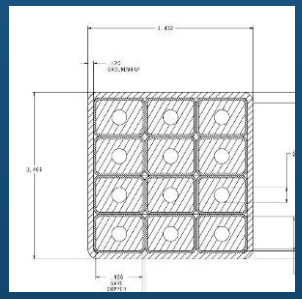
TF Coil Subassembly

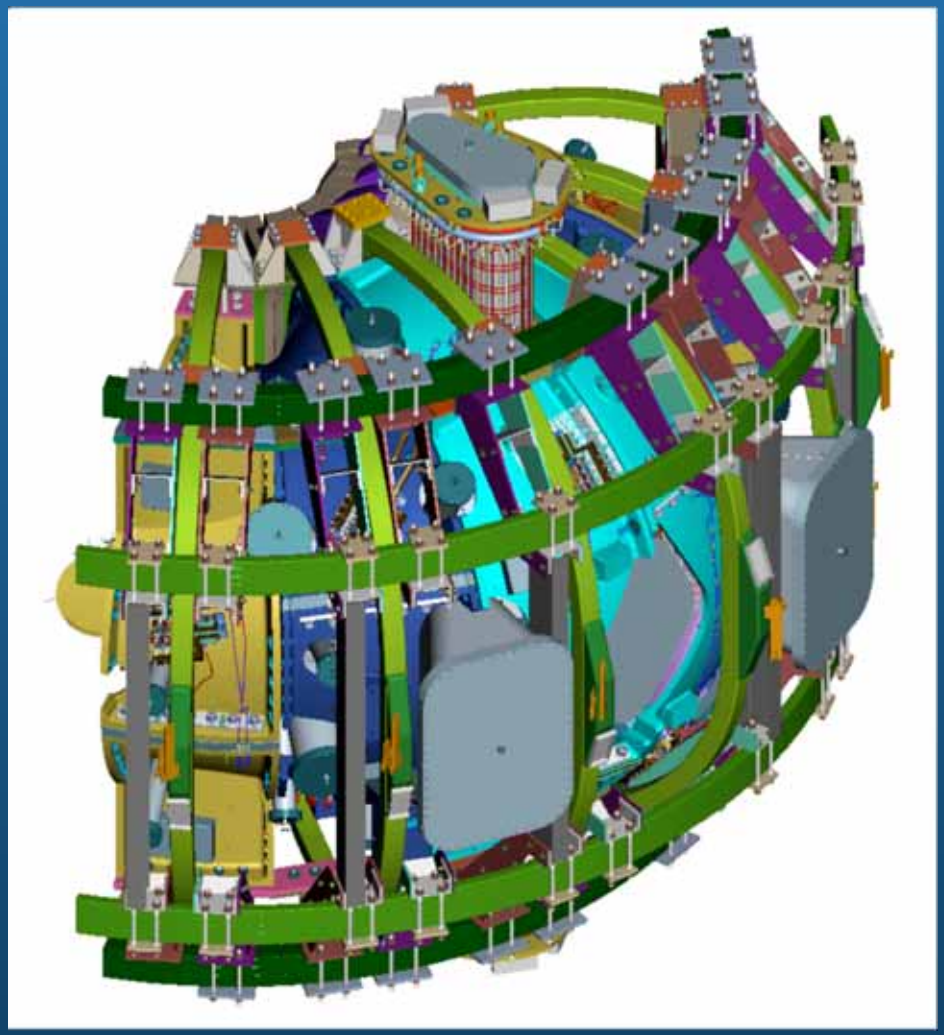
Coil Winding +
Wedge Castings =
TF Coil Subassembly

- D Shaped Wedging Coil
- SS castings on leading edge
- 3x4 Cross-section
- Solid Copper Conductor
- LN2 Cooled



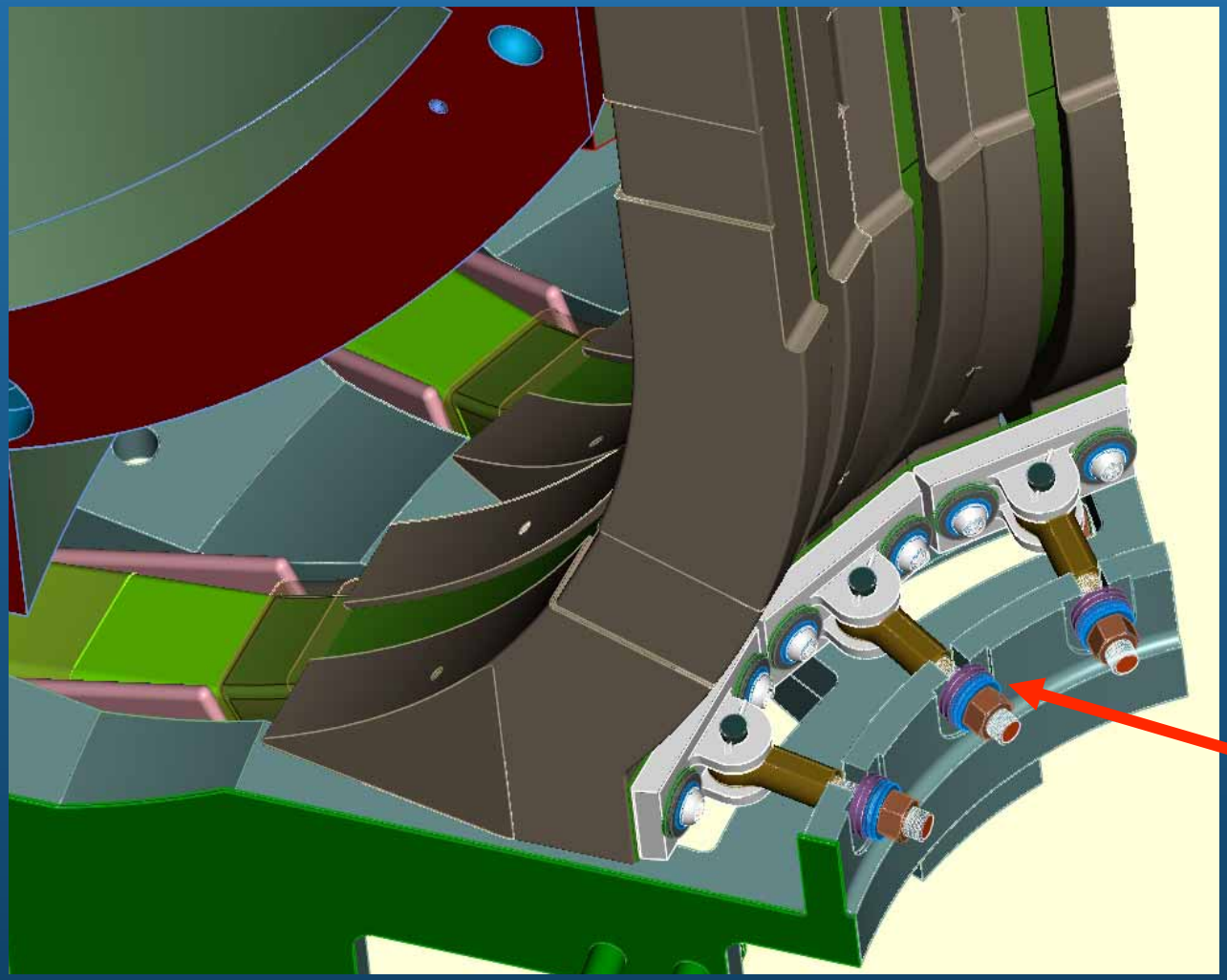
Structure Reacts Critical Loads

- TF Coils Assembled over Modular Coils
- Centering forces reacted through wedging
- Structure mounted to modular coil winding form reacts out of plane loads



NCSX Conventional Coils

Jack Screw Device Added Pulls Coil Forward



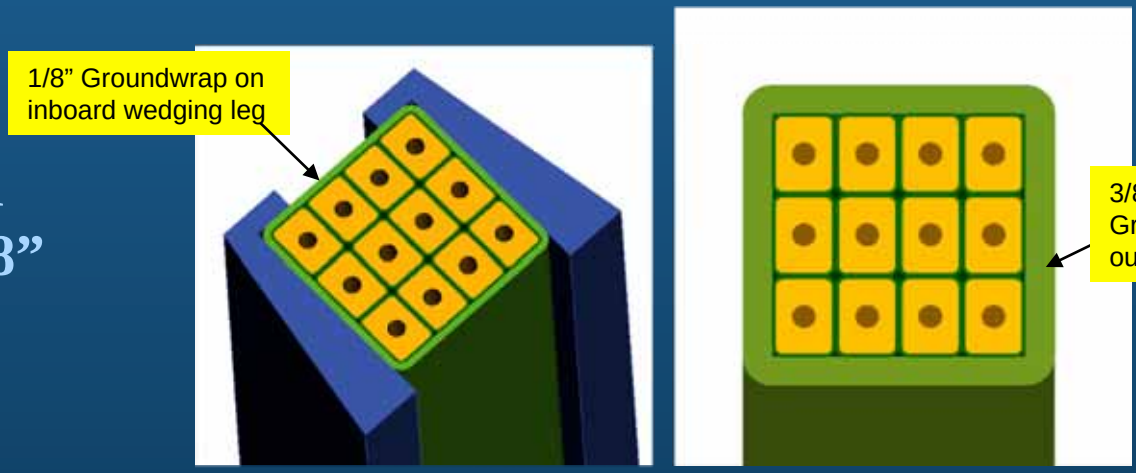
Bellville washers ensure constant 4000 lbf load

Winding Pack Insulation Scheme

TF Turn Insulaton					
1/2 Lap Layer Kapton	Kapton	0.002		7.8	
	Adhesive	0.0015			
	Kapton	0.002		0	
	Adhesive	0.0015			
	Glass	0.007		0.63	
	Glass	0.007		0.63	
	Glass	0.007		0.63	
	Glass	0.007		0.63	
	Glass	0.007		0.63	
	Glass	0.007		0.63	
		0.049	**Inches**	**11.58**	**KV**
Ground Wrap TF					
Twenty One 1/2 Lap Layer	Glass	0.009		0.81	
x 21	Glass	0.009		0.81	
		0.375	**Inches**	**33.8**	**KV**

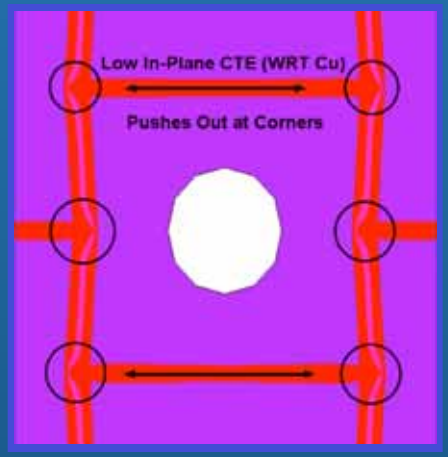
- Kapton Tape applied directly to conductor to enhance turn to turn dielectric standoff and allow for decoupling of insulation from conductor during cool down.

- Inner TF leg ground wrap thickness is 1/8”
- Outer leg of TF coil allows for the use of tough 3/8” ground wrap



Stress Analysis Insulation - Testing

- Analysis showed risk of insulation cracking due to thermal stresses
- Original Plan to resolve thermal stress on winding pack issues
  - Remove Kapton to increase adhesion
  - Test to provide tensile stress allowables
  - Required greater than 10 MPa
- Results from CTD Testing Yielded Poor Results for Tensile strength / adhesion



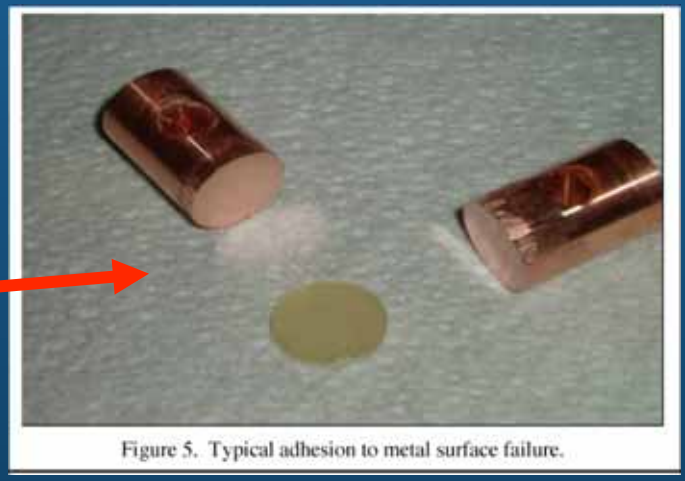


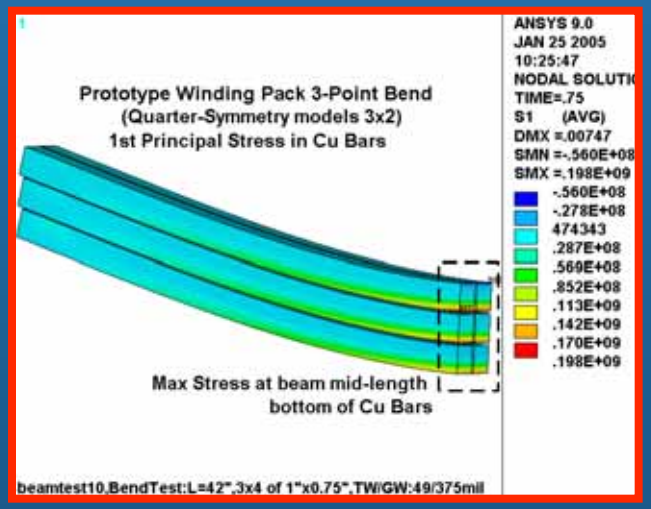
Figure 5. Typical adhesion to metal surface failure.

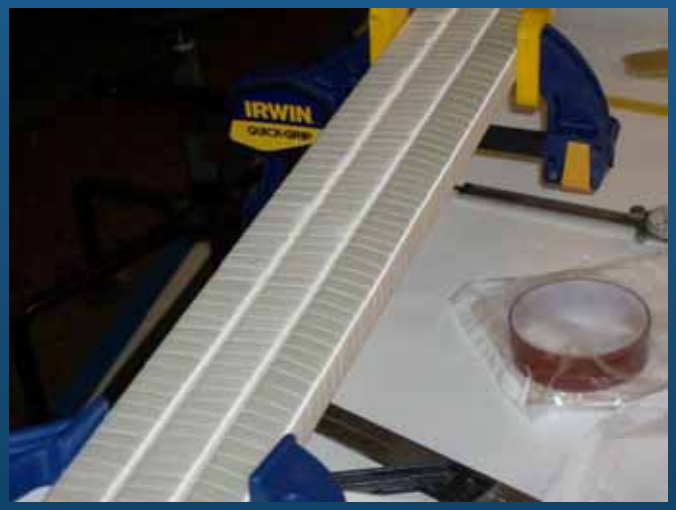
PDR Winding Pack Insulation Scheme

- Original insulation scheme was re-evaluated and evolved to address thermal stress issue
- ½ Lap Layer of Kapton to provide primary dielectric strength
- System to allow loss of adhesion to conductor
- Releasing Kapton layer resolves thermal stress issue.
- Analysis verifies that coil stiffness is adequate after releasing insulation from conductors
- Prototype testing proved out insulation winding pack approach

