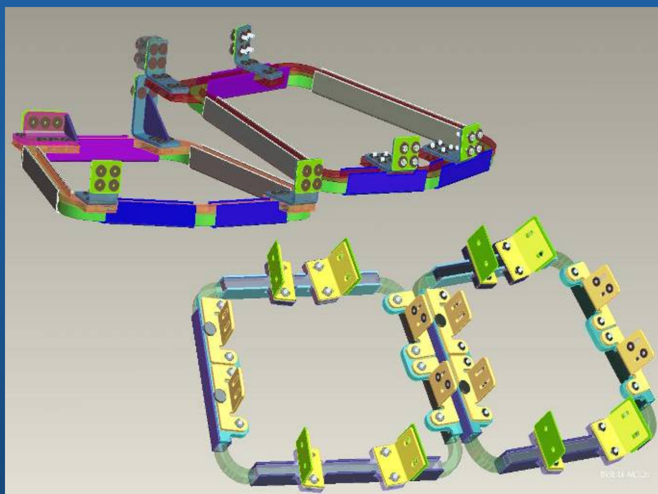
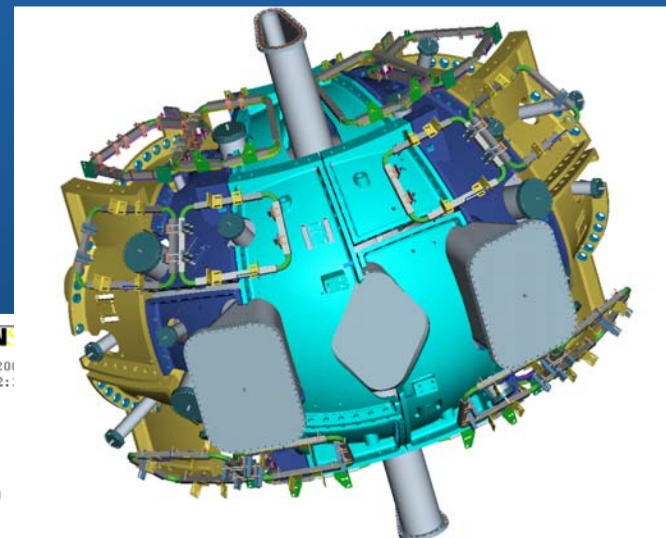
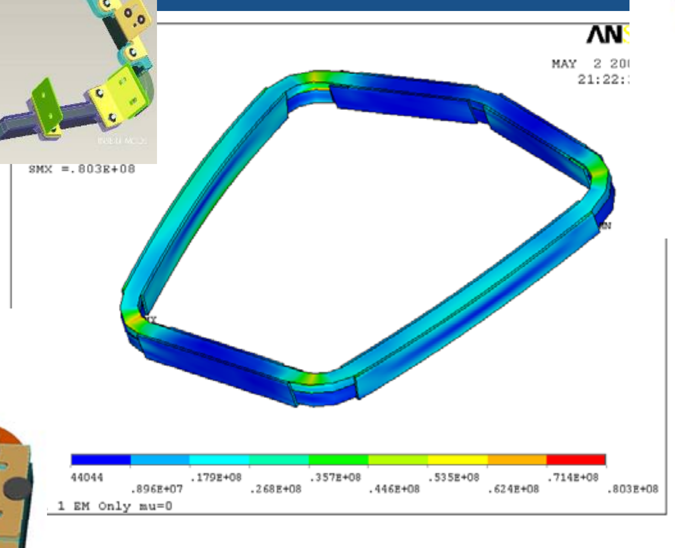
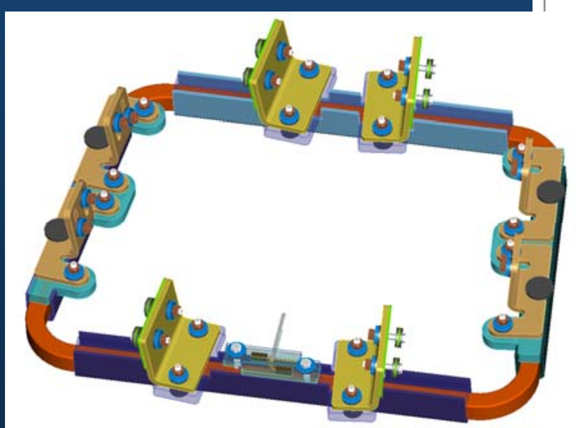
NCSX Trim Coil Final Design Review









Richard Upcavage

Joe Rushinski

Art Brooks

Mike Kalish

Charge

- 1. Are all required analyses complete and formally checked and adequate to establish that the proposed design is feasible and meets established design criteria?
- 2. Are the drawings and documentation adequate to support the procurement and/ or manufacturing process, installation, and ready for sign-off?
- 3. Is the plan for installation of the trim coils compatible with the machine assembly plans?
- 4. Is the Product Specification (CSPEC) complete and satisfactory? Are the interfaces adequately defined?
- 5. Is the Work Planning form current, and have the applicable requirements been satisfied?
- 6. Have the chits from the PDR been resolved?
- 7. Are updated cost and schedule estimates available?

Outline

- Requirements
- Design
- R&D
- Analysis
- Interfaces
- PDR Chit Resolution
- Cost and Schedule
- Summary

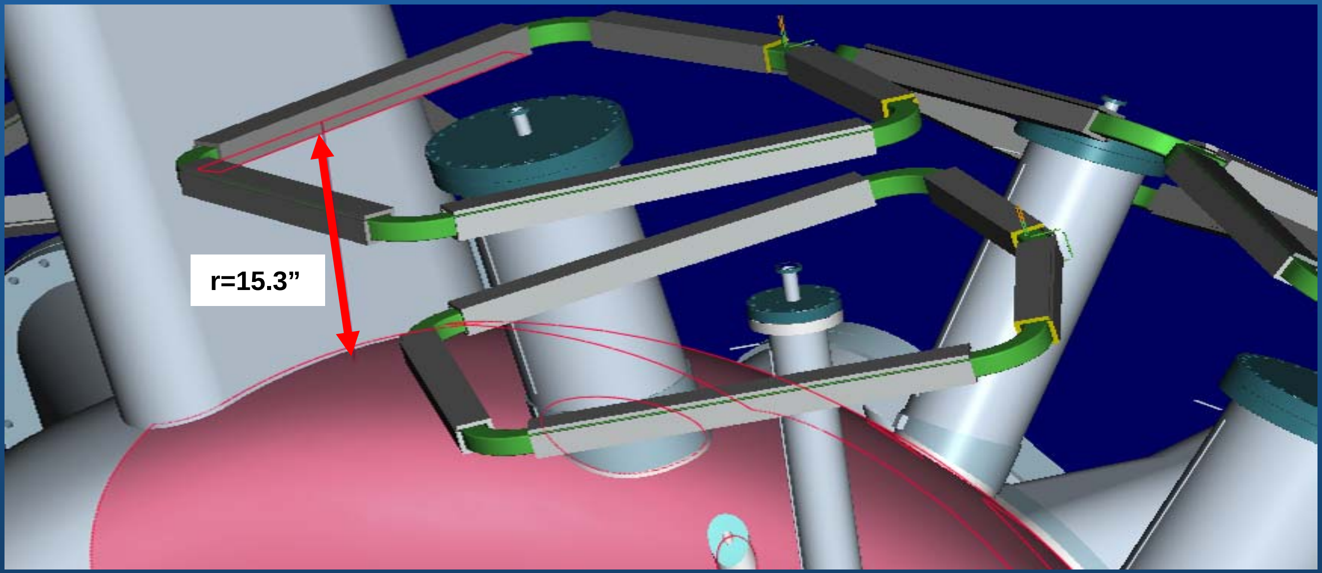
Summary- Requirements

- **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
- **Achievable Response Time of 20ms**
- **Installation at Start of Station 5**

Magnetic Permeability Requirement

- **Magnetic Permeability Required is 1.02 without further relief**

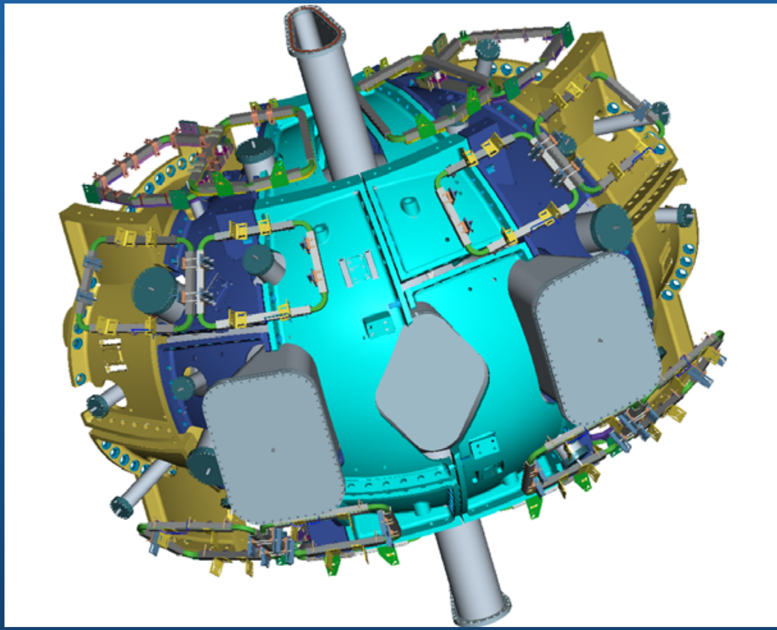
$$6 \cdot 10^{-5} > \frac{(\mu_r - 1) \cdot V_\mu}{r_\mu^{3}}$$

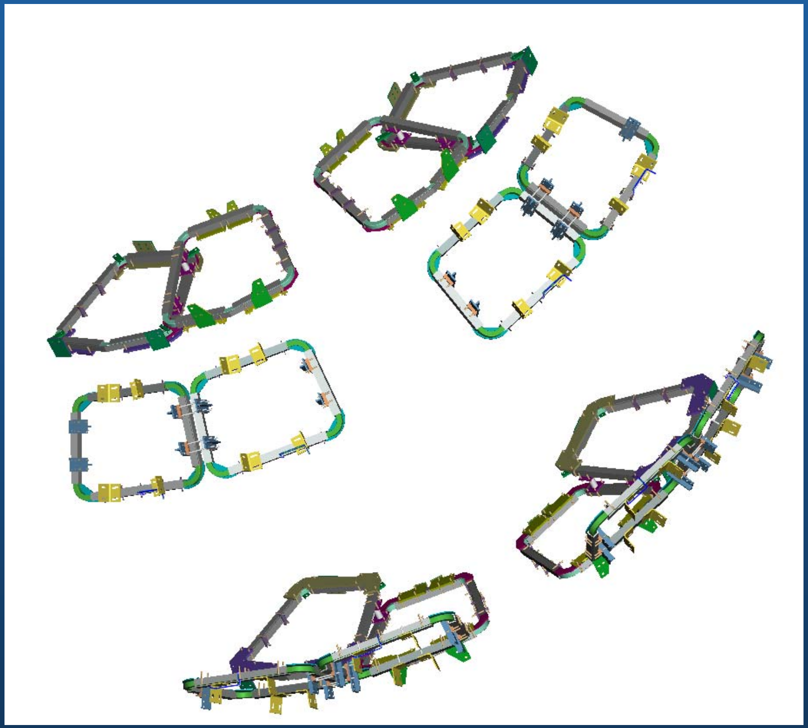


$$\frac{1}{50000} \cdot \frac{\left(3 \cdot r_\mu^{3} + 50000 V_\mu\right)}{V_\mu} = 1.005$$

required magnetic permeability not to be less than 1.02

Final 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

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		Using SVD Solution		Using NLP Solution	
Trim Coil Configuration	Total Number Coils	Total Island Size %Total Flux	Max Current kA-T	Total Island Size %Total Flux	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)					

Winding Pack Insulation Scheme

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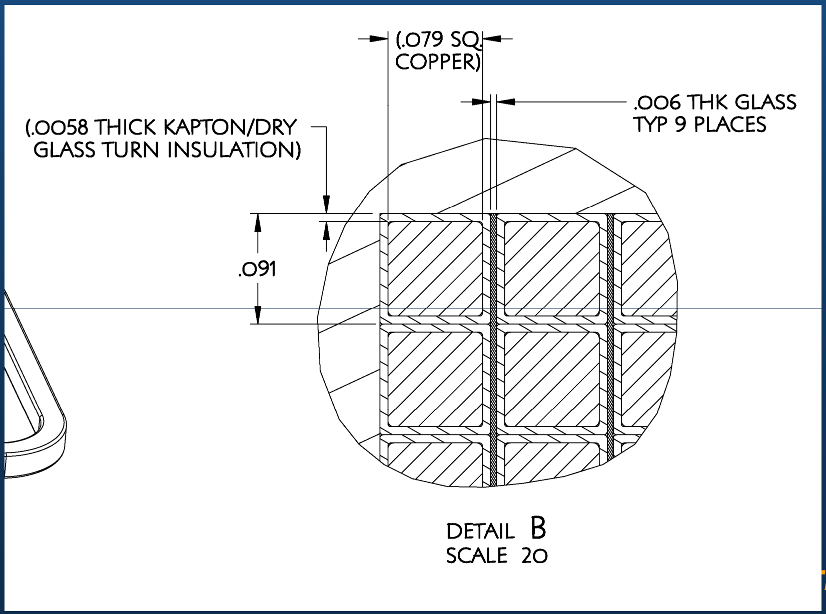
- Kapton Tape applied directly to conductor to enhance turn to turn dielectric standoff
- One half lap layer of glass to allow for epoxy impregnation
- Additional .006" thk by 1" wide glass between layers to wick epoxy



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	
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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**

Turn To Turn Voltage Standoff Requirement

- Calculated Turn to Turn Break Down Voltage exceeds requirement by a factor of 16

NCSX Coil Voltage Standoff Requirements Turn to Turn		
3/6/2008		
Operating Voltage (KV)	per coil for coils in series	1.00
For Turn to Turn Voltage Divide Total Voltage By #Layers-1	note: = #coils x #Boundaries	10.00
Turn to Turn (KV)		0.10
Design Requirement for Volatge Standoff (Turn to Turn x10) (KV)		**1.00**
Turn to Turn Glass Thickness		0.005
Calculated Coil Turn to Turn Long Term Break Down (90V/mil) (KV)		0.86
Calculated Kapton Standoff (KV)		15.40
Calculated Total Turn to Turn Break Down Voltage (KV)		**16.26**
Safety Factor **(Calculated Break Down Voltage / Design Requirement for Voltage Standoff)**		**16.3**

