Review of Twisted Racetrack Windings / Asm

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16 April 2004

Outline

Charge to reviewers:

- Does the twisted racetrack coil represent the desired features of the prototype and production modular coils?
- Does it meet requirements for measurement, diagnostics, testing?
- Are models/drawings of the clamps and chill plates ready for fabrication?
- Is the design consistent with coil winding and VPI plans?

Outline of presentation:

- Requirements and test objectives
- Overview of design
- Performance evaluation
- Work to be done

Purpose

- Twisted racetrack coil is one of four test articles (incl UT coil)
- First to demonstrate prototypical winding assembly and clamp design

Coil Electrical Parameters

Calculated quantity		Flat Racetrack	Twisted Racetrack	Prototype (Coil type C)	Production Coil type A	Production Coil type B	Production Coil type C
Number of elec turns per winding pack		14	9	9	10	10	9
Number of electrical turns per coil		28	18	18	20	20	18
Number of physical turns per electrical turn		1	4	4	4	4	4
Conductor width, with serve	in	0.625	0.350	0.350	0.350	0.350	0.350
Conductor height, with serve	in	0.500	0.391	0.391	0.391	0.391	0.391
packing fraction		0.78	0.78	0.78	0.78	0.78	0.78
Winding resistance at RT	ohms	1.366E-02	7.201E-02	1.506E-02	1.848E-02	1.802E-02	1.506E-02
Winding resistance at 120K	ohms	1.772E-03	2.111E-02	5.136E-02	6.304E-02	6.146E-02	5.136E-02
Winding resistance at 80K	ohms	7.835E-04	1.081E-02	6.662E-03	8.177E-03	7.972E-03	6.662E-03
Inductance - windings only	Henries	6.63E-04	7.91E-03	7.90E-03	1.240E-02	9.230E-03	7.900E-03
Time constant - windings only, RT	seconds	4.85E-02	1.10E-01	5.25E-01	6.71E-01	5.12E-01	5.25E-01
Time constant - windings only, 120K	seconds	3.74E-01	3.75E-01	1.54E-01	1.97E-01	1.50E-01	1.54E-01
Time constant - windings only, 80K	seconds	8.46E-01	7.32E-01	1.19E+00	1.52E+00	1.16E+00	1.19E+00
Max operating current per elec turn	Amps	N/A	N/A	N/A	40908	41561	40598
Maximum test current	Amps						

Goals for winding form fabrication

Objective		Metric
11	**Obtain first sample casting from EIO team**	
111	Pattern from Lawton	accurate translation of CAD data to pattern
112	pouring	riser design correctly predicted by flow solidification model?
113	distortion due to heat treat	part stays within machining allowance
115	radiography	buried defects within expected range
114	weld repairs	hours spent performing weld repairs
116	permeability of casting	permeability within 1.02 limit
12	**Obtain first sample machining of semi-prototypical casting**	
121	machining simulation and NC tape	Part can be machined
122	Fixturing	Part can be held and manipulated on machine
123	machining winding contour	winding contour within tolerance
124	Clamp features - pockets, tapped holes	clamp features within tolerance
125	potting groove	functional groove is provided
126	metrology datum targets	targets are useable and durable
127	permeability change due to surface work hardening	permeability within 1.02 limit
13	**Measurement of winding form at PPPL**	
131	Use of datum targets	targets are visible, useable and repeatable
132	Measurement of winding contour	contour measurements match 123 above
133	Measurement of clamp features	clamp features match 124 above
134	Best fit of as measured part to data	datum target locations can be redefined to optimize fit of selected features to theoretical part
14	**Preparation of first prototypical winding form for winding**	
141	mold release	Mold release prevents copper chill plate from sticking to winding form
142	kapton insulation	Maintains electrical isolation of chill plate
143	forming and attachment of internal copper chill plates	winding-side surface is accurate enough to place windings
144	weld studs	all studs welded to full structural integrity and geometric accuracy
145	winding start blocks at leads	start blocks attached with geometric accuracy of +/- 0.02 in.

Goals for coil winding process

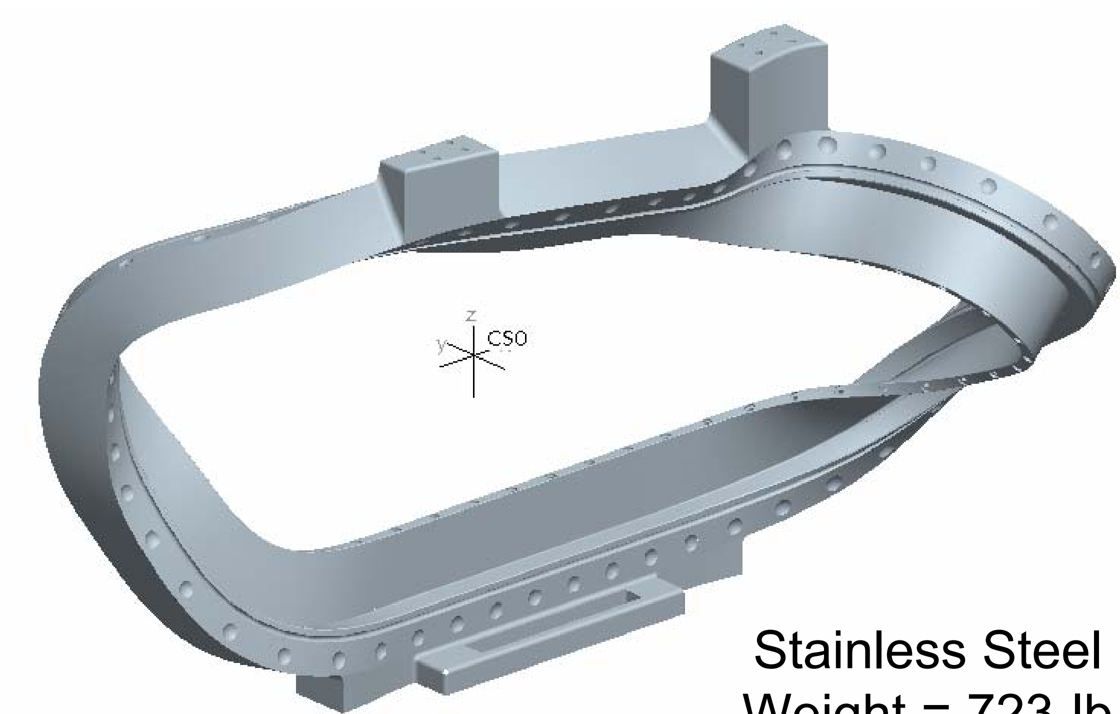
21	**Placing and "setting" conductor**	
211	Clamping conductor	winding clamps work as designed and are frequent enough to restrain winding within accuracy requirements
212	Measuring for shims	surface of as-wound layers can be measured and shim height calculated
213	Placing layer to layer shims	surface of layer after shimming meets or exceed tolerance requirements
214	Placing lateral shims between B and C rows	total winding width is within tolerance
225	Handling layer to layer joggles	joggles can be clamped and held with sufficient accuracy to keep lead geometry from wandering
22	**Leads**	
221	Initial placement and start of winding	placement in start blocks is within accuracy requirements
222	routing of 4 parallel turns at end of winding and interleaving with first turns	Lead arrangement can be clamped and held to required accuracy
223	dip soldering and re-insulating ends of leads	conductor ends can be trimmed to proper length and soldered into end lugs without damaging or contaminating rest of winding
224	conductor attachment to lead block	soldered end lugs match lead block properly
23	**Finishing winding pack stackup**	
231	forming of external chill plates	chill plates can be formed and fitted to winding pack
232	attachment of external chill plates to internal chill plates	thermal connection can be reliably made at both ends
233	forming and brazing of cooling tubes and pads	tube geometry is predictable and layout matches winding pack
234	attachment of cooling tubes to external chill plates	fastening system works without undue thermal isolation
235	attachment of G-11 pads at clamp locations	pads can be accuratel fitted and held in place and extra glass roving used to fill gaps
24	**VPI**	
241	application of self-fusing tape, including juggling of winding clamps and sealing around leads	tape forms good seal, removing clamps one by one does not distort winding
242	application of "french toast" pressure shell over bag	shell can be applied between clamps and is contained without wicking into clamps or clamp springs
243	pump down	winding pack pumps down to required pressure
244	heating to reduce viscosity	coil can be heated in autoclave to proper temperature in controlled manner without distorting winding or losing vacuum seal
245	epoxy impregnation	epoxy is contained within bag system
246	pressure cycling	vacuum/pressure/"milking" is successful
247	heating for cure	temperature can be raised in the proper time period without causing temperature gradients in winding form that result in distortion of winding
248	controlled cooldown	cooldown accomplished in controlled manner without distorting winding
249	cure shrinkage	shrinkage of winding relative to winding form is within predicted limits
25	**winding pack completion**	
251	cleanup of coil	excess epoxy can be removed, as well as self fusing silicone tape under winding clamps
252	attachment of final clamps and "tuning" preload	winding clamps replaced with operational clamps and the clamp preload set successfully

Goals for coil testing

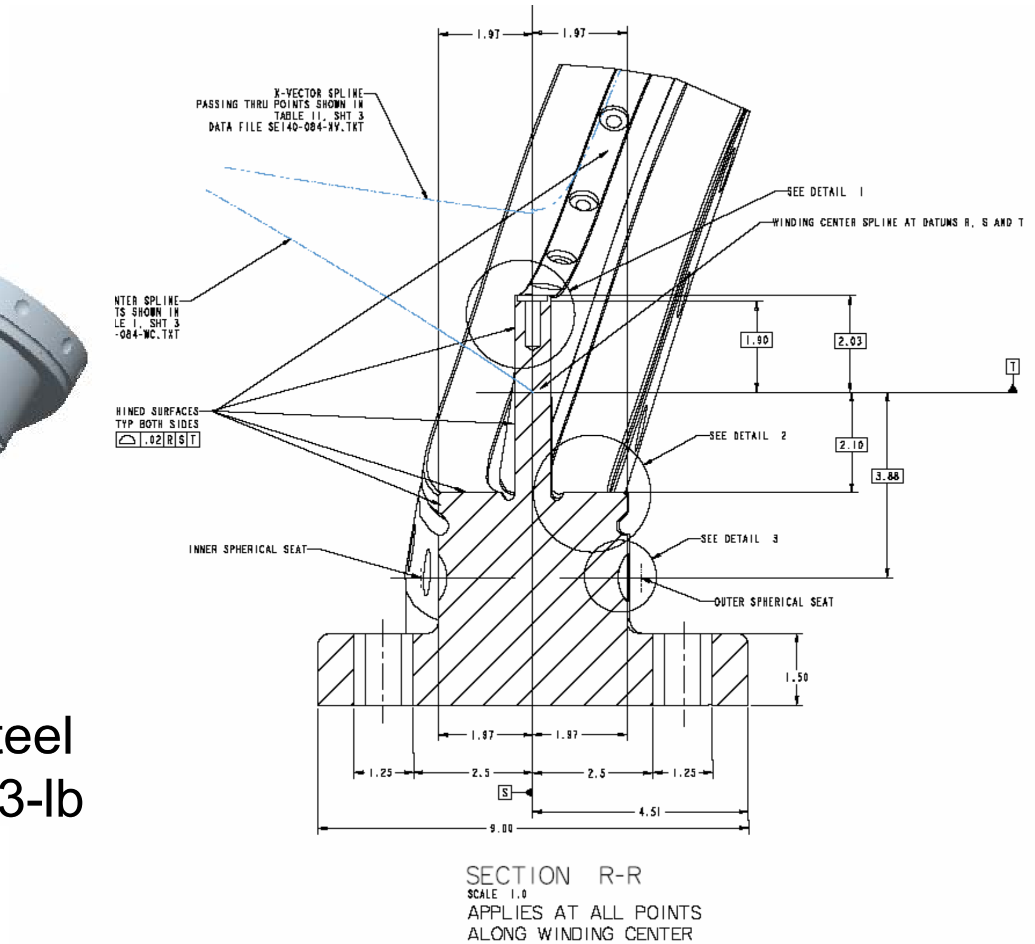
31	**Geometric tests**	
311	Gross winding pack shape relative to theoretical	as-measured winding pack geometry within acceptable tolerance
312	Winding form shape	as-measured winding winding form shape is the same as pre-potted shape
313	magnetic field measurement	field measurements consistent with geometric measurements
32	**electrical tests**	
321	resistance	Resistance at room temperature and LN2 temperature matches prediction
322	time constant / inductance	decay time matches prediction
33	**hydraulic tests**	
331	Flow rate	Required flow rate can be achieved
332	pressure drop of LN2	Pressure drop matches prediction for range of flow rates
34	**Thermal tests**	
341	cooldown from RT to LN2 temp	winding form and winding pack cool down as expected
342	heating during current pulse	temperature rise during current pulse matches prediction
343	cooldown between pulses	Winding returns to pre-shot temperature within 15 minutes
35	**Structural tests**	
351	Strain in winding form from cooldown to LN2 temp	Measured strain in winding form matches prediction within 20%
352	Strain in winding form from magnetic loads	Measured strain in winding form matches prediction within 20%
353	gaps between winding packs and tee before, during and after magnetic loading.	Distortion of winding pack relative to winding form matches prediction within 20%
36	**fatigue tests**	
361	change in resistance vs strain in winding pack, cycles	no detectable (< 5%) change for number of cycles tested
362	changes/increases in deflection vs number of cycles	no detectable (< 5%) change for number of cycles tested
363	degradation in cooling behavior vs cycles	no detectable (< 5%) change for number of cycles tested
364	degradation in clamps (wear in insulation, loss of preload, bending/breaking of studs, thread loosening) vs cycles	no detectable degradation for number of cycles tested
365	degradation in crossover and lead connections vs number of cycles	
37	**Instrumentation**	
371	temp instrumentation is reliable and accurate	Temperature signals have consistent response and accuracy
372	strain instrumentation is reliable and accurate	Strain signals do not drift
373	deflection instrumentation is accurate	deflection measurement technique is repeatable
374	voltage taps work	voltage tap system can be used as reliable signal for coil protection system
38	**Power feeds (coax leads)**	
381	Power feeds can be routed as needed and work at LN2 temp	bend radius consistent with specs
382	Power feeds work at LN2 temp	no degradation, voltage drop matches prediction
383	Power feeds do not introduce heat leak to coils	lead temperature matches coolant temperature during idle
384	Power feeds do not "kick" or put undo strain on coil lead terminations	no appreciable movement when energized
385	error fields within limits	error fields from coax power feeds negligible
386	Frost at warm end of power feed can be controlled	low power blower can eliminate frost at warm end