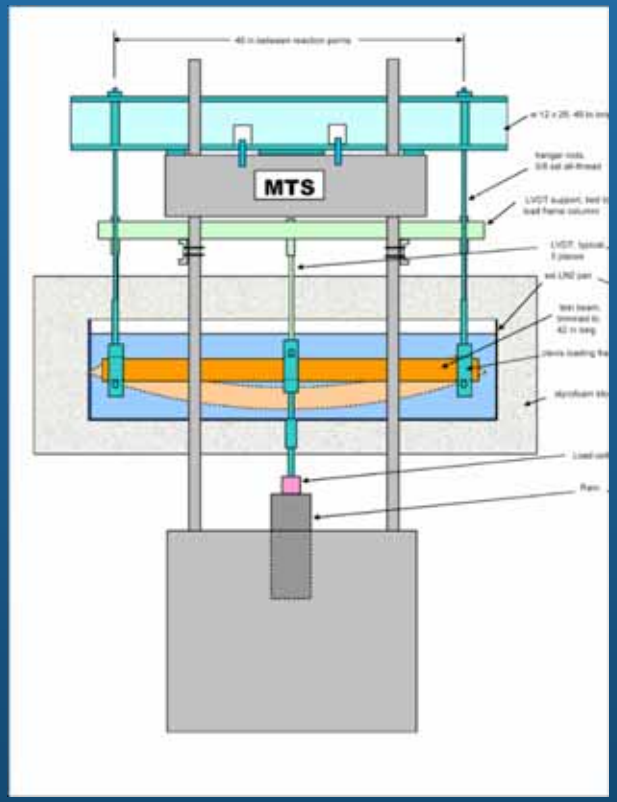
Prototype Bar Testing

- Prototype bar underwent both thermal and stress cycling
- Proved durability of winding pack design
  - mechanical properties maintained after more than 2x stress at life
  - successful hipot tests
- Proved validity of FEA as measured by:
  - bench mark of mechanical properties to Bar model before and after cycling of prototype
- While the test bar was not identical to the PF geometry cyclical stresses tested were 5x greater than PF cyclical stresses
- Insulation scheme is identical to PF Coils



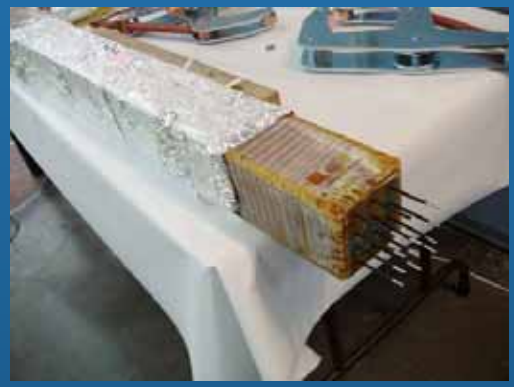


Testing Prototype Bar, Thermal / Fatigue/ Electrical



Test Equipment

Sealed Insulation box with test bar Inside

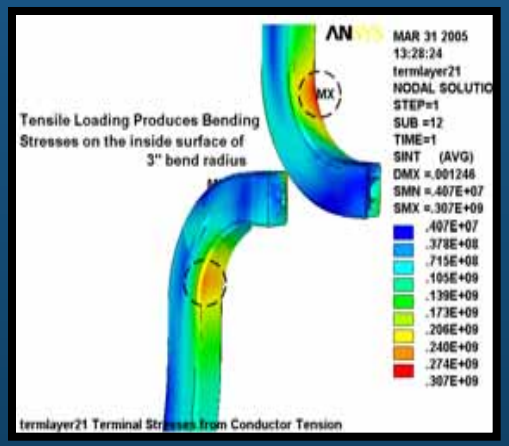


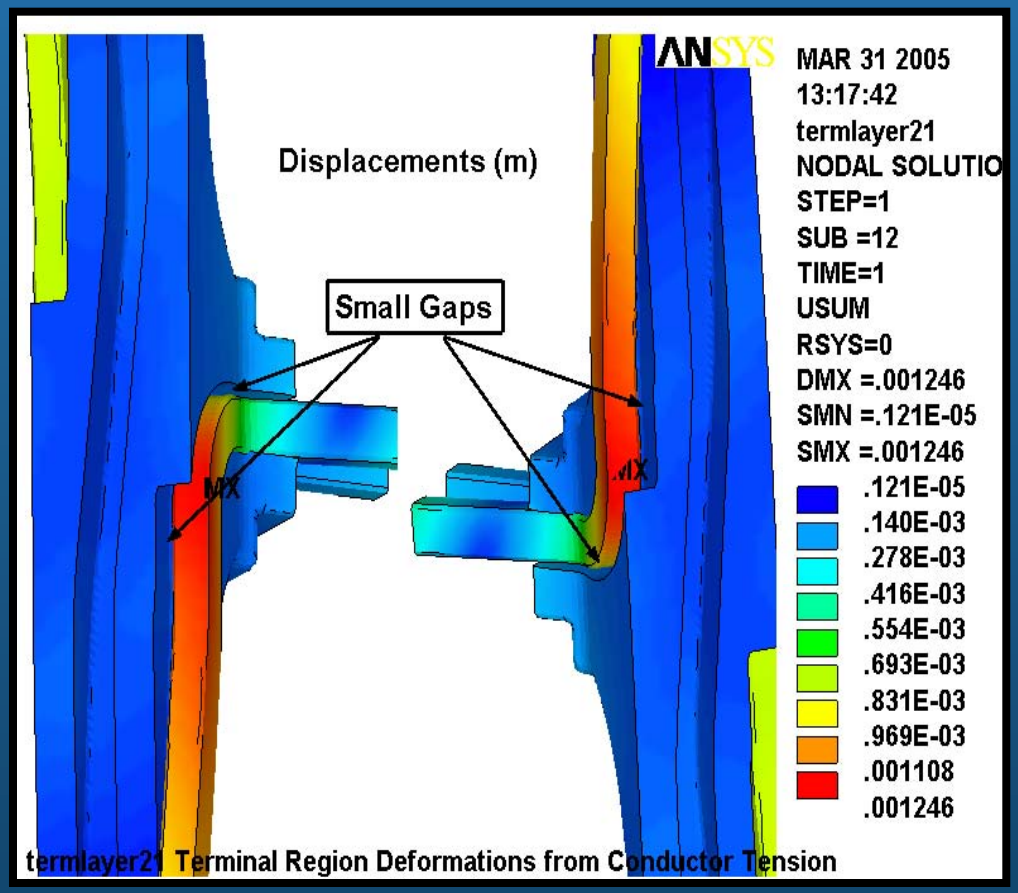
Bar Fitted with Probes for Electrical Testing after Cycling

Test Bar in the fixture with insulation box

Lead Redesign – PDR Design = High Stresses

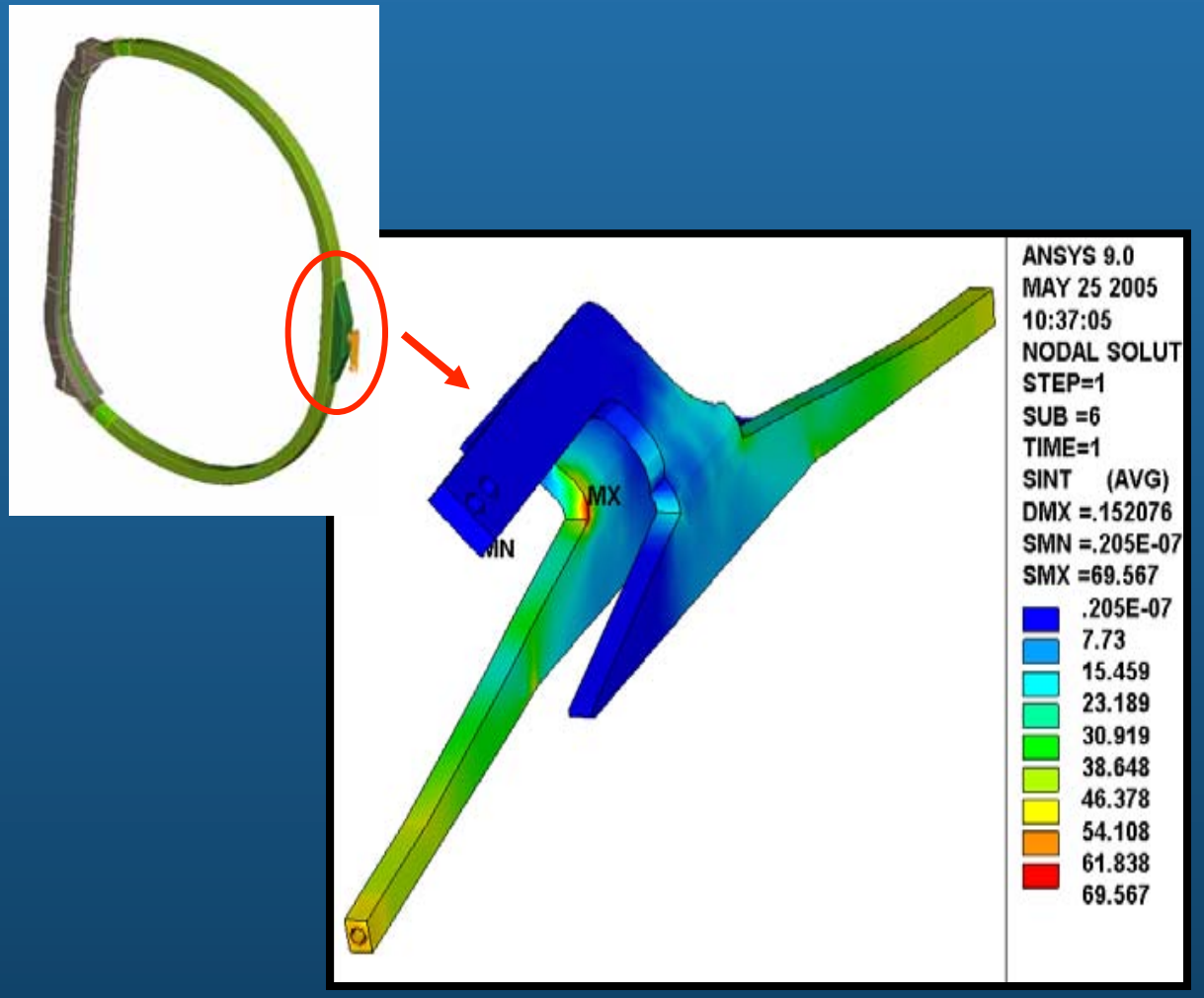
- PDR Lead Design Produced stresses as high as 300MPa
- Lead Area was redesigned and analyzed



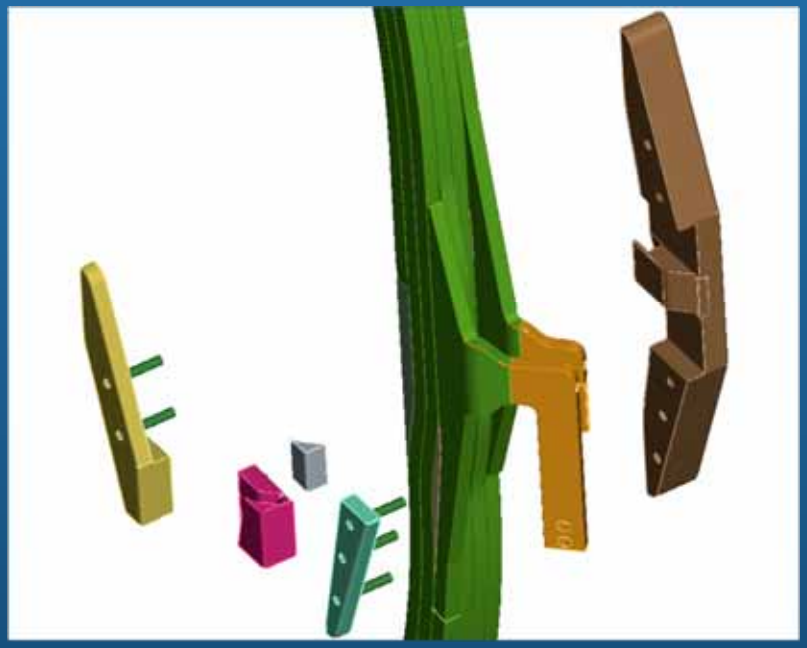


Lead Redesign – Stress Analysis Cu

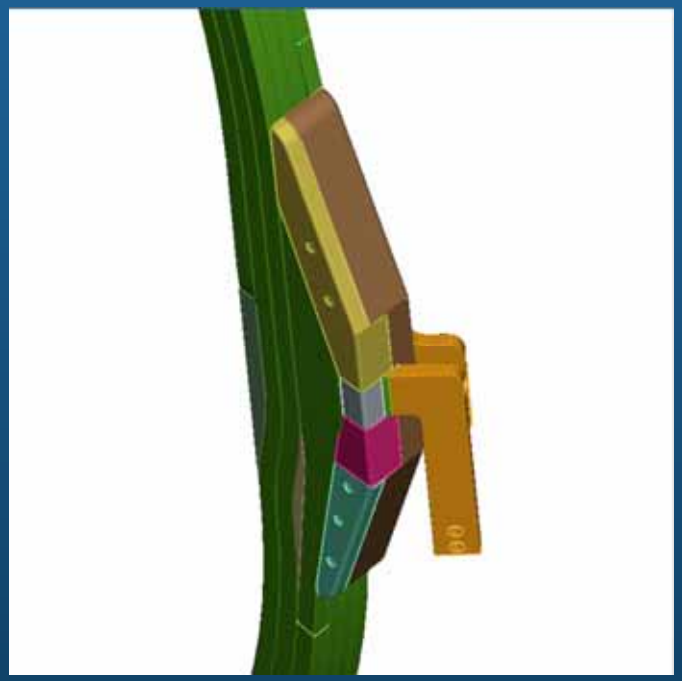
- Redesigned lead area lowers maximum copper stress from 300 MPa to 70 MPa
- This compares to a maximum allowable stress of 270 MPa (1.5Sm)
- The equivalent alternating stress is only 27 MPa which easily meets the fatigue design requirement
- Annealing of Braze area is addressed in specification



Lead Design – FDR Design

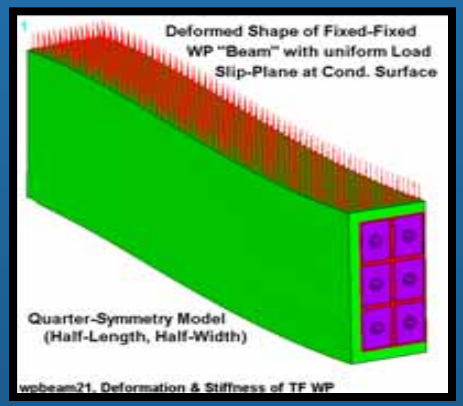


- Lead Spur added to distribute stresses
- Lead Blocks transfer load to opposing lead spur

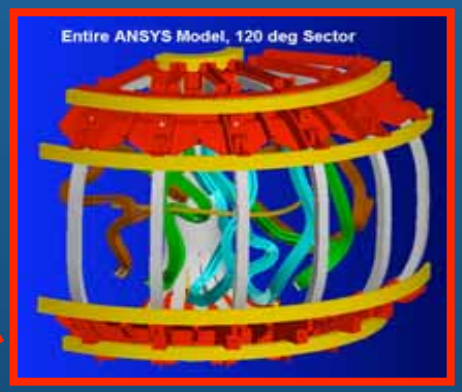


- G11 Pins help carry shear load

Evolution of Structural Design Calculations (PDR)

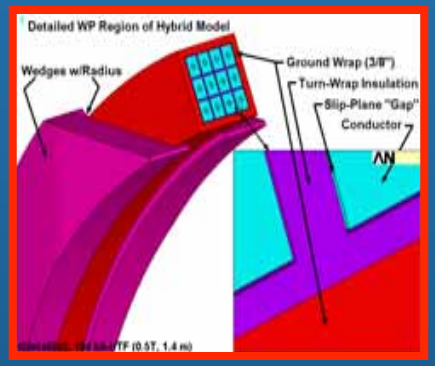


Smeared Properties



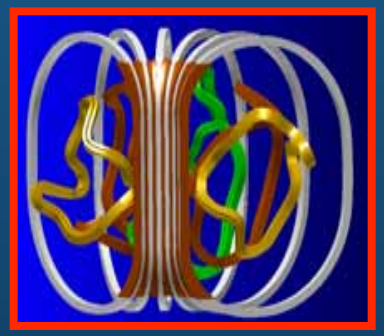
Global Model Deformations

Worst Case Loading



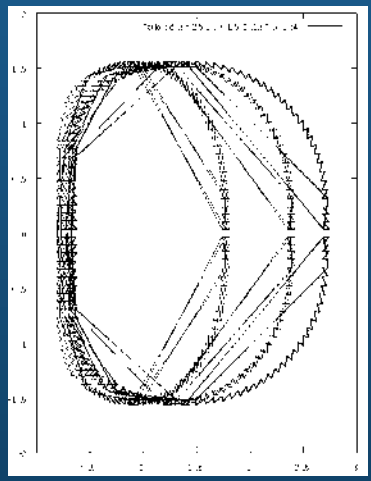
Stress Analysis
.5 Tesla TF Only

Model Modified



Radial Preload

Deformations



Island Study

NCSX Conventional Coils

Deflections Produce some non-ideal Flux Islands (as analyzed by A. Brooks)