Ground Plane Voltage Standoff Requirement

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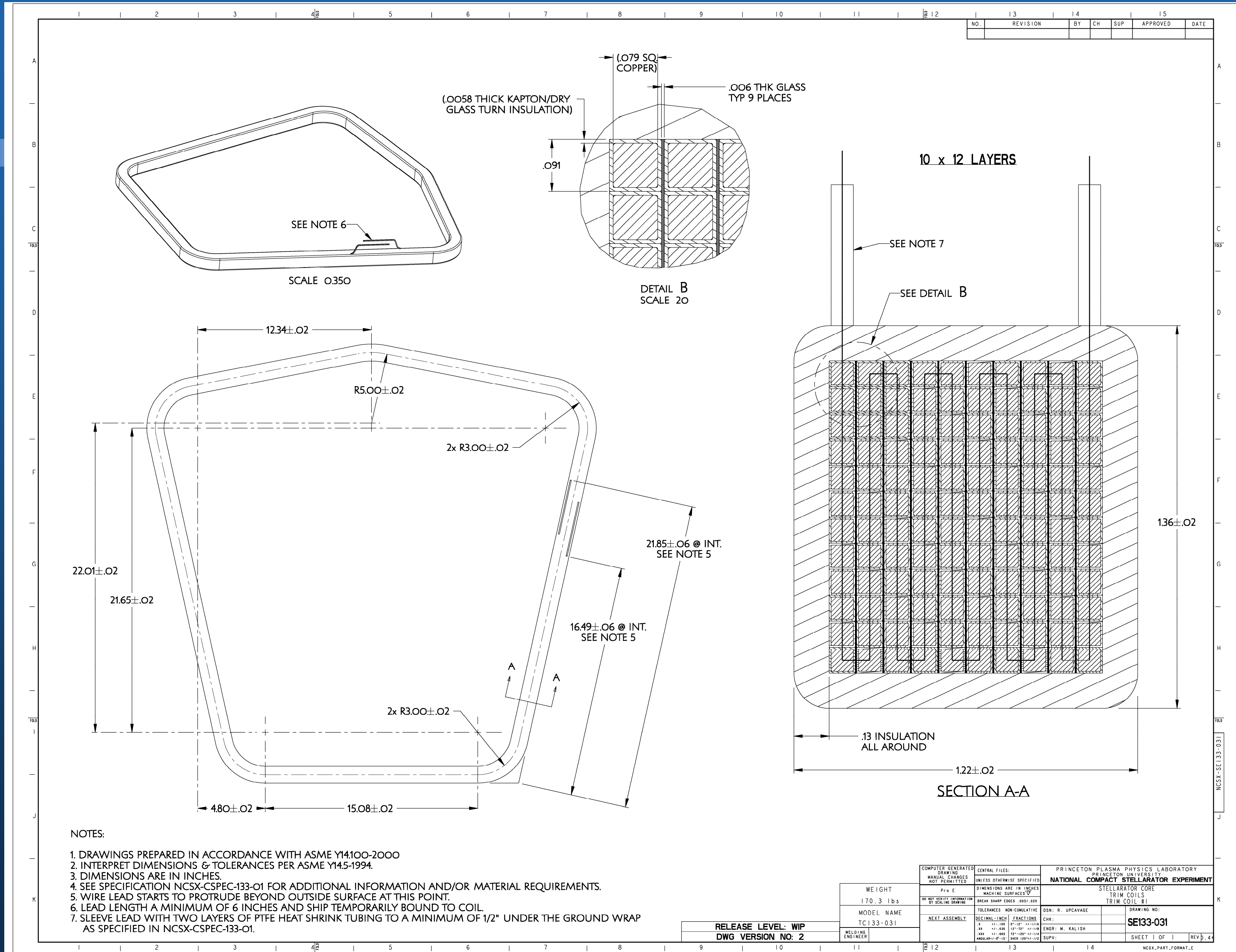
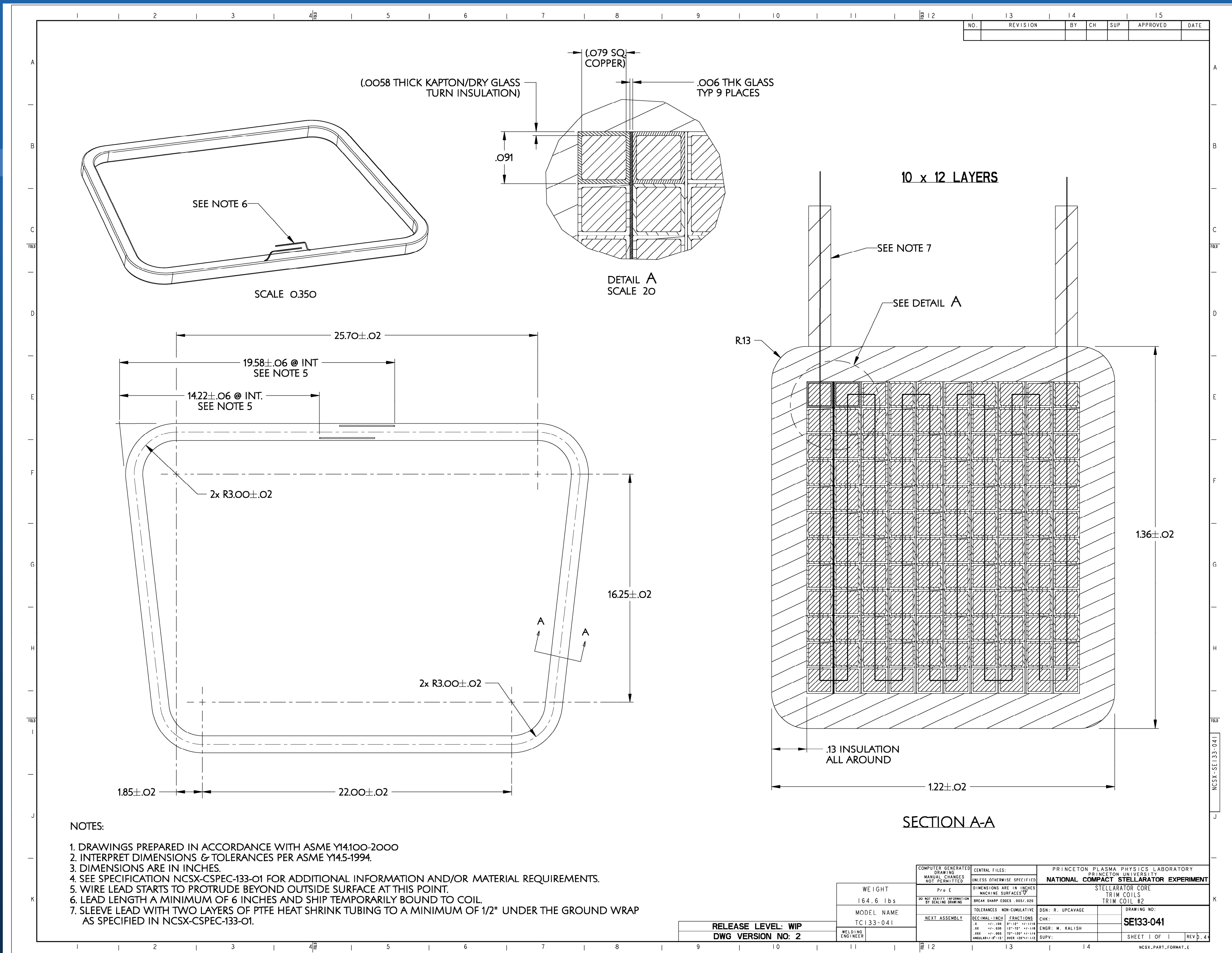
- Calculated Break Down Voltage to Ground exceeds design requirement by a factor of 2.8

NCSX Coil Voltage Standoff Requirements Ground Plane		
Max Operating Voltage (KV)		1.00
Maintenance Field Test Voltage (KV)	(Operating Volatage x 2) + 1	3.00
Manufacturing Test Voltage (KV)	Maintenance Test Voltage x 1.5	4.50
Design Volatge Standoff Requirement (KV)	Manufacturing Test Voltage x 1.5	**6.75**
Calculated Coil Turn Long Term Break Down (90V/mil+Kapton)		8.13
Calculated Ground Wrap Long Term Break Down		10.8
Calculated Standoff to Ground KV	Ground + Turn Insulation	**18.9**
Safety Factor to GND (Standoff to Ground / Design Voltage Standoff Requirement)		**2.8**

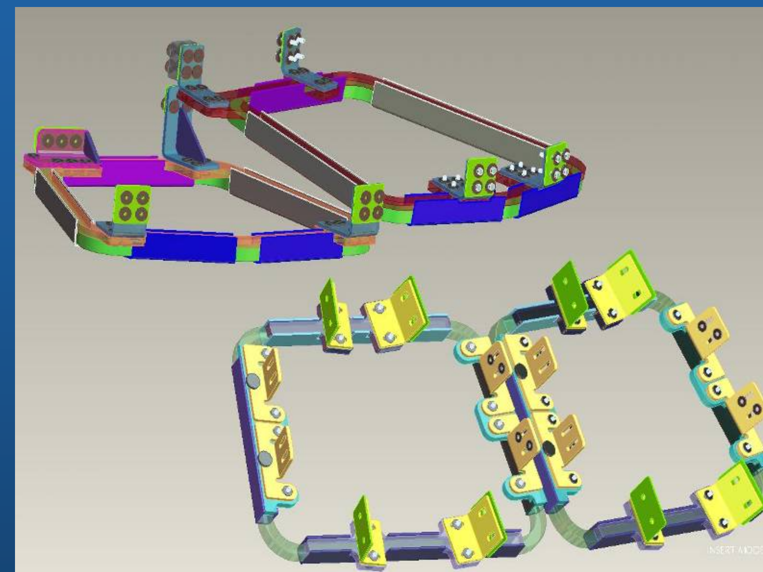

(.079 SQ. COPPER)
.006 THK GLASS TYP 9 PLACES
(.0058 THICK KAPTON/DRY GLASS TURN INSULATION)
.091
DETAIL B
SCALE 20
SEE NOTE 6
SCALE 0.350
10 x 12 LAYERS
SEE NOTE 7
SEE DETAIL B
1.36±.02
.13 INSULATION ALL AROUND
1.22±.02
SECTION A-A
12.34±.02
R5.00±.02
2x R3.00±.02
21.85±.06 @ INT. SEE NOTE 5
16.49±.06 @ INT. SEE NOTE 5
22.01±.02
21.65±.02
2x R3.00±.02
4.80±.02
15.08±.02
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.
RELEASE LEVEL: WIP
DWG VERSION NO: 2
WEIGHT
170.3 lbs
MODEL NAME
TC133-031
PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL COMPACT STELLARATOR EXPERIMENT
STELLARATOR CORE
TRIM COILS
TRIM COIL #1
DSN: R. UPCAVAGE
ENGR: M. KALISH
SE133-031
NCSX-SE133-031

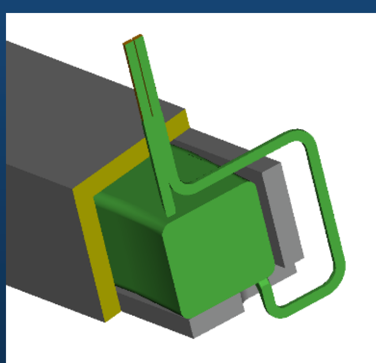

(.079 SQ. COPPER)
(.0058 THICK KAPTON/DRY GLASS TURN INSULATION)
.006 THK GLASS TYP 9 PLACES
.091
DETAIL A
SCALE 20
SEE NOTE 6
SCALE 0.350
10 x 12 LAYERS
SEE NOTE 7
SEE DETAIL A
R.13
1.36±.02
.13 INSULATION ALL AROUND
1.22±.02
SECTION A-A
25.70±.02
19.58±.06 @ INT
SEE NOTE 5
14.22±.06 @ INT.
SEE NOTE 5
2x R3.00±.02
16.25±.02
A
A
2x R3.00±.02
1.85±.02
22.00±.02
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.
RELEASE LEVEL: WIP
DWG VERSION NO: 2
WEIGHT 164.6 lbs
MODEL NAME TC133-041
PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
NATIONAL COMPACT STELLARATOR EXPERIMENT
STELLARATOR CORE
TRIM COILS
TRIM COIL #2
DSN: R. UPCAVAGE
ENGR: M. KALISH
SE133-041
NCSX-SE133-041

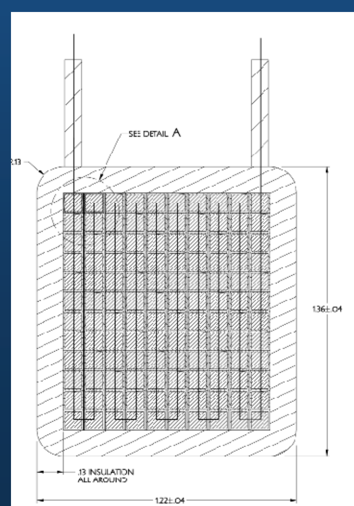
Structural Design

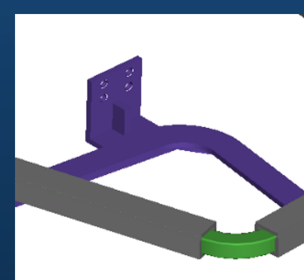
NCSX

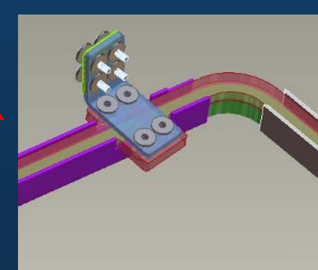
- As the result of PDR Chits and further fabrication assembly reviews design improvements were implemented
  - **11x11 build changed to 10x12 so leads both protrude from top**
  - **Interface brackets bolted to ¾" plate instead of welded**







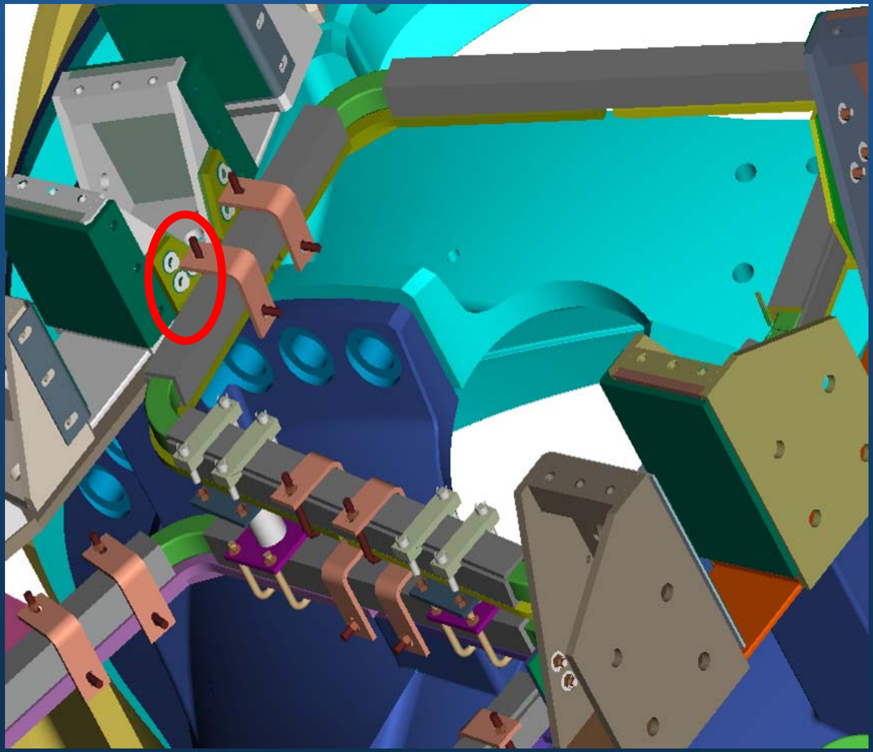


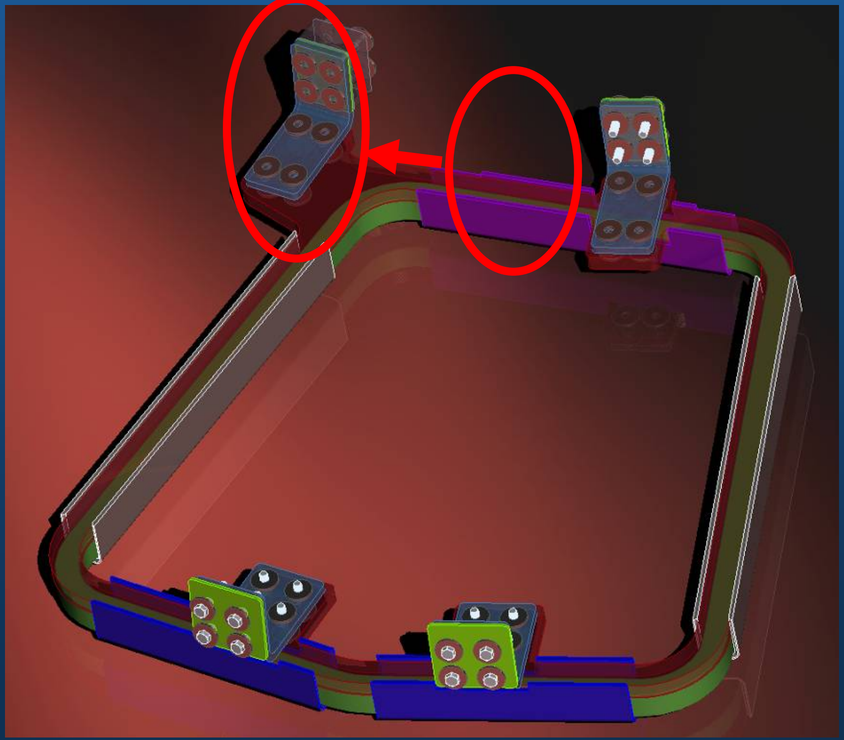


Structural Design

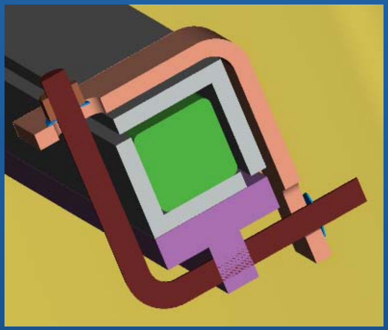
NCSX

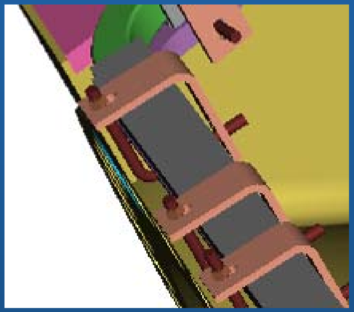
- Mounting points spread out to resist moment and lower stresses