Winding form geometry

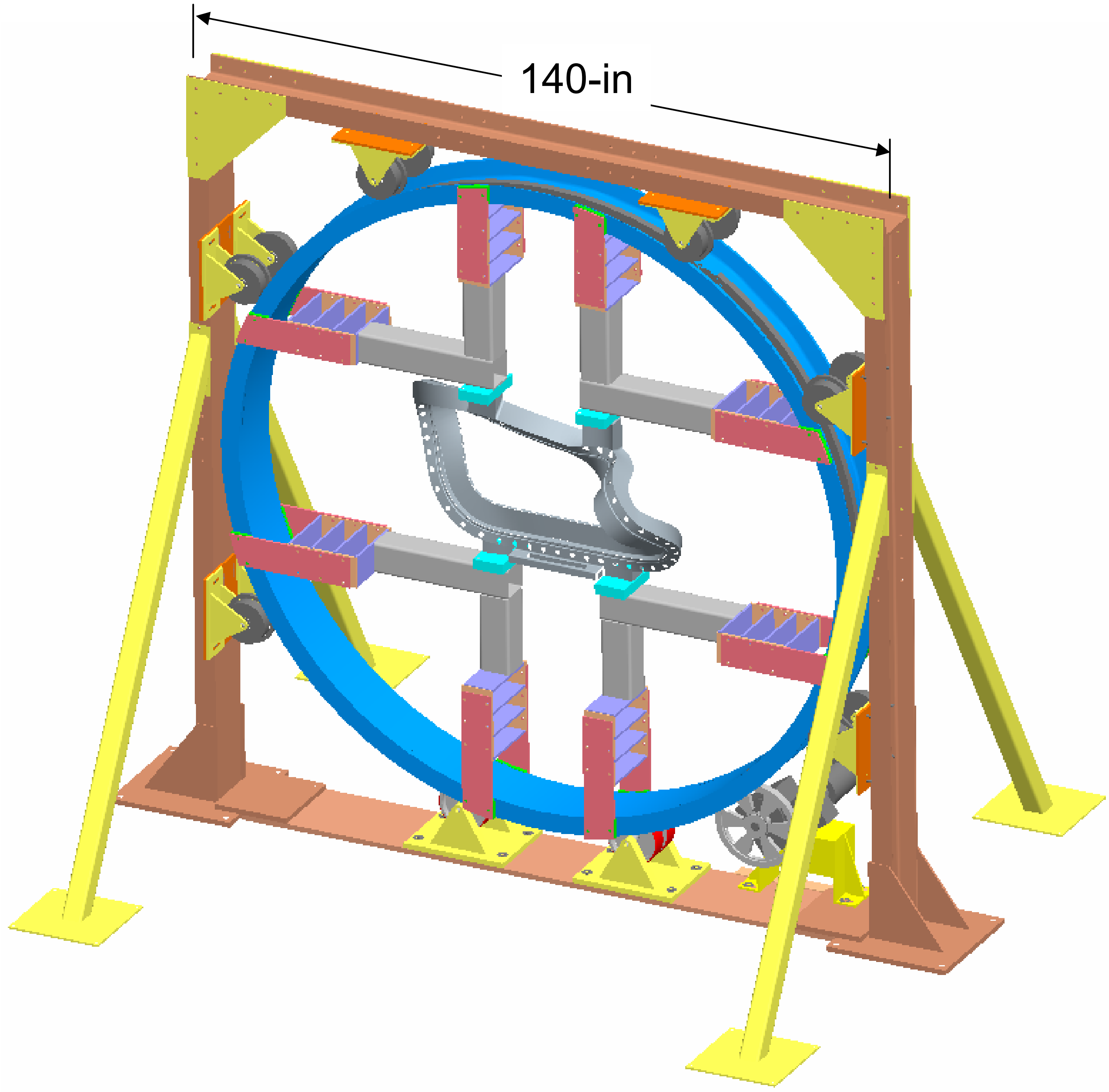
- Winding path is composite of production coil “worst” regions
- Machined features identical to prototype modular coil
- Currently being machined, delivery by end of April



Stainless Steel
Weight = 723-lb

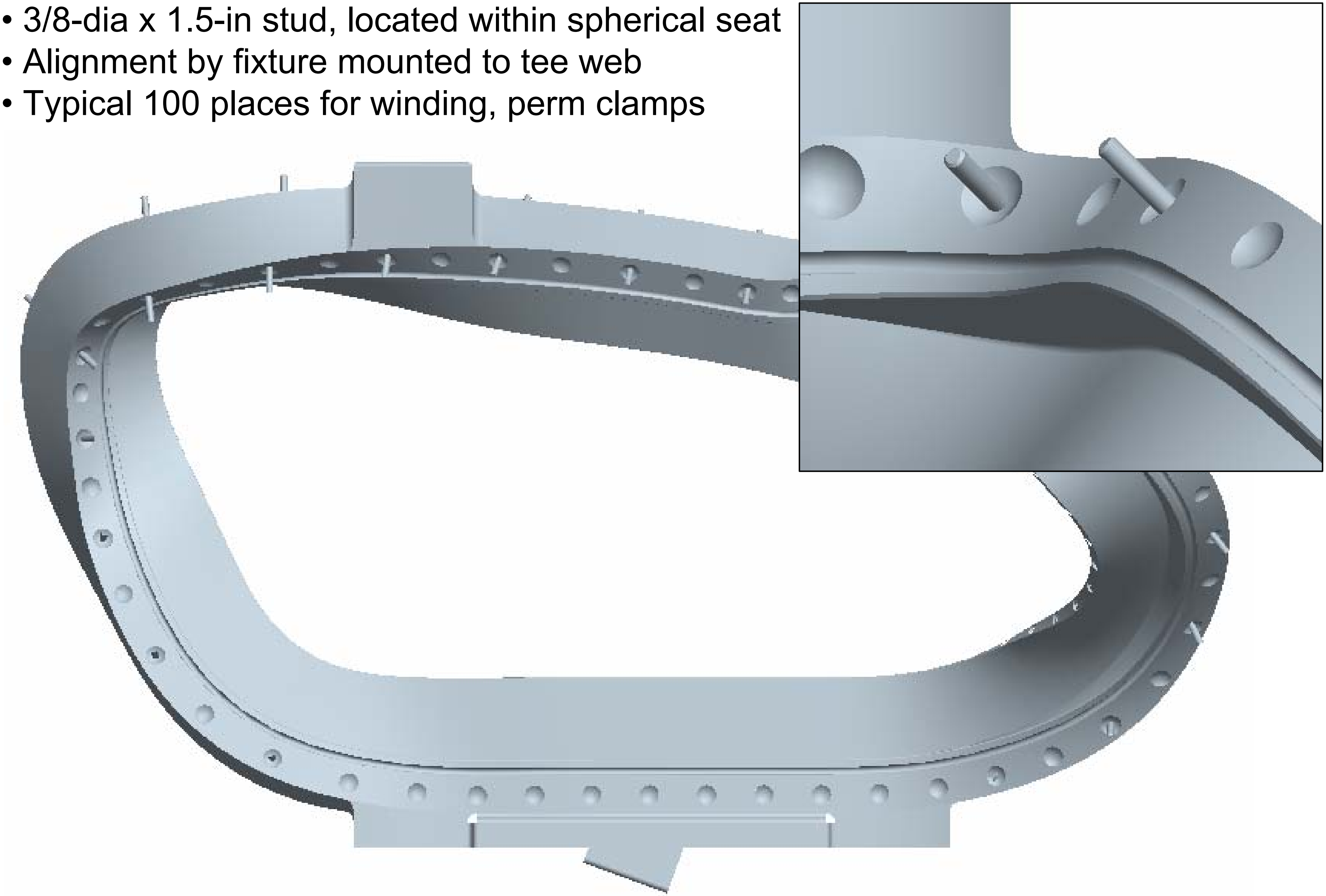


Winding form in turning fixture



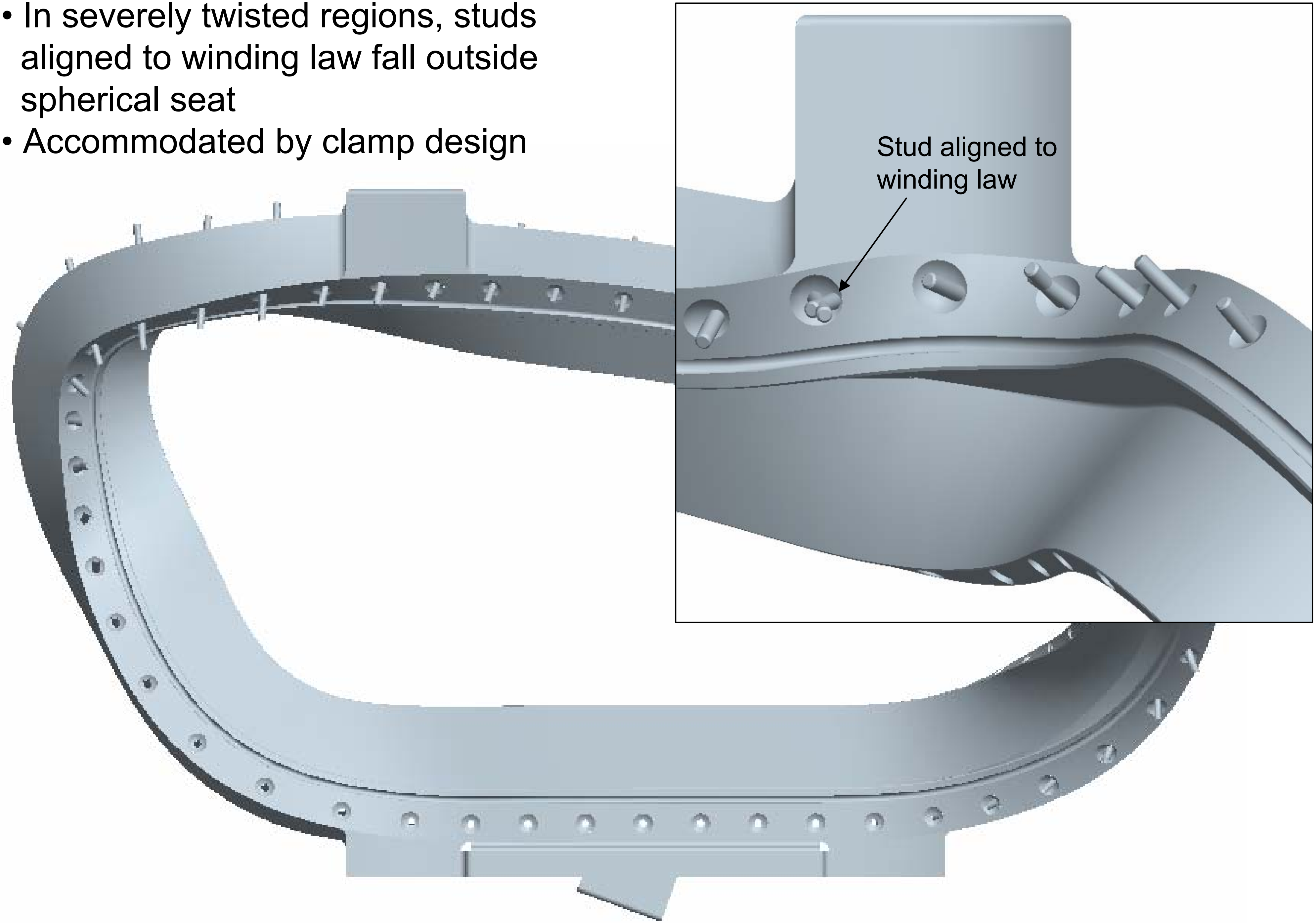
Features to be added

- 3/8-dia x 1.5-in stud, located within spherical seat
- Alignment by fixture mounted to tee web
- Typical 100 places for winding, perm clamps



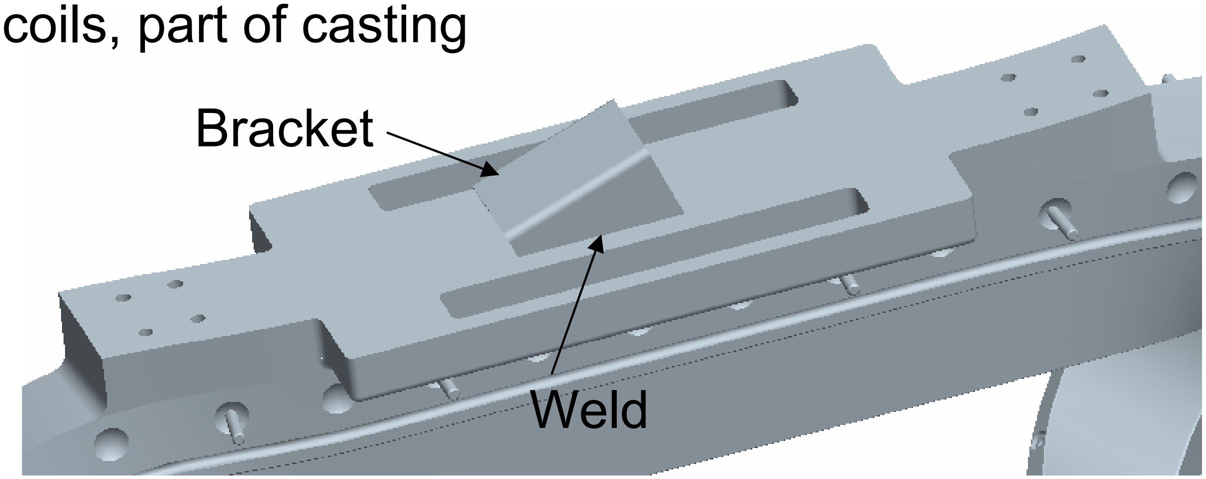
Stud alignment varies

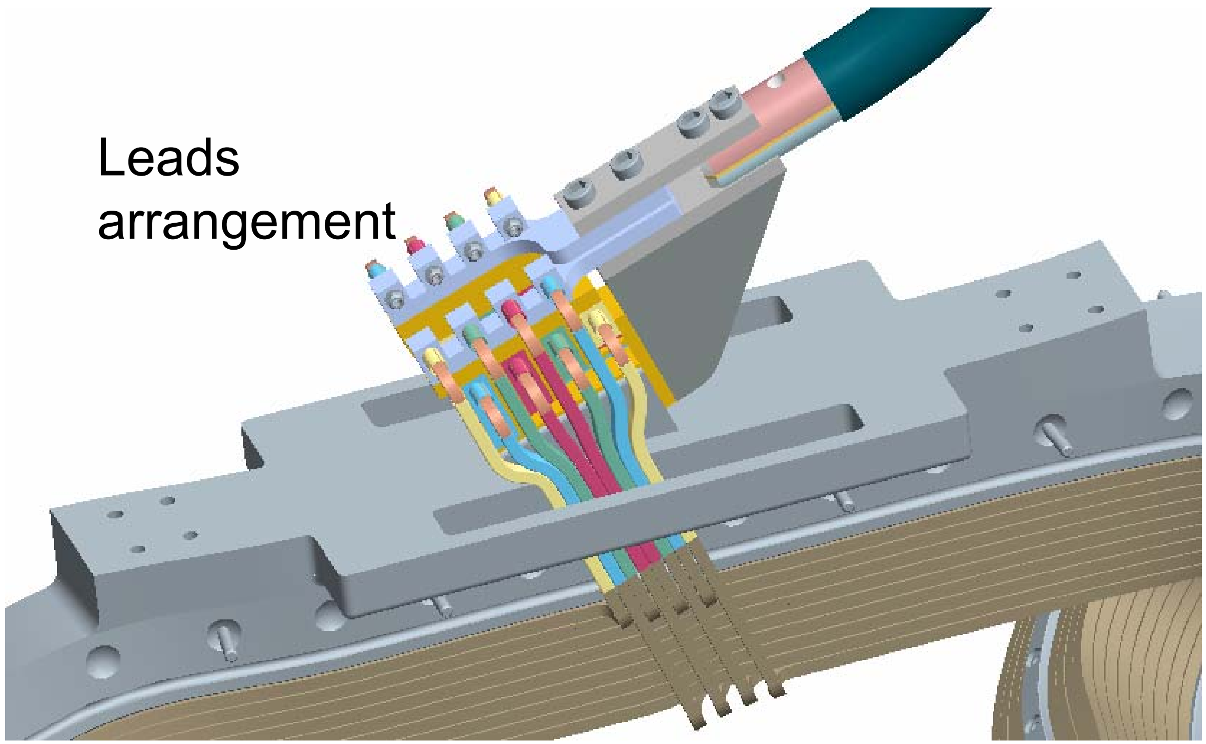
- In severely twisted regions, studs aligned to winding law fall outside spherical seat
- Accommodated by clamp design