* Global requirement is that toroidal flux in island regions shall not exceed 10%
* Leads and Transitions must have a less than 1% effect on toroidal flux in island regions

- Effects of islands analyzed for original and new insulation scheme
- Island size due to these deflections are within 1% requirement for individual systems chosen to satisfy overall 10% requirement
- Separate analysis shows islands from leads and transitions are well below 1% requirement

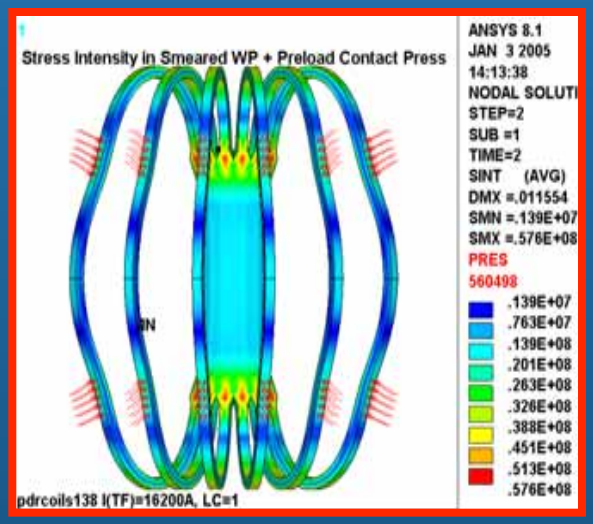
Island Size, % Total Flux				
			Resonance	
ID	Scenario	3/5	6/10	3/6
tfdisp25	TF @ 0.5T	0.02	0.00	0.00
tfdisp26	1.7T Ohmic	0.23	0.10	0.11
tfdisp27	2.0T High Beta	0.10	0.04	0.04
tfdisp29	TF @ 0.5T	0.01	0.00	0.00
tfdisp30	1.7T Ohmic	0.35	0.13	0.15
tfdisp31	2.0T High Beta	0.24	0.08	0.09
tfdisp38	TF @ 0.5T	0.02	0.00	0.00
tfdisp39	1.7T Ohmic	0.40	0.13	0.15
tfdisp40	2.0T High Beta	0.27	0.08	0.09

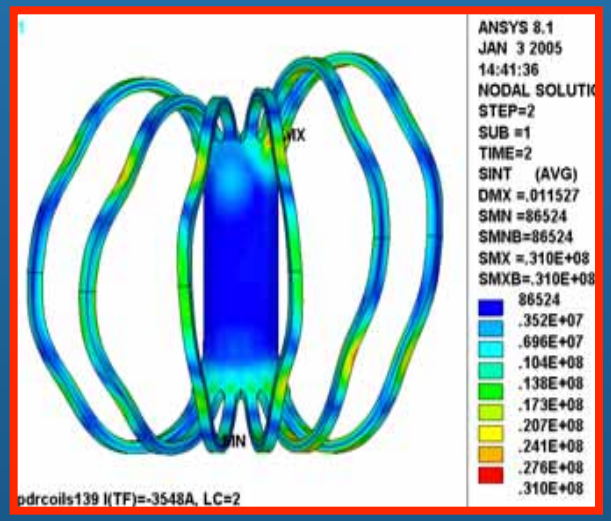
2x6 Winding 10/26/04

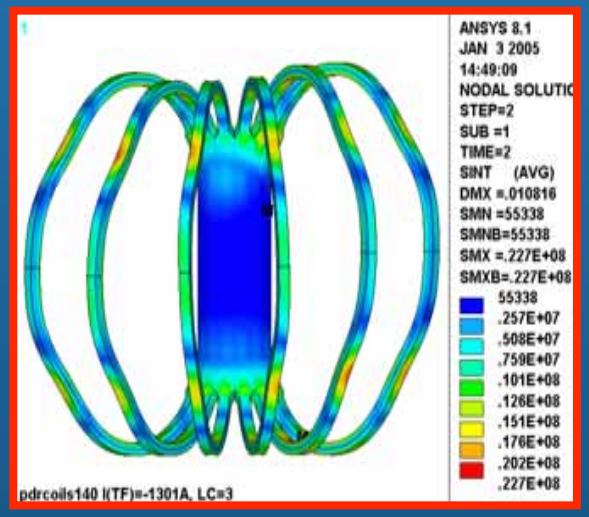
3x4 Winding 12/16/04

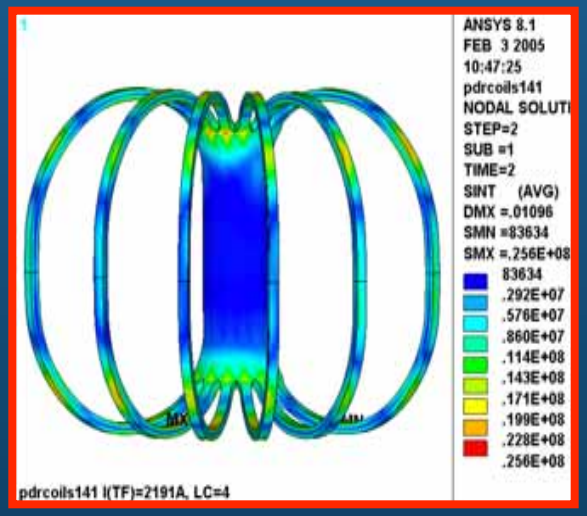
3x4 Winding 12/30/04

Global Model Gives Indication of Relative Stress Level Among Worst Case Time Points









LC1(0.5 T TF): 58 MPa LC2 (1.7T Ohmic): 31MPa LC3(2T High-β): 23 MPa LC4(320kA Ohmic): 26 MPa

TF Manufacturing Process

- Winding
- Induction Brazing
- Wedge Magnetic Permeability
- Vacuum Impregnation
- Coil Geometry Maintained Within Tolerances
- Precise Wedge Cut of front leg
- Electrical Testing Successful
- Final Hi-Pot Testing at Cryogenic Temperature

Fabrication of TF Coil Assemblies

First Coil - Final Cryogenic Electrical Testing

Second Coil Machine cut of Wedge

Third Coil ready for Vacuum Impregnation

Fourth Coil Winding

Planarity Geometry Check

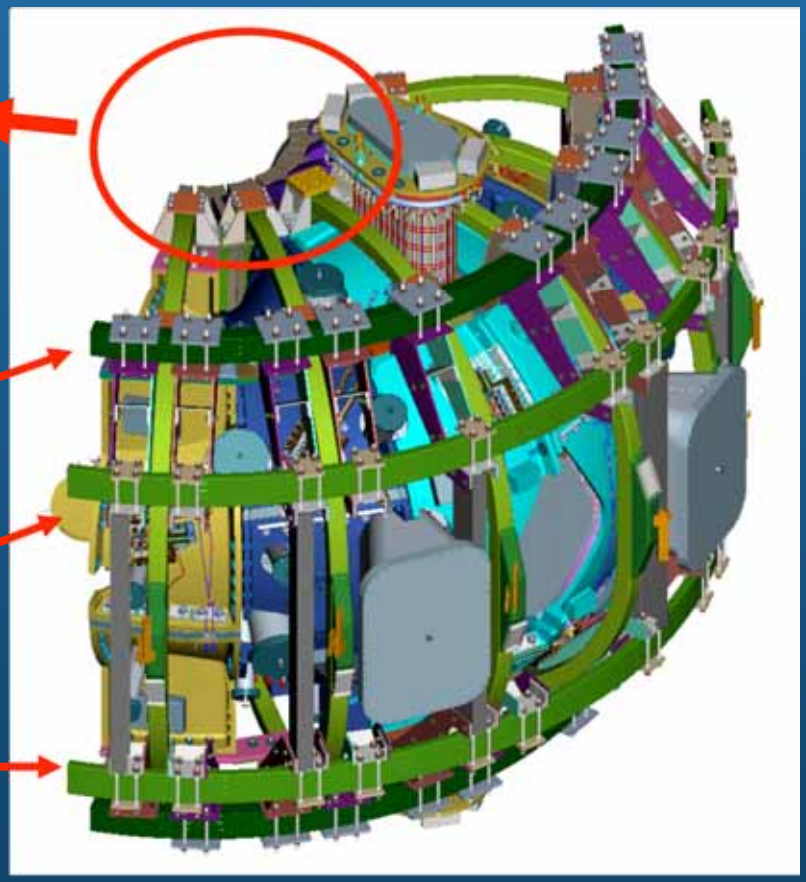
- Height of center line of coil checked against the center plane of the coil and deviations are recorded.

Wedge Geometry

- A precisely machined wedge template is used to inspect the wedge angle as well as the location of coil with respect to the intersecting axis formed by the angle

- The remaining coil geometry is located with respect to the axis described by the intersecting wedge planes by referencing back to an inspected point on the fixture
- The true position tolerance with respect to flatness and planarity of the wedge cut is inspected using a probe on the CNC machine

PF Coils



PF4 Upper

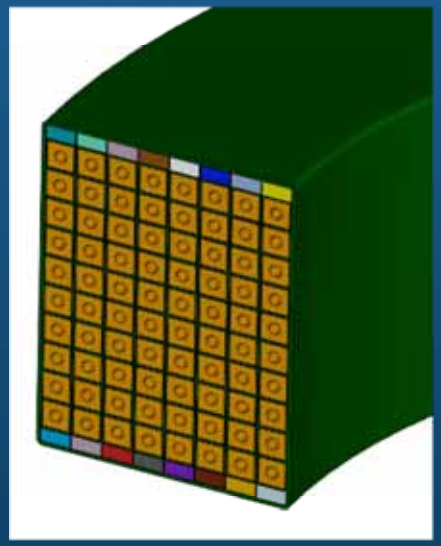
PF5 Upper

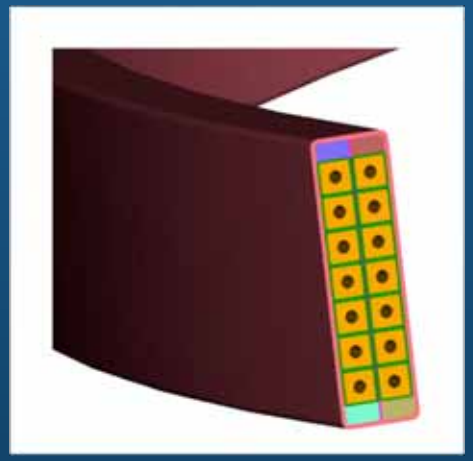
PF6 Upper

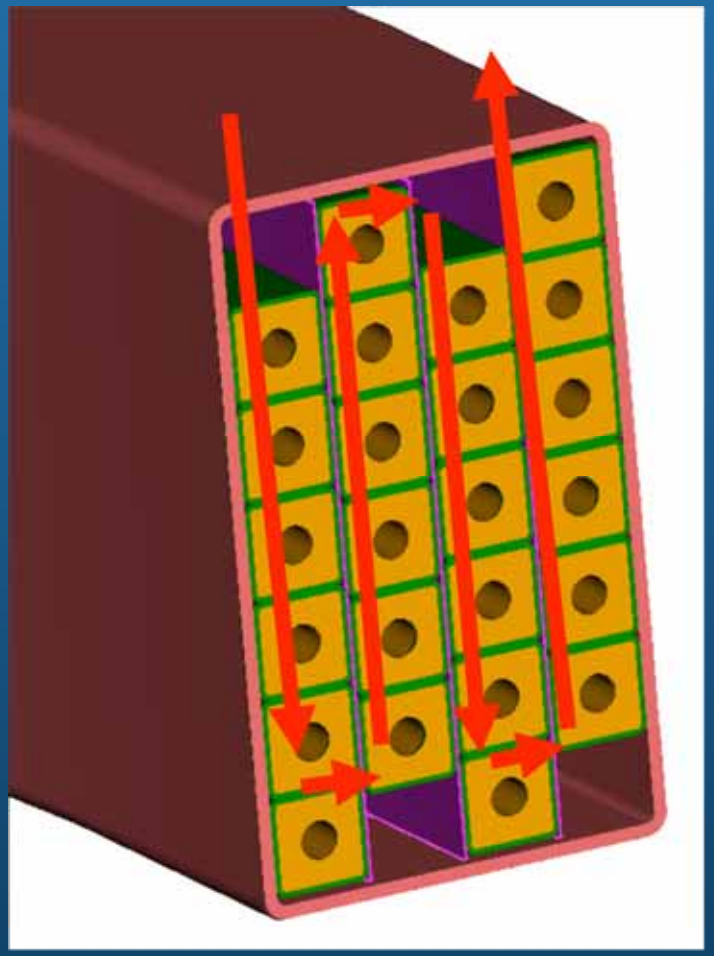
PF6 Lower

PF Coil Cross Section

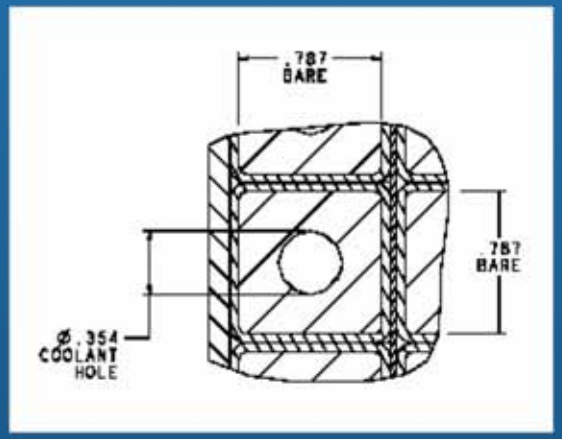
- PF Coils of conventional design
- Rectangular cross section
- Round Geometry