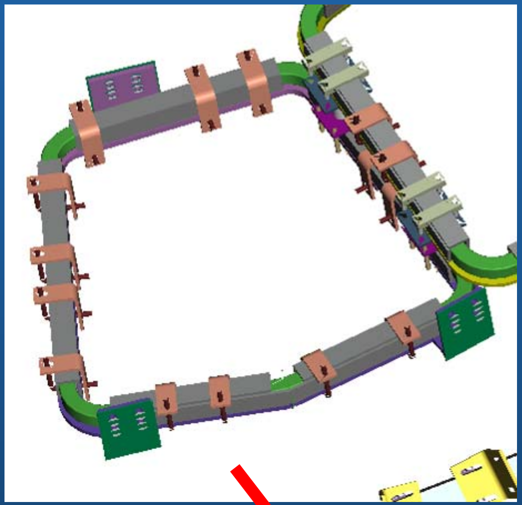




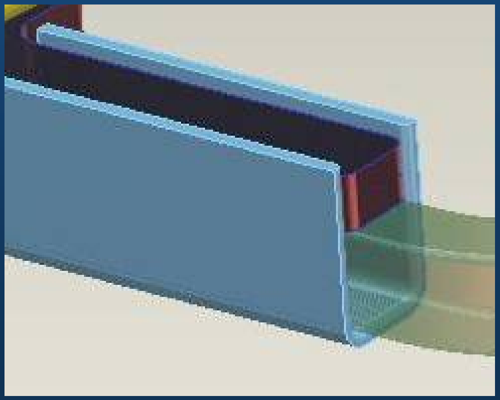
Structural Design

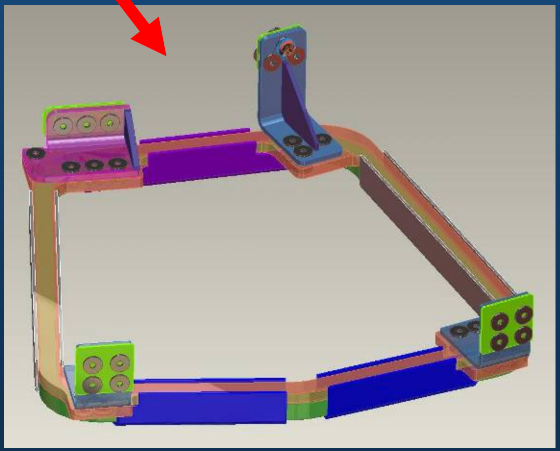






- Diagonal clamps replaced with welded U Channel





Structural Design

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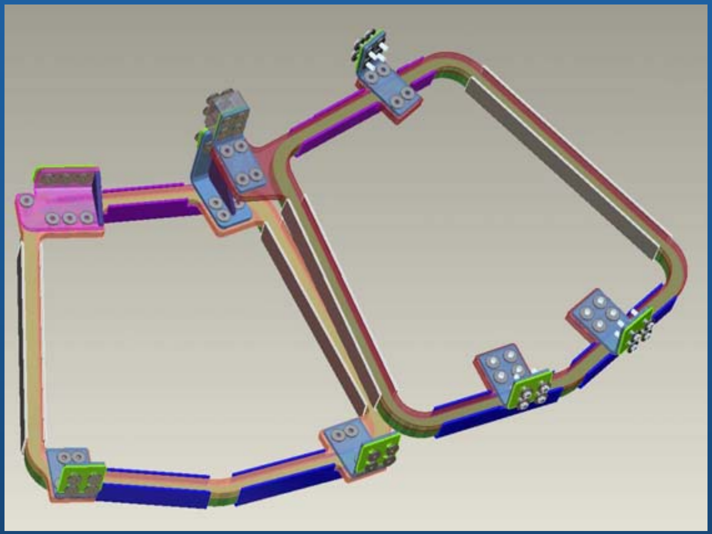
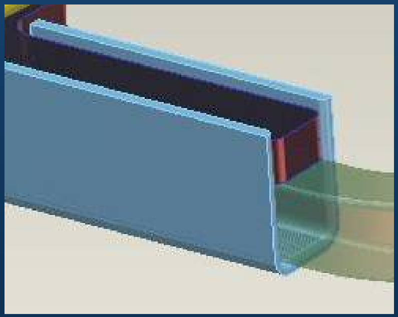
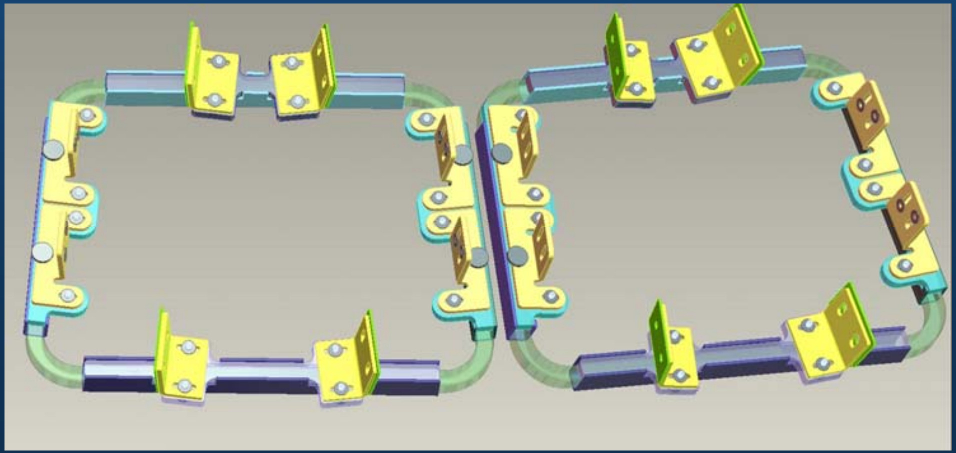
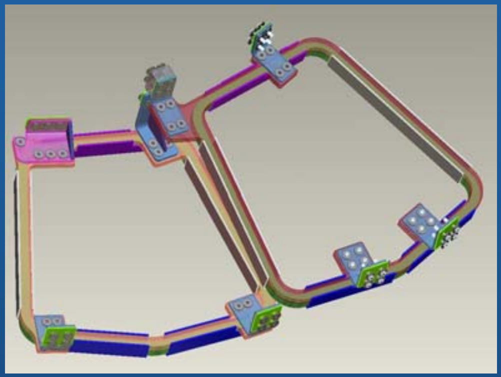
- Coil Assemblies assembled off line and then bolted to TF and PF Coils supports
- Brackets offer 3 degrees of adjustment
- Custom shimming may be required to correct for angle in one plane only
- With all frames accurately machined a representative aluminum template can be used to pre-fab shims if required

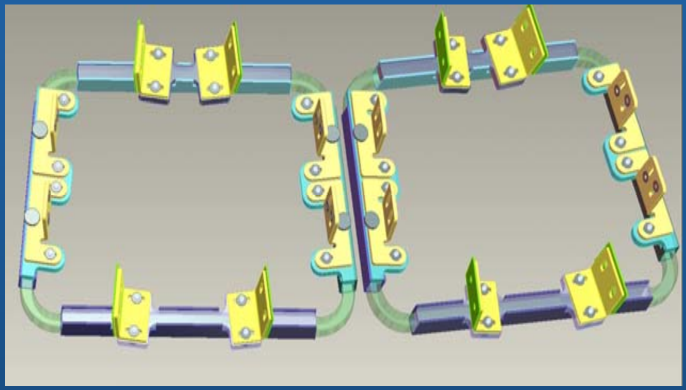


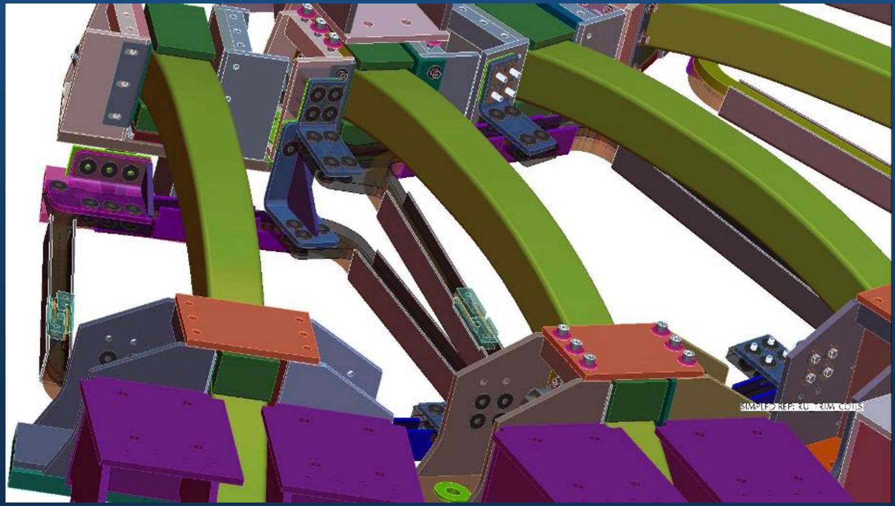


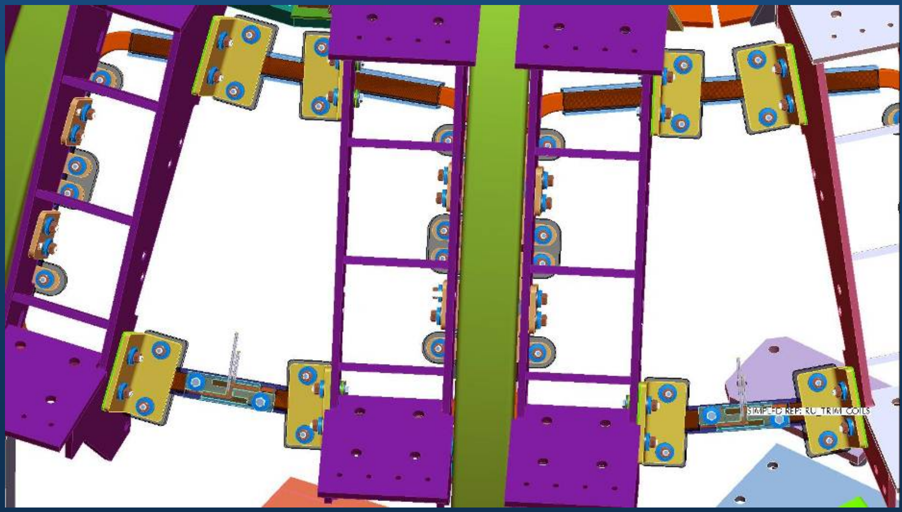


Structural Design





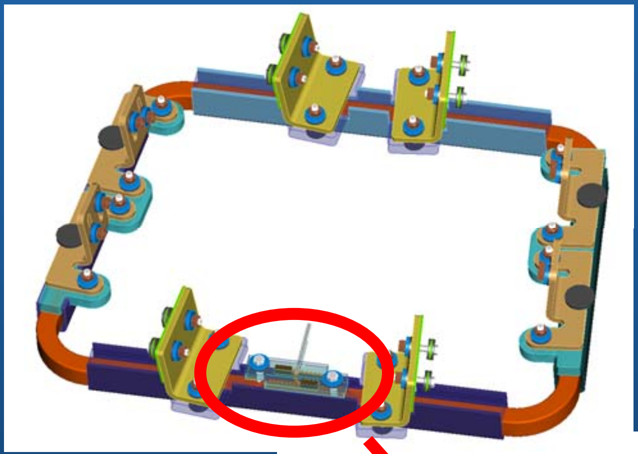


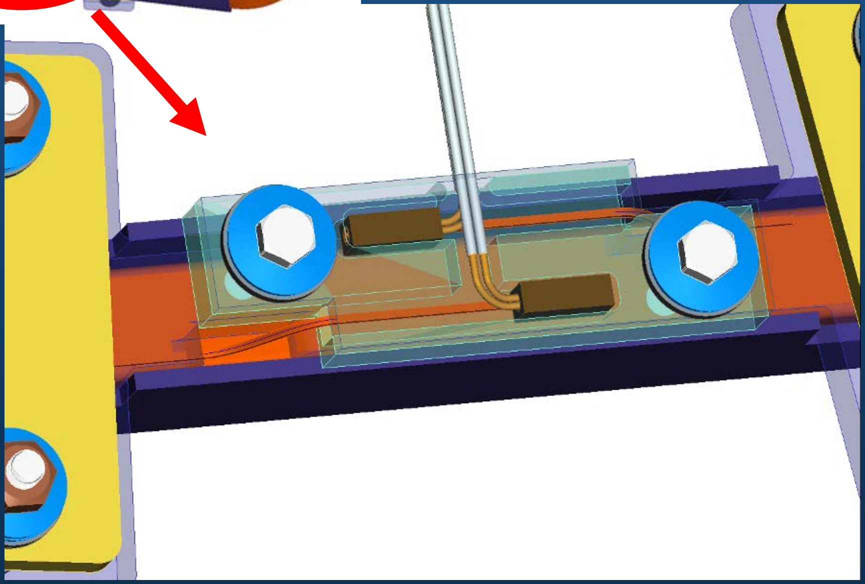


Coil Leads Supports

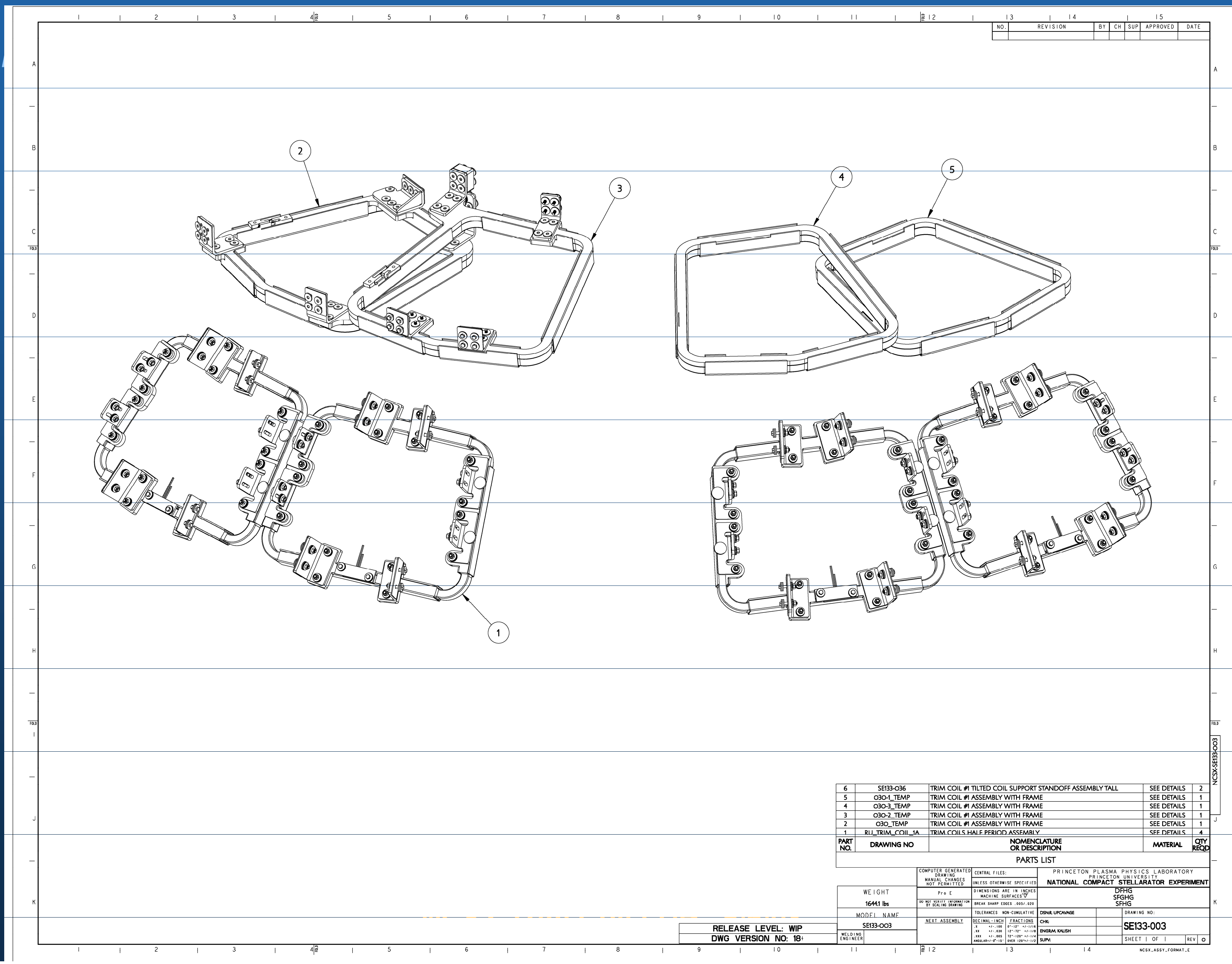
NCSX

- 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

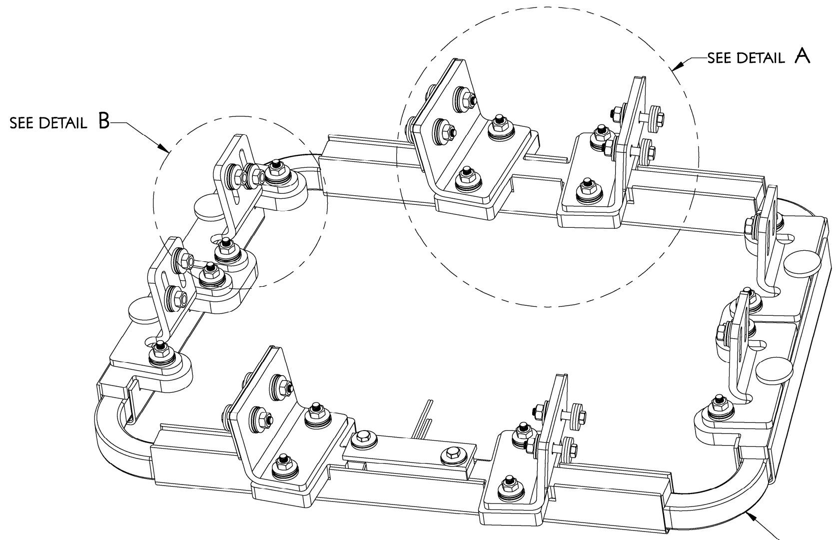




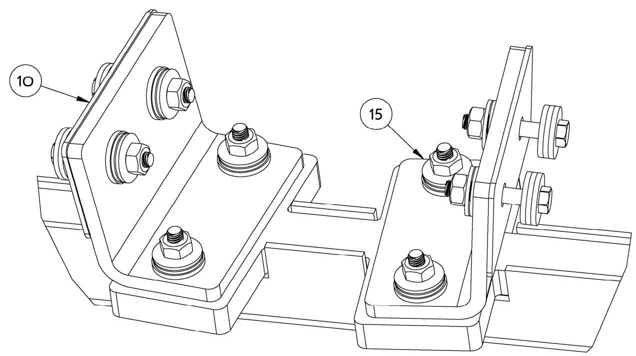
Trim Coil Assembly Drawings



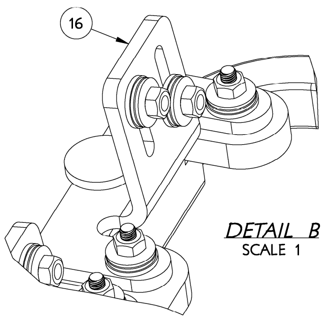
NO.	REVISION	BY	CH	SUP	APPROVED	DATE



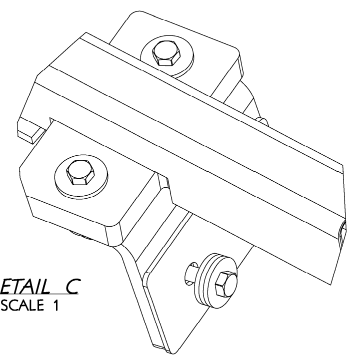
TOP VIEW



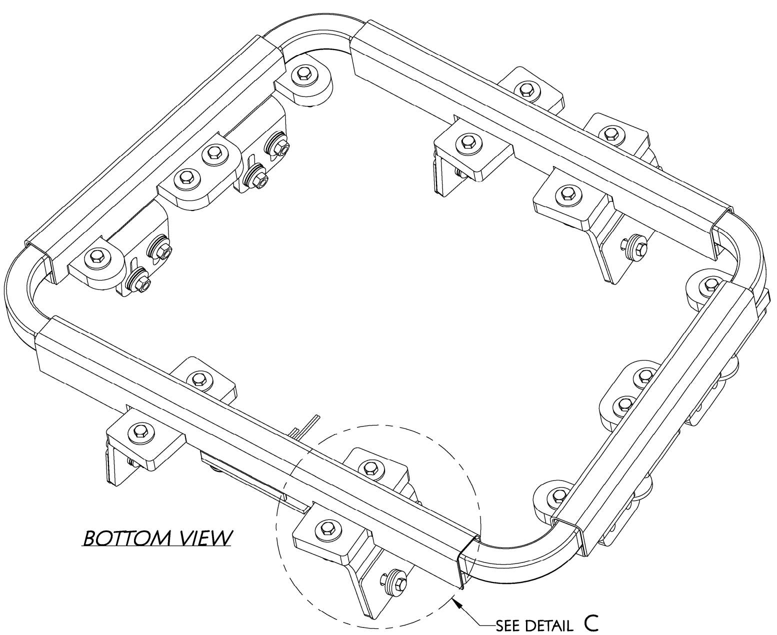
DETAIL A
SCALE 1



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:	PRINCETON PLASMA PHYSICS LABORATORY PRINCETON UNIVERSITY NATIONAL COMPACT STELLARATOR EXPERIMENT	
Pro E	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES MACHINE SURFACES 125 √	STELLARATOR CORE TRIM COILS TRIM COIL PERIOD ASSEMBLY	
DO NOT VERIFY INFORMATION BY SCALING DRAWING	BREAK SHARP EDGES .005/.020		
	TOLERANCES NON-CUMULATIVE	DSN:R. UPCAVAGE	DRAWING NO:
NEXT ASSEMBLY	DECIMAL-INCH: .X +/-.100; .XX +/-.030; .XXX +/-.005; ANGULAR+/-0°-15′ FRACTIONS: 0"-12" +/-1/16; 12"-72" +/-1/8; 72"-120" +/-1/4; OVER 120"+/-1/2	CHK: ENGR:M. KALISH SUPV:	RU_TRIM_COIL_1A SHEET 1 OF 1 — REV 0