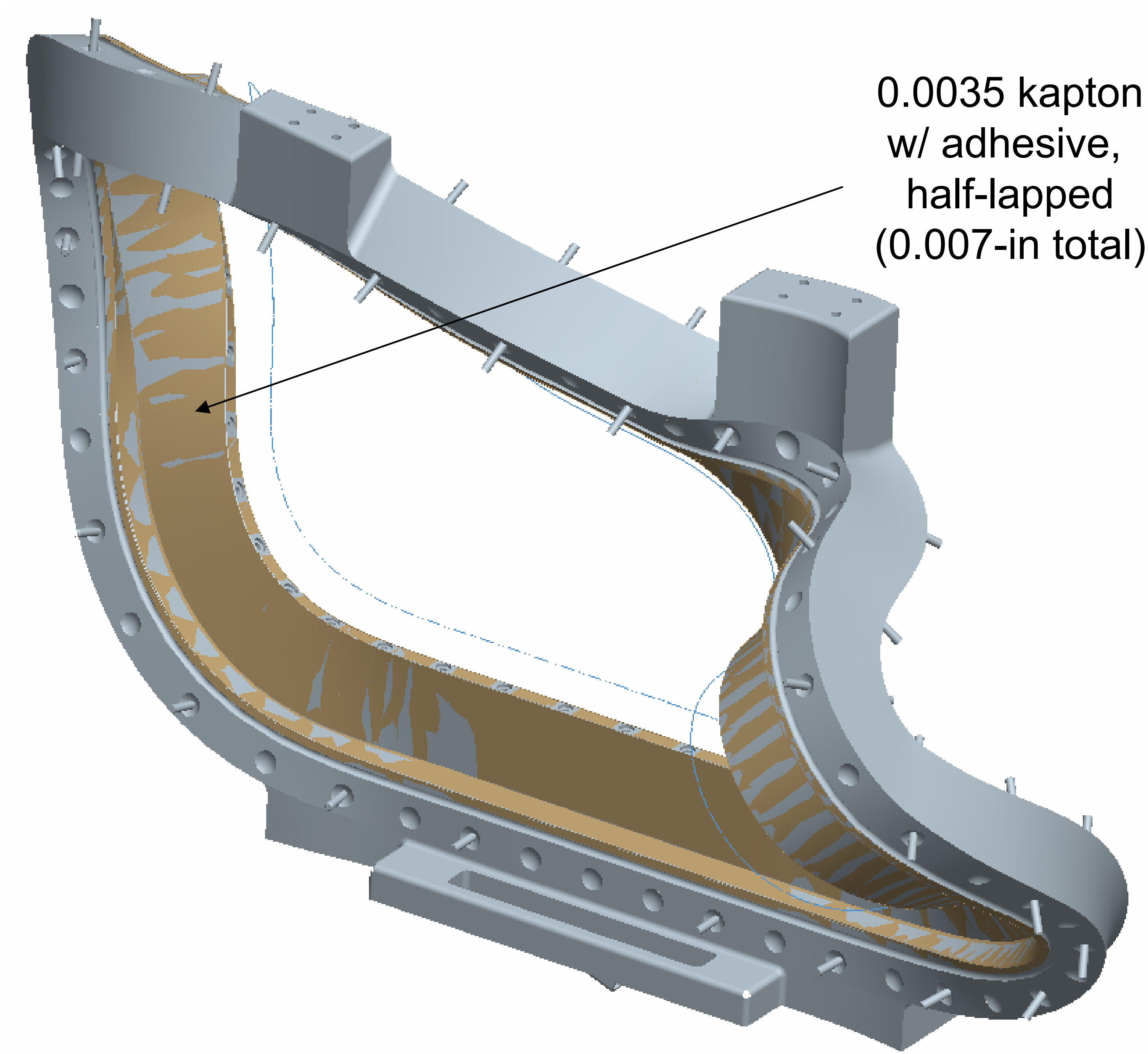
Bracket to be added

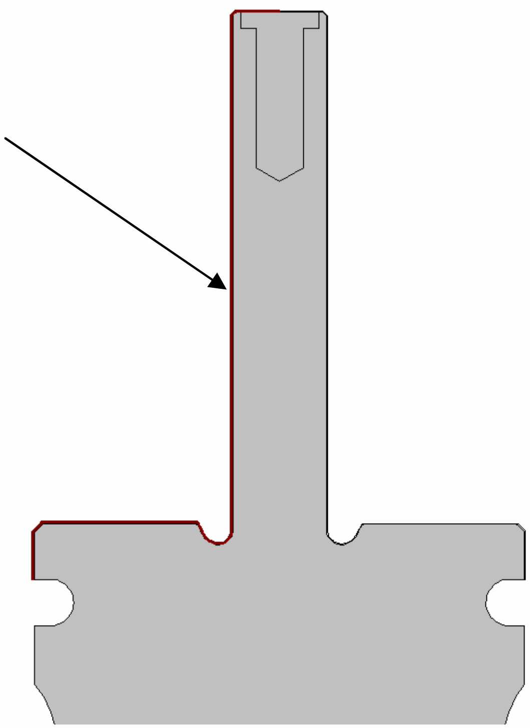
- Bracket needed to mount prototypical terminal block
- In production coils, part of casting