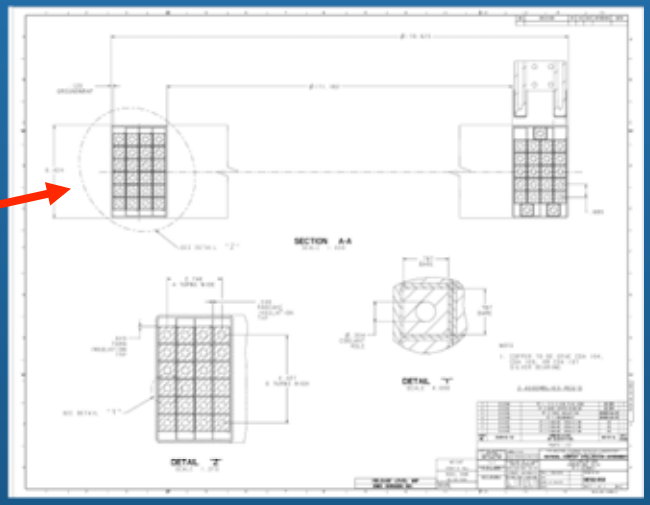


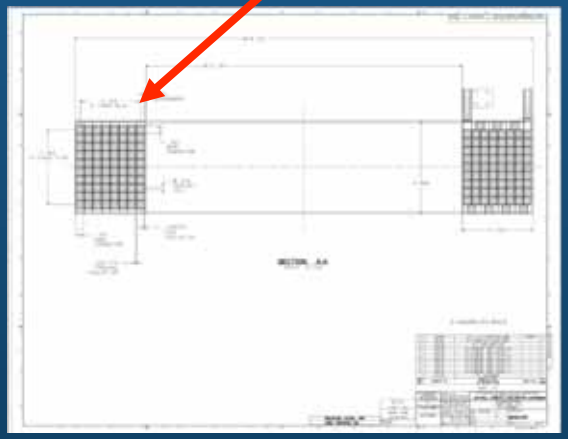


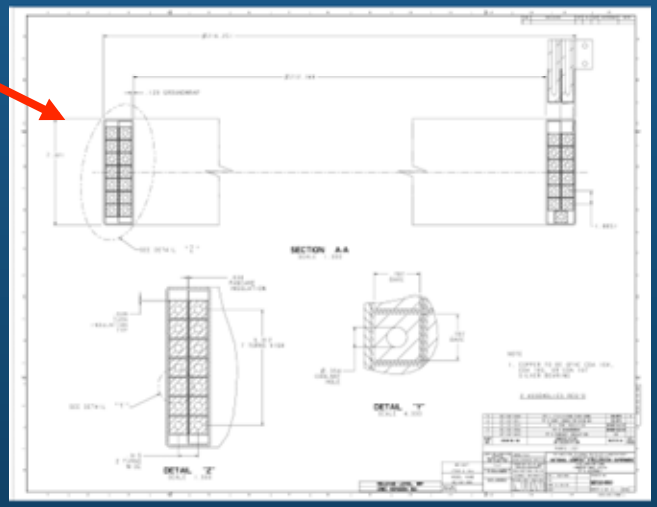


PF Coils, Conductor







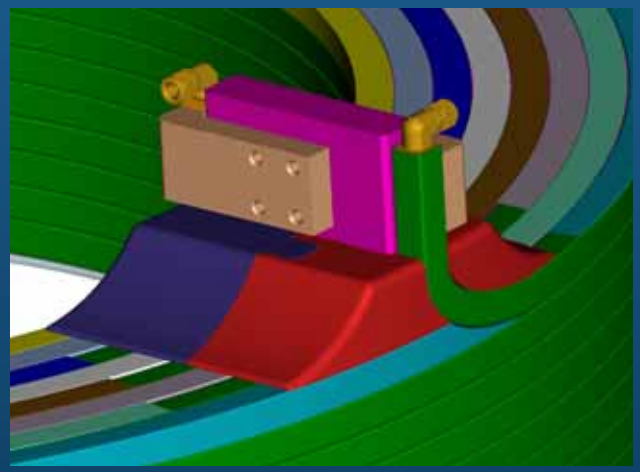


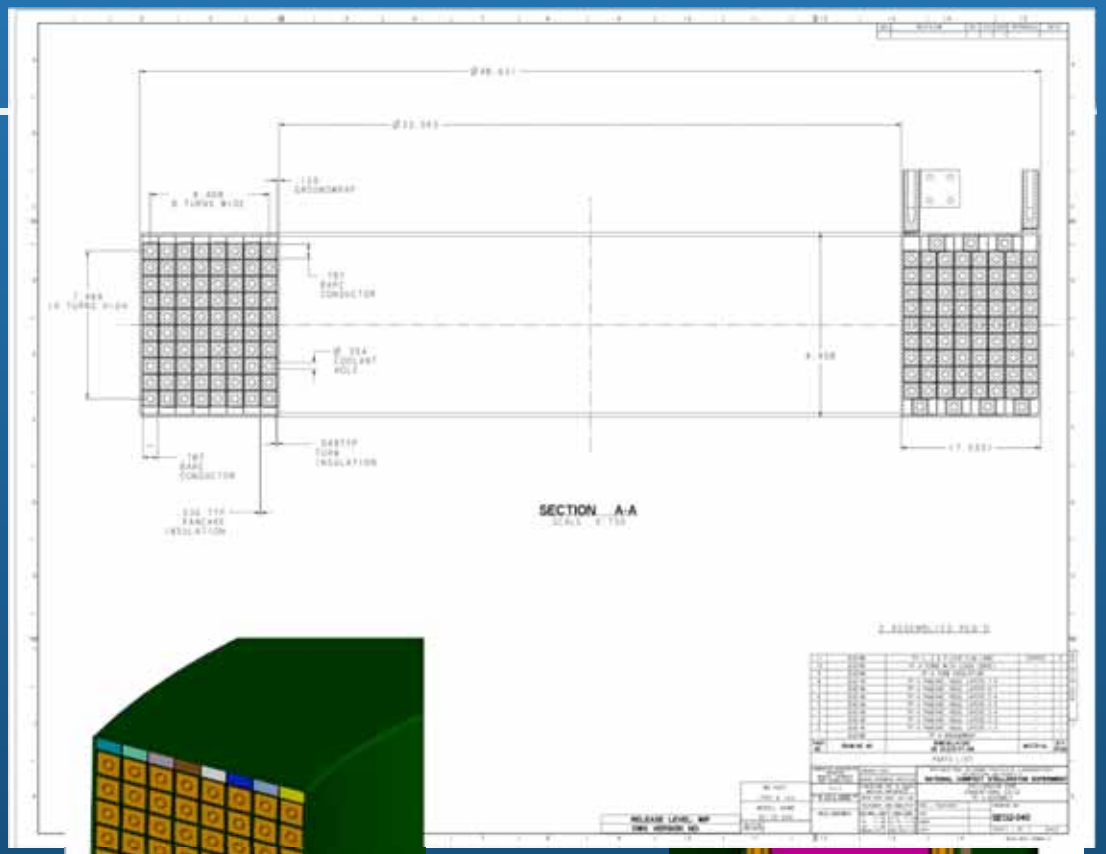
- A single copper conductor size is used for all three different types of PF coils to simplify their manufacture and reduce costs.

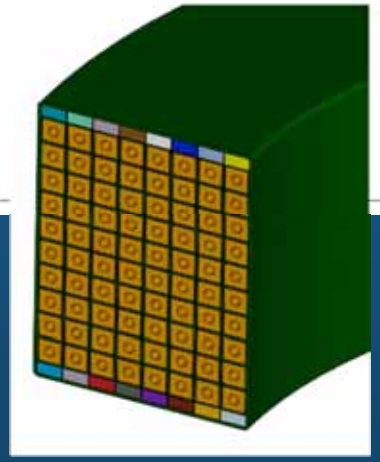
PF4 Geometry

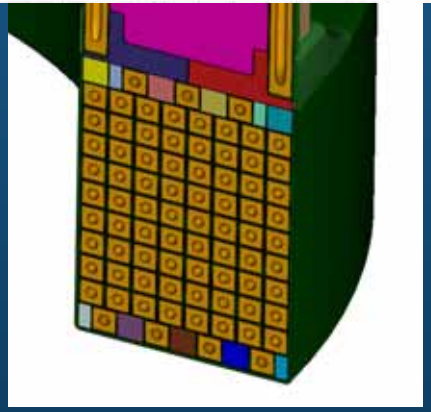
NCSX

- Turns
  = 80
- Outer Diameter
  = 49 inches
- Cross Section
  = 10 x 7.5 inches
- Conductor Length
  = 861 ft







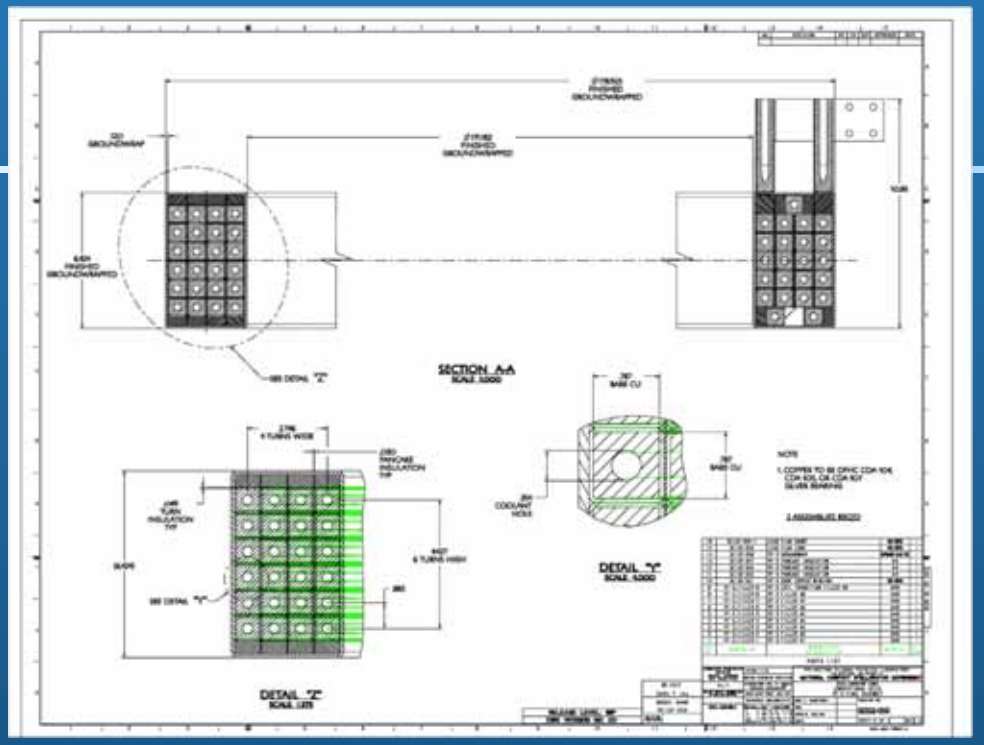


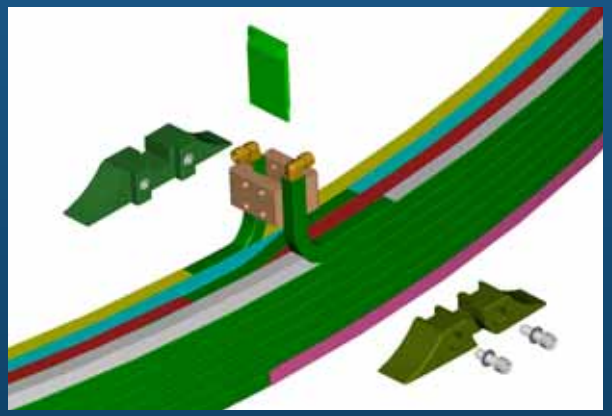
NCSX Conventional Coils

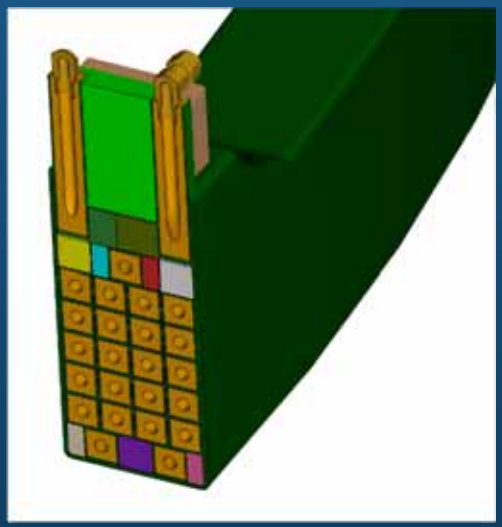
PF5 Geometry

NCSX

- Turns
  = 24
- Outer Diameter
  = 179 inches
- Cross Section
  = 7.7 x 6.4 inches
- Conductor Length
  = 1100 ft

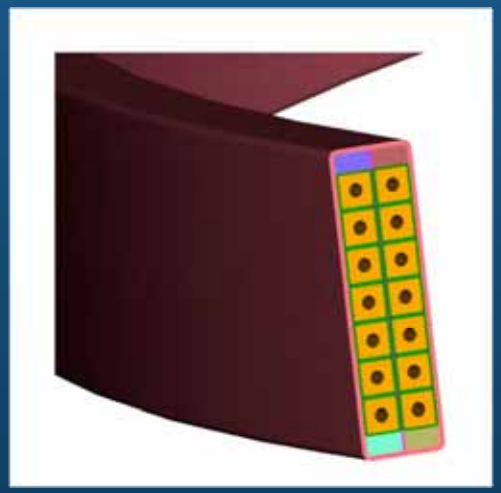


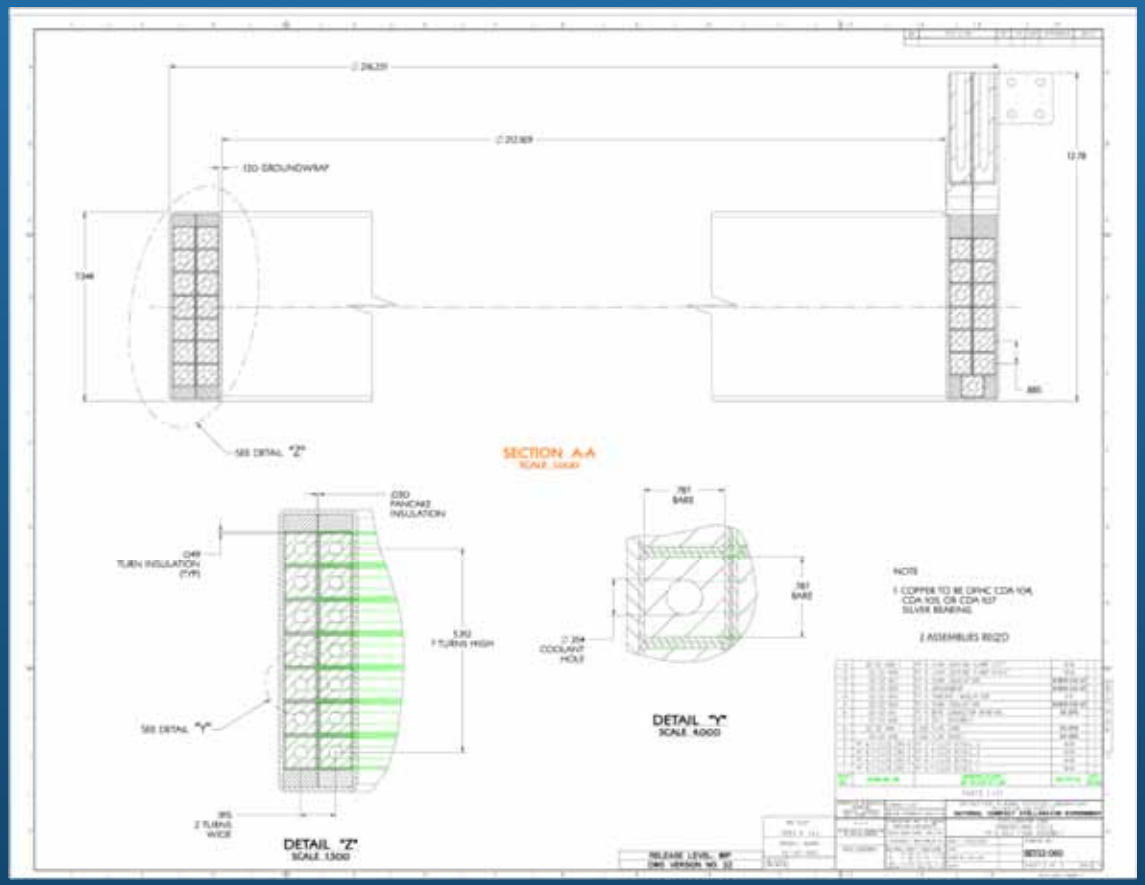




PF6 Geometry

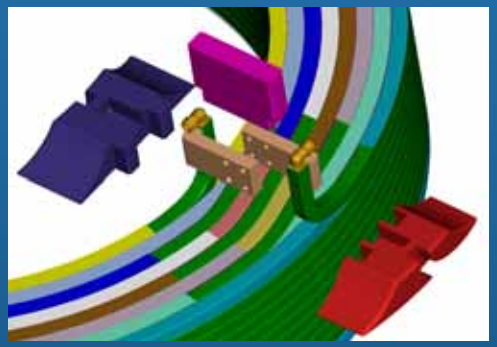
- Turns
  = 14
- Outer Diameter
  = 216 inches
- Cross Section
  = 7.3 x 2.0 inches
- Conductor Length
  = 786 ft

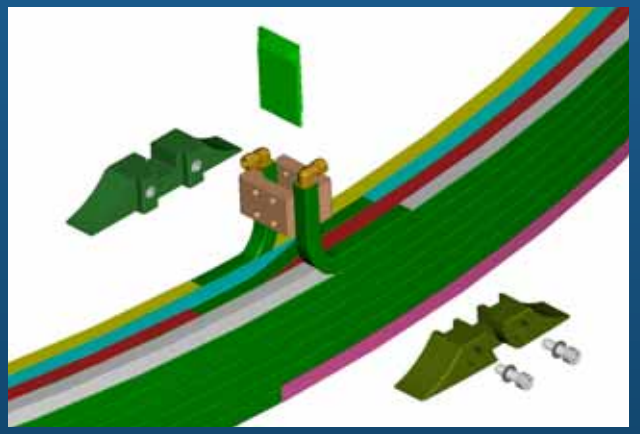


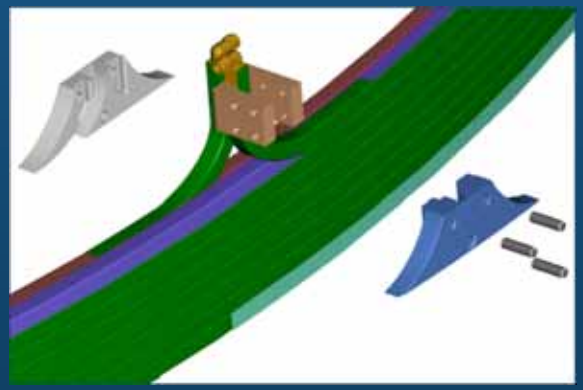


Lead Blocks

- Leads Locked together by G11 Blocks
- Forces on leads very low on the order of 10 lbs excluding exterior fields







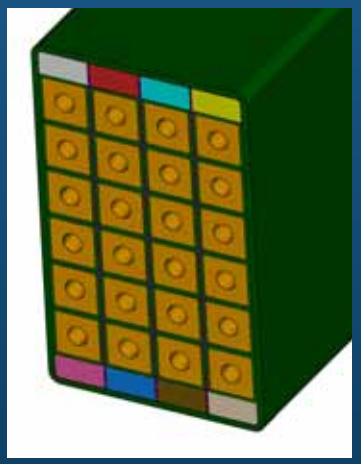
Winding Pack Insulation Design

PF Turn Insulaton					
1/2 Lap Layer Kapton	Kapton	0.002		7.8	
	Adhesive	0.0015			
	Kapton	0.002		0	
	Adhesive	0.0015			
	Glass	0.007		0.63	
	Glass	0.007		0.63	
	Glass	0.007		0.63	
	Glass	0.007		0.63	
	Glass	0.007		0.63	
	Glass	0.007		0.63	
		0.049	**Inches**	**11.58**	**KV**
Ground Wrap PF					
Twenty One 1/2 Lap Layer	Glass	0.009		0.81	
x 21	Glass	0.009		0.81	
		0.375	**Inches**	**33.8**	**KV**

- Kapton Tape applied directly to conductor to enhance turn to turn dielectric standoff and allow for decoupling of insulation from conductor during cool down.