WEIGHT: 183.8 lbs

MODEL NAME: RU_TRIM_COIL_1A

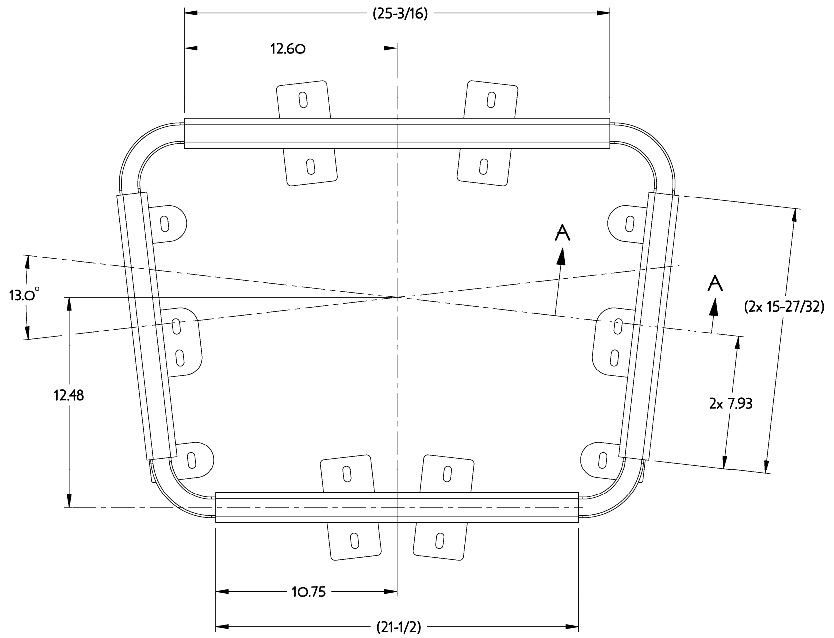
WELDING ENGINEER

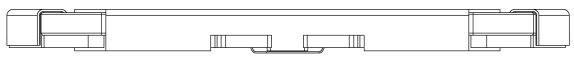
RELEASE LEVEL: WIP

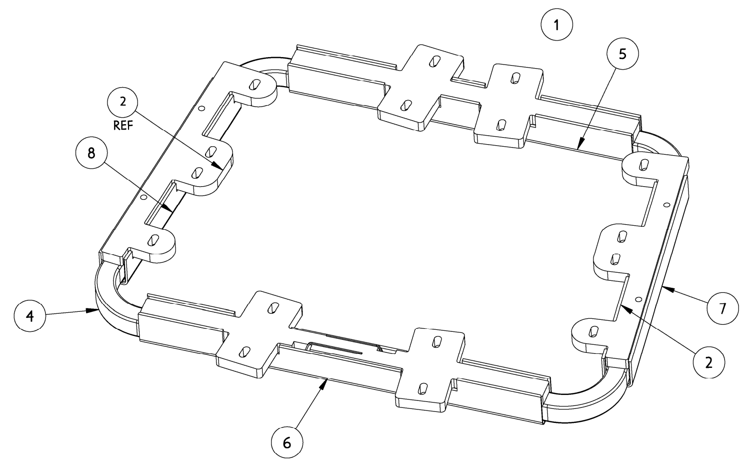
DWG VERSION NO: 13

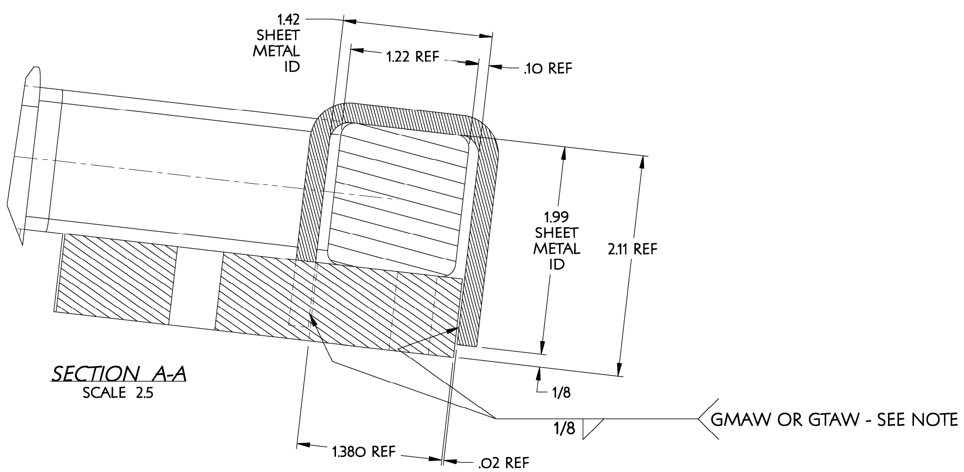
NCSX_ASSY_FORMAT_E

NO.	REVISION	BY	CH	SUP	APPROVED	DATE









SECTION A-A
SCALE 2.5

NOTES:
1. WELDING SHALL BE PERFORMED IN ACCORDANCE WITH THE REQUIREMENTS OF AWS 01 OR PPL PPPL PROCEDURE ENG-037. VISUAL WELD INSPECTION SHALL BE PERFORMED IN 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

Pro E

DO NOT VERIFY INFORMATION BY SCALING DRAWING

DIMENSIONS ARE IN INCHES
MACHINE SURFACES 125√

BREAK SHARP EDGES .005/.020

reagg
yufkfyuk
tlklk

MODEL NAME: RU_TRIM_COIL_1A_WELDMENT

NEXT ASSEMBLY

TOLERANCES NON-CUMULATIVE

DECIMAL-INCH		FRACTIONS	
.X	+/-.100	0"-12"	+/-1/16
.XX	+/-.030	12"-72"	+/-1/8
.XXX	+/-.005	72"-120"	+/-1/4
ANGULAR+/-0°-15'		OVER 120"	+/-1/2

DSN: R. UPCAVAGE
CHK:
ENGR: M. KALISH
SUPV:

WELDING ENGINEER

DRAWING NO: RU_TRIM_COIL_1A_WELDMENT

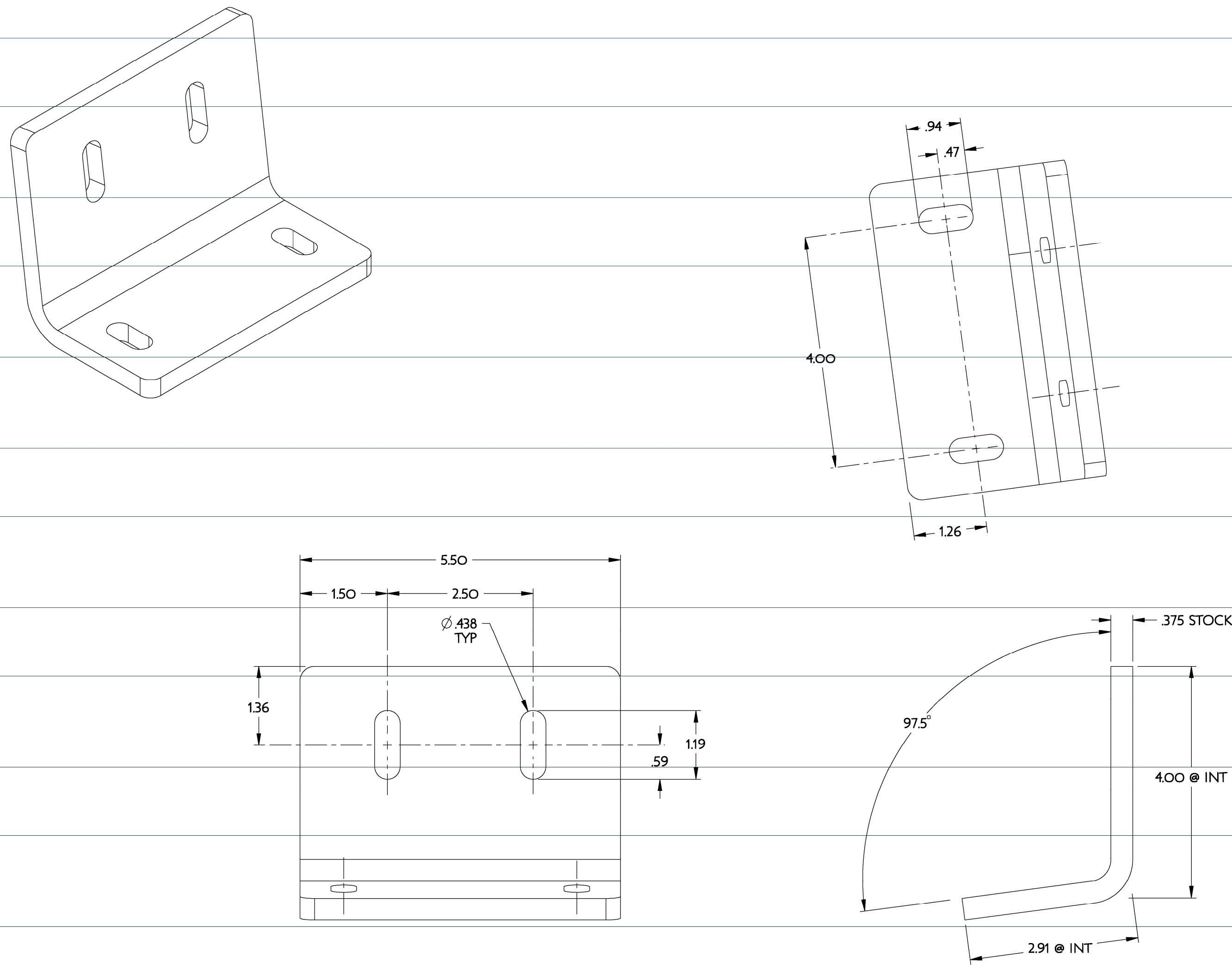
SHEET 1 OF 1 | REV 0

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

NCSX-RU_TRIM_COIL_1A_WELDMENT

NCSX_ASSY_FORMAT_E

NO.	REVISION	BY	CH	SUP	APPROVED	DATE



NOTES:
1. VENDOR TO PROVIDE DOCUMENTATION CERTIFYING THAT:
   A. STOCK MATERIAL TO EXHIBIT PERMIABILITY OF LESS THAN 1.02 Mu.
   B. IF AFTER WORKING OR MACHINING, MAGNETIC PERMEABILITY IS GREATER THAN 1.02 Mu, PART IS TO BE VACUUM HEAT TREATED AT 1100° C FOR 2.5 HOURS TO BRING THE MAGNETIC PERMEABILITY BELOW 1.02 Mu.

RELEASE LEVEL: WIP
DWG VERSION NO: 9+

WEIGHT 3.6 lbs	COMPUTER GENERATED DRAWING MANUAL CHANGES NOT PERMITTED	CENTRAL FILES:	PRINCETON PLASMA PHYSICS LABORATORY PRINCETON UNIVERSITY **NATIONAL COMPACT STELLARATOR EXPERIMENT**
MODEL NAME SE133-047-1	Pro E	UNLESS OTHERWISE SPECIFIED	STELLARATOR CORE TRIM COILS TRIM COIL #2 UPPER MOUNTING BRACKET
WELDING ENGINEER	DO NOT VERIFY INFORMATION BY SCALING DRAWING	DIMENSIONS ARE IN INCHES MACHINE SURFACES 125√	DSN: R. UPCAVAGE
	NEXT ASSEMBLY	BREAK SHARP EDGES .005/.020	CHK:
		TOLERANCES NON-CUMULATIVE	ENGR: M. KALISH
		DECIMAL-INCH: .X +/-.100; .XX +/-.030; .XXX +/-.005; ANGULAR +/-0°-15′ — FRACTIONS: 0"-12" +/-1/16; 12"-72" +/-1/8; 72"-120" +/-1/4; OVER 120" +/-1/2	SUPV:
			DRAWING NO: **SE133-047**
			SHEET 1 OF 1 — REV 0.1+

NCSX-SE133-047

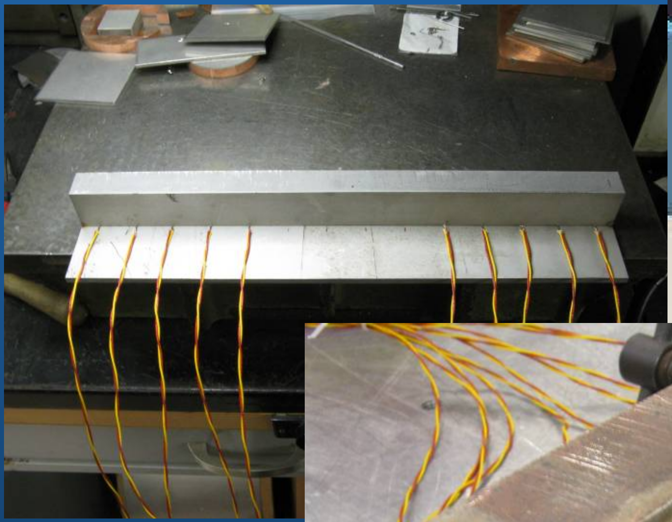
NCSX_PART_FORMAT_E

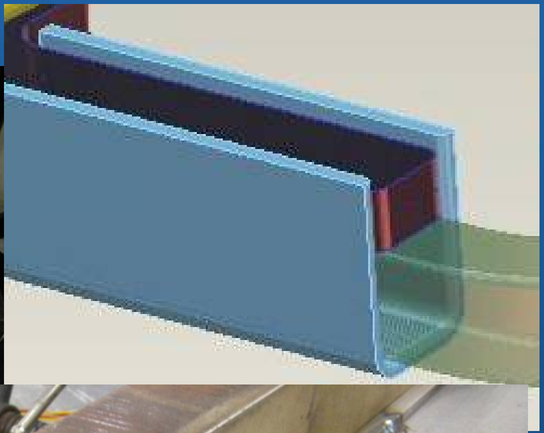
Structure - Magnetic Permeability

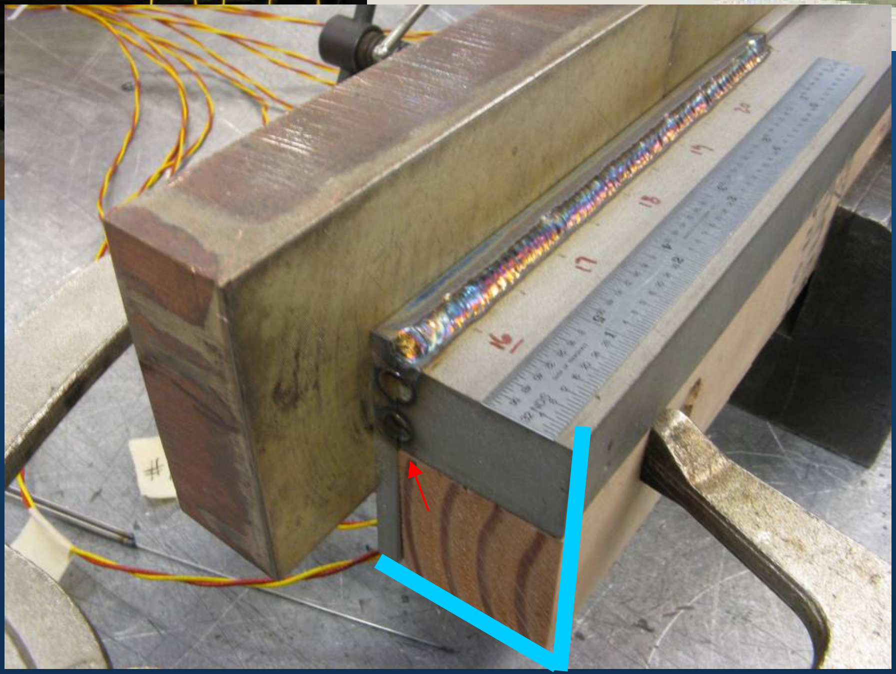
- **Estimate includes A286 non magnetic hardware**
- **Bellville washers are Inconel**
- **Individual Mounting Brackets Inconel**
- **U Channel and Base (¾ inch) Support Plates are 316 SS**
  - Vendor to certify that stock material exhibited magnetic permeability of less than 1.02 Mu
  - If after working or machining part has magnetic permeability greater than 1.02 Mu, part is to be vacuum heat treated at 1100 C for 2.5hrs to bring the magnetic permeability below 1.02Mu