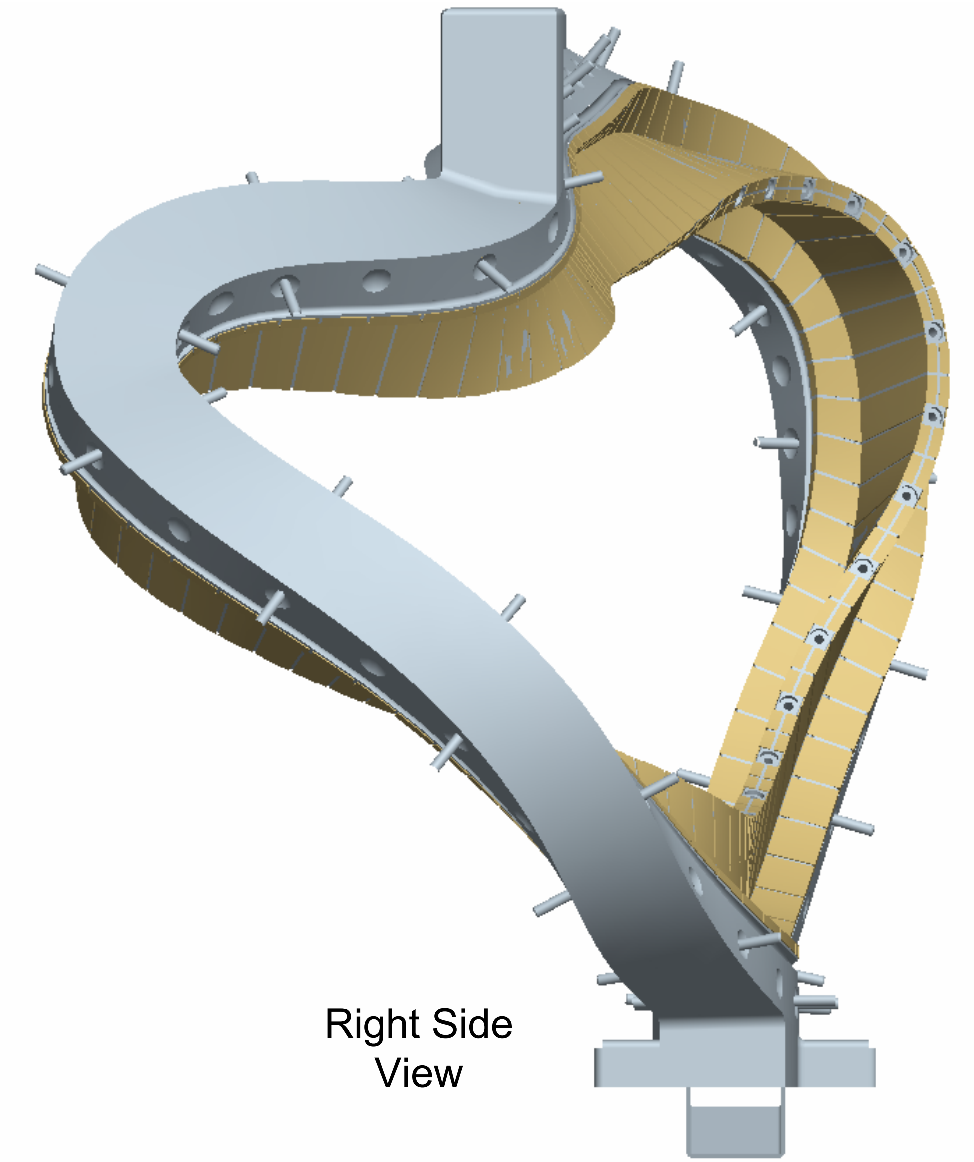
First layer – electrical insulation



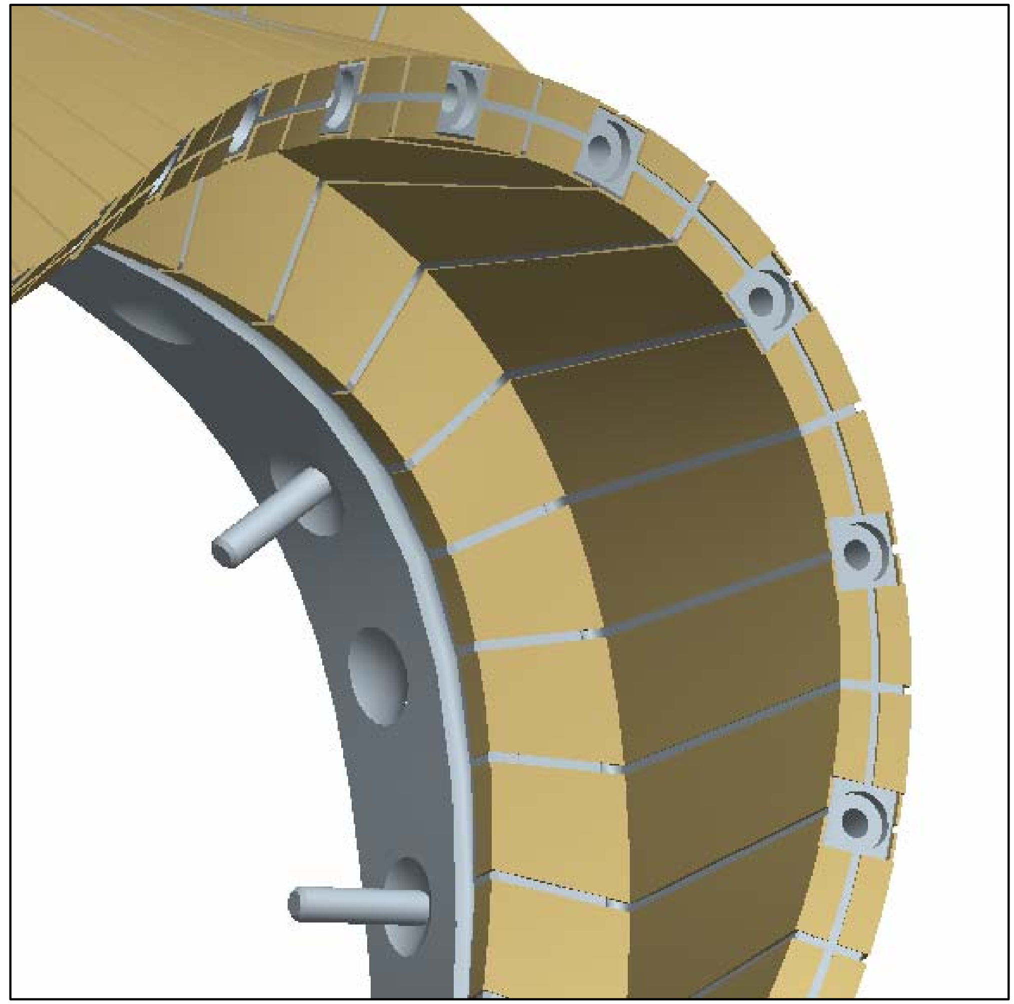


Second layer – copper cladding

- Copper sheet, 0.040-in thick
- Approx dims = 1.4 x 6.1-in
- Qty = 200 parts

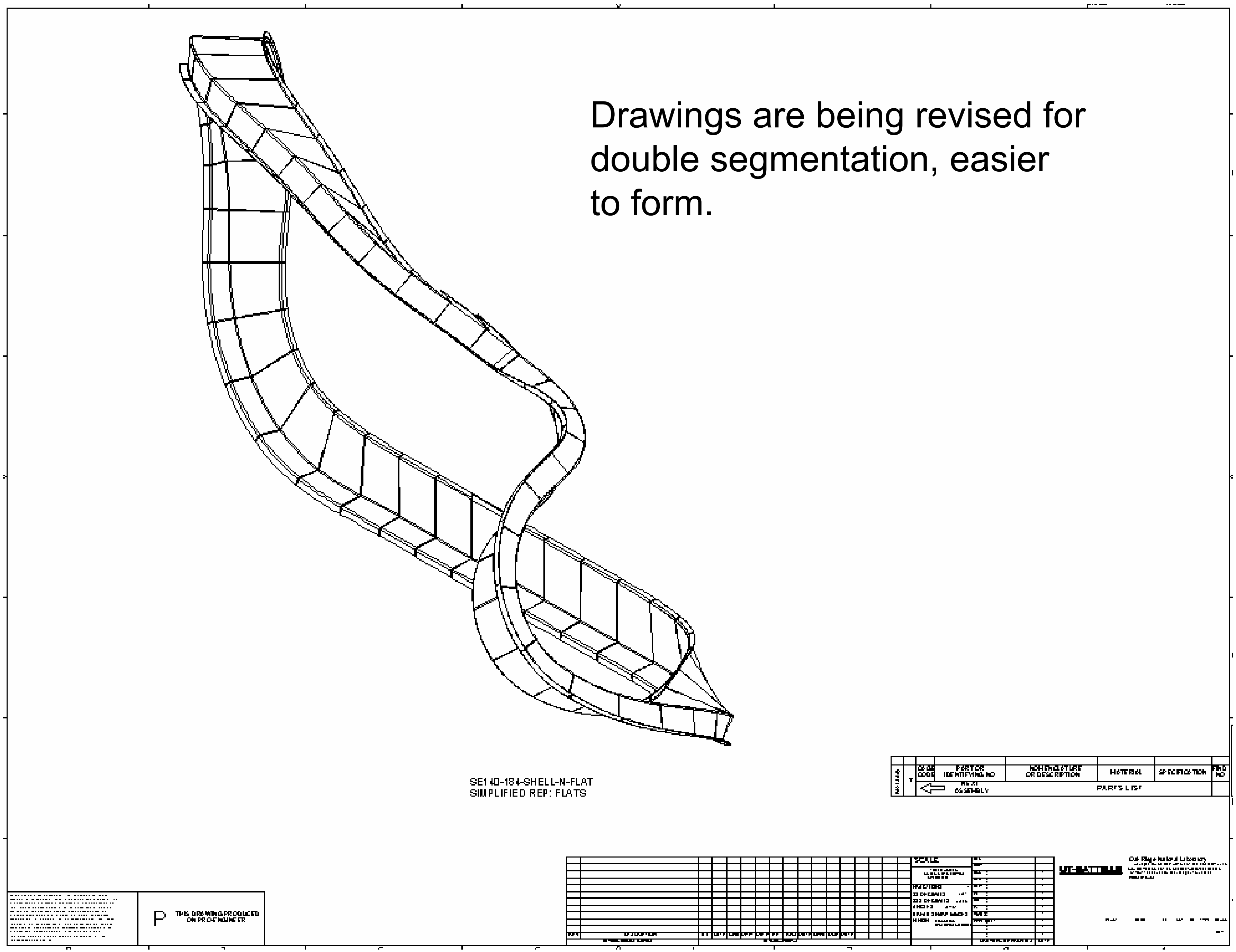


Right Side View



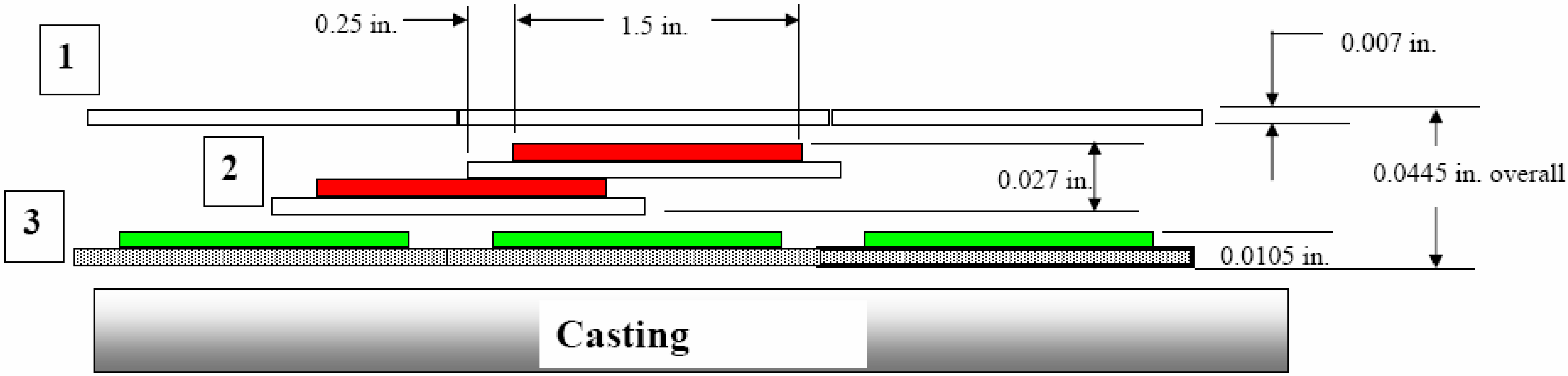
Drawings based on 3-in segmentation

Drawings are being revised for double segmentation, easier to form.



Developed shapes for 3-in segmentation

Third layer – ground insulation



1 (1) Butt lapped layer
0.007 in. thick S-2 glass [2 inch nom. wide]

2 (1) Half-lapped layer of composite:

- 0.007 in. thick glass [2 inch nom. wide] & 0.0065(HN) Kapton [1.5 nom. wide] with adhesive
- X 2 = 0.027 in. thick

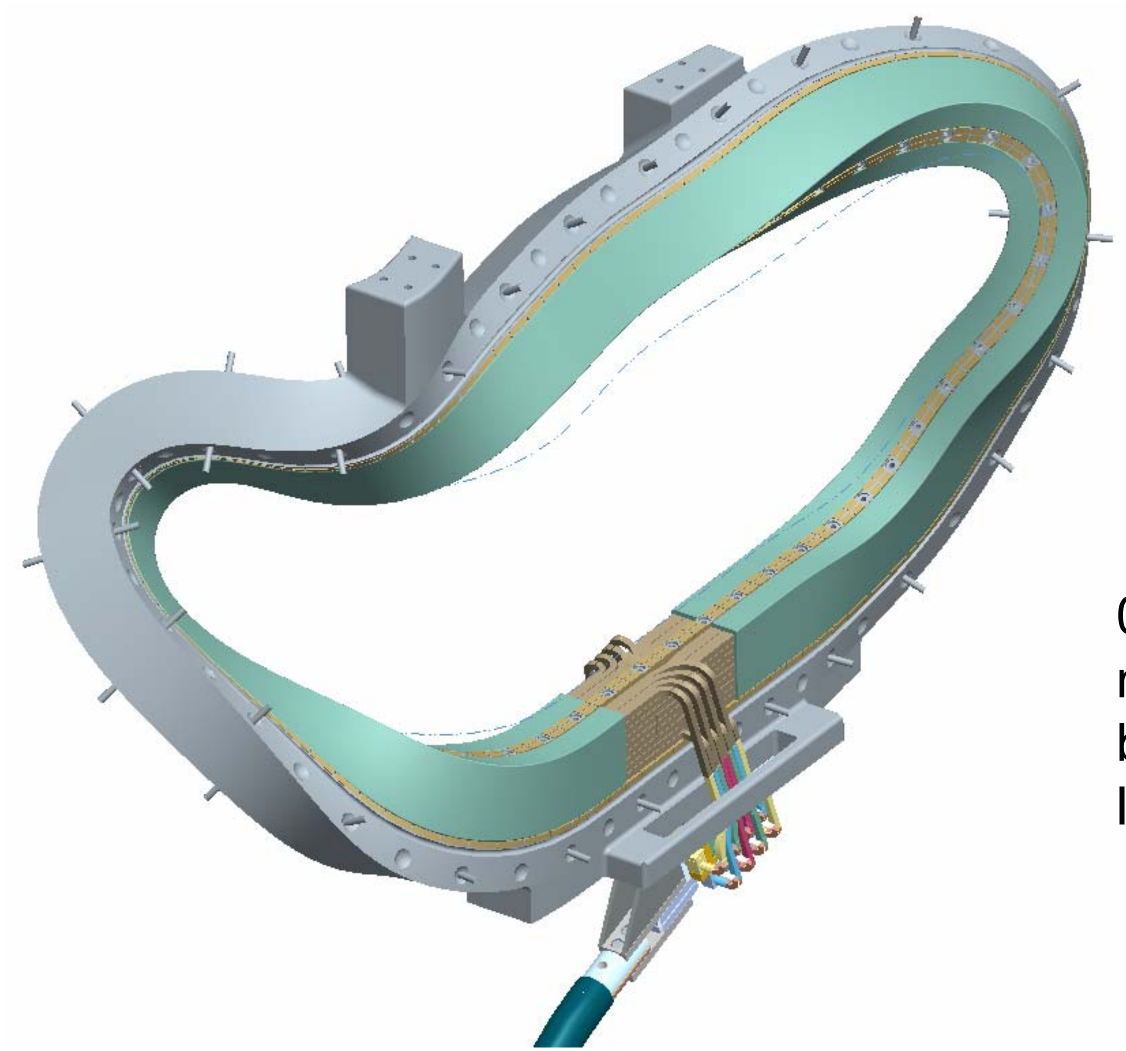
3 (1) Butt lapped layer of composite:
-0.007 in. thick glass [2 inch nom. wide] and 0.0035 (HN) Kapton [1.5 nom. wide]) with adhesive

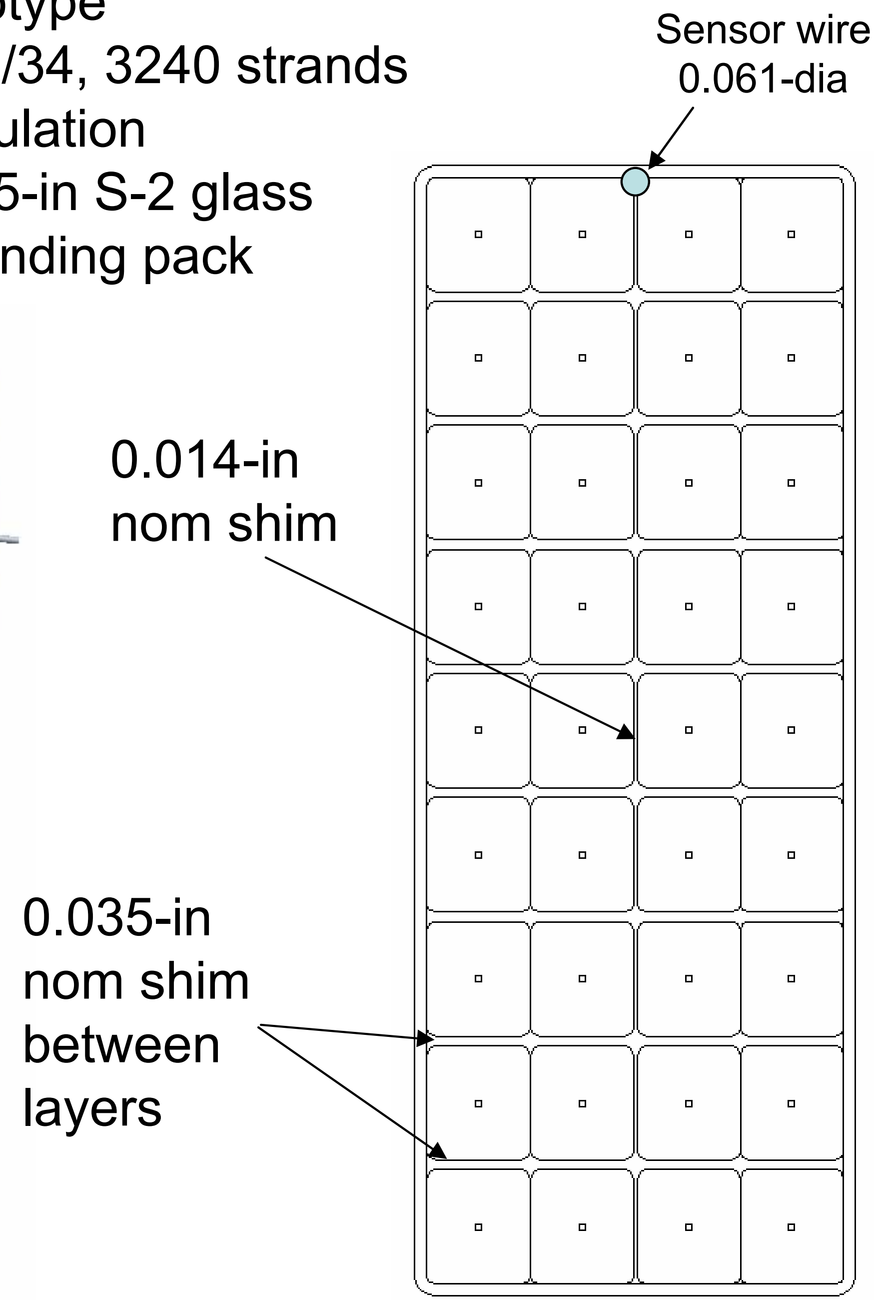
Tracking distance = 1.0 inches

March 24, 2004
J.H. Chrzanowski

Winding pack

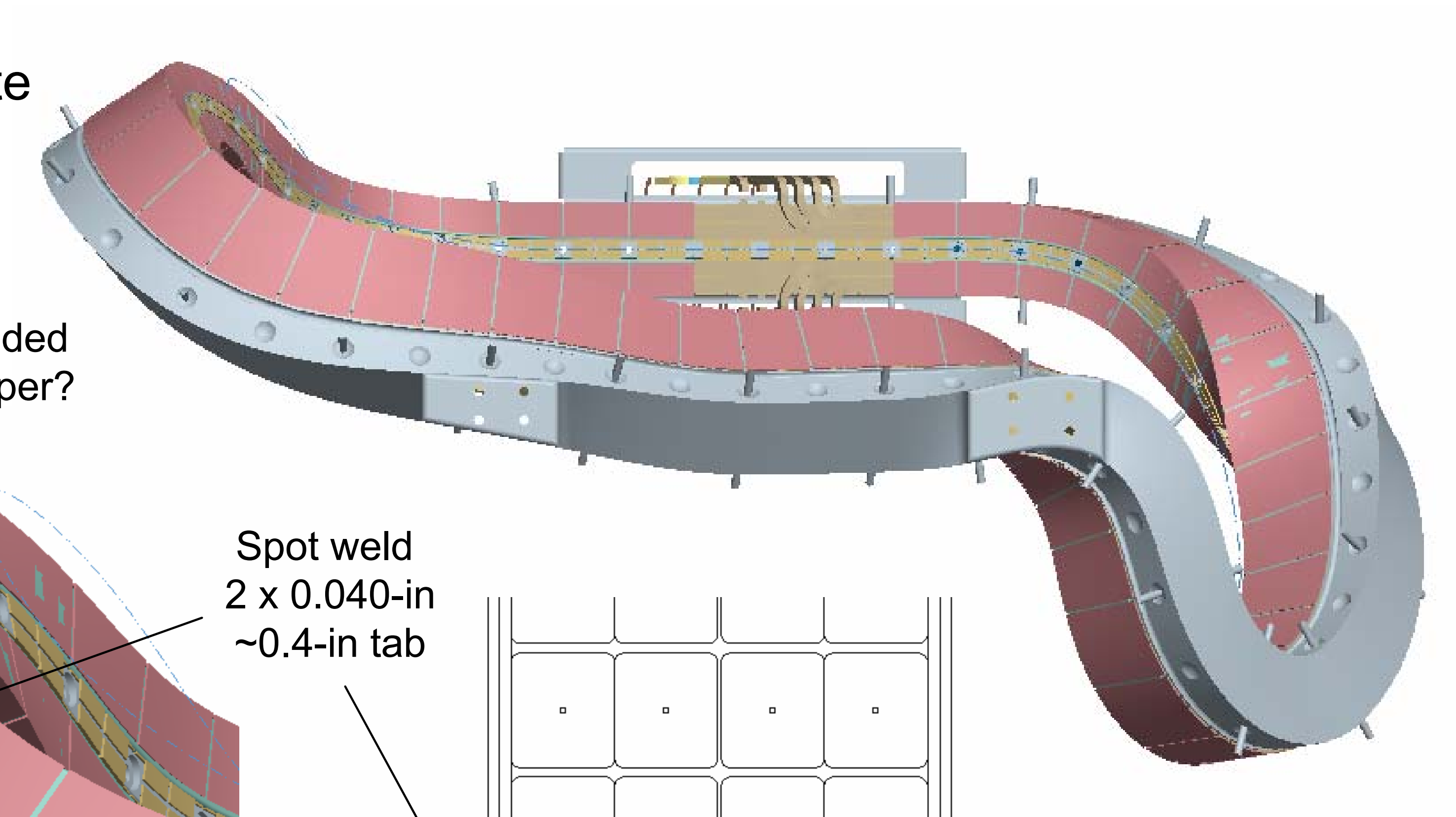
- 4-in-hand, 9 turns / winding pack as in prototype
- Conductor is OFHC copper, 34-ga, 12x5/54/34, 3240 strands
- Conductor dims = 0.372w x 0.413h, incl insulation
- Insulation = 0.004-in nylon serve, 2 x 0.0055-in S-2 glass
- Total length = 432-ft, weight = 573-lb per winding pack