- Generous 3/8” of ground wrap applied to provide “bullet proof” protection to prevent unforeseen potential damage

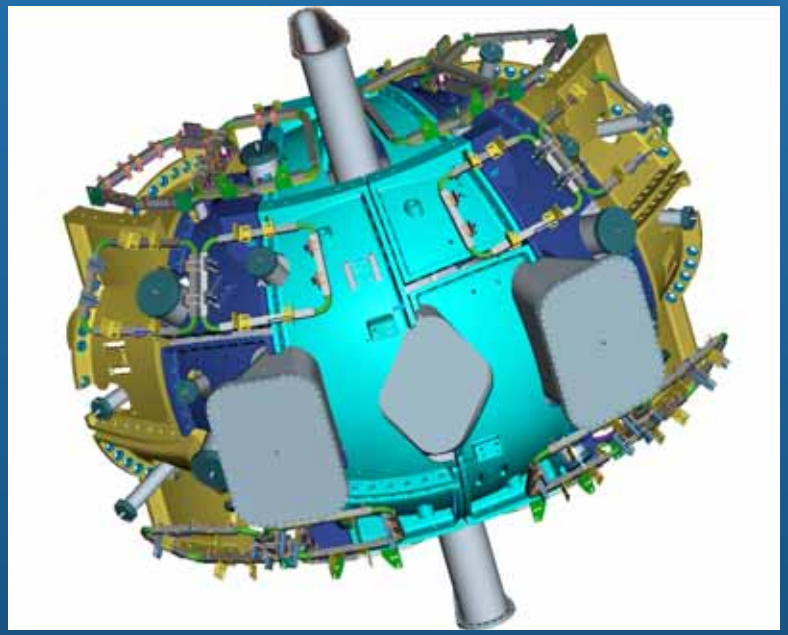
3/8” of Ground Wrap Insulation

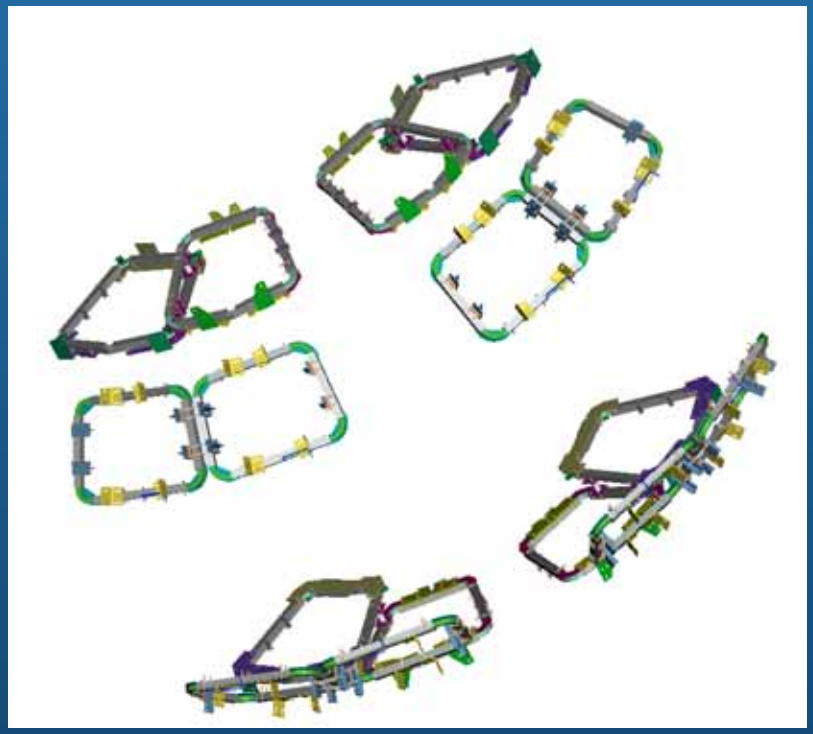


Manufacturability - Manufacturing Tolerances

- Requirement = In plane and out of plane installed perturbations shall be less than +/- 3mm
- Coil specification will require +/- 1.5mm using half of the allowable installed tolerance budget
- D Shaped NCSX TF Coils have been manufactured to about a +/- 1.5mm tolerance in their free state but a guarantee of that over the larger diameters for the PF Coils is not guaranteed
- Coil as it is removed from the VPI mold will be within +/- 1mm but coil is likely to distort in it's free state
- Support structure must be capable of re-shaping coil as required
- Coils can be positioned during installation to average out of tolerance conditions

Trim Coil Configuration





- 48 Coils
- Only two coil types
- All Coils Planar
- Top bottom symmetric half period patterns

48 Coil Trim Coil Configuration Meets Design Objective with Margin

Design Point
< 10% Islands
< 20 kA-T

NCSX

Trim Coil Configuration	Total Number Coils	Using SVD Solution: Total Island Size %Total Flux	Using SVD Solution: Max Current kA-T	Using NLP Solution: Total Island Size %Total Flux	Using NLP Solution: Max Current kA-T
Original 36 coils, 24 circuits	36	4.42	8.34	3.35	10.00
Original with 12 Midplane Coils	48	4.41	7.85	2.55	10.00
All Inner/Outer Coils Only (as Modified)	54	4.30	9.96	2.87	10.00
All Inner/Outer Coils Only (as Modified)	48	4.29	11.36		
(but without Outer AA)		6.95	10.00		
All Inner/Outer & Midplane Coils	66	4.26	9.21	2.17	10.00
All Inner/Outer & Midplane Coils	60	4.25	9.56		
(but without Outer AA)					
All Inner/Outer Coils (port12 split)	**60**	4.47	10.00	2.89	10.00
(with Outer AA Coils)		4.21	10.30		
All Inner/Outer Coils (port12 split)	**54**	7.98	10.00	3.00	10.00
(without Outer AA Coils)		4.18	11.88		
All Inner/Outer Coils (port12 split)	**48**	8.49	10.00	**3.12**	10.00
(without Outer AA and CC Coils)		4.06	12.25		
Above Plus Wings Distorted +40 mils		-	-	**3.88**	10.00
(Stellarator Symmetric) -40 mils		-	-	**3.88**	10.00
Above Plus Wings Distorted +40 mils		-	-	**3.25**	10.00
(1 HP Only, Non Stellarator Sym)					

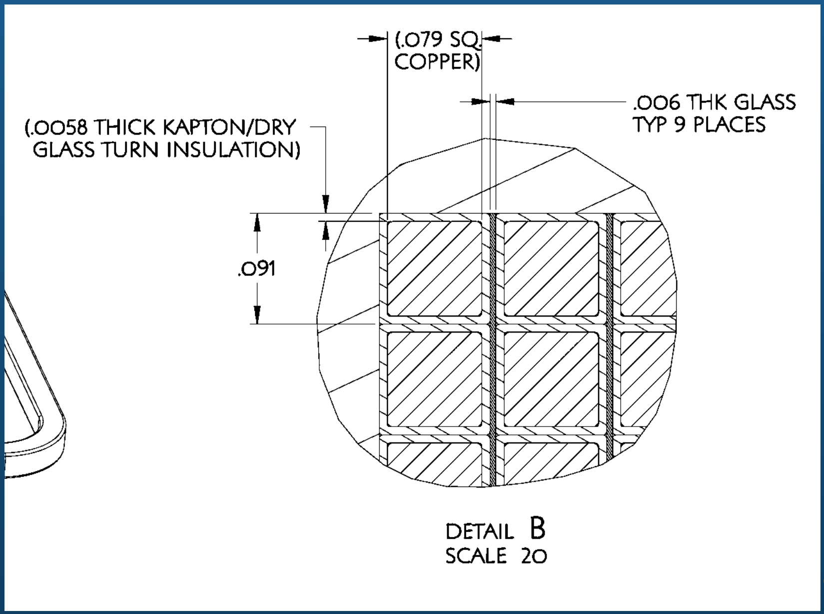
Trim Coil Requirements

- **Meet Requirements when subjected to GRD reference scenarios**
- **Island Suppression 10%**
  - 20 kAmp Turns
  - 48 Coil Configuration
- **Thermal Excursions and Stress within limits**
  - 2 second pulse every 15 minutes
  - 167 amps
- **Withstand Operating Voltages**
  - Max Operating Voltage 1.0kV
  - Design Standoff Voltage to Ground of 6.7 kV
  - Design Standoff Voltage Turn to Turn of 1.0 kV
- **Winding Tolerances**
  - Installed tolerance +/-12mm
  - Fabrication tolerance +/- 6mm
  - Location measured to within 2mm

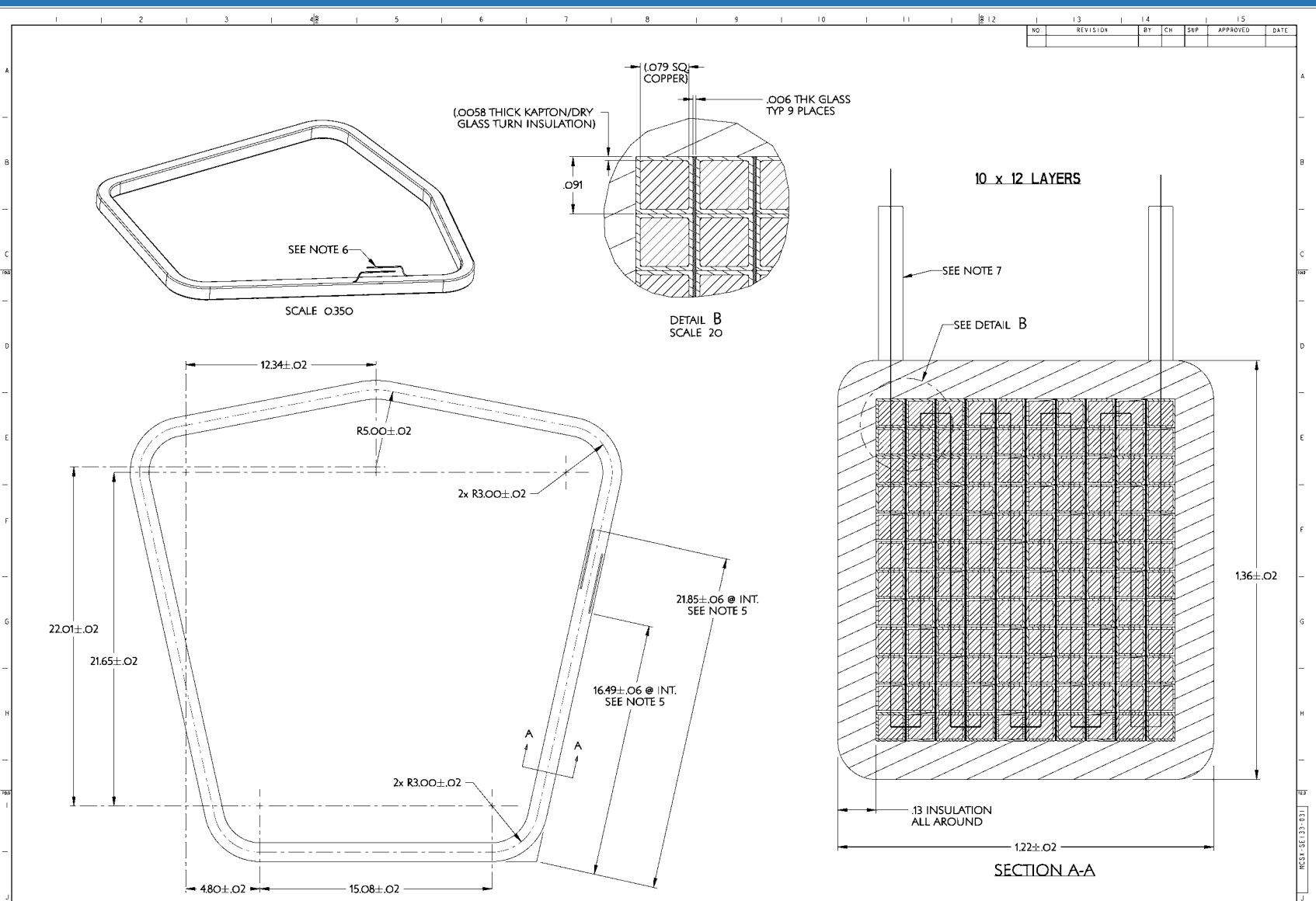
Winding Pack Insulation Scheme

NCSX

- Kapton Tape applied directly to conductor to enhance turn to turn dielectric standoff
- One half lap layer of glass to allow for epoxy impregnation
- Additional .006” thk by 1” wide glass between layers to wick epoxy