R&D Weld Testing Setup

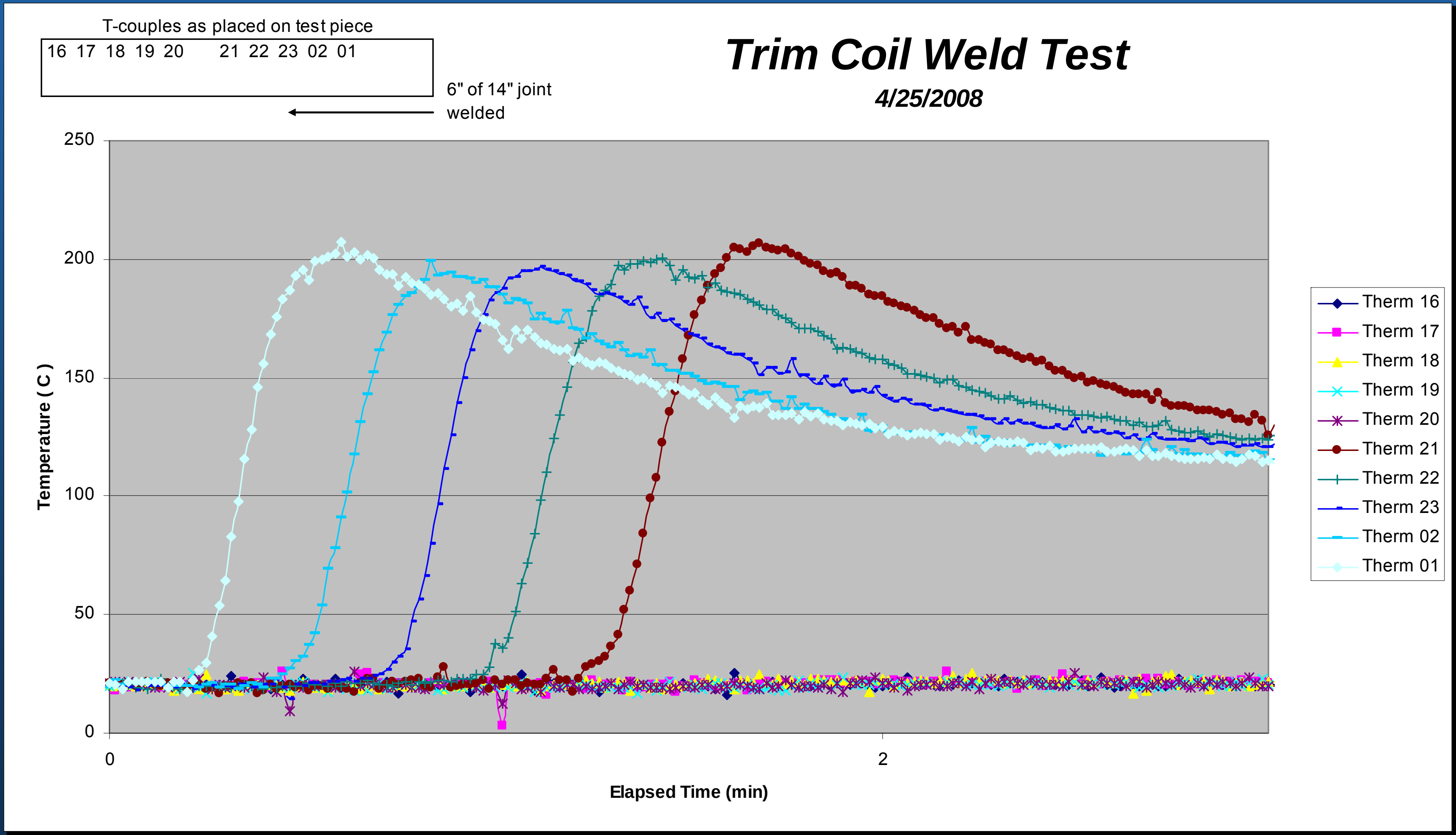
- Testing to assure U Channel welding did not exceed 120C at coil surface
- Wooden Block assembled to mockup of Coil Structure
- Ten thermocouples record temperature
- Method and results logged for assembly procedure