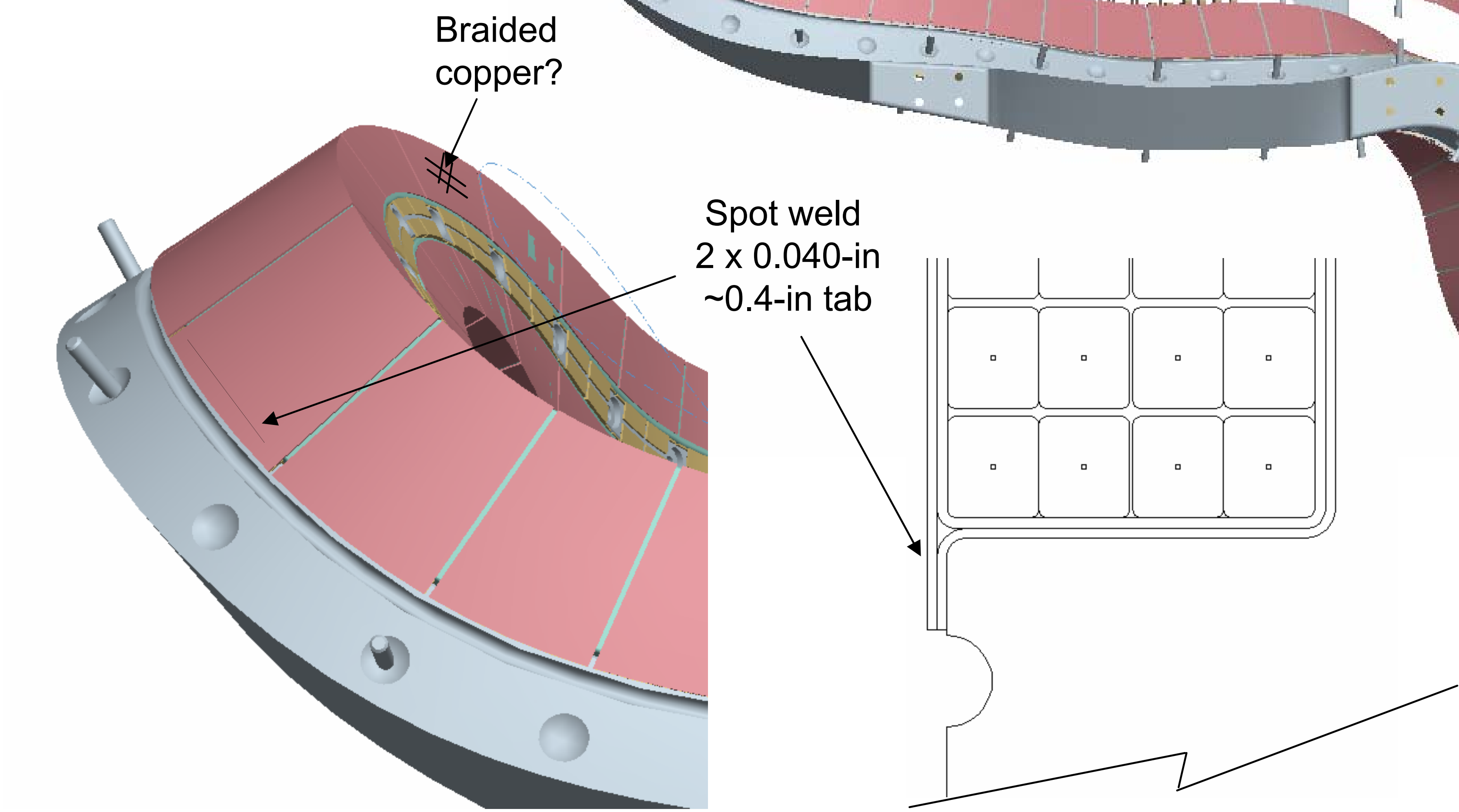




Outer chill plate and cooling

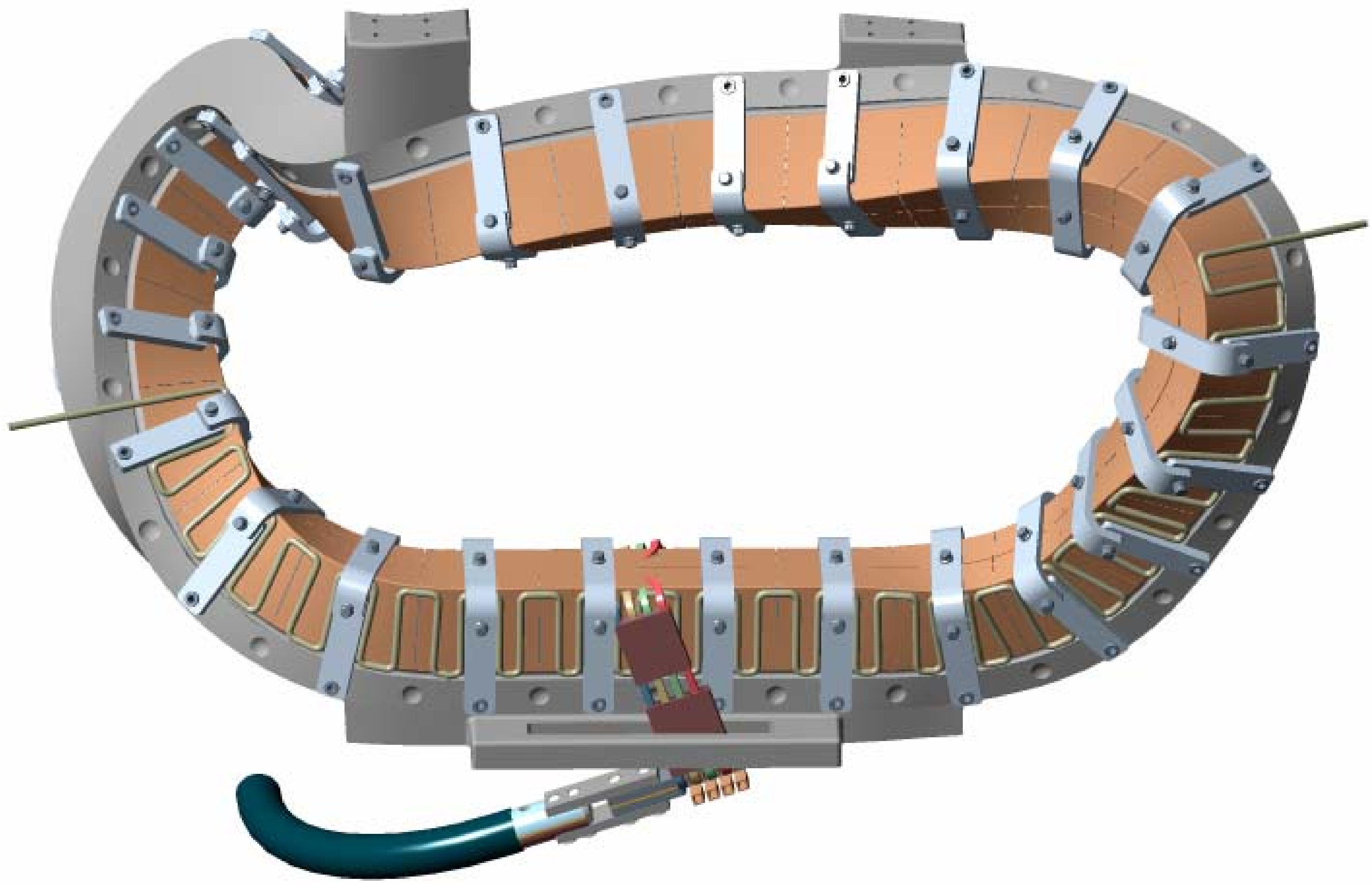
- Copper sheet, 0.040-in thick
- Approx dims = 3 x 6-in
- Qty = 100 parts
- Attached to inner plate at tee base





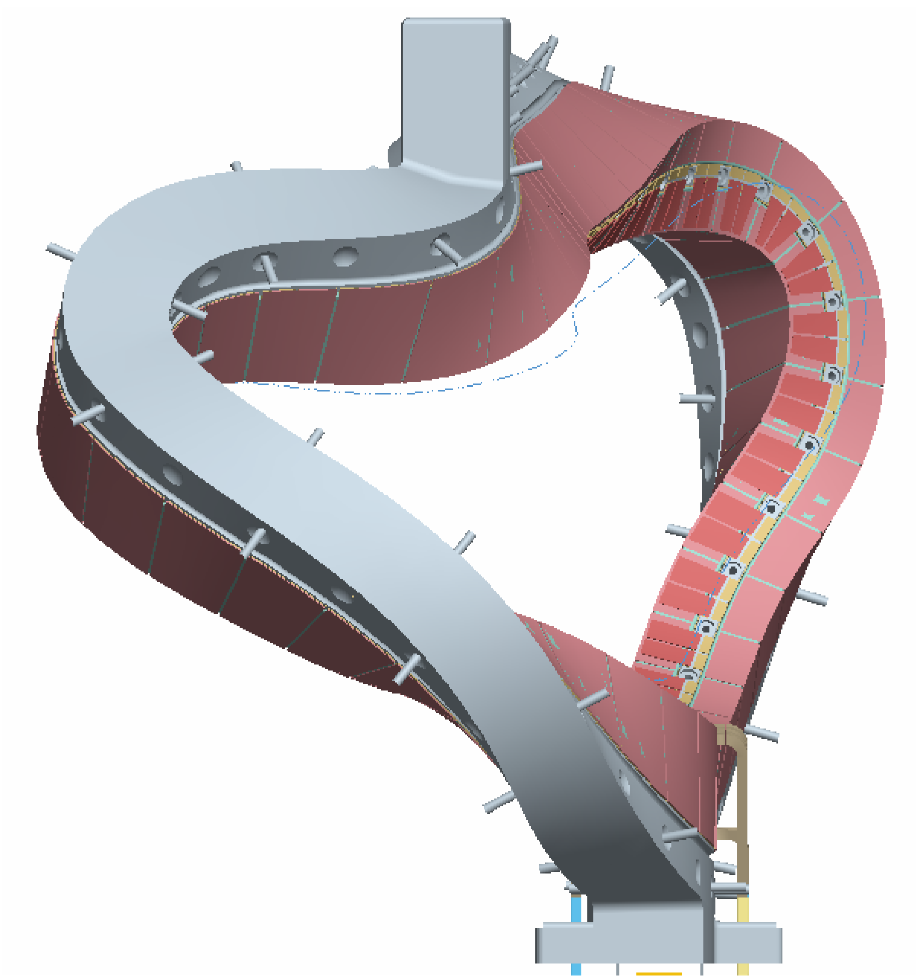
Cooling tubes

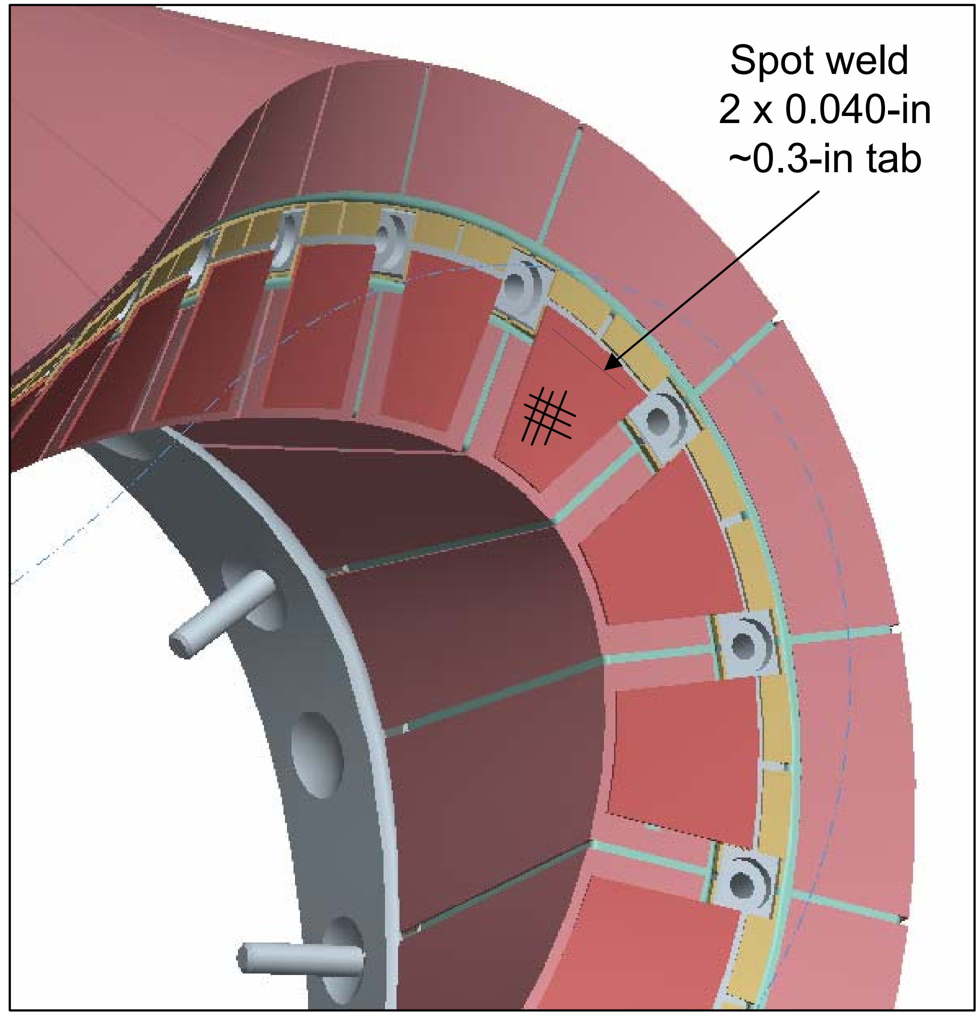
- 3/8-dia copper tube, 4 circuits, ~25-ft ea
- Models / drawings not complete

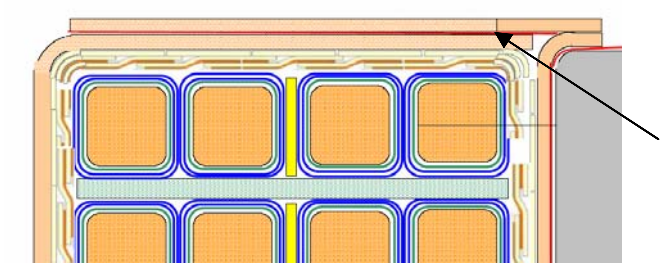


Outer chill plate (2)

- Copper sheet, 0.040-in thick
- Approx dims = 2 x 3-in
- Qty = 100 parts
- Attached to inner plate at tee web

