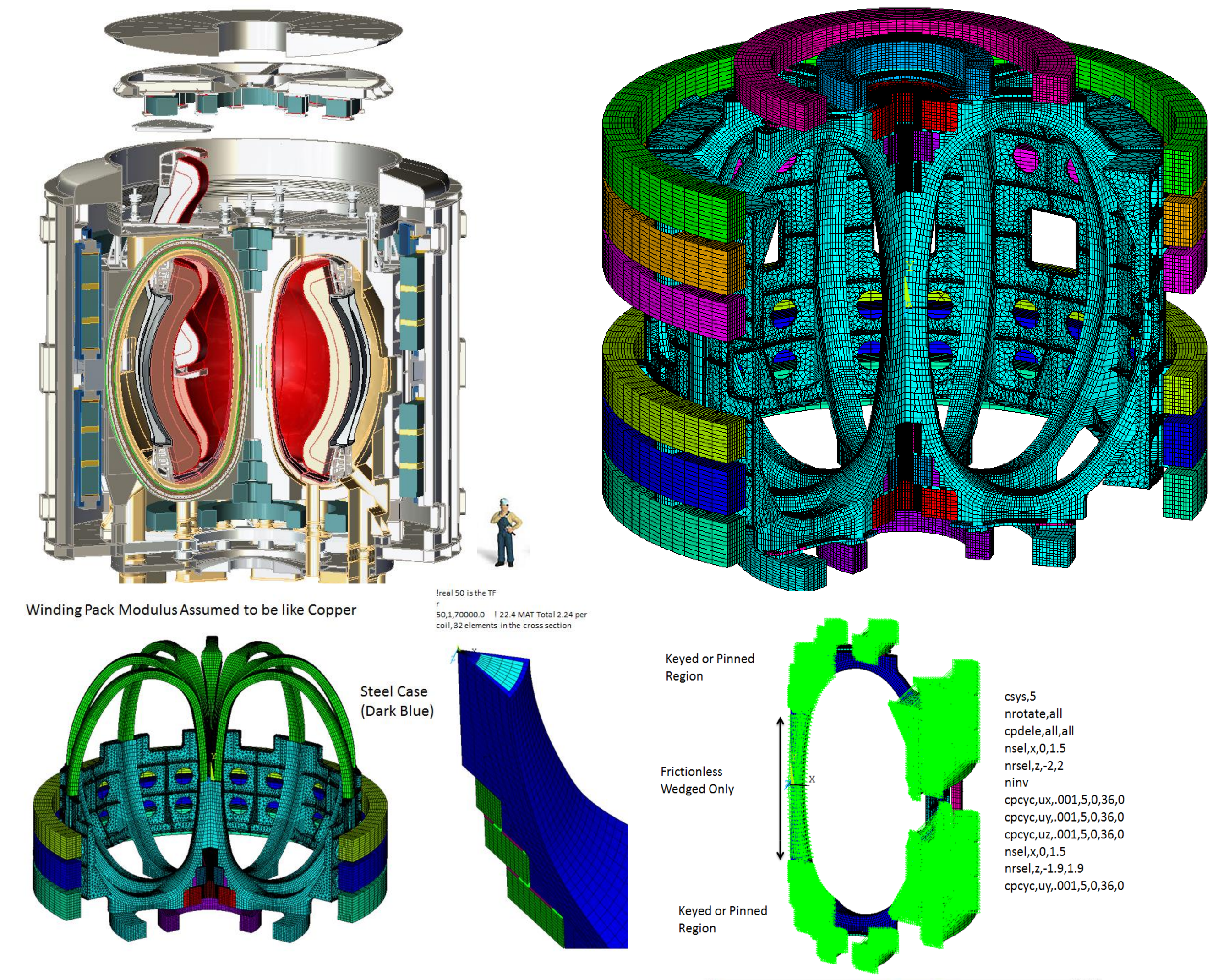
Out-of-Plane Support in PPPL Copper Multiturn TF