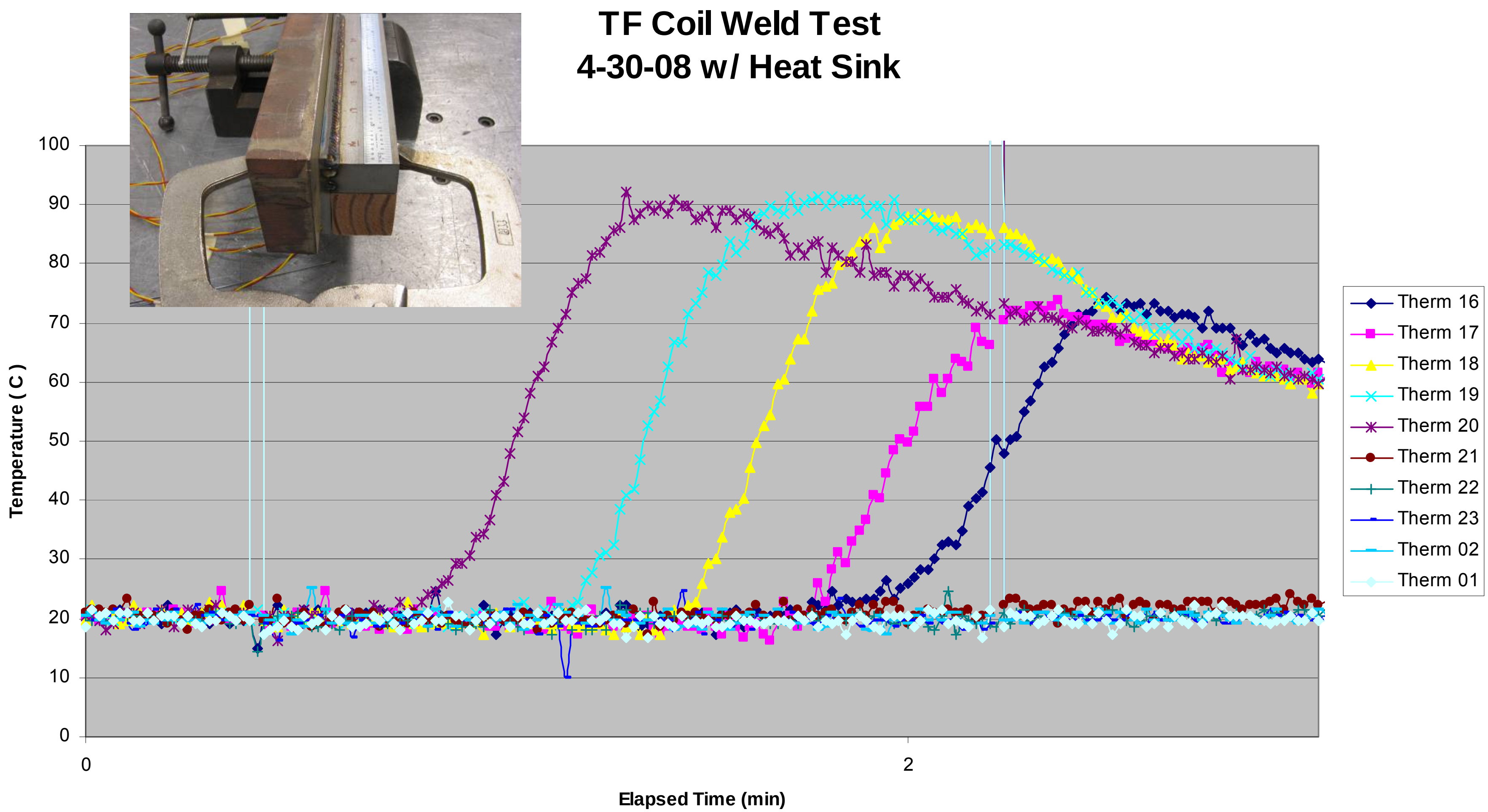




R&D Weld Testing- No Heat Sink

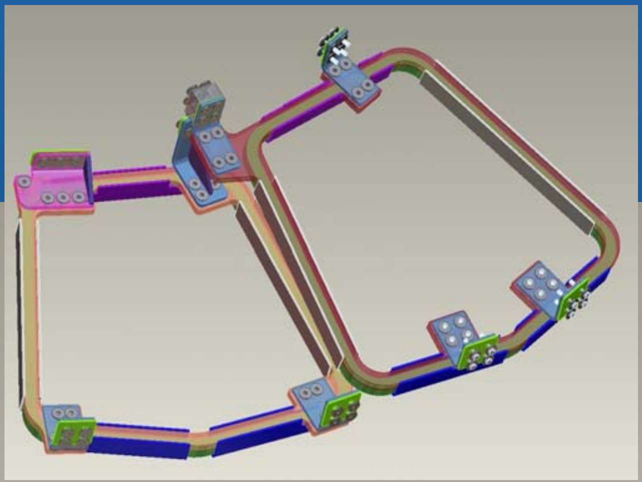


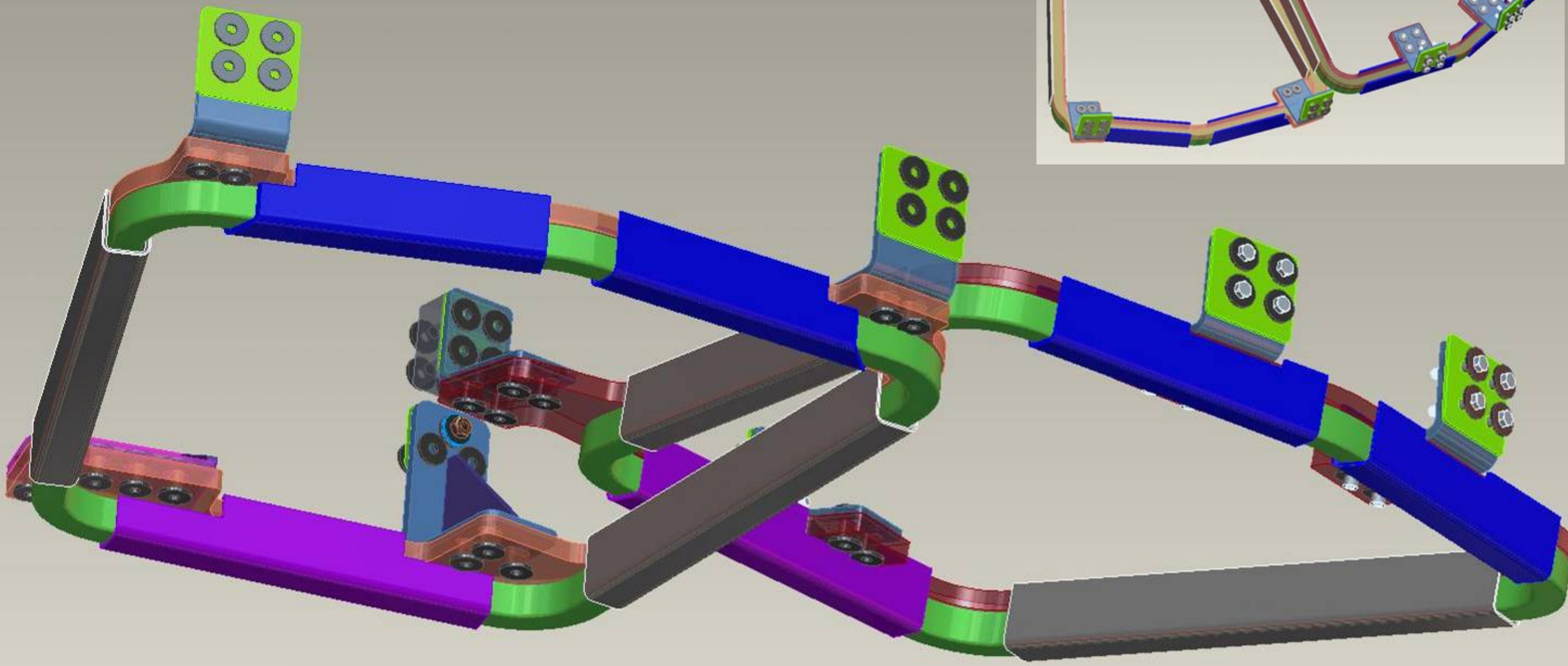
R&D Weld Testing- With Heat Sink



Structural Design for Analysis

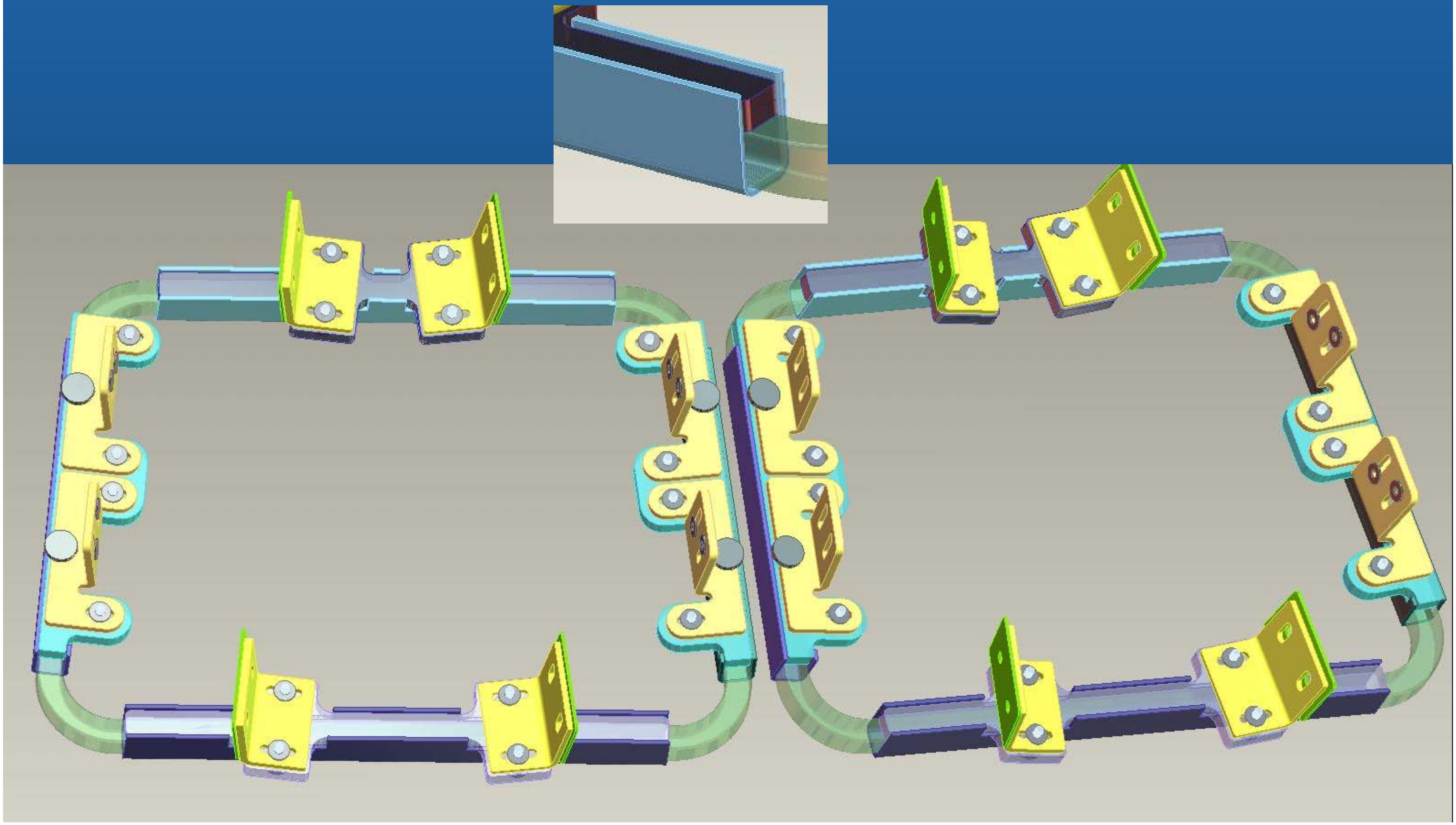
NCSX





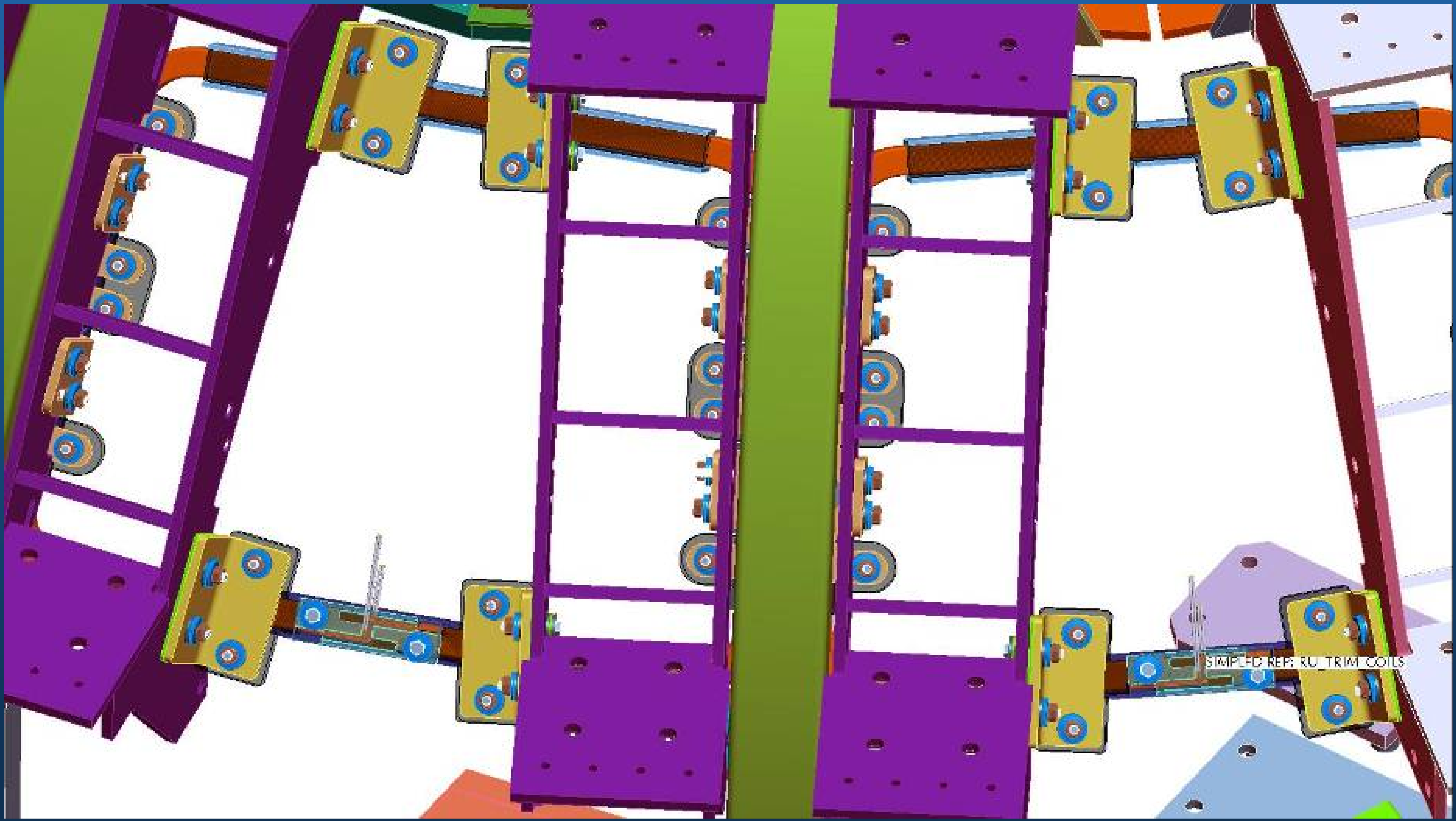
Structural Design for Analysis

Structural Design for Analysis



Structural Design for Analysis

NCSX



Trim Coil Stress Analysis – Overview

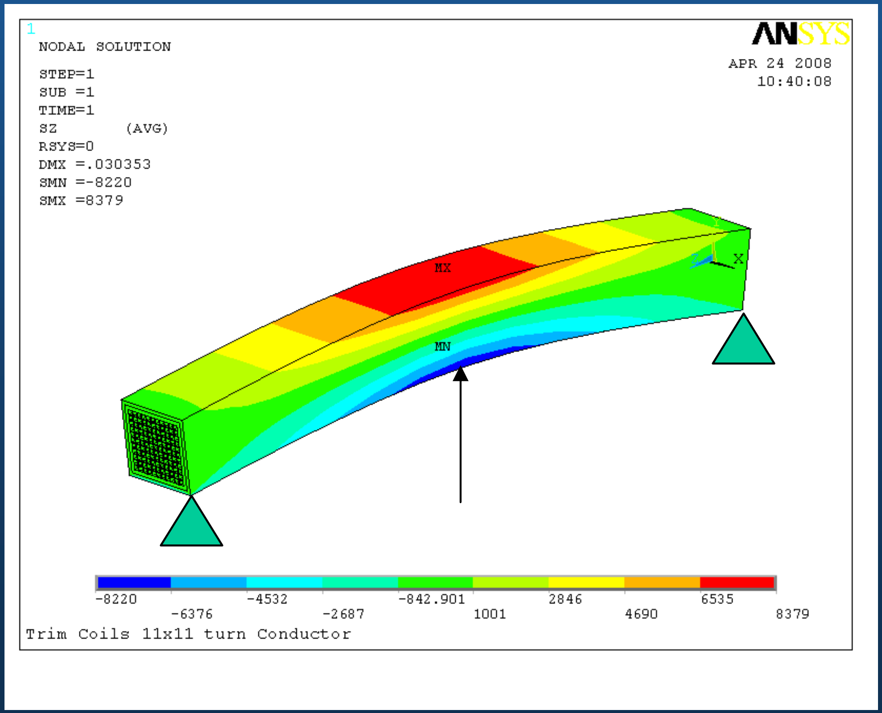
- **Local Model of Conductor Copper/Insulation to establish equivalent flexural properties and stress scale factors**
- **Finite Element Modeling Features**
- **Force Scan of Many Load Cases**
  - Establish running load of 80#/in as worse case
- **Summary Stress Table**
- **ANSYS Detailed Stress Plots**
- **Summary of additional load cases**
- **Bolting and Brackets**

Conductor Modeled with Equivalent Properties calculated from Flexural Modulus Simulation

Equivalent Flexural Modulus and Stress Scaling for Trim Coils

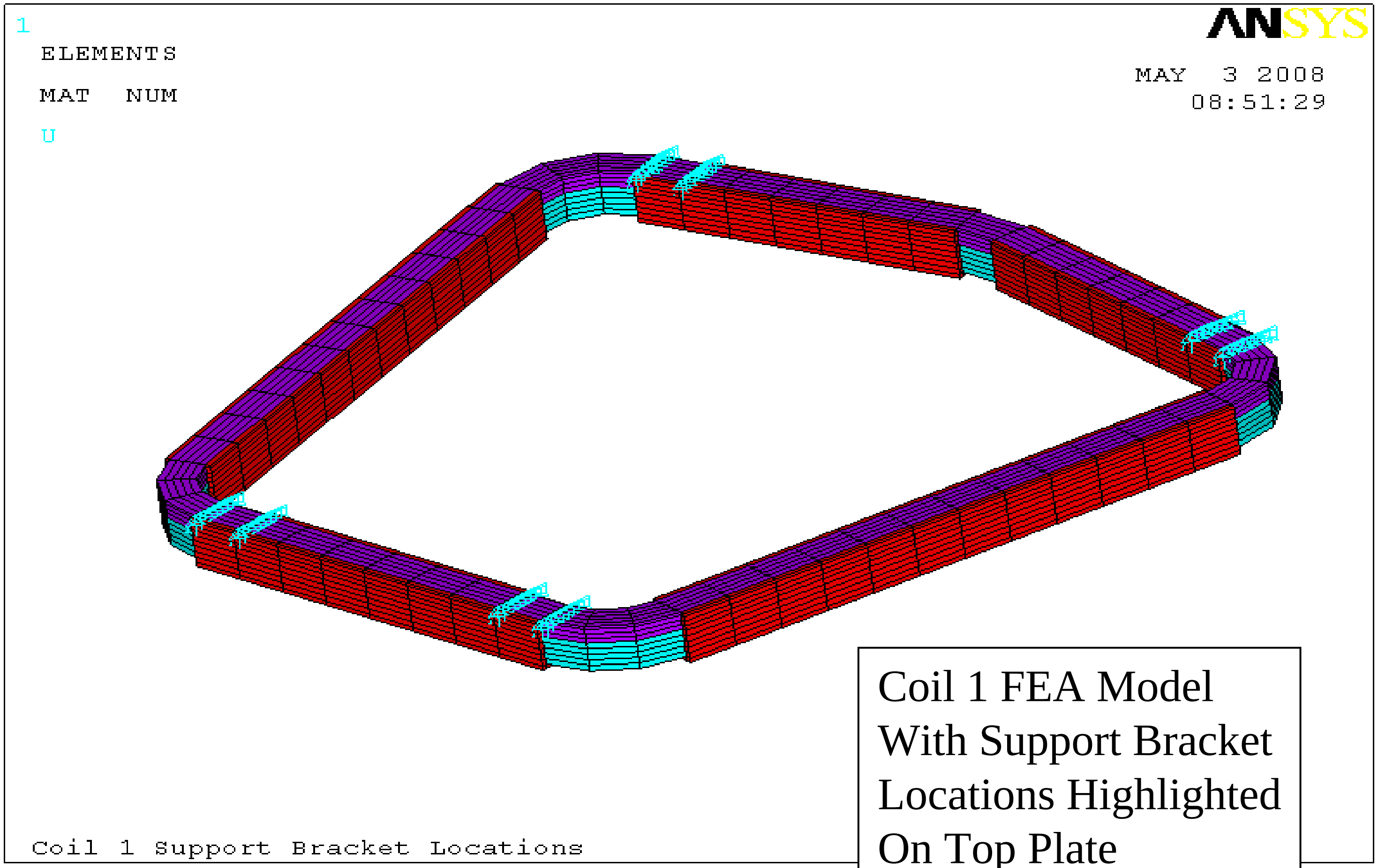
	E, Mpsi	Sz, psi	E, Mpsi	Sz, psi	Sz/Sz	Sz/Sz_max
Cu Wire	17	18390	5.85	6620	2.78	2.19
Insulation	1.5	2111	5.85	8379	0.25	0.25

- 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



FEA Coil Model

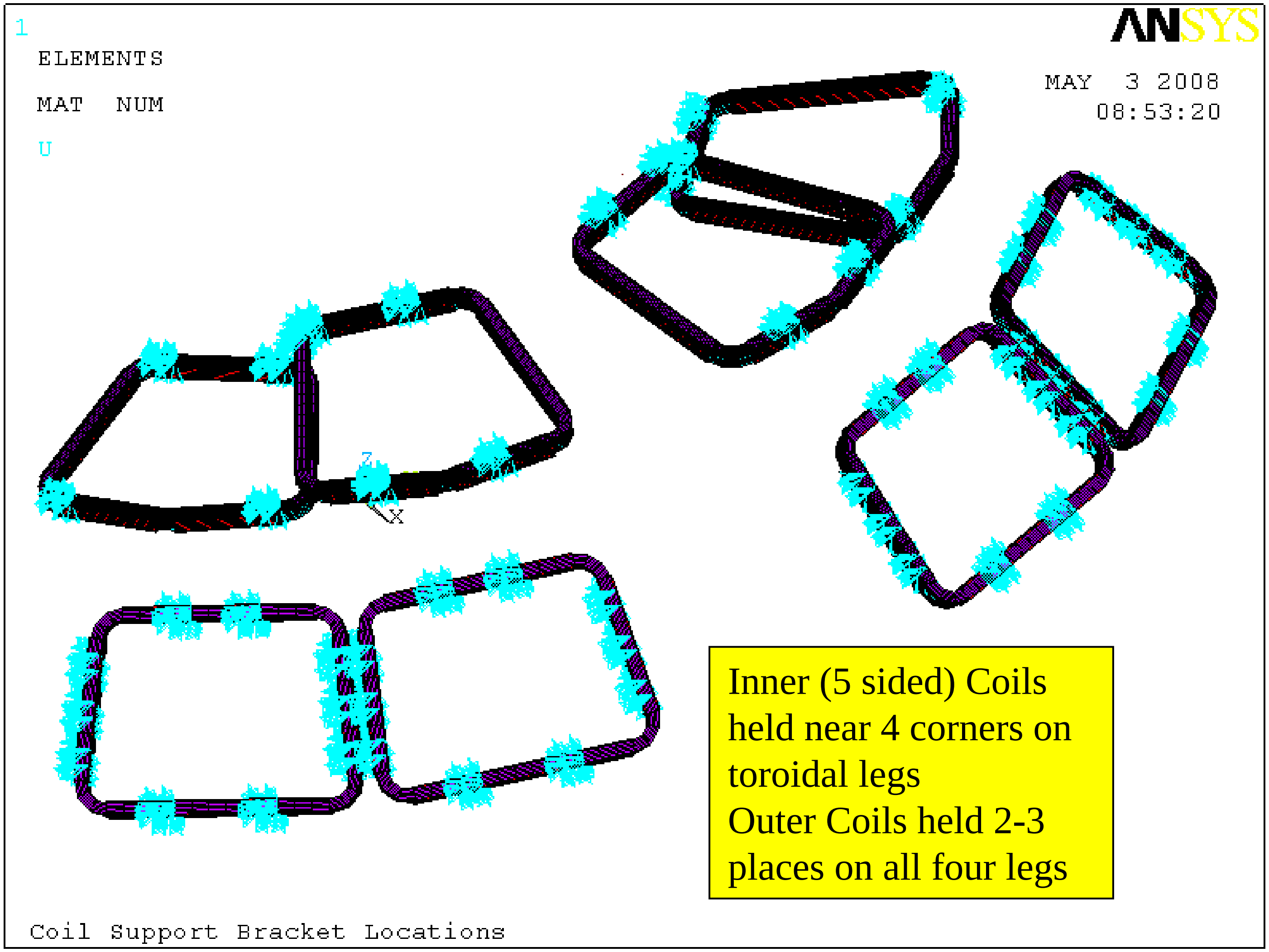
NCSX



Coil 1 FEA Model With Support Bracket Locations Highlighted On Top Plate

FEA Model – All Coils

NCSX



Inner (5 sided) Coils held near 4 corners on toroidal legs
Outer Coils held 2-3 places on all four legs

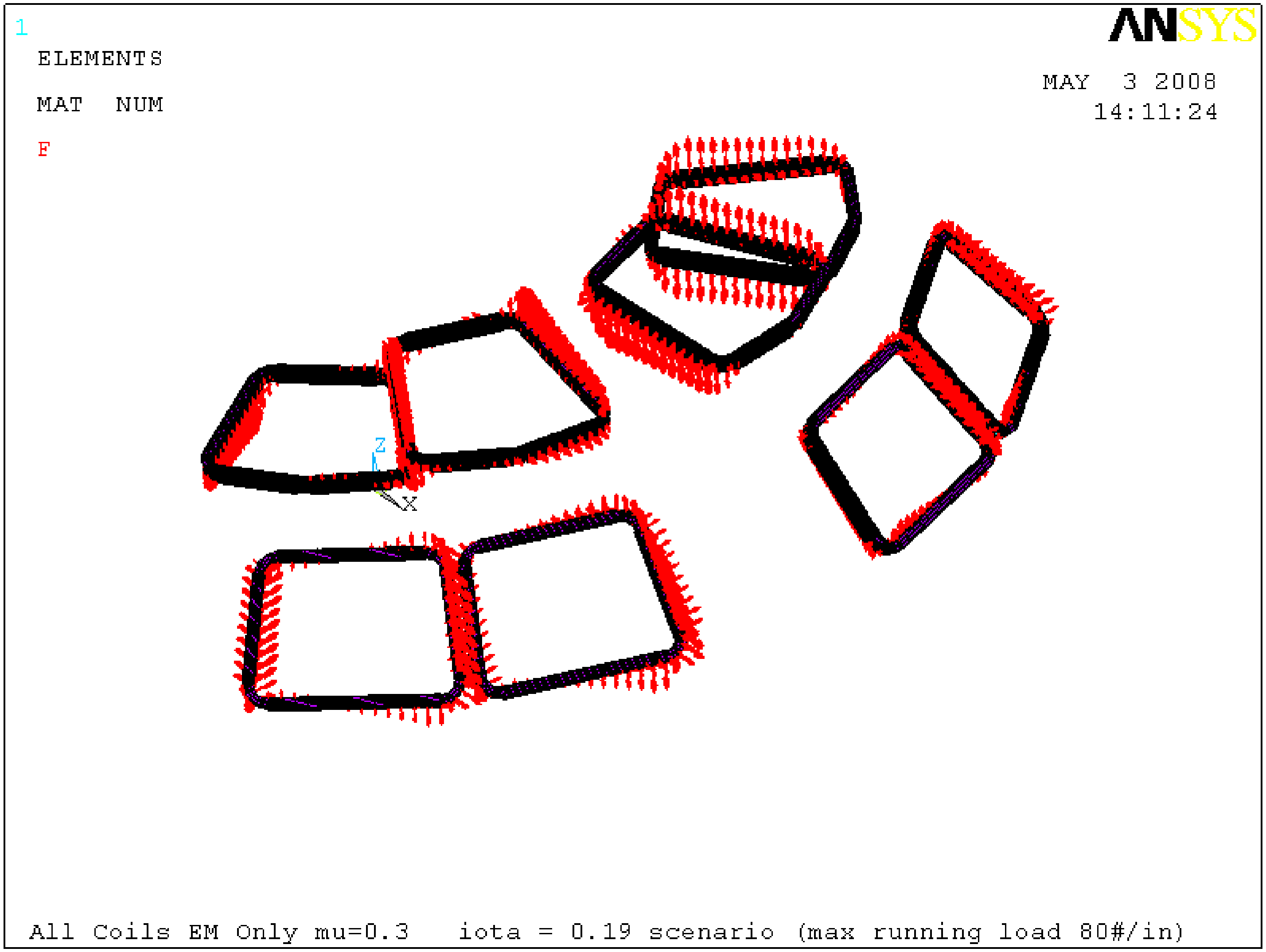
Load Cases Investigated for EM Forces

- 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

Iota = 0.19 Scenario Force Distribution

NCSX



Stress Result Summary
(nodal peak stresses)