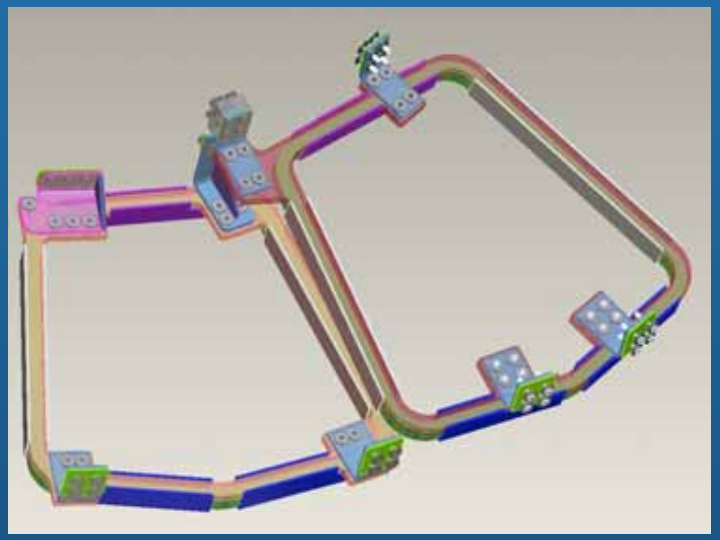


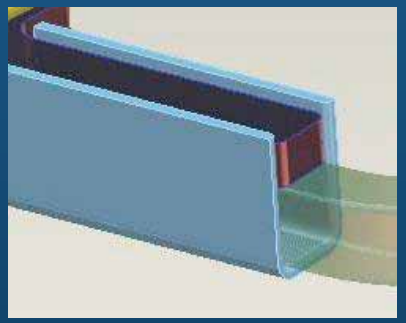
Trim Ground Wrap					
1/2 Lap Layer Dry Glass	Glass	0.006		0.54	
	Glass	0.006		0.54	
1/2 Lap Layer Dry Glass	Glass	0.006		0.54	
	Glass	0.006		0.54	
1/2 Lap Layer Dry Glass	Glass	0.006		0.54	
	Glass	0.006		0.54	
1/2 Lap Layer Dry Glass	Glass	0.006		0.54	
	Glass	0.006		0.54	
1/2 Lap Layer Dry Glass	Glass	0.006		0.54	
	Glass	0.006		0.54	
1/2 Lap Layer Dry Glass	Glass	0.006		0.54	
	Glass	0.006		0.54	
1/2 Lap Layer Dry Glass	Glass	0.006		0.54	
	Glass	0.006		0.54	
1/2 Lap Layer Dry Glass	Glass	0.006		0.54	
	Glass	0.006		0.54	
1/2 Lap Layer Dry Glass	Glass	0.006		0.54	
	Glass	0.006		0.54	
1/2 Lap Layer Dry Glass	Glass	0.006		0.54	
	Glass	0.006		0.54	
		0.12	**Inches**	**10.8**	**KV**
Trim Turn to Turn					
1/2 Lap Layer Dry Glass	Glass	0.0012		0.108	
	Glass	0.0012		0.108	
	Kapton	0.0017		7.7	
	Kapton	0.0017			
		0.0058	**Inches**	**7.9**	**KV**

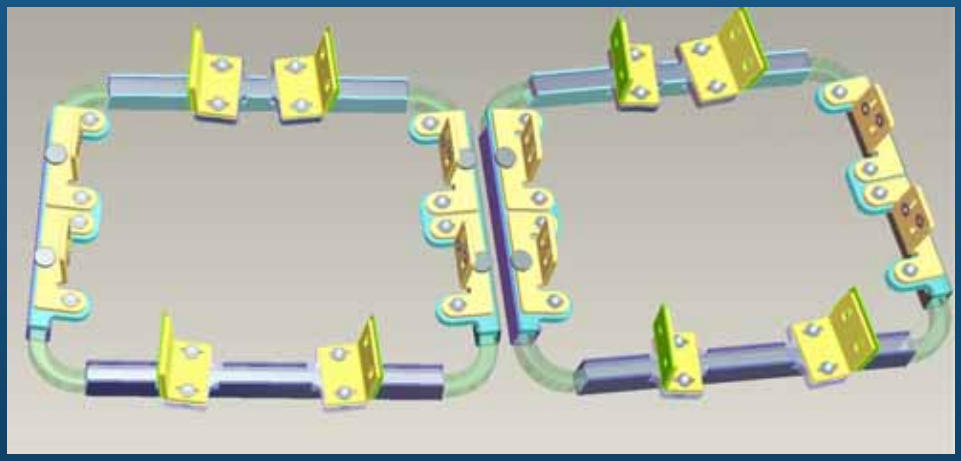

NO. REVISION BY CH SUP APPROVED DATE
(.079 SQ. COPPER)
.006 THK GLASS TYP 9 PLACES
(.0058 THICK KAPTON/DRY GLASS TURN INSULATION)
.091
SEE NOTE 6
SCALE 0.350
DETAIL B
SCALE 20
10 x 12 LAYERS
SEE NOTE 7
SEE DETAIL B
12.34±.02
R5.00±.02
2x R3.00±.02
21.85±.06 @ INT.
SEE NOTE 5
22.01±.02
21.65±.02
16.49±.06 @ INT.
SEE NOTE 5
A
A
2x R3.00±.02
4.80±.02
15.08±.02
1.36±.02
.13 INSULATION ALL AROUND
1.22±.02
SECTION A-A
NOTES:
1. DRAWINGS PREPARED IN ACCORDANCE WITH ASME Y14.100-2000
2. INTERPRET DIMENSIONS & TOLERANCES PER ASME Y14.5-1994.
3. DIMENSIONS ARE IN INCHES.
4. SEE SPECIFICATION NCSX-CSPEC-133-01 FOR ADDITIONAL INFORMATION AND/OR MATERIAL REQUIREMENTS.
5. WIRE LEAD STARTS TO PROTRUDE BEYOND OUTSIDE SURFACE AT THIS POINT.
6. LEAD LENGTH A MINIMUM OF 6 INCHES AND SHIP TEMPORARILY BOUND TO COIL.
7. SLEEVE LEAD WITH TWO LAYERS OF PTFE HEAT SHRINK TUBING TO A MINIMUM OF 1/2" UNDER THE GROUND WRAP AS SPECIFIED IN NCSX-CSPEC-133-01.
WEIGHT
170.3 lbs
MODEL NAME
TC133-031
RELEASE LEVEL: WIP
DWG VERSION NO: 2
PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL COMPACT STELLARATOR EXPERIMENT
STELLARATOR CORE
TRIM COILS
TRIM COIL B1
DRAWN: R. UPCAVAGE
CHK:
ENGR: M. KALISH
SUPV:
DRAWING NO:
SE133-031
SHEET 1 OF 1
REV: 4
NCSX_PART_FORMAT_E

Structural Design

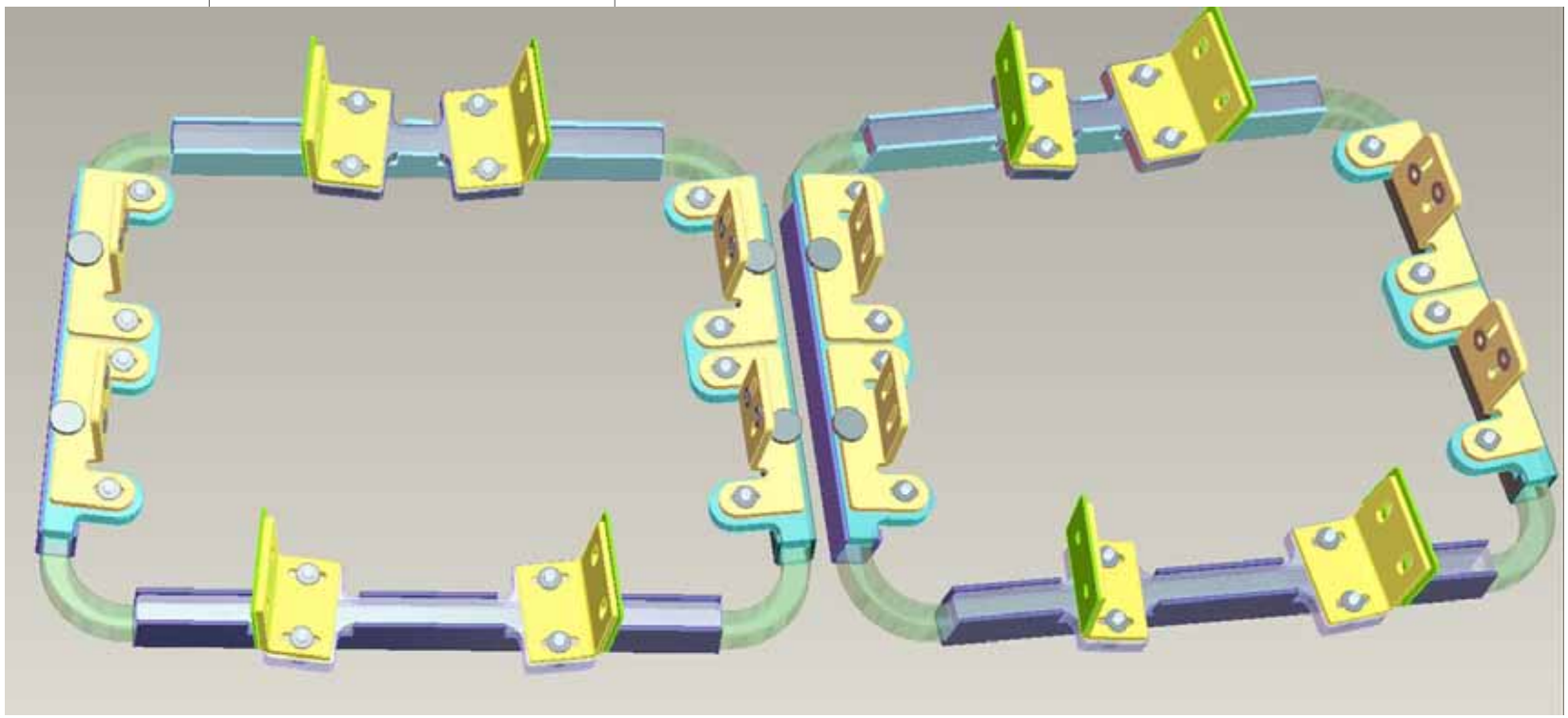
- Coil Assemblies assembled off line and then bolted to TF and PF Coils supports
- Brackets offer 3 degrees of adjustment
- Custom shimming may be required to correct for angle in one plane only
- With all frames accurately machined a representative aluminum template can be used to pre-fab shims if required

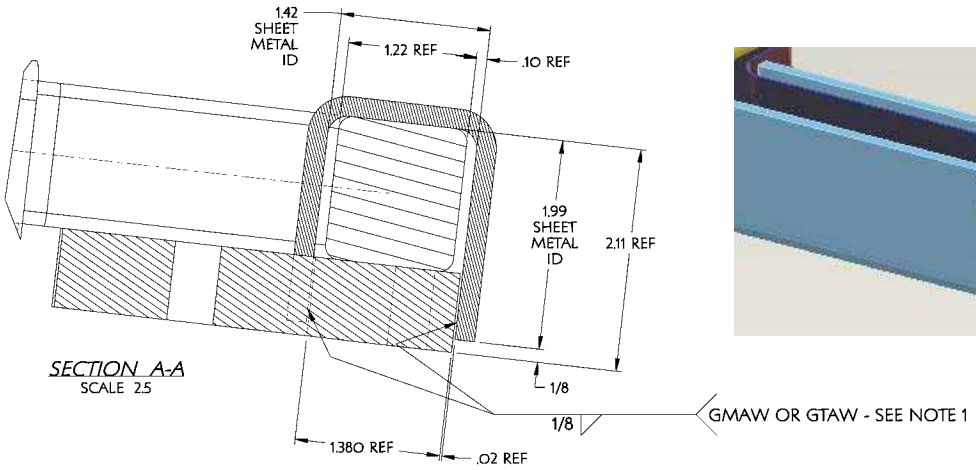






NO.	REVISION	BY	CH	SUP	APPROVED	DATE





SECTION A-A
SCALE 2.5

LL BE PERFORMED IN ACCORDANCE WITH THE REQUIREMENTS OF
L PPPL PROCEDURE ENG-037. VISUAL WELD INSPECTION SHALL BE
N ACCORDANCE WITH THE ACCEPTANCE CRITERIA OF AWS D1.1 Section 6.

PART NO.	DRAWING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	QTY REQD
8	SE133-044-4	TRIM COIL #2 CHANNEL SUPPORT CAP #3	304L SS/STL	1
7	SE133-044-3	TRIM COIL #2 CHANNEL SUPPORT CAP #3	304L SS/STL	1
6	SE133-044-2	TRIM COIL #2 CHANNEL SUPPORT CAP #2	304L SS/STL	1
5	SE133-044-1	TRIM COIL #2 CHANNEL SUPPORT CAP #1	304L SS/STL	1
4	SE133-041	TRIM COIL #2 GROUND-WRAPPED ASSEMBLY	COPPER/EPOXY	1
3	RU_TRIM_COIL_BASE_SUPPORT_1A	TRIM COIL #2 SUPPORT BASE #1	304L SS/STL	1
2	RU_TRIM_COIL_BASE_SUPPORT_3	TRIM COIL #2 SUPPORT BASE #3	304L SS/STL	2
1	RU_TRIM_COIL_BASE_SUPPORT_1	TRIM COIL #2 SUPPORT BASE #1	304L SS/STL	1

PARTS LIST

COMPUTER GENERATED DRAWING MANUAL CHANGES NOT PERMITTED

CENTRAL FILES: UNLESS OTHERWISE SPECIFIED

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL COMPACT STELLARATOR EXPERIMENT

WEIGHT
122.6 lbs

DIMENSIONS ARE IN INCHES
MACHINE SURFACES

DO NOT SCRIPT INFORMATION BY SCALING DRAWING

BREAK SHARP EDGES .005/.020

TOLERANCES NON-CUMULATIVE
DECIMAL-INCH FRACTIONS

MODEL NAME

NEXT ASSEMBLY

DSIGN'R: LIPCAVAGE
CHK'R:
ENGR'R: KALISH
SUPV:

DRAWING NO:
RU_TRIM_COIL_1A_WELDMENT

RELEASE LEVEL: ***
DWG VERSION NO: 13+

WELDING ENGINEER

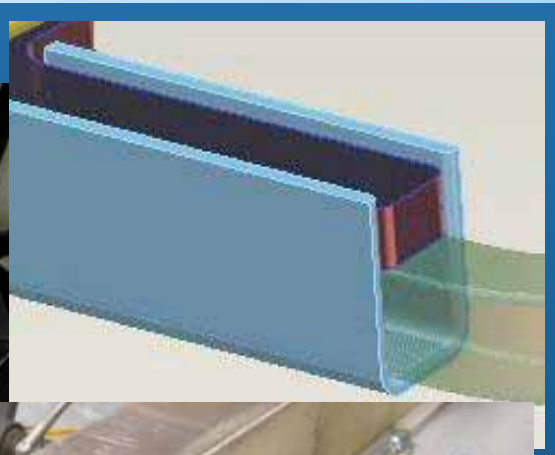
SHEET 1 OF 1 REV 0

NCSX_ASSY_FORMAT_E

NCSX-RU_TRIM_COIL_1A_WELDMENT

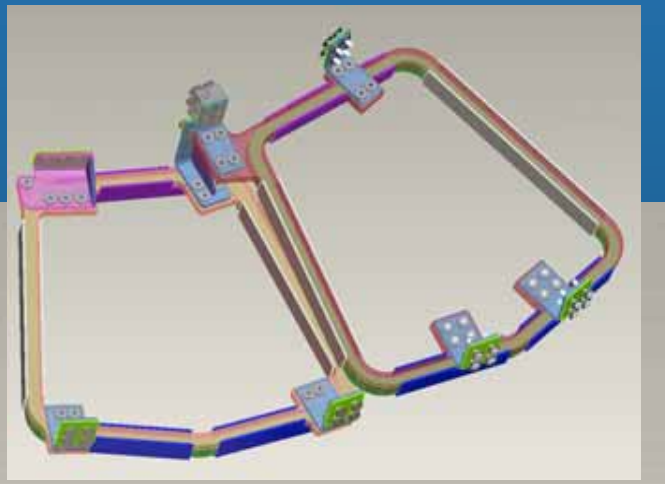
R&D Weld Testing Setup

- Testing to assure U Channel welding did not exceed 120C at coil surface
- Wooden Block assembled to mockup of Coil Structure
- Ten thermocouples record temperature
- Method and results logged for assembly procedure