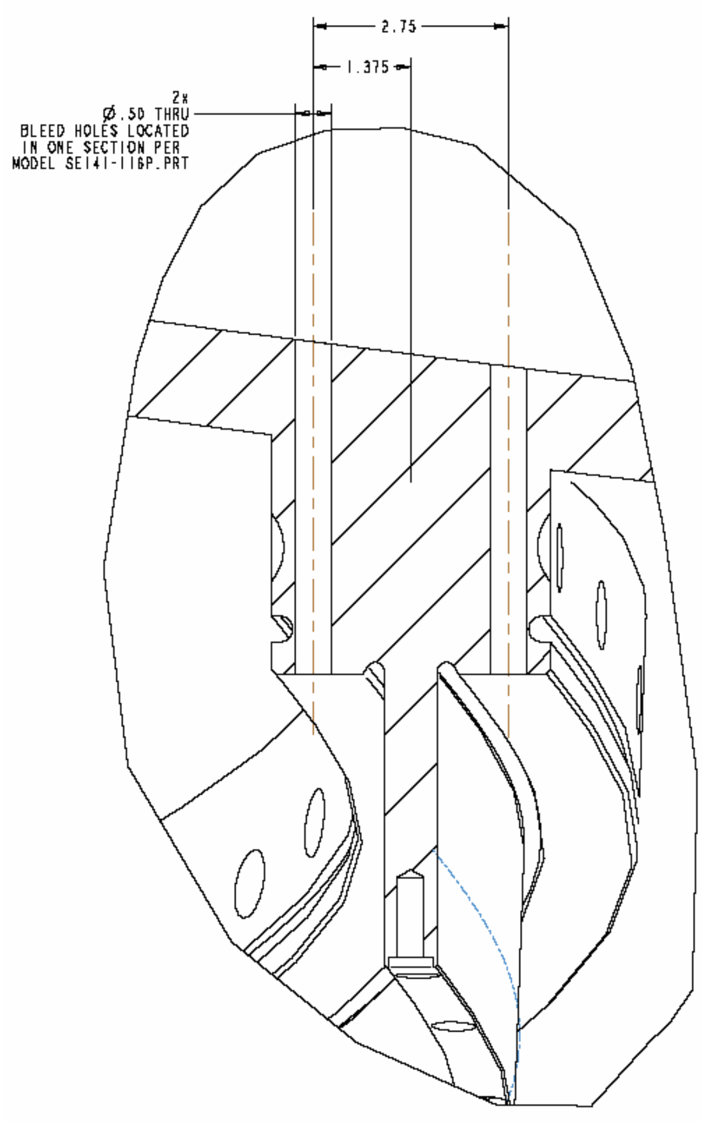


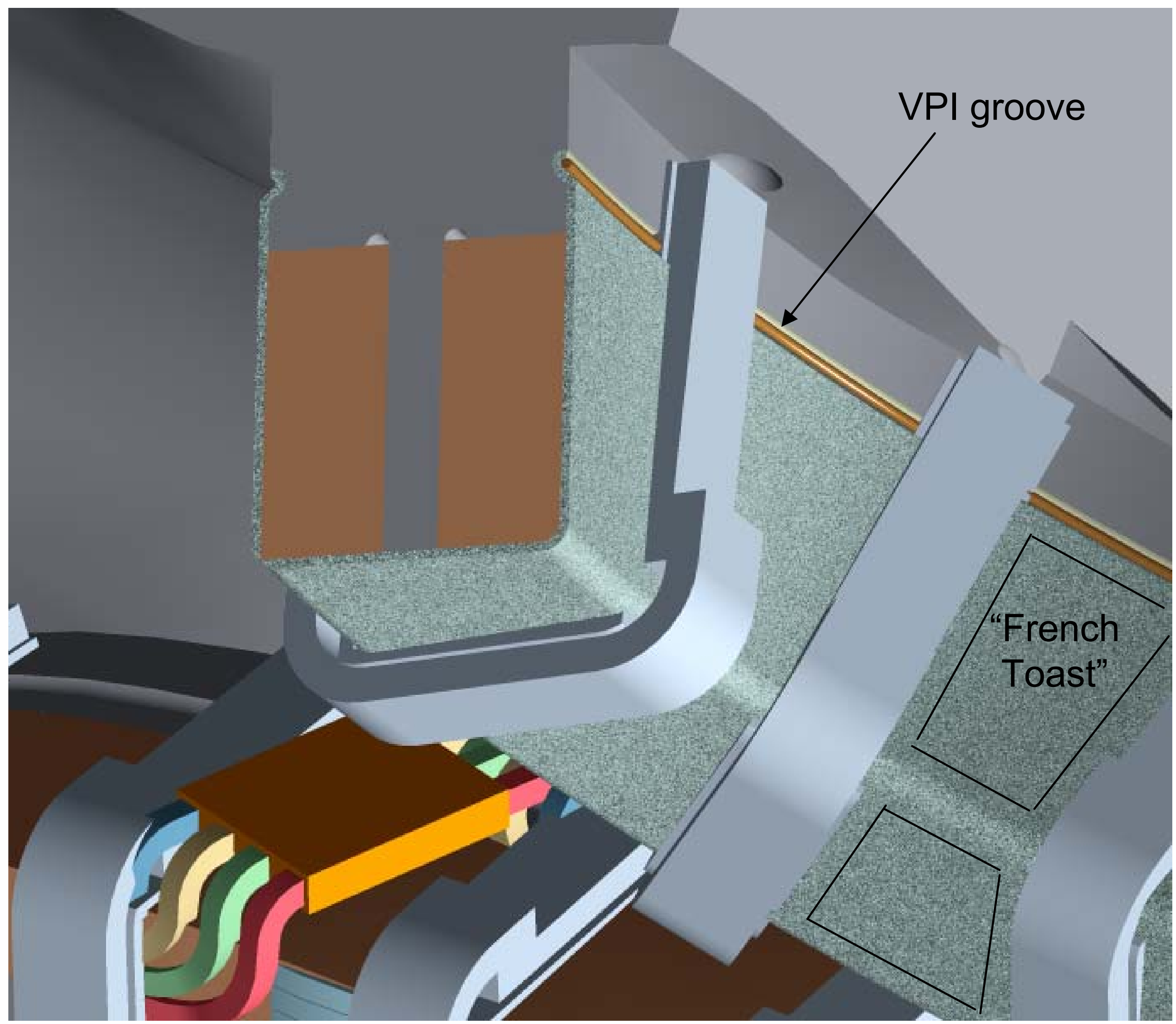




VPI bag mold

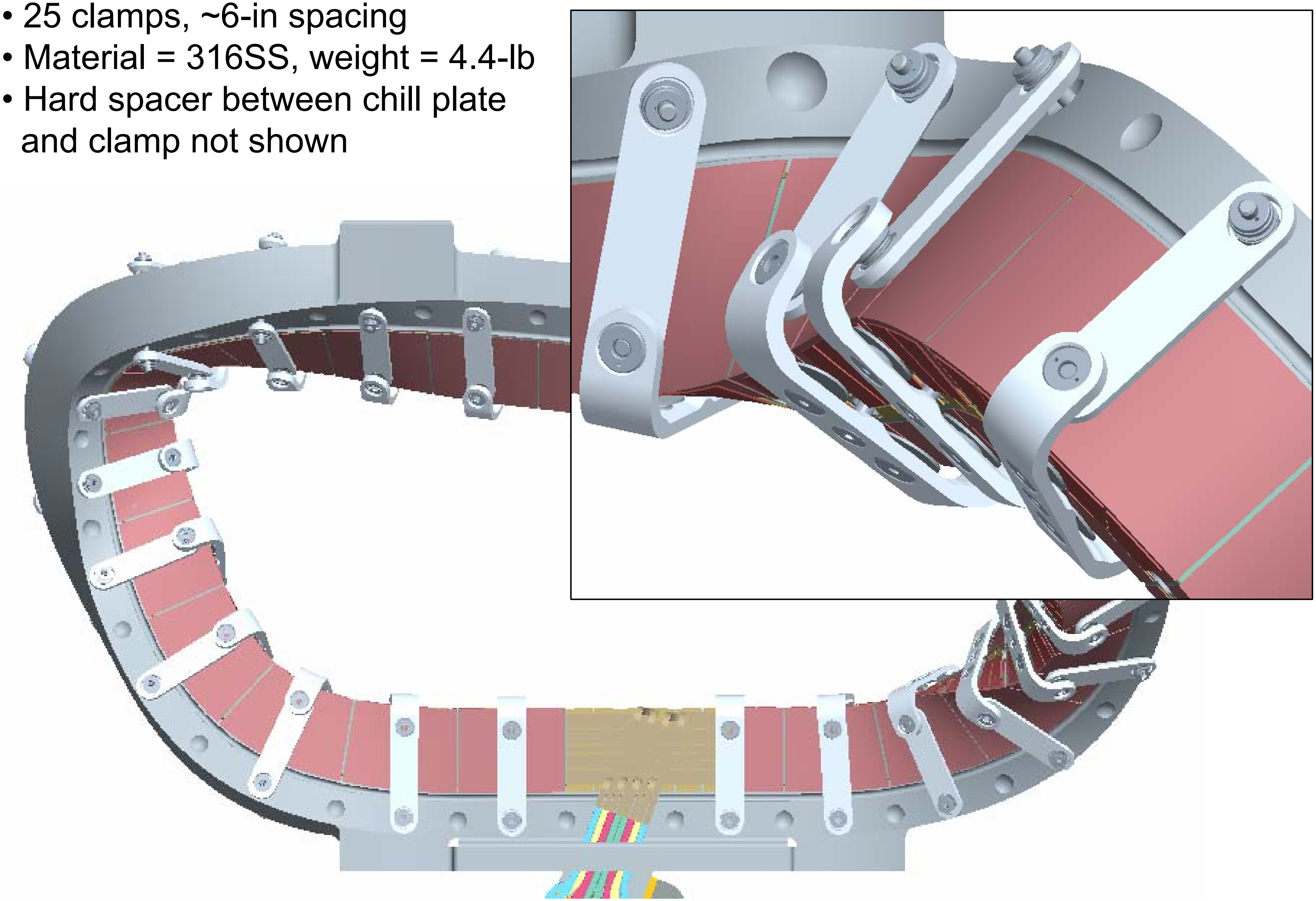
- VPI mold composed of epoxy impregnated felt and silicon rubber tape
- Located between winding pack and clamps, sealed by base groove
- Bleed holes at “top” position



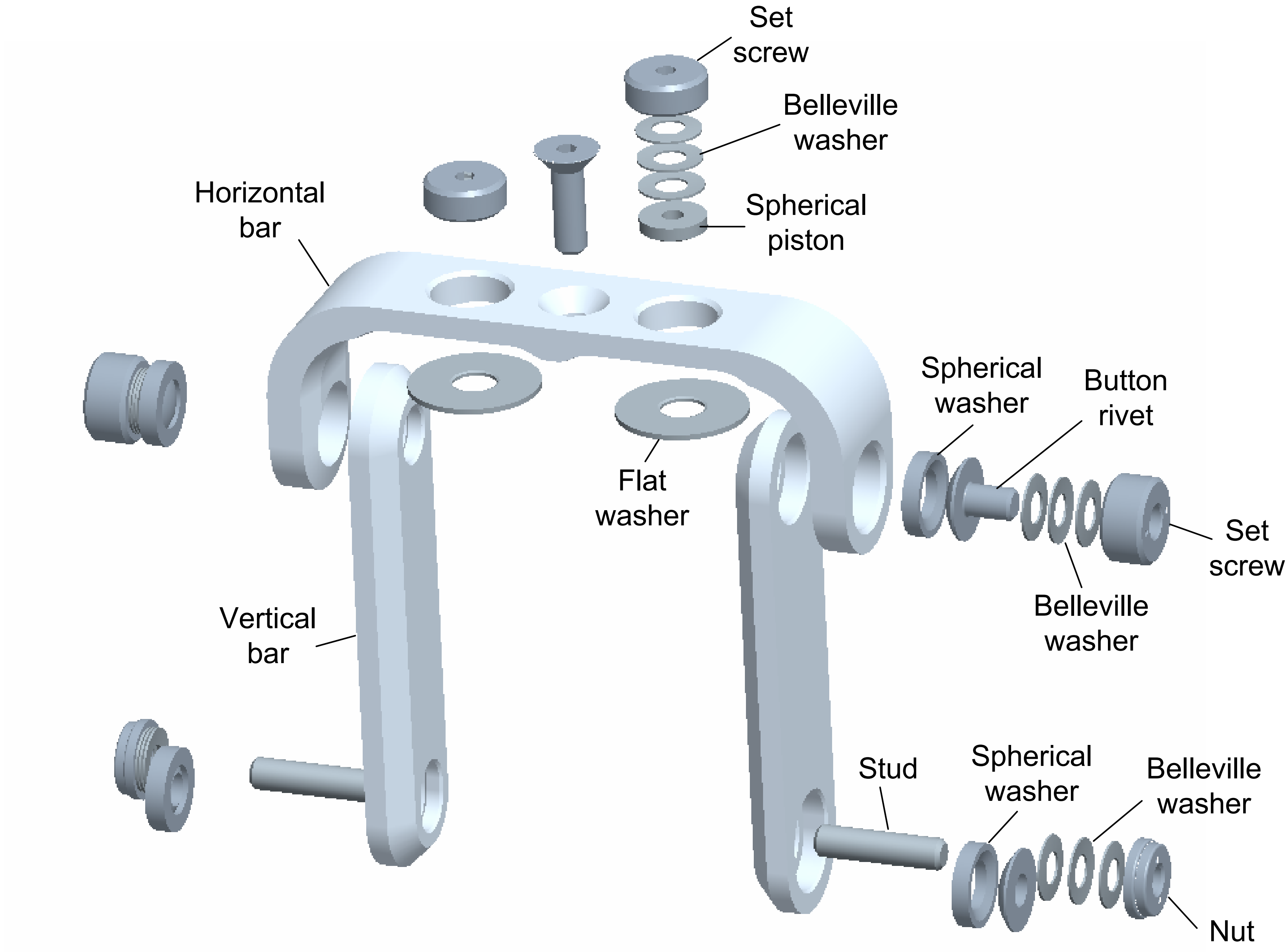


Clamp assemblies

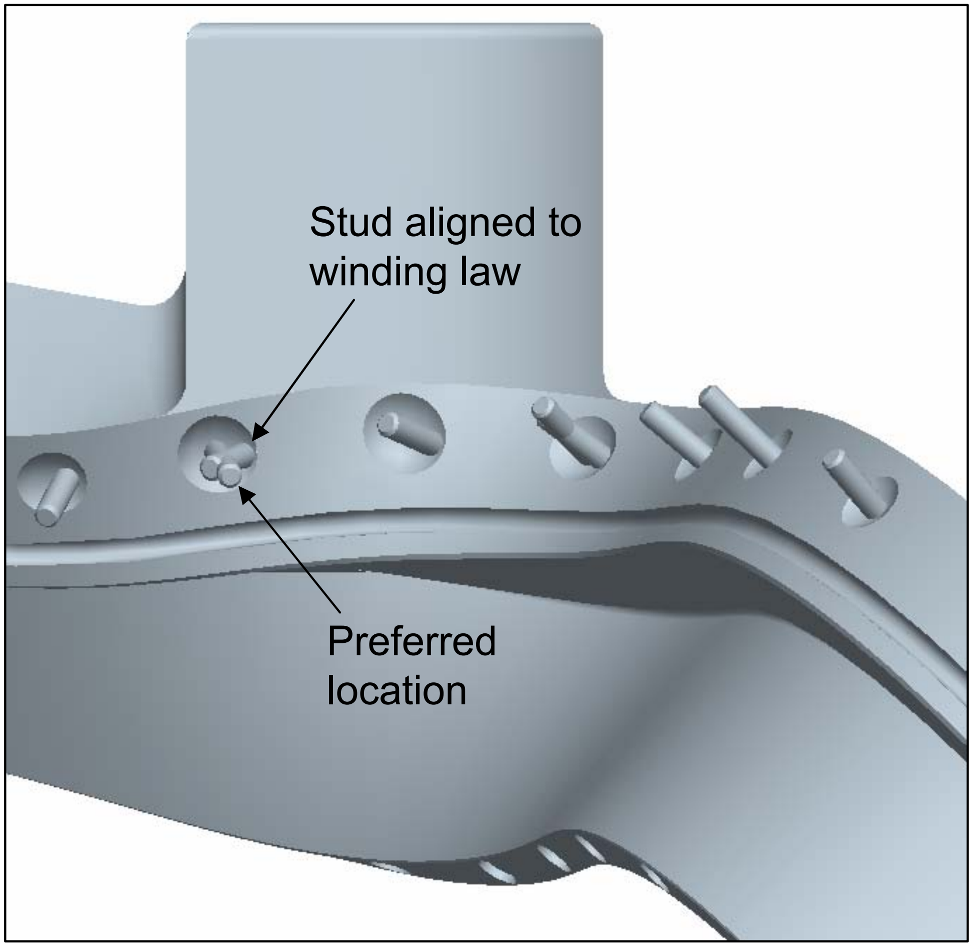
- 25 clamps, ~6-in spacing
- Material = 316SS, weight = 4.4-lb
- Hard spacer between chill plate and clamp not shown