NCSX

		Max Von Mises Stress					
		Cond Composite	Copper	Insulation	Plate	U Channel	
No Friction	mu=0.0						
Coil1	CD+EM	32.5	71.5	8.1	113.0	186.0	Mpa
		4.6	10.2	1.2	16.1	26.6	ksi
	EM Only	19.9	43.8	5.0	44.2	34.1	Mpa
		2.8	6.3	0.7	6.3	4.9	ksi
	CD Only	25.0	55.0	6.3	106.0	198.0	Mpa
		3.6	7.9	0.9	15.1	28.3	ksi
Friction	mu=0.3						
Coil1	CD+EM	27.4	60.3	6.9	120.0	196.0	Mpa
		3.9	8.6	1.0	17.1	28.0	ksi
	EM Only	23.1	50.8	5.8	72.7	54.9	Mpa
		3.3	7.3	0.8	10.4	7.8	ksi
	CD Only	24.5	53.9	6.1	96.3	174.0	Mpa
		3.5	7.7	0.9	13.8	24.9	ksi
Friction	mu=0.3						
All Coils	CD+EM	33.9	74.6	8.5	166.0	257.0	Mpa
		4.8	10.7	1.2	23.7	36.7	ksi
	EM Only	22.9	50.4	5.7	79.2	116.0	Mpa
		3.3	7.2	0.8	11.3	16.6	ksi
	CD Only	25.5	56.1	6.4	117.0	188.0	Mpa
		3.6	8.0	0.9	16.7	26.9	ksi

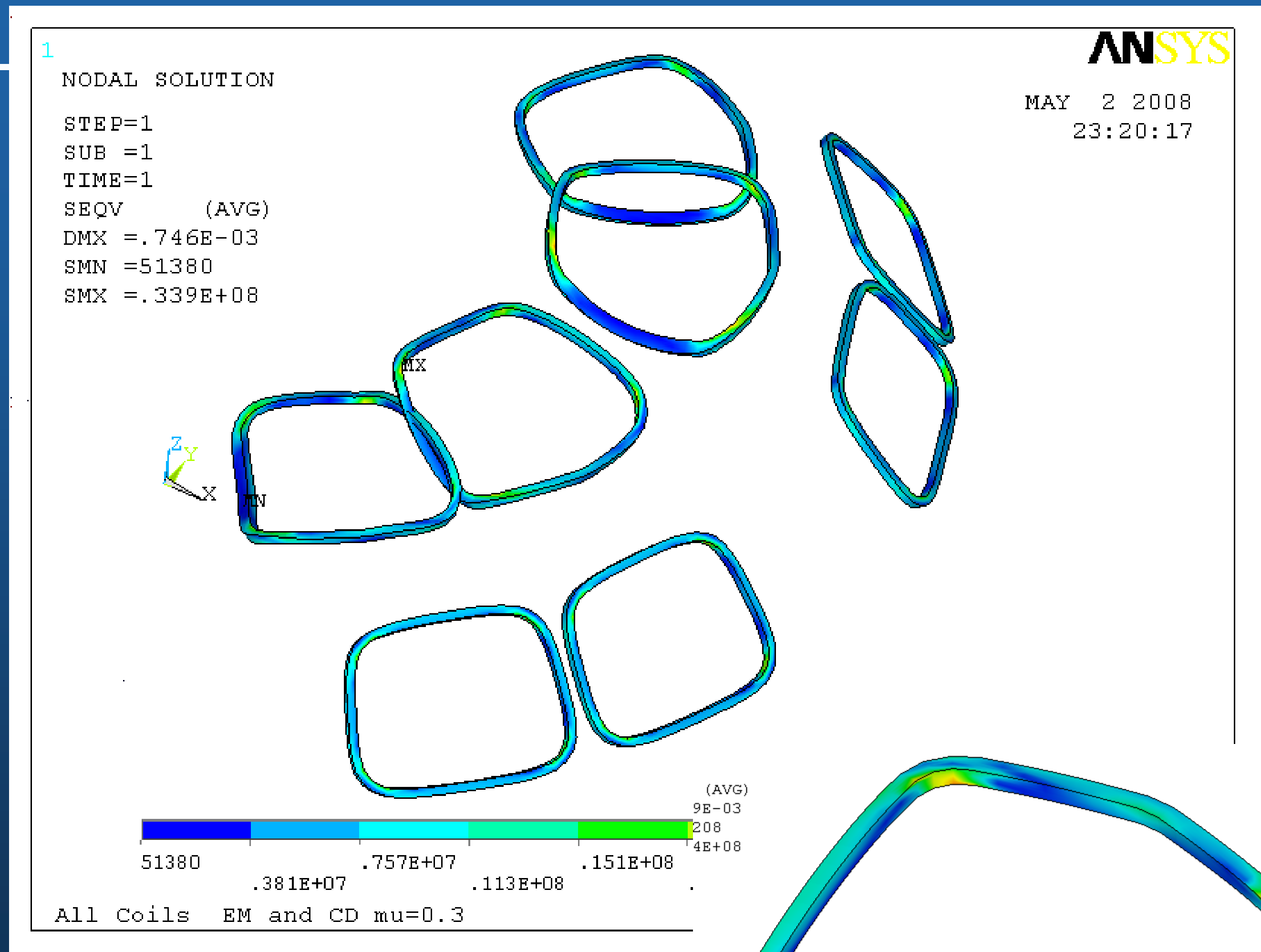
Conductor Stress Result

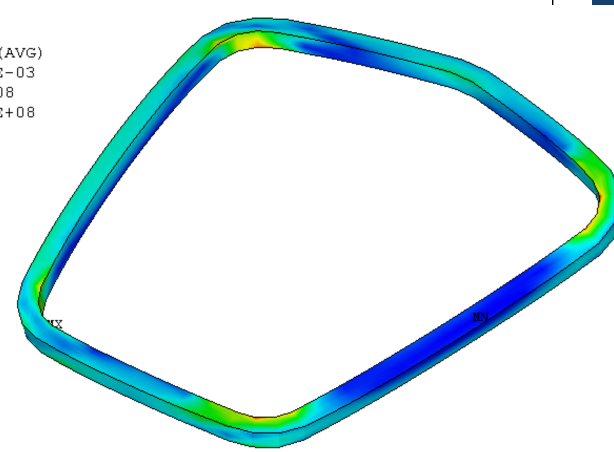
NCSX

- 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)





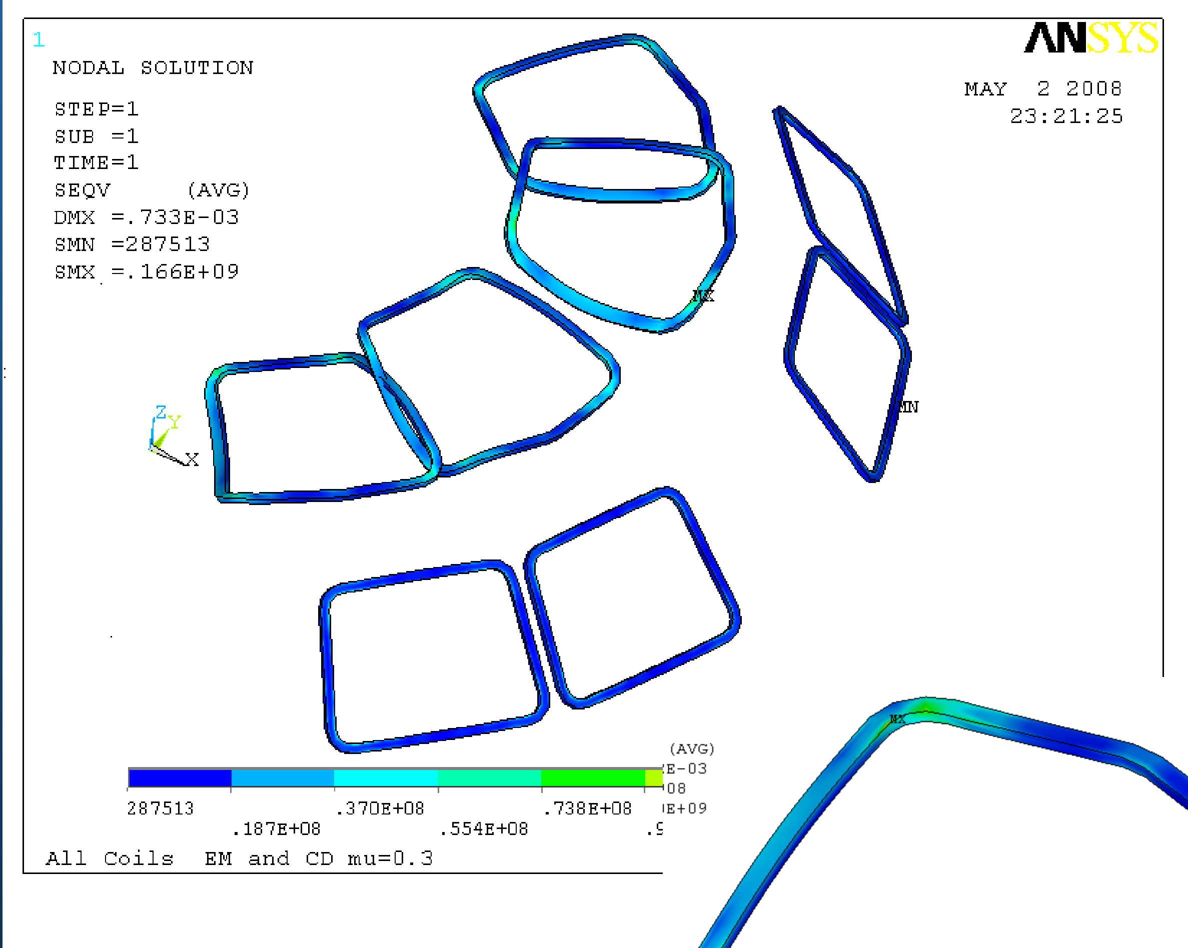
¾" Support Plate Stress Result

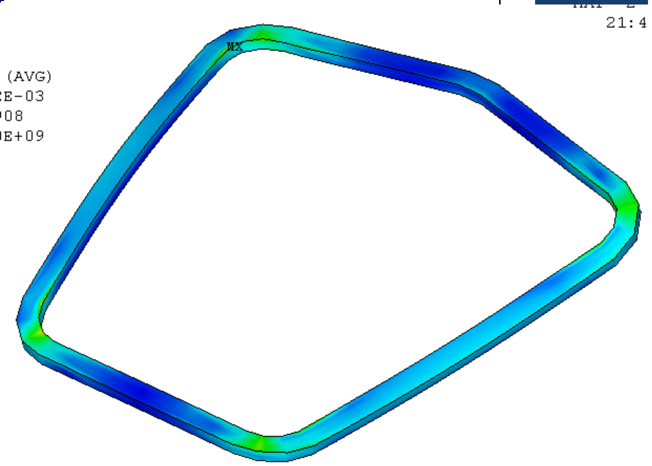
NCSX

- 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)

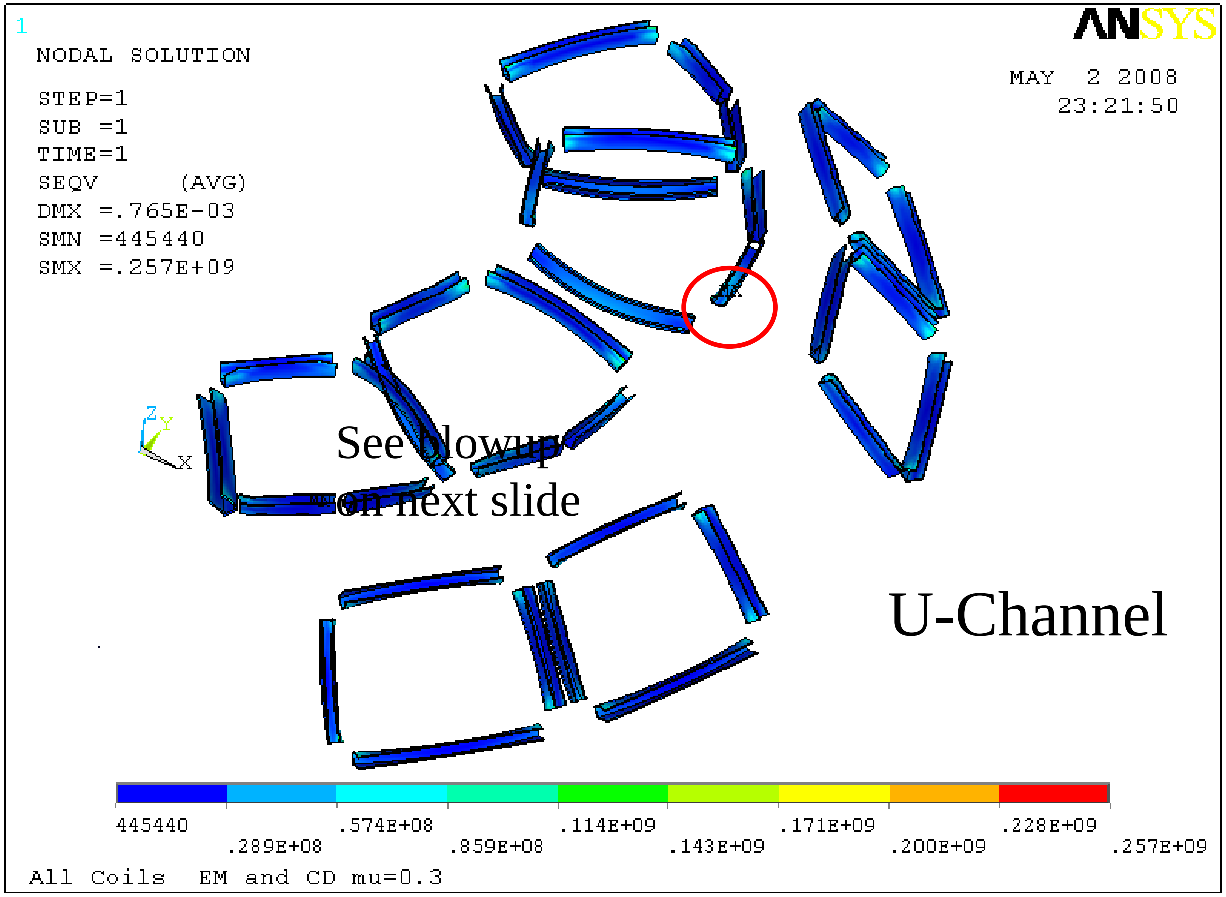




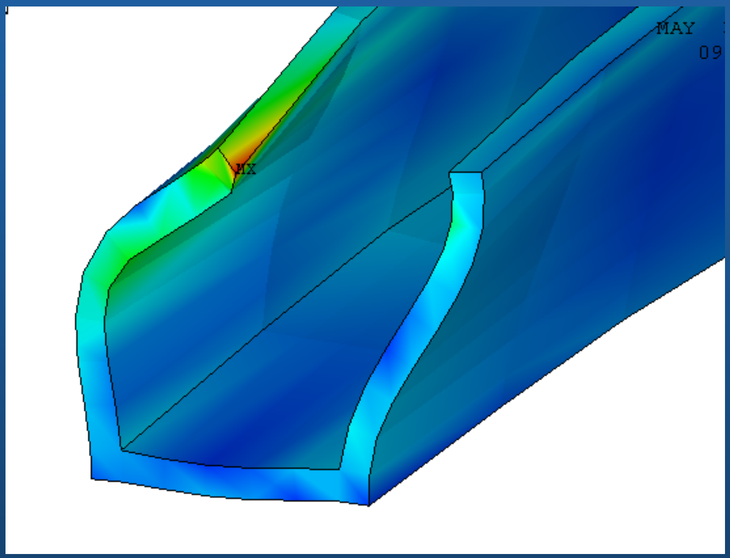
U Channel Stress Result

NCSX

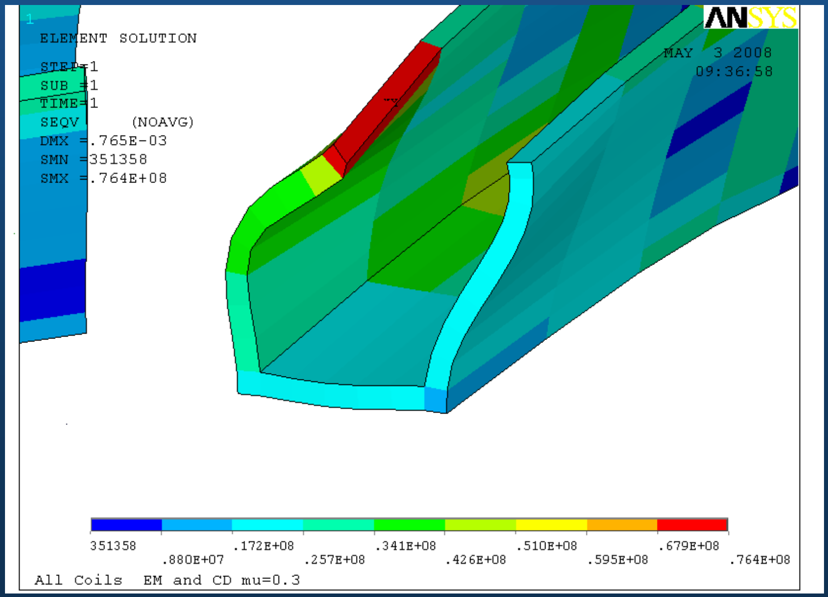
- EM only= 16.6 ksi
- Allowable= 1.5Sm=35.0ksi (Primary Member Stress)
- Cool Down only= 26.9ksi
- Allowable 3xSm=60.0ksi (for secondary thermal stress + primary)
- CD+EM= 36.7ksi
- Allowable 3xSm=60.0ksi (for secondary thermal stress + primary)
- Element Average Stress is only 30% of Max Stress Result 36.7ksi→10.9ksi



U Channel: EM Loads + Cool Down



Peak Node Stress at Weld
In Coil 3 U-Channel
36.7 ksi



Element Average
Stress Much Lower
10.9 ksi

Comparison of EM Scenarios

NCSX

- Original run with iota=.19 case
- Additional two load cases Run
- .5T TF Case some stresses marginally higher but within allowables