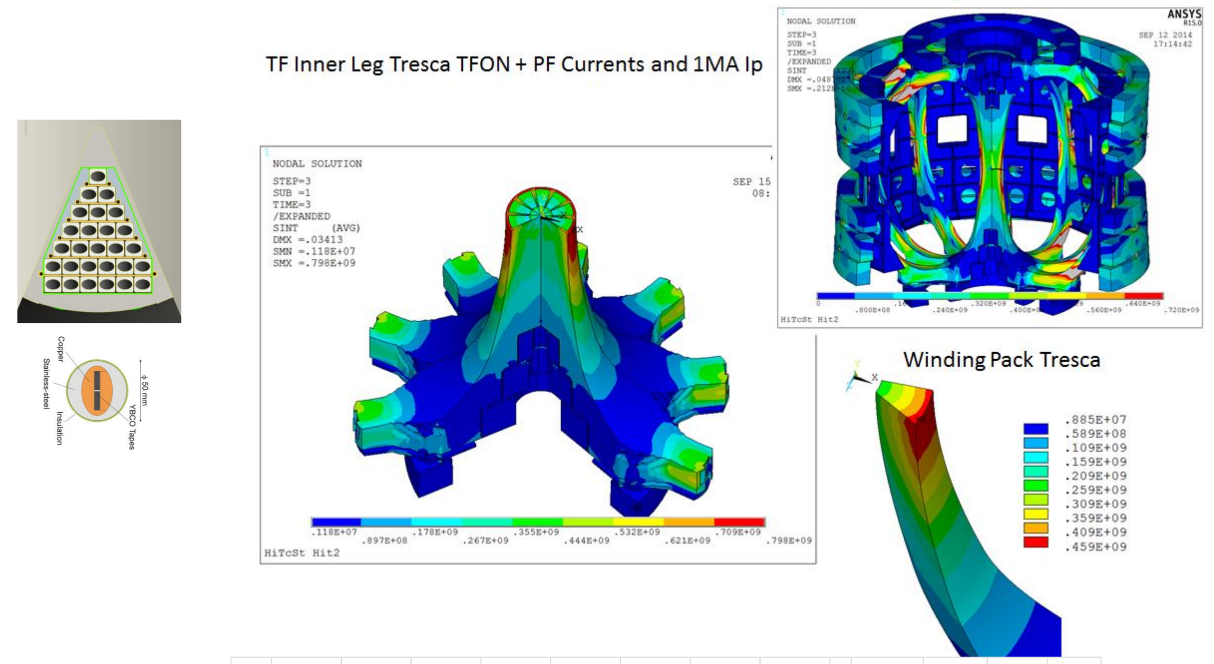


Torsional Shear should be less than (~.3) * Hoop Compression
Where the torsional shear is 15 Mpa you need -50 MPa and at the equatorial plane OD you have -24 MPa. A design friction factor of 15/24 = .625 would be needed. Note that at the inner radius of the TF you have -80 Mpa compression or better. A clever shaping of the TF Bitter plate could push the compression out to where you need it. A similar solution might work at the "flare" near the bottom of PF1