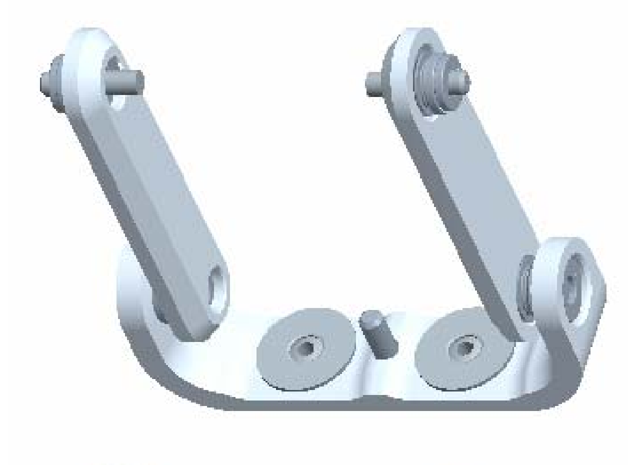


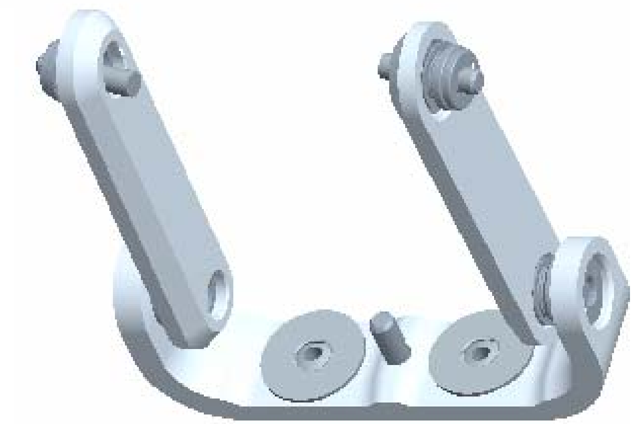
Clamp exploded view

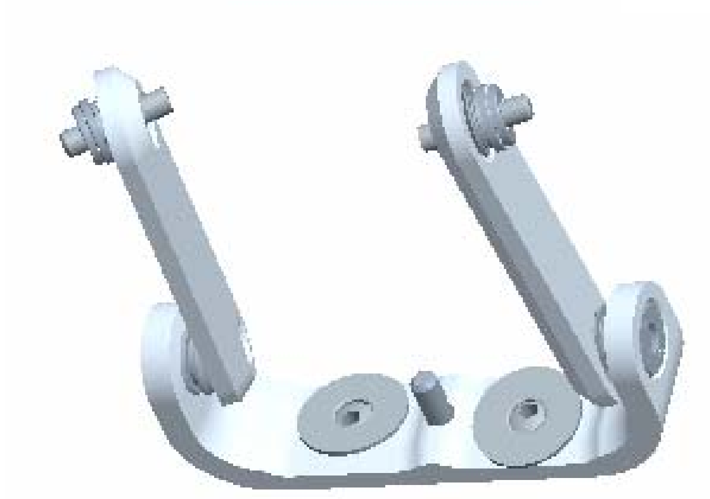


Assembly positions









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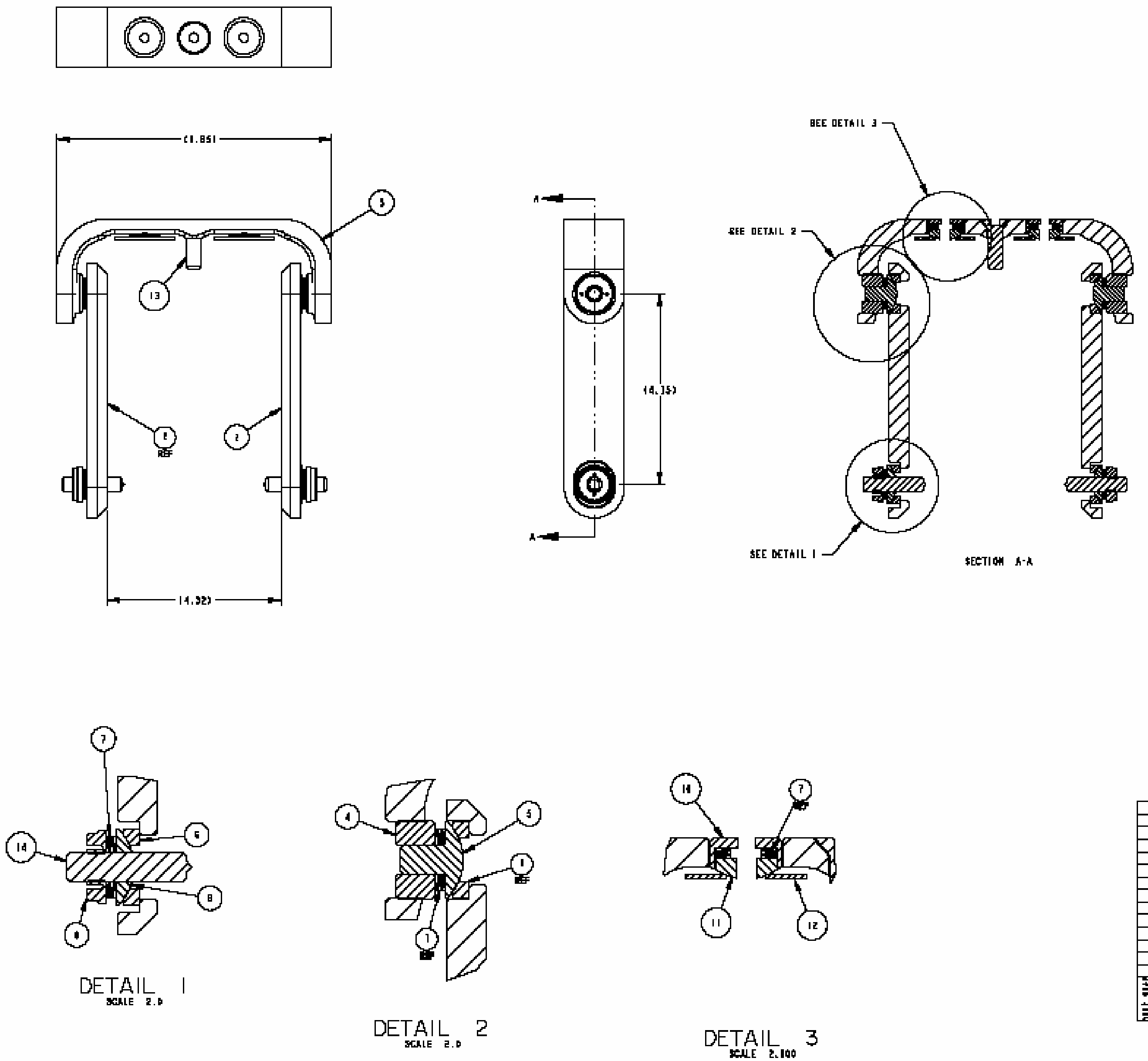

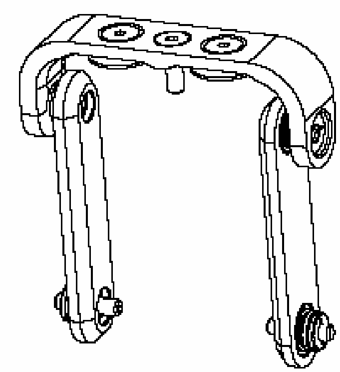

QTY REQD		CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
	2		SE1405-265	STUD, WELD, 3/8-16 UNC-2A	316 STAINLESS STEEL	--	14
	1		SE1405-264	SCREW, 3/8-16 UNC-2B X 1 1/4	316 STAINLESS STEEL	--	13
	2		SE1405-263	WASHER, FLAT, 3/4 OD, 3/8 ID	316 STAINLESS STEEL	--	12
	2		SE1405-262	PISTON, SPHERICAL, 3/4 IN	316 STAINLESS STEEL	--	11
	2		SE1405-261	SCREW, SET, 10/16-28 UNEF-2A X 3/8	316 STAINLESS STEEL	--	10
	2		SE1405-260	NUT, PIN DRIVE, 3/8-16 UNC-2B	316 STAINLESS STEEL	--	9
	2		SE1405-259	WASHER, SPHERICAL, TYPE C	316 STAINLESS STEEL	DIN 6319-NI	8
	10		SE1405-258	WASHER, BELLEVILLE, 3/4 OD, 3/8 ID	316 STAINLESS STEEL	--	7
	4		SE1405-257	WASHER, SPHERICAL, TYPE D	316 STAINLESS STEEL	DIN 6319-NI	6
	2		SE1405-256	RIVET, SPECIAL BUTTON HEAD	316 STAINLESS STEEL	--	5
	2		SE1405-255	SCREW, SET, 1-8 UNEF-2A X 1 1/2	316 STAINLESS STEEL	--	4
	1		SE1405-254	BAR, CLAMP, HORIZONTAL	316 STAINLESS STEEL	--	3
	2		SE1405-253	BAR, CLAMP, VERTICAL	316 STAINLESS STEEL	--	2
	1		SE1405-252	CLAMP ASSEMBLY, 40 TURN	--	--	1
			NEXT ASSEMBLY				

PARTS LIST

P THIS DRAWING PRODUCED ON PRO-ENGINEER

SCALE NOTED	PAUL MILLER	UT-BATTELLE	Oak Ridge National Laboratory
FRACTIONS	PAUL MILLER	NATIONAL COMPACT STELLARATOR EXPERIMENT	
FINISH		CLAMP ASSEMBLY, 40 TURN	
		PLANT X-10	BLDG 5700
		SE1405-252	

NAME:PAUL DENNIS MILLER OBJECT:SE1405-253 DATE:16-Apr-04 11:07:02

NOTES:

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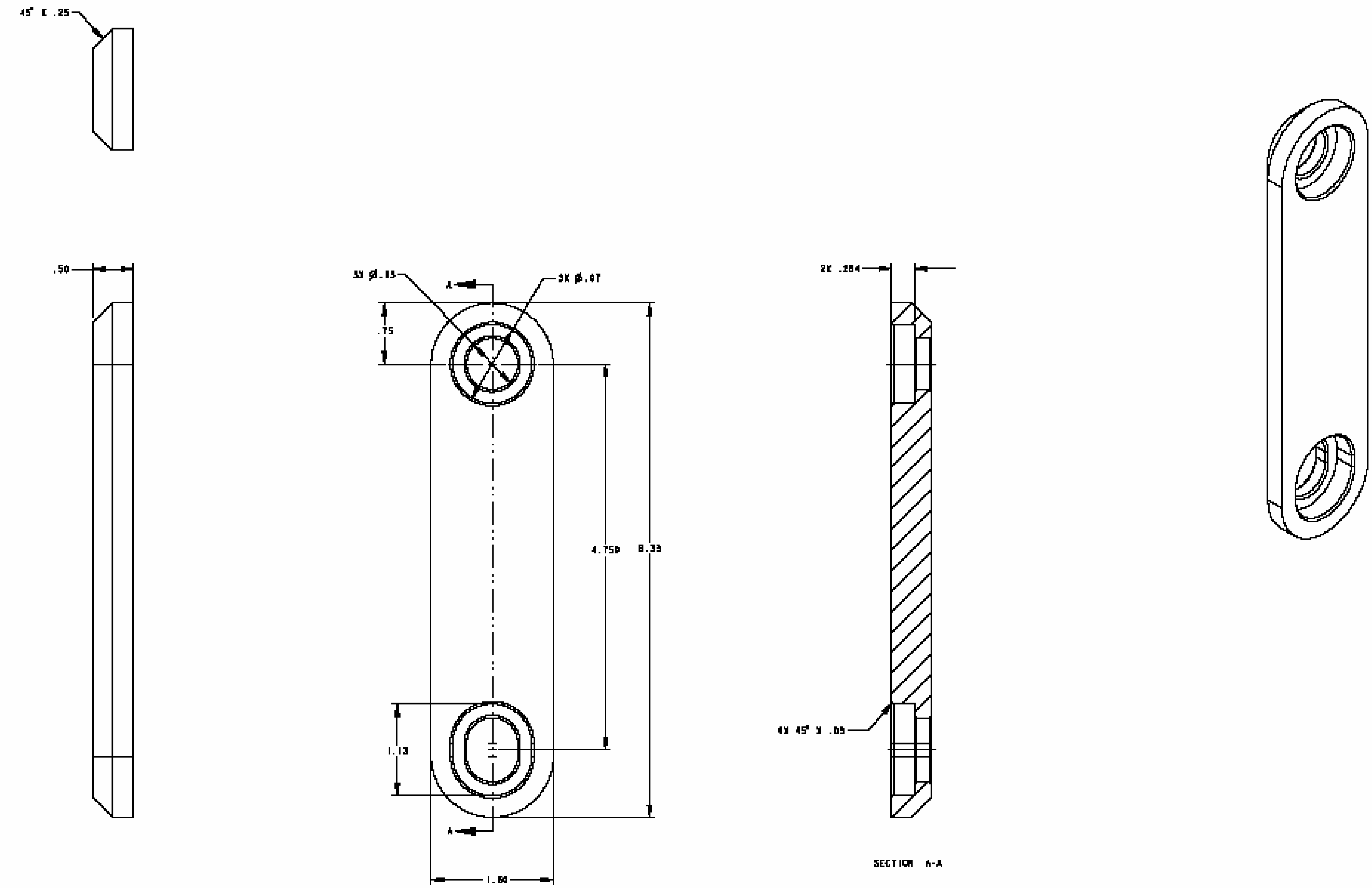

	SE1405-253	BAR, CLAMP, VERTICAL	316 STAINLESS STEEL	--	1
CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
NEXT ASSEMBLY		PARTS LIST			