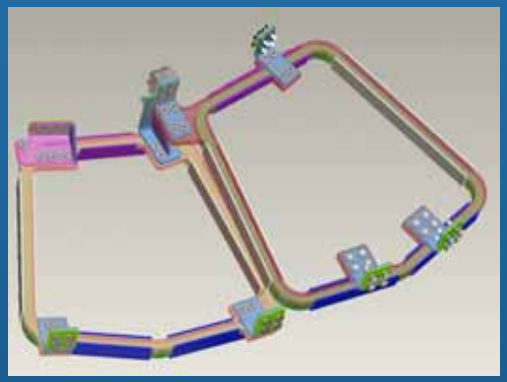


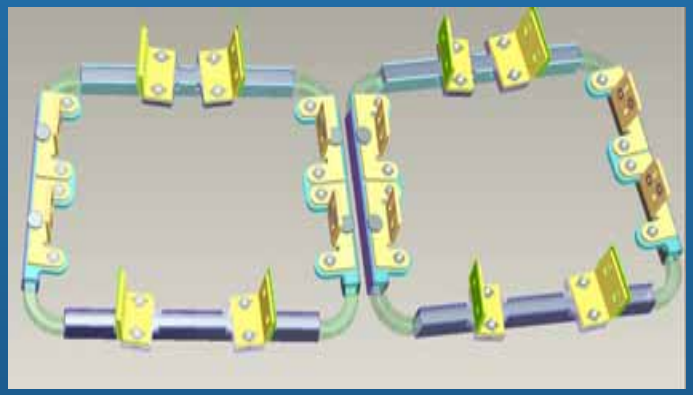
R&D Weld Testing- With Heat Sink

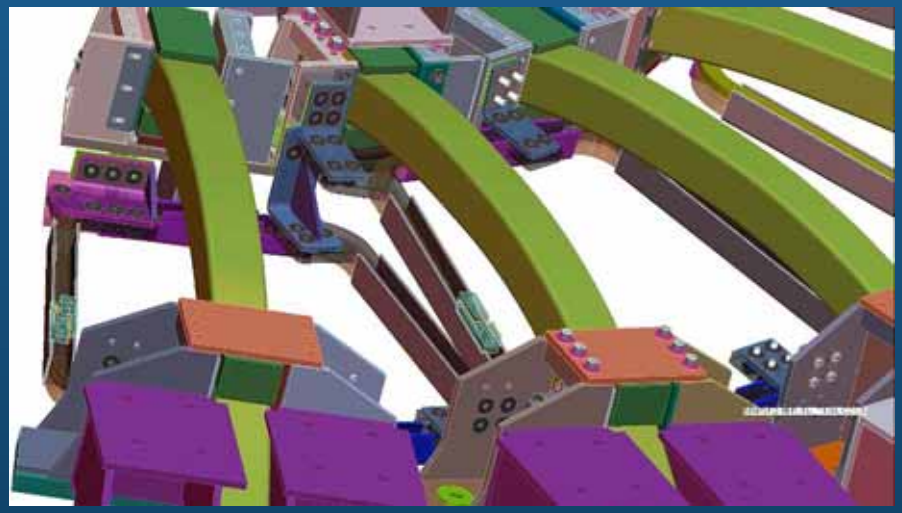
Structural Design Upper / Lower Coils

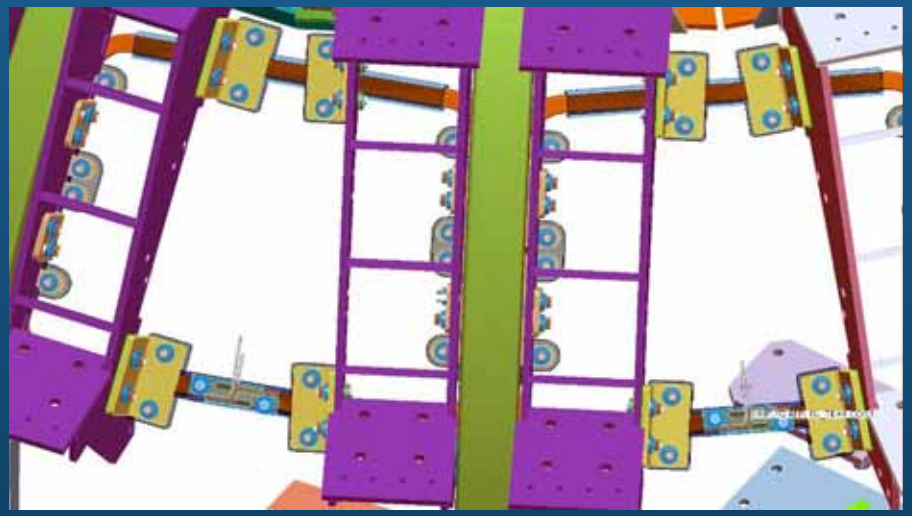


Structural Design - Installed

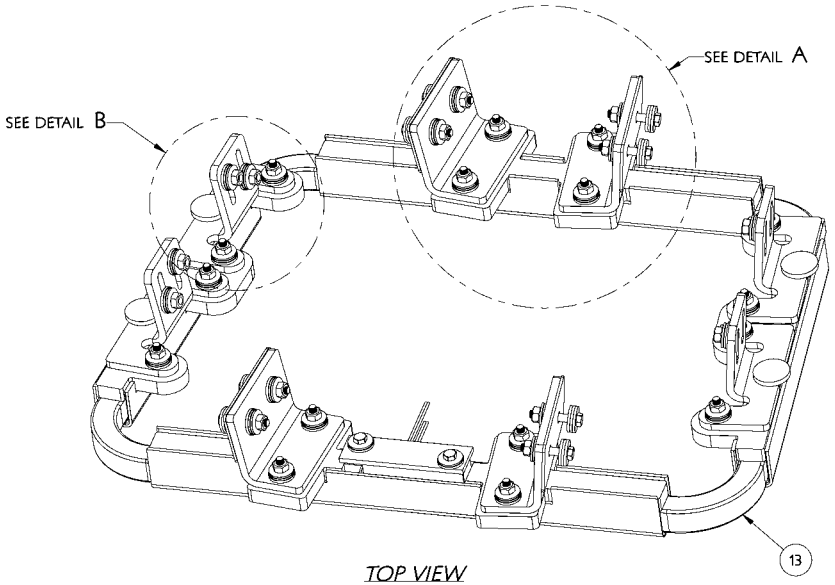




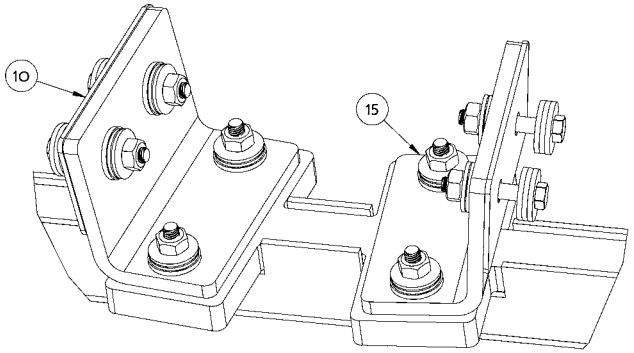




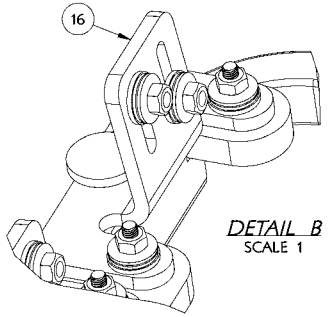
NO.	REVISION	BY	CH	SUP	APPROVED	DATE



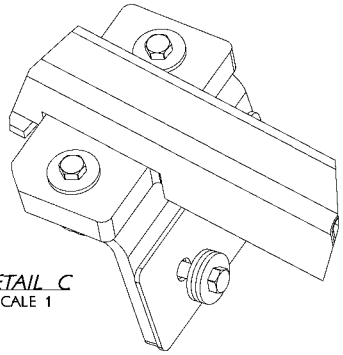
TOP VIEW



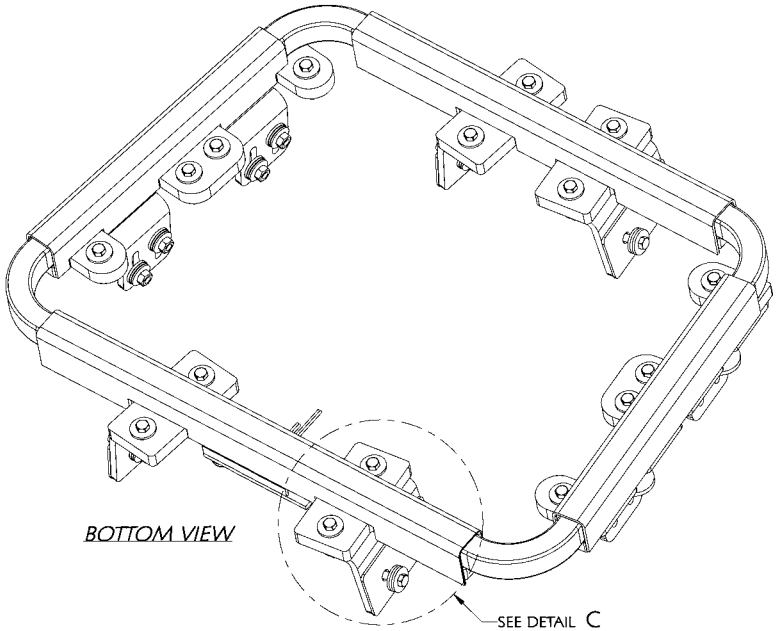
DETAIL A
SCALE 1



DETAIL B
SCALE 1



DETAIL C
SCALE 1



BOTTOM VIEW

PART NO.	DRAWING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	QTY REQD
16	SE133-047-4	TRIM COIL #2 UPPER/LOWER MOUNTING BRACKET LEFT	304L SS/STL	4
15	SE133-047-1	TRIM COIL #2 UPPER/LOWER MOUNTING BRACKET LEFT	304L SS/STL	4
14	RU_WASHER	3/8 FLAT WASHER	STN STL	67
13	RU_TRIM_COIL_1A_WELDMENT	TRIM COILS HALF PERIOD ASSEMBLY	SEE DETAILS	1
12	RU_NUT	3/8-16 UNC STANDARD HEX NUT	STN STL	32
11	RU_INSULATER_WASHER	3/8 FLAT WASHER	STN STL	8
10	RU_G10_INSULATOR_A	--	--	4
9	RU_G10_CONTACTB	--	--	1
8	RU_G10_CONTACT_BOTTOM	--	--	1
7	RU_BRAZE_BLOCK	--	--	2
6	RU_BRACKET_STOP	--	--	4
5	RU_BELVILLE	3/8 DISC SPRING 114 LBS (P max)	STN STL	66
4	RU_12_GAGE_WIREA	--	--	1
3	RU_12_GAGE_WIRE	--	--	1
2	92198A633			24
1	92198A630	3/8 - 16 UNC X 1 3/4 LG HEX HD McMASTER CARR #92198A630	18-8 STN STL	2

PARTS LIST

NCSX.RU_TRIM_COIL_1A

COMPUTER GENERATED DRAWING MANUAL CHANGES NOT PERMITTED

CENTRAL FILES:

UNLESS OTHERWISE SPECIFIED:
Pre E
DIMENSIONS ARE IN INCHES
MACHINE SURFACES
DO NOT SCALE DRAWING
DO NOT VERIFY INFORMATION BY SCALING DRAWING
BREAK SHARP EDGES .005/.020
TOLERANCES NON-CUMULATIVE
DECIMAL - INCH
FRACTIONS
NEXT ASSEMBLY

WEIGHT
183.8 lbs

MODEL NAME
RU_TRIM_COIL_1A

WELD NO
ENGINEER

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL COMPACT STELLARATOR EXPERIMENT
STELLARATOR CORE
TRIM COILS
TRIM COIL PERIOD ASSEMBLY

DSNR. UPCHARGE
CHK.
ENGRM. KALISH
SUPV.

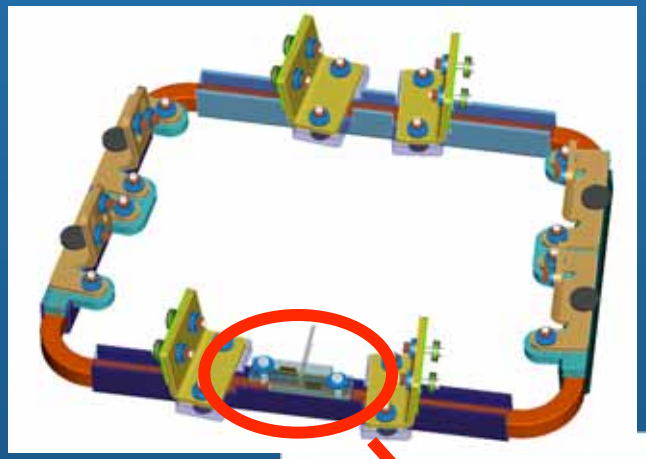
DRAWING NO:
RU_TRIM_COIL_1A
SHEET 1 OF 1
REV 0

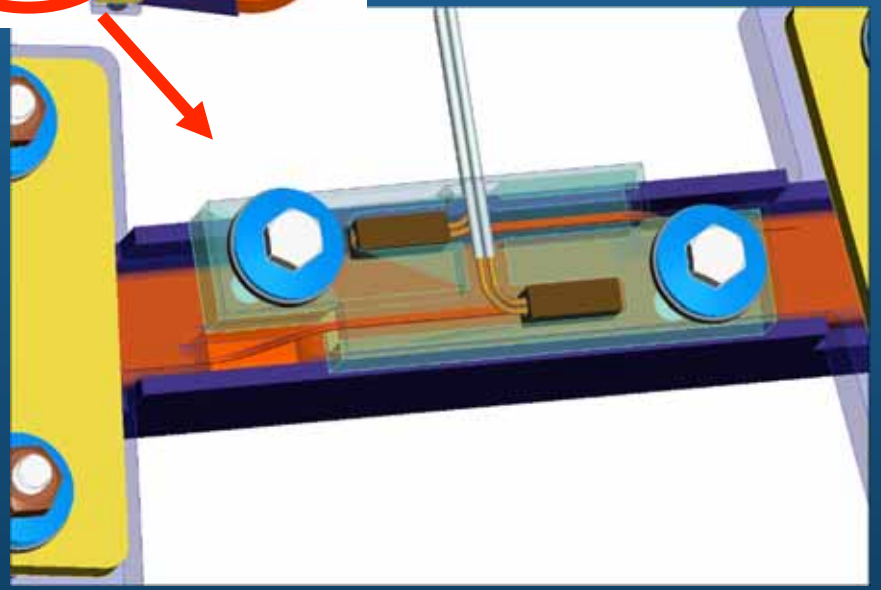
RELEASE LEVEL: WIP
DWG VERSION NO: 13

NCSX_ASSY_FORMAT_E

Coil Leads Supports

- Leads protrude from a notch in the ¾ inch support plate
- Leads are sleeved with Teflon for improved dielectric standoff
- Leads and Trim Coil cables are brazed into a copper transition block
- G11 blocks strain relieve leads and cable transition



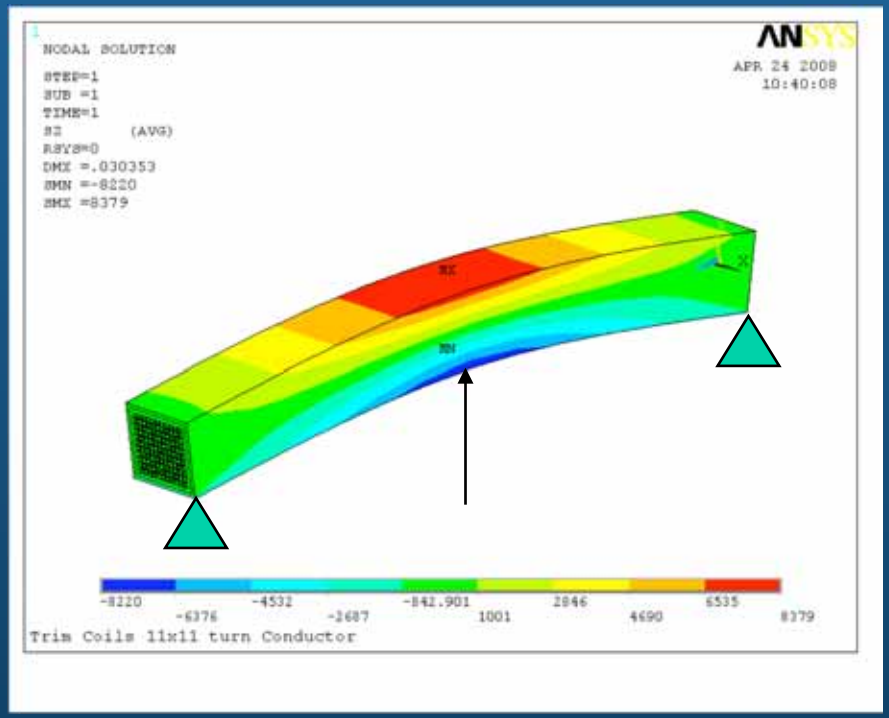


Conductor Modeled with Equivalent Properties calculated from Flexural Modulus Simulation