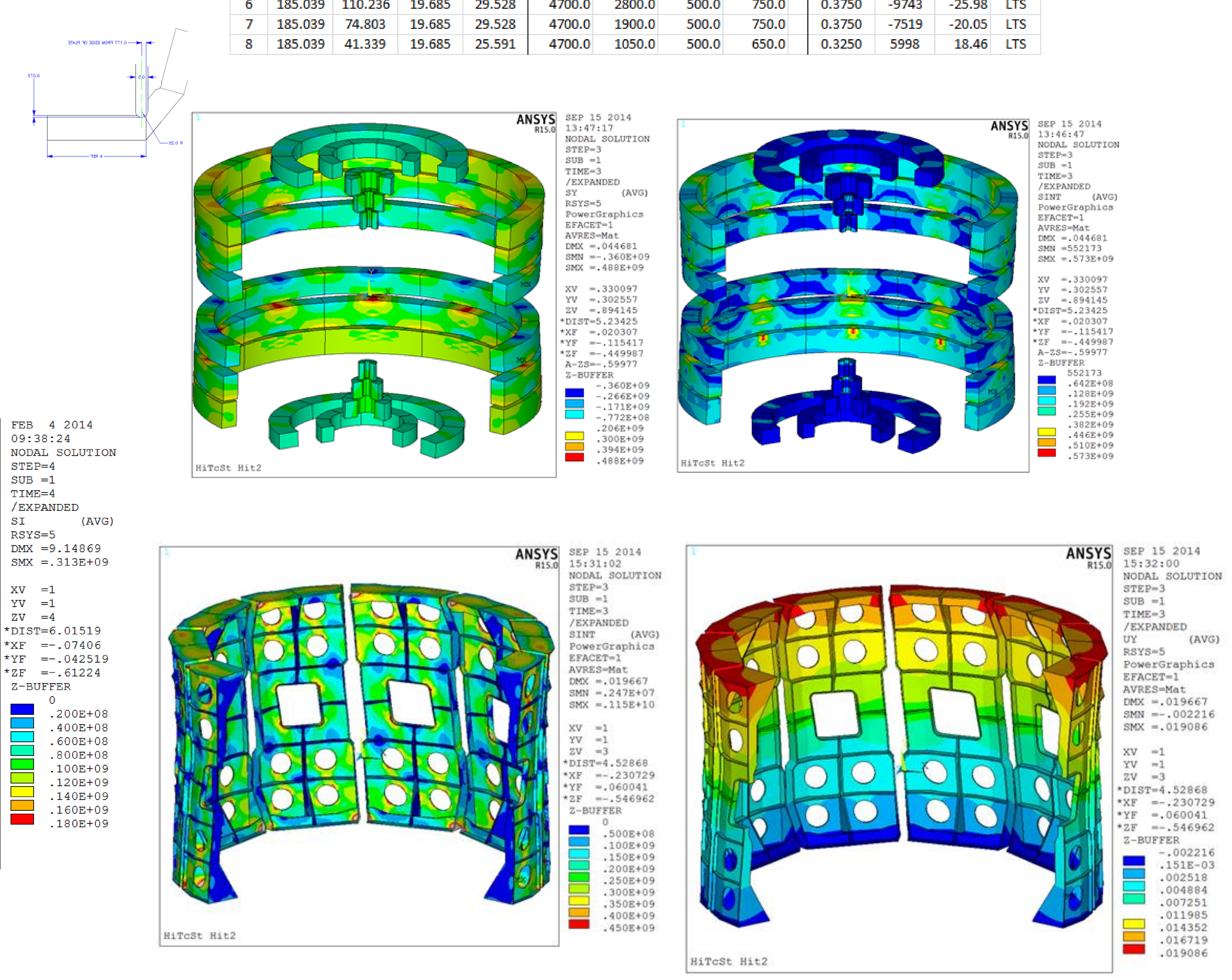
The torsional shear is at a max at the equatorial plane. Shown are some results with the wedged area located at the outer build of the TF coil. The required friction factor is the ratio of the shear divided by the hoop compression. Plots of the required friction factor are included. A max friction factor of .35 is needed. The R&D program for NCSX recommended plasma sprayed alumina and obtained friction factors of .5 to .7 . I think alumina has radiation resistances similar to MgO - but friction behavior would also have to be confirmed

2 m HTS ST Stress



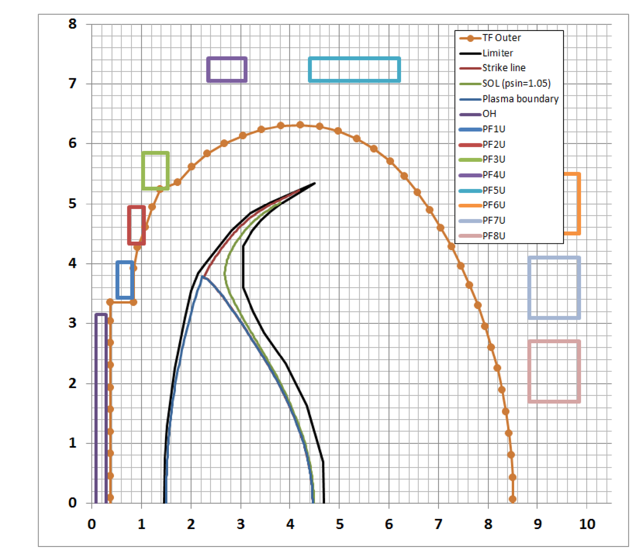


PF GEOMETRY and coil currents												
PF	R (in)	Z (in)	DR (in)	DZ (in)	R (mm)	Z (mm)	DR (mm)	DZ (mm)	(m^2)	(kA)	A/m^2	
1	7.087	88.583	6.693	19.685	180.0	2250.0	170.0	500.0	0.0850	2500	29.41	LTS
2	11.811	110.236	11.811	19.685	300.0	2800.0	300.0	500.0	0.1500	4500	30.00	HTS
3	19.685	131.890	15.748	19.685	500.0	3350.0	400.0	500.0	0.2000	4000	20.00	LTS
4	49.213	157.480	15.748	17.717	1250.0	4000.0	400.0	450.0	0.1800	-729	-4.05	LTS
5	98.425	157.480	23.622	17.717	2500.0	4000.0	600.0	450.0	0.2700	9142	33.86	HTS
6	185.039	110.236	19.685	29.528	4700.0	2800.0	500.0	750.0	0.3750	-9743	-25.98	LTS
7	185.039	74.803	19.685	29.528	4700.0	1900.0	500.0	750.0	0.3750	-7519	-20.05	LTS
8	185.039	41.339	19.685	25.591	4700.0	1050.0	500.0	650.0	0.3250	5998	18.46	LTS