  Note that GRD does not include Trim Coil current for .5T TF but case run with full 20 Kamp turns
- 2T HB stress results lower than iota=.19

Friction	mu=0.3	Max Von Mises Stress					
All Coils	EM Only	Cond Composite	Copper	Insulation	Plate	U Channel	
iota=0.19		22.9	50.4	5.7	79.2	116.0	Mpa
		3.3	7.2	0.8	11.3	16.6	ksi
0.5T TF		24.1	53.0	6.0	103.0	152.0	Mpa
		3.4	7.6	0.9	14.7	21.7	ksi
2T HB t=0.197s		13.4	29.5	3.4	46.3	38.9	Mpa
		1.9	4.2	0.5	6.6	5.6	ksi

Bolts and Brackets

NCSX

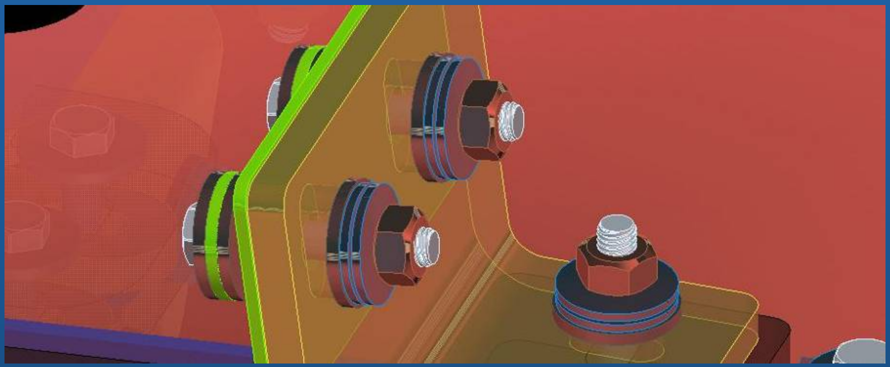
- Bracket must resist in friction a lateral load of 2038lbf
- Two series (cupped) Bellville washers provide preload of 5800 lbs tensile preload per bolt
- Three bolts provides 3480lbf to resist lateral force for worst case running load of 80lbf

- Bracket Stress for worst case running load

  Max Stress = 52 ksi bending

  Deflection = .009”
- Inconel required for support brackets

  Allowable Stress Bending at LN2 temp = 1.5Sm = 140Ksi

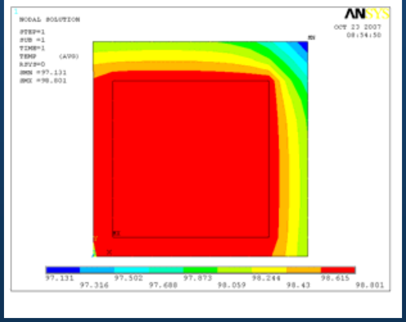


bolt size	0.375		
threads/in.	16.000		
Pitch diameter	0.334		
tensile area	0.077	Eq. 2.1 "An Intro. to th	
Tensile Yield strength	189000	A286 Stud as shipped	
Ultimate tensile str.	211000	A286 Stud as shipped	
Tension allowable	126000	2/3 Yield for Stud	
Max Axial load/bolt	9764	At tension allowable	
Applied Axial load/bolt	5800		
coeff. Of frict.	**0.200**		
Frict. Load/bolt	1160		
Total no. bolts	*3*		
total frict. Load	3480		
lateral load on box	2038		
Friction F.S.	**1.7**		
calc torque to get axial load using simple formula	32		

Coil Cooling Analysis
Comfortable Design Margins With Convection Cooling

NCSX

- **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



Interfaces

- **Modular Coils, PF and TF Coils**
  - EM loads from the Modular, PF and TF coils were calculated and incorporated into the stress analysis
- **Coil Support Structure**
  - Interfaces defined by Pro-E Model
- **Liquid Nitrogen System**
  - Coils are convection cooled
  - No pressurized LN2 flow required

Interfaces

- **Electrical Leads**
  - Individual leads will be provided capable of handling an equivalent RMS current of 8 amps (165 amps for 2 seconds every 15 minutes)
  - Interfacing Cables will be 4 twisted 12 awg wires brazed into the lead block on the coil
- **Coil Protection System and I&C**
  - One thermocouple will be provided on each Trim Coil to be used as necessary to monitor temperatures during operation
- **Magnetic Diagnostic Loops**
  - No diagnostic loops will be provided on the Trim Coils

Interfaces

Assembly

– Coils locations will be measured after assembly at a minimum of four points

- **Electrical Grounding**
  - Trim Coils will not have a ground plane but will provide a single point ground wire for each of the isolated inner coils
  - One ground wires for each rail of the outer coils that bridges the modular coil joint will be provided
  - The two rails on the outer coils that do not bridge a joint will not be isolated from the modular coils

PDR Chit Resolution

NCSX

#	Chit / Audit Finding [Originator]	Review Board Recommendation	Project Disposition	Responsibility
1	The Project needs to define the range of operating scenarios required and final analysis for trim coils needs to be consistent with this. Heitzenroeder	Concur. Expected operating scenarios to be documented in the GRD	Complete - Art Brooks along with Mike Z evaluated additional TF Coil operating scenerios included in analysis. we are now using four flexibility equilibria recently provided by Mike Z. in our design work. "These are used to implement existing GRD requirements (3.2.1.5.3.4). I suggest we document the coil currents for any equilibria that we use as design requirements in the Technical Data section of the GRD (Appendix A)" - Hutch	Neilson
2	Per SRD 3.1.2.11 (d); WBS4 is only responsible to feed power to the coils. Ramakrishnan	Concur. GRD currently states that all coils require diagnostic loops. GRD mut be updated to include the appropriate requirements for the trim coils.	"The GRD does not require diagnostic loops on all coils. The SRD, paragraph 3.1.2.10 is correct and there is no conflict." - Hutch	Neilson
3	Per SRD 3.1.2.11 (e) Grounding; Please note that this is a floating system. Ground fault protection will be provided. Coil casings have to be preferablymade continuous so that external ground leads can be brought out in a couple of places. Ramakrishnan	Concur. (1) SRD must be updated to include Trim Coil grounding details. (2) Drawings need to show ground connections.	Complete- Coil cases Isolated and floating and grounded in one location each with a wire. Out board individual legs of coils which do not bridge field period segments are not isolated from the modular coil cases	Kalish

PDR Chit Resolution (continued)

4	Do we need to physically measure the location of the trim coils at all? Could we make the measurements only via magnetic measurements (later). Zarstorff	Concur. This interface requirement should be defined in the Trim Coil SRD.	Complete- Project has defined requirement to measure after installation. It is in approved SRD	Kalish
5	We should hold a peer review on upgrade mid-plane trim coil locations and supports. Zarnstorff	Concur. Peer Review to be scheduled	Will Follow FDR for Trim Coils "I agree that we should lay out where the upgrade trim coils are going to go and identify whatever space and mounting features are needed. Then have a peer review to make decisions" - Hutch	Kalish
6	Need to do combined fields analysis with TF=+/-0.5T scenarios representing the flexibility range in the GRD. Zarnstorff	Concur. See Chit #1. After GRD is updated. Perform required analysis	Complete - Art Brooks along with Mike Z evaluated additional TF Coil operating scenerios included in analysis. TBD whether these requirements will be officially in the GRD but they are covered herer either way Project will appropriatly capture in GRD	Kalish

PDR Chit Resolution (continued)

7	Look at the resonant frequencies of the structure of the trim coils, which being light and small and inductively coupled, could lead to interesting vibration and resonance phenomena depending on how the power supply waveform comes out. I suspect that experience on TFTR and other machines up there gives you a lot of knowledge on this already. Harris	Concur. Consider performing analysis once operating scenarios and parameters are established and documented.	"The vacuum vessel vibrations on ATF were a product of a system with large power supply ripple (it was a 6-phase rectifier), strong inductive coupling between the coil and the vacuum vessel (the coil was wound into a helical groove in the VV), and a thin vacuum vessel wall (0.25-in. stainless as a I remember). NCSX is better off in all these respects. Moreover, the NCSX trim coils are mechanically well isolated from the VV by the MC shell, so it is difficult to see how any VV acoustic vibrations would couple to the trim coils. The risk of this being a problem is very low, so no further analysis is needed." Hutch	Neilson
8	(1) Simulate Induced Voltages. (2) Provide Inductance Matrix. (3) Calculate resistances of coils. Ramakrishanan	Concur. Furnish this information to WBS4	Art is updating inductance Matrix	Kalish
9	Establish by calculations that the stipulated time response is achievable with the calculated coil parameters. Ramakrishnan	Concur. See Chit #8	Raki to reafirm with updated inductance matrix	Kalish

PDR Chit Resolution (continued)

10	Some level of simulation of proposed scenarios that include the trim coils needs to be executed. This is needed to ensure that power supply specs are realistic and/or sufficient. Hatcher	Concur. Simulations need to be repeated once final configurations and parameters are established.	Consider as part of future power supply design	Raki
11	Don't put thermocouples on every trim coil. It does not seem necessary given your thermal margin. Consider putting thermocouples on 1 or 2 coils/ half-period to sense overall cryostat temperature distribution. Zarnstorff	Concur. These details need to be included in the Trim Coil SRD and drawings.	Added to Specificaton	Kalish
12	Add G-10 or stainless steel strips strips between support angle and coil to avoid corner raduis interference. Heitzenroeder	Concur. Coil corner details will be addressed in final design drawings	Complete- In assembly drawings	Kalish
13	Consider solid (thicker) solid bar stock as Stiffening Plate. Consider Inconel 601 Bar Stock. Dahlgren	Concur. Will consider	Complete- Design now includes solid bars	Kalish

PDR Chit Resolution (continued)

14	Consider aluminum as material for structure. Insulate the one cover structure that bridges the gap in the base structure to prevent an eddy current loop. Use a single Kapton layer for insulation. Zarstorff	Concur. Will consider	Considered- SS provided margin for deflections and eliminated edy current issues - Design is 316 SS	Kalish
15	Cutting the support bases from plate will generate lots of waste. Consider casting the bases, or fabricating them some other way. Zarstorff	Concur. Will consider	Considered- Water jet cutting of SS supports allows flexibility to build in house and provides lowest risk to schedule. Casting has proven to be involved and would require final machining most likey exceeding costs of water jet cutting stock plate, Design is 3/4" plate	Kalish
16	Consider a 10 X 12 turn coil configuration to bring both leads out at the top (or bottom). Dahlgren	Concur. Will consider	Complete- Design is now 10x12	Kalish

PDR Chit Resolution (continued)

16	Consider a 10 X 12 turn coil configuration to bring both leads out at the top (or bottom). Dahlgren	Concur. Will consider	Complete- Design is now 10x12	Kalish
17	Consider 120 turns so that the leads are on one side. Ramakrishnan	Concur. Will consider	Considered- Water jet cutting of SS supports allows flexibility to build in house and provides lowest risk to schedule. Casting has proven to be involved and would require final machining most likey exceeding costs of water jet cutting stock plate, Design is 3/4" plate	Kalish
18	Can the casings of multiple coils be made continuous such that external ground wires be brought (out) only at controlled places for the whole system? Ramakrishnan	Concur. See Chit #3	Complete- grounding scenerio reviewed with Raki now includes isolated coils each individually grounded to the MCWF	Kalish

Other PDR Issues Resolved

- “Chits to Self” From PDR Complete
  - √ “Ground Isolation Needs Detail Design”
  - √ “Lead Support Concept Not Complete”
  - √ “Material Selection Required- Mag. Permeability Issues”
  - √ “Assembly Issues need to be fleshed out”

Cost- Coil

- **Coil Cost Revisited**
  - Original Coil Cost Estimate based on custom conductor and out of plane coils $736K
  - New Design with off the shelf conductor and planar coils drops estimate to $583K
  - Suggest procurement of two spares for each coil type for a delta of +$42K

Coil Cost Spread Sheet

Trim Coil Material Estimate								
		Trim1	**Trim2**	**Trim3**	**Trim4**	**Total # Coils**		
II. Materials M&S								
Number of Coils		**0.00001**	**24**	**0.00001**	**24**	48		
Conductor With Insulation Cost Per LB		**$12**	**$12**	**$12**	**$12**		Vendor quote	
Conductor With Insulation Cost Per Coil	**$**	**$688**	**$363**	**$329**	**$362**			
Epoxy volume reqd. (15% void fraction)	l	0.58	0.30	0.28	0.30			
Epoxy cost/liter	$/l	$79	$79	$79	$79		$300 per gallon as paid for	
Epoxy cost per coil	**$**	**$46**	**$24**	**$22**	**$24**			
Material Costs Epoxy all Coils		**$0**	**$579**	**$0**	**$578**			
Material Costs Conductor with Insulation all Coils		**$0**	**$13,897**	**$0**	**$13,869**			
Material Costs Total		**$0**	**$14,476**	**$0**	**$14,446**	**$28,923**		
Everson Budgetary Estimate								
Total Material Cost All Trim Coils								**$28,923**
Cost from Everson Budgetary Estimate out of Plane		$8,450	$7,575	$7,575	$7,575			
Adjusted Cost for Planar Coils		$8,450	$6,439	$6,439	$6,439			
Total Cost for Fixtures		$0	$30,000	$0	$30,000			**$60,000**
Recurring Costs for N Coils no materials		$0	$154,530	$0	$154,530			**$309,060**
Total Cost For N Coils with Materials		$0	$199,006	$0	$198,976			
Total Cost All Coils								**$397,983**
Everson Budgetary Estimate (adjusted for uncertainty)		Fixtures =						
Total Material Cost All Trim Coils								**$28,923**
Manufacturing Cost from Everson Budgetary Estimate		$8,450	$6,439	$6,439	$6,439			
Total Cost for Fixtures		$0	$30,000	$0	$30,000			**$90,000**
Recurring Costs for N Coils no materials		$0	$154,530	$0	$154,530			**$463,590**
Total Cost For N Coils with Materials		$0	$199,006	$0	$198,976			
Total Cost All Coils								**$582,513**

Hardware Cost Spread Sheet

NCSX

U Brackets	$12,818	U Channel Material Cost	8
3/4 SS	38400	.75 inch Plate Cost	8
Brackets	5760	Bracket Material Cost	40
	$56,978		
# of Bolts	1536		
Cost per Bolt	20		
Cost per Nut	8		
Cost per Washer	5		
Hardware Cost	**$81,408**		
Forming U Bracket	27		
# U Brackets	216		
Cost	**$5,832**		
Water Jet			
Hrs per Coil	8		
Total Hrs	384		
$ per Hr	84		
	$32,256		
Bend and Drill Brackets	**$48,384**		
G10 Insulator Fabrication	**$6,720**		
G10 Block Fabrication	**$24,192**		
Fabricate Assembly	16		
All Coils	768		
Cost	**$64,512**		
Total Cost	**$289,370**		
Uncertainty Factor	**25%**		
Cost for Hardware			$289,370
Cost for Hardware adjusted for uncertainty			**$361,712**

- **Structure Cost Revisited**
  - Original Costs based on estimate of # of brackets per length = $364K
  - New Cost Estimate based on actual design = $362K
  - Cost would escalate $256K if ¾” plate and U Channel is Inconel
  - Assembly costs must be re-evaluated (will be lower)

Coil Procurement Schedule

NCSX

- **Work begun early to expedite schedule**
- **Relatively simple industry standard design should maximize # of bids**
- **Coils Specification and SOW in review**

Task #	Description	Responsi-ble	Duration	Planned Start	Planned Finish	Actual Start	Actual Finish
1.	Committee meets to review Source Selection Plan	KR/JHC	1 day	5/1/08	5/1/08		
2.	Requisition issued	JHC	3 days	5/2/08	5/5/08		
3.	Trim Coil FDR	MK/JHC	1 day	5/6/08	5/6/08		
4.	Source Selection Plan drafted	KR	1 day	5/9/08	5/9/08		
5.	Specification/Drawings Finalized	MK/JHC	4 days	5/7/08	5/13/08		
6.	RFP issued	KR	1 day	5/16/08	5/16/08	?	
7.	Pre-Proposal Tele/Video Conference	KR	1 day	5/22/08	5/22/08		
8.	Proposals due	KR	1 day	6/4/08	6/4/08		
9.	Evaluation Complete & clarifications requested	PANEL	7 days	6/5/08	6/13/08		
10.	Best and Final due	JHC/KR	2 days	6/16/08	6/18/08		
11.	Committee Recommendation Completed	PANEL	1 day	6/19/08	6/19/08		
12.	Project Decision	DR	1 day	6/20/08	6/20/08		
13.	Subcontract Negotiation	KR	3 days	6/23/08	6/26/08		
14.	Subcontract Awarded	KR	1 day	6/27/08	6/27/08		

Summary / Charge

NCSX

- 1. Are all required analyses complete and formally checked and adequate to establish that the proposed design is feasible and meets established design criteria?

  Analysis report complete and partially checked
- 2. Are the drawings and documentation adequate to support the procurement and/ or manufacturing process, installation, and ready for sign-off?

  Coil Drawings are ready for checking and signoff, support drawings are being detailed
- 3. Is the plan for installation of the trim coils compatible with the machine assembly plans?

  Yes - Additional meetings with Mike Viola, Tom Brown, and John Edwards have facilitated design improvements to ease assembly
- 4. Is the Product Specification (CSPEC) complete and satisfactory? Are the interfaces adequately defined?

  Yes - CSPEC and SOW are complete and in review cycle. SRD is signed off
- 5. Is the Work Planning form current, and have the applicable requirements been satisfied?

  Yes - WP #1435 , Detailed and Assembly drawings must be signed off to complete requirements
- 6. Have the chits from the PDR been resolved?

  Yes
- 7. Are updated cost and schedule estimates available?

  Yes