Equivalent Flexural Modulus and Stress Scaling for Trim Coils

	E, Mpsi	Sz, psi	E, Mpsi	Sz, psi	Sz/Sz	Sz/Sz_max
Cu Wire	17	18390	**5.85**	6620	2.78	**2.19**
Insulation	1.5	2111	**5.85**	8379	0.25	**0.25**

- Detailed Model of 120 Turn Coil
- Distinct Elements for Copper and Glass Insulation
- Equivalent properties used for large composite model
- Results from composite model scaled to determine maximum stresses



Load Cases Investigated for EM Forces

- **All GRD Load Cases at Multiple (5) time points**
- **Additional Flexibility Cases Identified by Physics**
  - Iota Scan (2)
  - Shear Scan (2)
- **Max Running Loads Found**
  - 80 lb/in Inner Coils
  - 60 lb/in Outer Coils
- **Subsequent analysis is run for the worst load case iota .19 case**

- **2T High Beta**
- **1.7T High beta**
- **1.2T Long Pulse**
- **1.7T Ohmic**
- **320KA Ohmic**
- **0.5 T TF**
- **Iota/Shear Scan**
  - iota -0.10
  - iota 0.19 (High TF Field)
  - iota +0.20
  - iota 0.65

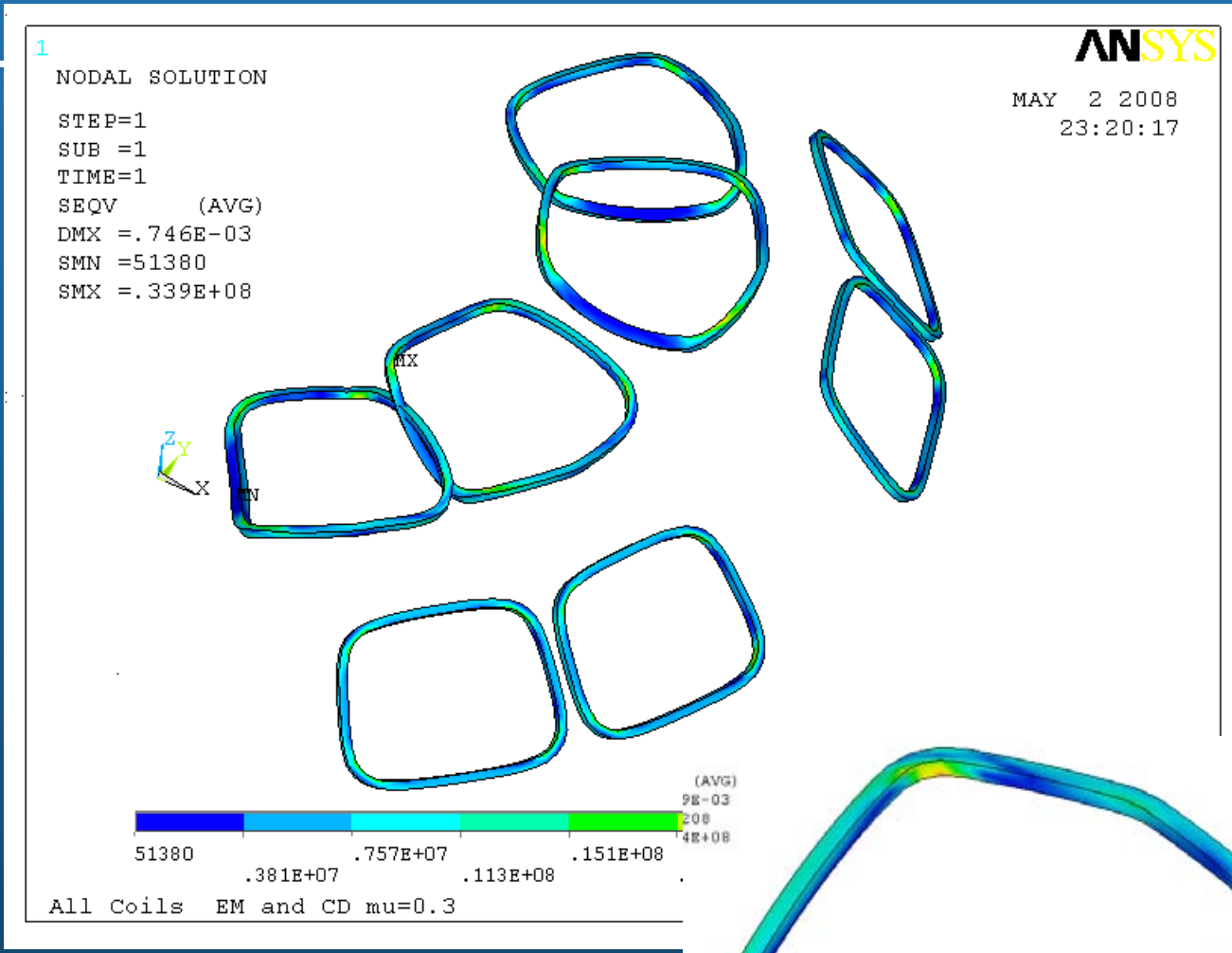
Conductor Stress Result

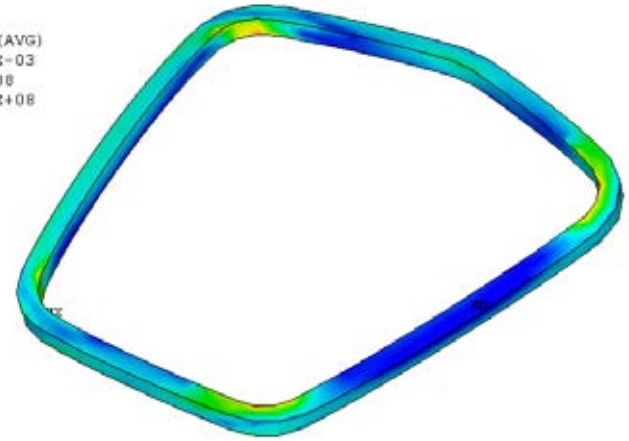
NCSX

- EM only= **7.3Ksi**
- EM only allowable= 1.5Sm=**10.3ksi** (at 77K for local bending)

- Cool Down only= **8ksi**
- CD only allowable 3xSm=**20.7ksi** (for secondary thermal stress + primary)

- CD+EM= **10.7ksi**
- Allowable 3xSm=**20.7ksi** (for secondary thermal stress + primary)

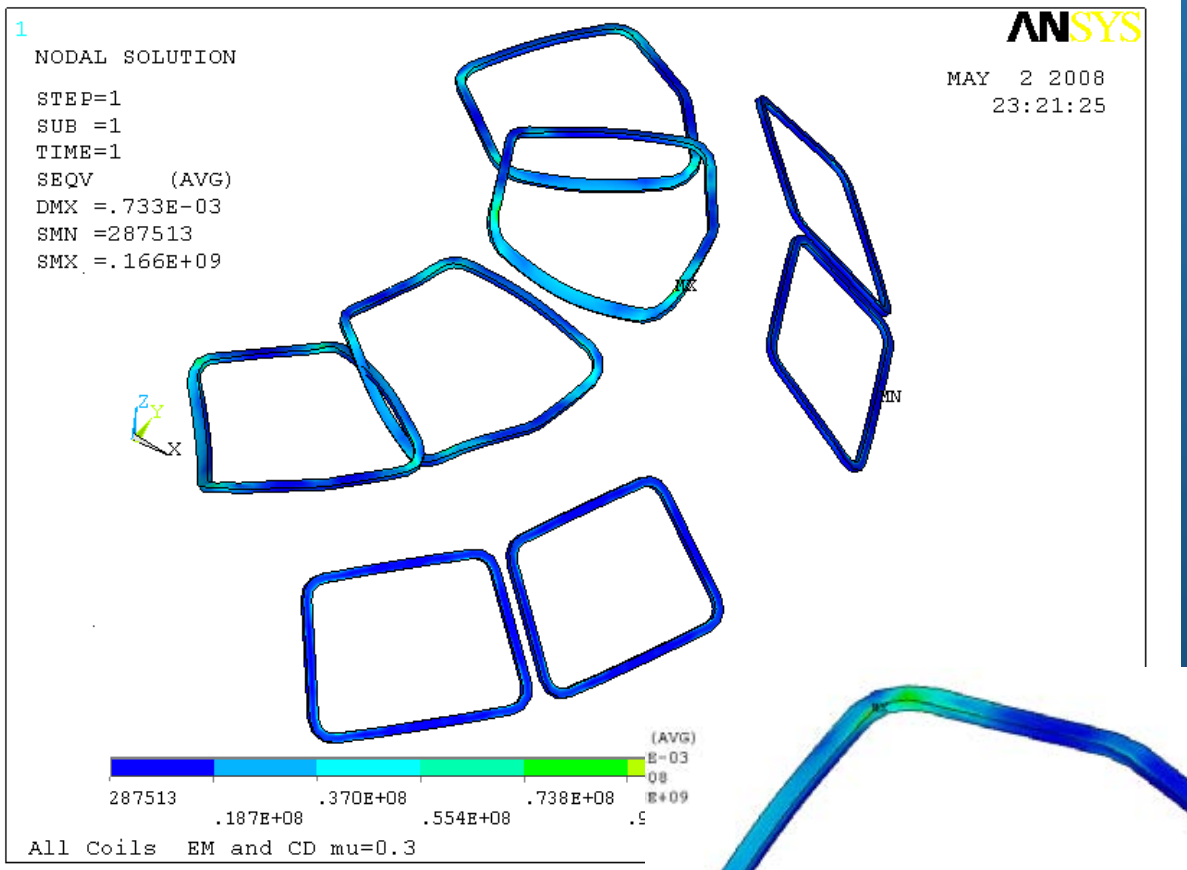


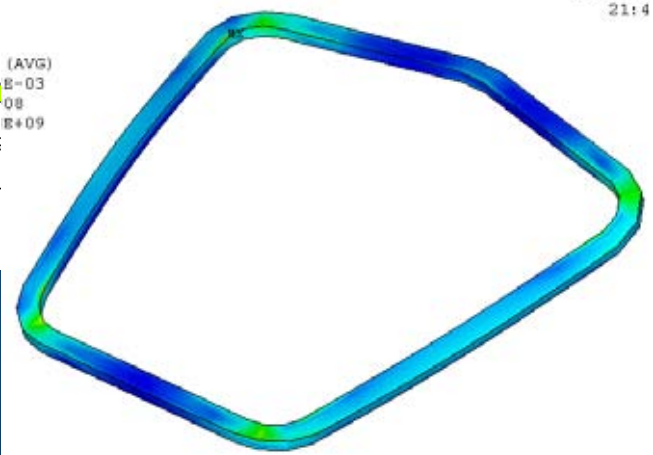


NCSX Conventional Coils

¾” Support Plate Stress Result

- EM only= **11.3ksi**
- EM only allowable= Sm=**20.0ksi** (Primary Member Stress)
- Cool Down only= **16.7ksi**
- Allowable 3xSm=**60.0ksi** (for secondary thermal stress + primary)
- CD+EM= **23.7ksi**
- Allowable 3xSm=**60.0ksi** (for secondary thermal stress + primary)





NCSX Conventional Coils

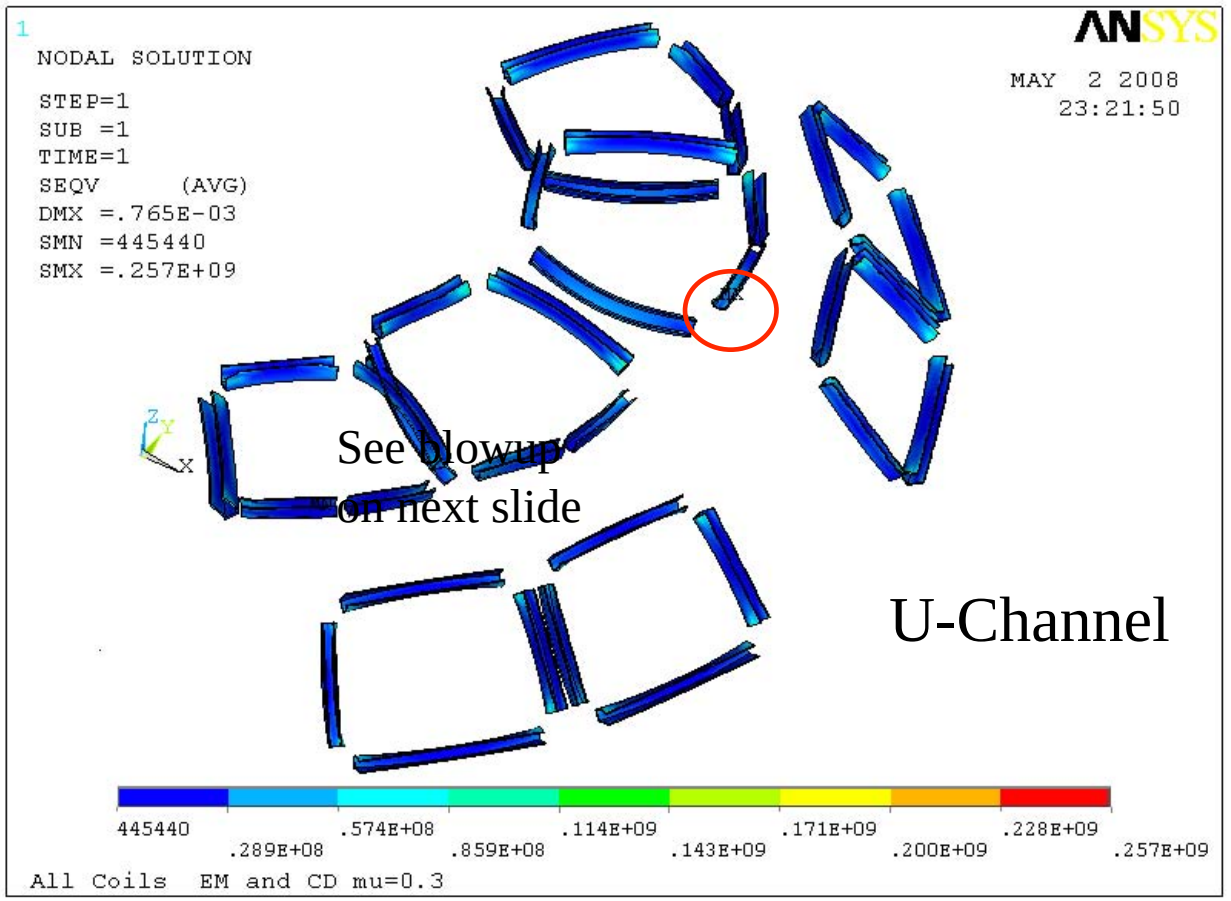
U Channel Stress Result

- EM only= 16.6 ksi
- Allowable= 1.5Sm=35.0ksi (Primary Member Stress)

- Cool Down only= 26.9ksi
- Allowable 3xSm=60.0ksi (for secondary thermal stress + primary)

- CD+EM= 36.7ksi
- Allowable 3xSm=60.0ksi (for secondary thermal stress + primary)

- Element Average Stress is only 30% of Max Stress Result 36.7ksi→10.9ksi



Coil Cooling Analysis
Comfortable Design Margins With Convection Cooling

- **Requirement**
  - 2 second pulse every 15 minutes
  - 20 Kamp Turns
  - Equivalent average power of 27 watts
- **For 120 Turn Coil With 2mm Conductor (10X20)**
  - Convection cooling adequate
  - Temperature increase per pulse is only approx.= 2.6 C
  - Equilibrium reached with temperature rise approx.= 9.0C
- **Margin Available**
  - Doubling the current to 40 amp turns
  - Equivalent Average Power of 107 watts
  - Temperature increase per pulse is only approx.= 10.3 C
  - Equilibrium reached with temp. rise approx.= 35C