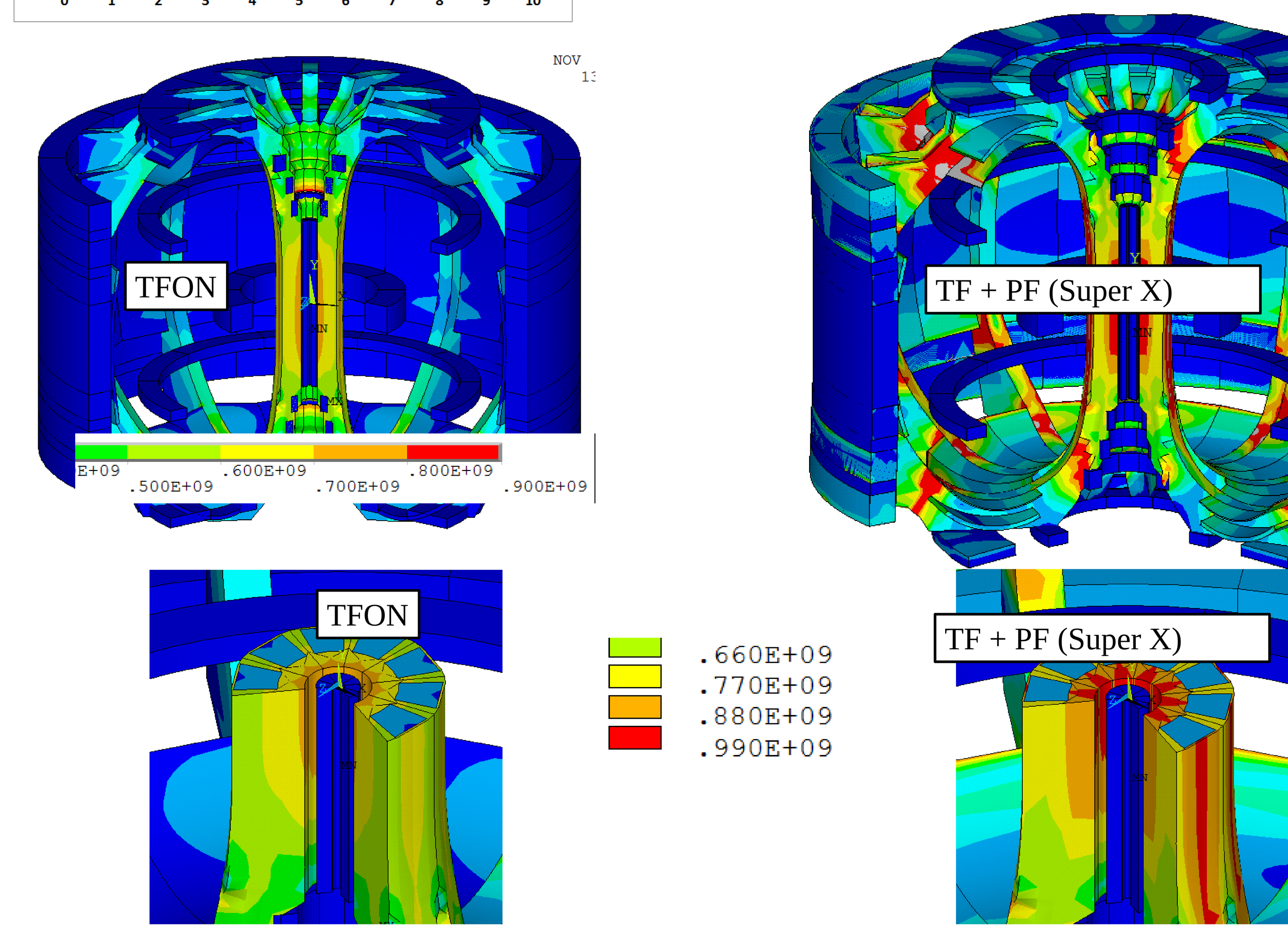


3 m HTS ST Pilot Stress

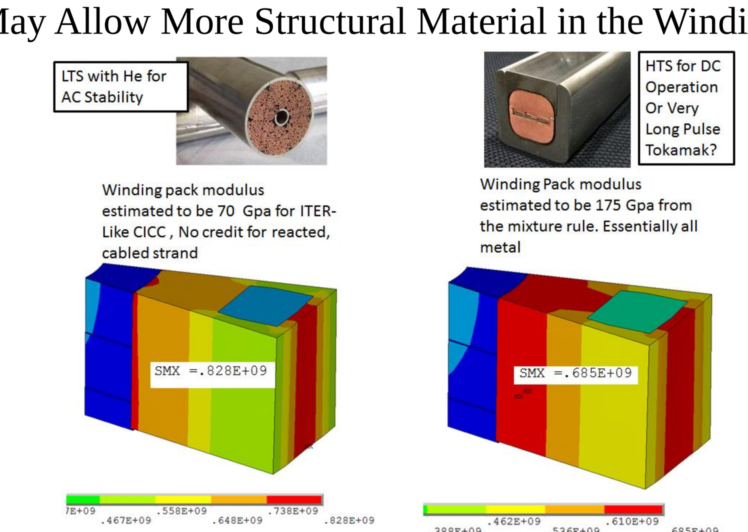
This version of the ST Pilot Plant is a 7T machine with 10 TF coils and a Super X divertor.. The out-of-plane loading will be challenging for this design



ST32
TF and PF Structural Analysis Systems Code Results
Peter H. Titus
Princeton Plasma Physics Laboratory
20151103 11:00:45
ST32 has 10 TF Coils, with 1 turns per coil
ST32 has a major radius of 3 m with a toroidal field of 7 at Ro
ST32 has a minor radius of 1.2 m
Section filename=hse7 divx,divy= 1 1
Case Radius set to 1.4 Case Width set to .6
OIS Radius set to 2 Case Width set to 1.2
Nose radius set to .423
ST32 Path has 8 Points in the TF Path
ST32 Path has been scaled 1 and shifted 0 m
ST32 has 20 Poloidal Field (PF) Coils
ST32 has 2 Poloidal Field (PF) Currents in the Scenario
Scenario 2 is being analyzed
Each TF sector is 36 degrees
The current per TF coil is: 10500334. amps



Study of HTS Current Density in the US-FNSF
HTS May Allow More Structural Material in the Winding Pack



Inner Leg Stress Dependence on Current Density

Reactor	Date	R0	Bo	Peak TF Field (T)	Num TF	Cur per TF Coil MAT	Inner Leg Total Area m^2	Winding Pack Area, m^2	Winding Pack Fraction of Inner Leg Area	Winding Pack Current Density, MA/m^2	Inner Leg TF Stress, Primary Membrane Tresca Mpa
FNSF		4.8	7.5	17.57	16	11.25	0.7273	0.48	0.66	23.4375	800
FNSF HTS		4.8	7.5		16	11.25	0.7272	0.2525	0.34722	44.5544554	658
ITER		6.2	5.3	10.55	18	9.128		0.5344		17.0808383	635
HTST 2meter	9/15/2014	2	7	13.165	12	2.24		0.03037		73.7669071	413
ST 3 Meter		3	7	16.655	16	6.563		0.17518		37.4643224	855
ST 3 Meter		3	7	17.023	10	10.5		0.2534		41.437648	924
KDEMO		7	7	16.87	16	15.313		1		15.313	850
CFETR		5.7	5	9.577	16	8.9065		0.52229		17.0527541	540
CFETR HTS	10/13/2015	5.7	7		16	12.469		1		12.469	960

Conclusion

Three versions of ST Pilot plants have been investigated.

Copper Multicoil ST:

In earlier ARIES studies, the TF was designed as a single conductor with high current power supplies. This allwed the inner leg to avoid insulation and allowed space for the needed water cooling. The feasibility of the large current power supplies was a potential issue and a conventional multi coil TF system was investigated. Analysis showed that frictional interactions between the inner legs could be sufficient too resist the out –of-plane loading.

2 Meter HTS machine

Stresses were manageable because a relatively small area was used for the HTS conductor, assuming a larger allowed current density. Keys, similar to the corner keys used in ITER were required to support the OOP loads

3 Meter HTS machine

With more realistic HTS winding pack current densities, and the PF loads applkied, the TF inner leg case stresses of ~900 Mpa are above the 666 Mpa allowable, and adjustments will be needed to the current densities and inner leg cross sections – or improved yield case materials will be needed. The OOP Loads for the currently specified PF currents are too high.