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SCALE NOTED

DRAWN PAUL MILLER
DESIGN PAUL MILLER

UT-BATTELLE
Oak Ridge National Laboratory

NATIONAL COMPACT STELLARATOR EXPERIMENT

BAR, CLAMP, VERTICAL

X-10 | 4700 | 3 | 1 | 1 | 3 | U

SE1405-253

NAME:PAUL DENNIS MILLER OBJECT:SE1405-254 DATE:16-Apr-04 11:06:44

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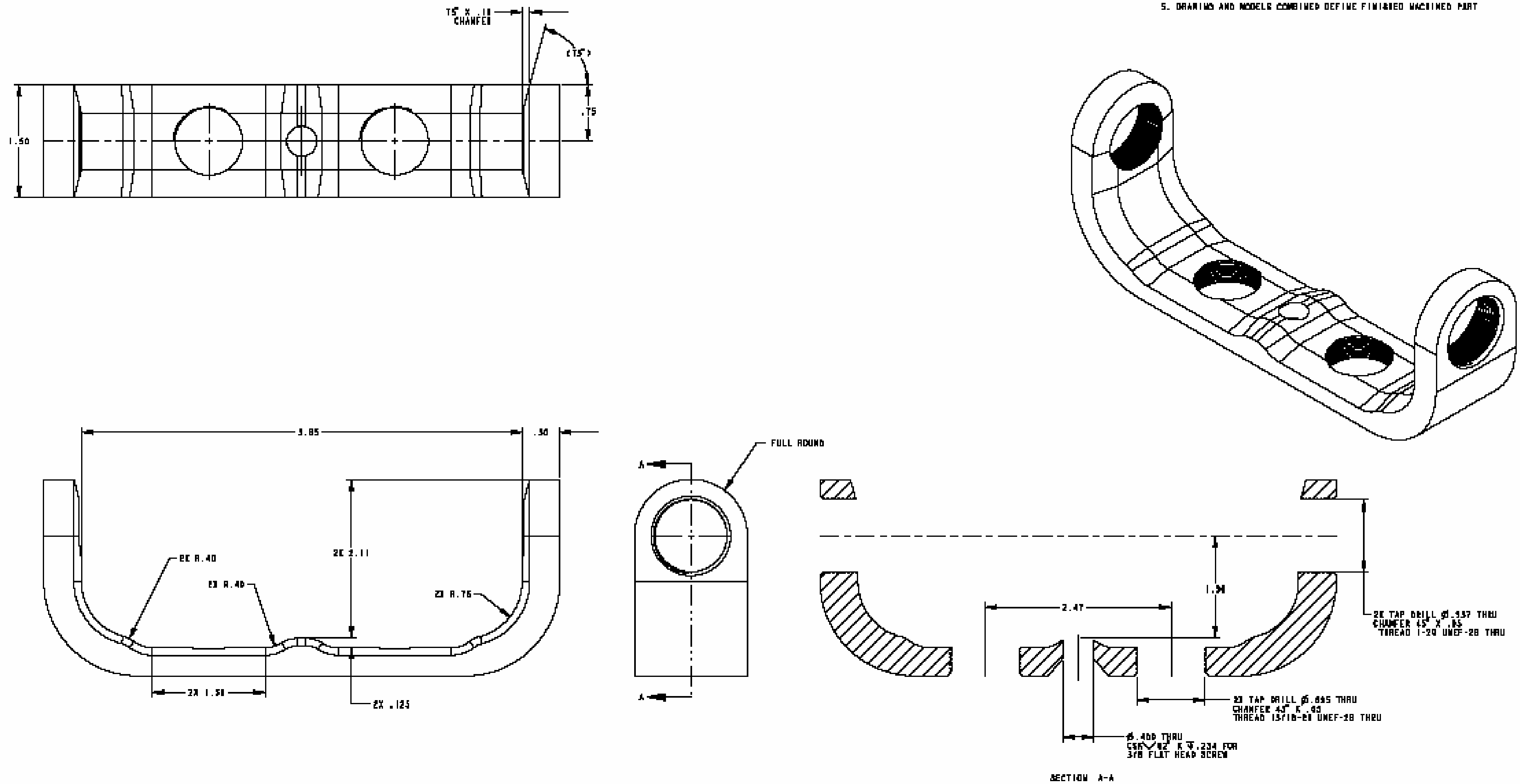
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART



	SE1405-254	BAR, CLAMP, HORIZONTAL	316 STAINLESS STEEL	--	1
CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
NEXT ASSEMBLY		PARTS LIST			

P THIS DRAWING PRODUCED ON PRO-ENGINEER

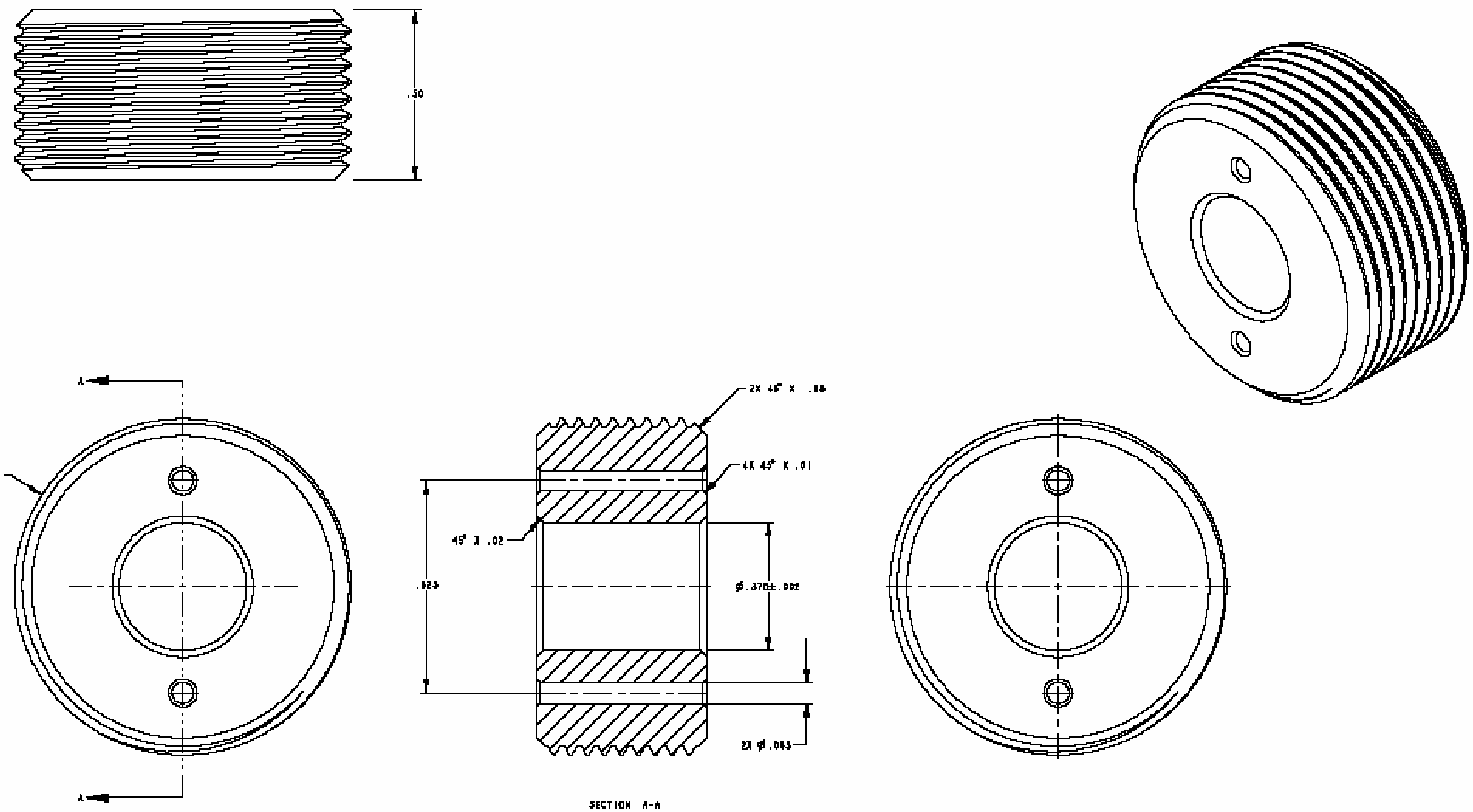
SCALE	NOTED
DRN	PAUL MILLER
DSN	PAUL MILLER
	UT-BATTELLE — Oak Ridge National Laboratory
	NATIONAL COMPACT STELLARATOR EXPERIMENT
	BAR, CLAMP, HORIZONTAL
PLANT	X-10
BLDG	6700
FL	3
TYPE	3
DWG NO	SE1405-254
REV	-

SE1405-254

NAME:PAUL DENNIS MILLER OBJECT:SE1405-255 DATE:16-Apr-04 11:06:23

NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M
2. DIMENSIONS ARE IN INCHES
3. DIMENSIONS APPLY AT ROOM TEMPERATURE, OPERATING TEMP @@ K
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART



		SE1405-255	SCREW, SET, 1-20 UNEF-2A X 1/2	316 STAINLESS STEEL	--	1
	CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
	NEXT ASSEMBLY		PARTS LIST			

P THIS DRAWING PRODUCED ON PRO-ENGINEER

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DSN PAUL MILLER

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NATIONAL COMPACT STELLARATOR EXPERIMENT

SCREW, SET, 1-20 UNEF-2A X 1/2

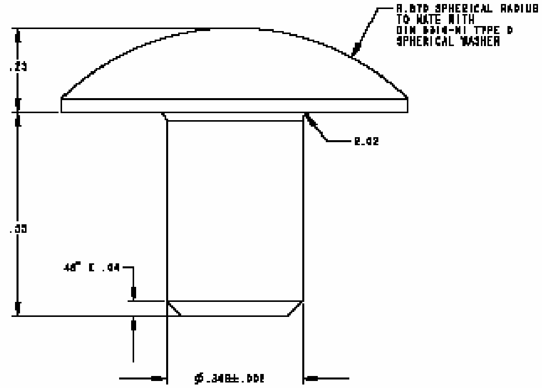
X-10 | 5700

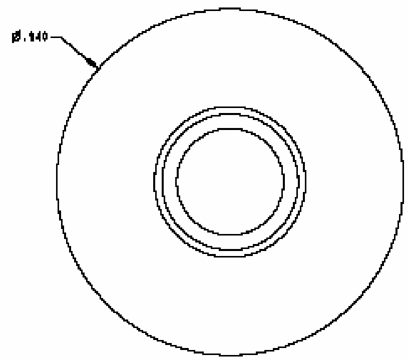
SE1405-255

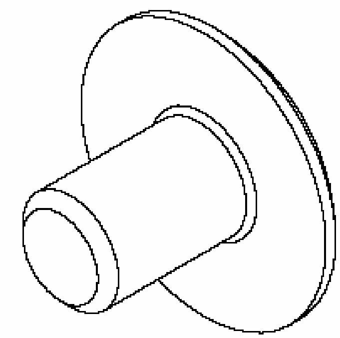
NAME:PAUL DENNIS MILLER OBJECT:SE1405-256 DATE:16-Apr-04 11:09:49

NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M
2. DIMENSIONS ARE IN INCHES
3. DIMENSIONS APPLY AT ROOM TEMPERATURE. OPERATING TEMP [illegible] K
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART







			SE1405-256	RIVET, SPECIAL BUTTON HEAD	STAINLESS STEEL	--	1
		CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		NEXT ASSEMBLY			PARTS LIST		

SE1405-256

P THIS DRAWING PRODUCED ON PRO-ENGINEER

SCALE NOTED

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NATIONAL COMPACT STELLARATOR EXPERIMENT

RIVET, SPECIAL BUTTON HEAD

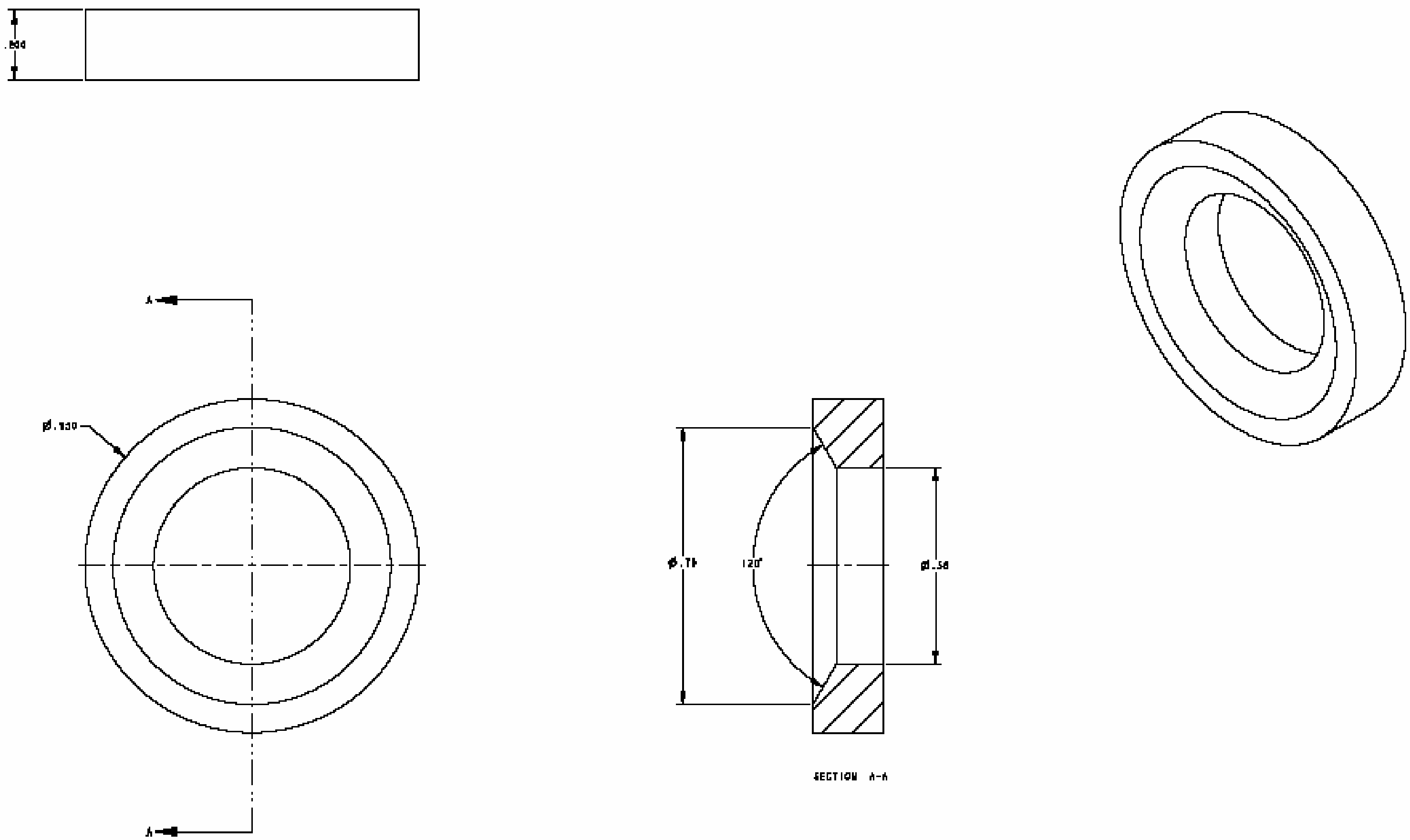
X-10

SE1405-256

NAME:PAUL DENNIS MILLER OBJECT:SE1405-257 DATE:16-Apr-04 11:09:34

NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M
2. DIMENSIONS ARE IN INCHES
3. DIMENSIONS APPLY AT ROOM TEMPERATURE, OPERATING TEMP 4K K
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART



			SE1405-257	WASHER, SPHERICAL, TYPE D	316 STAINLESS STEEL	DIN 6319-N1	1
		CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		NEXT ASSEMBLY		PARTS LIST			

SCALE NOTED

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NATIONAL COMPACT STELLARATOR EXPERIMENT

WASHER, SPHERICAL, TYPE D

X-10 | 5700 | 3 | 1 | 1 | 3 | U

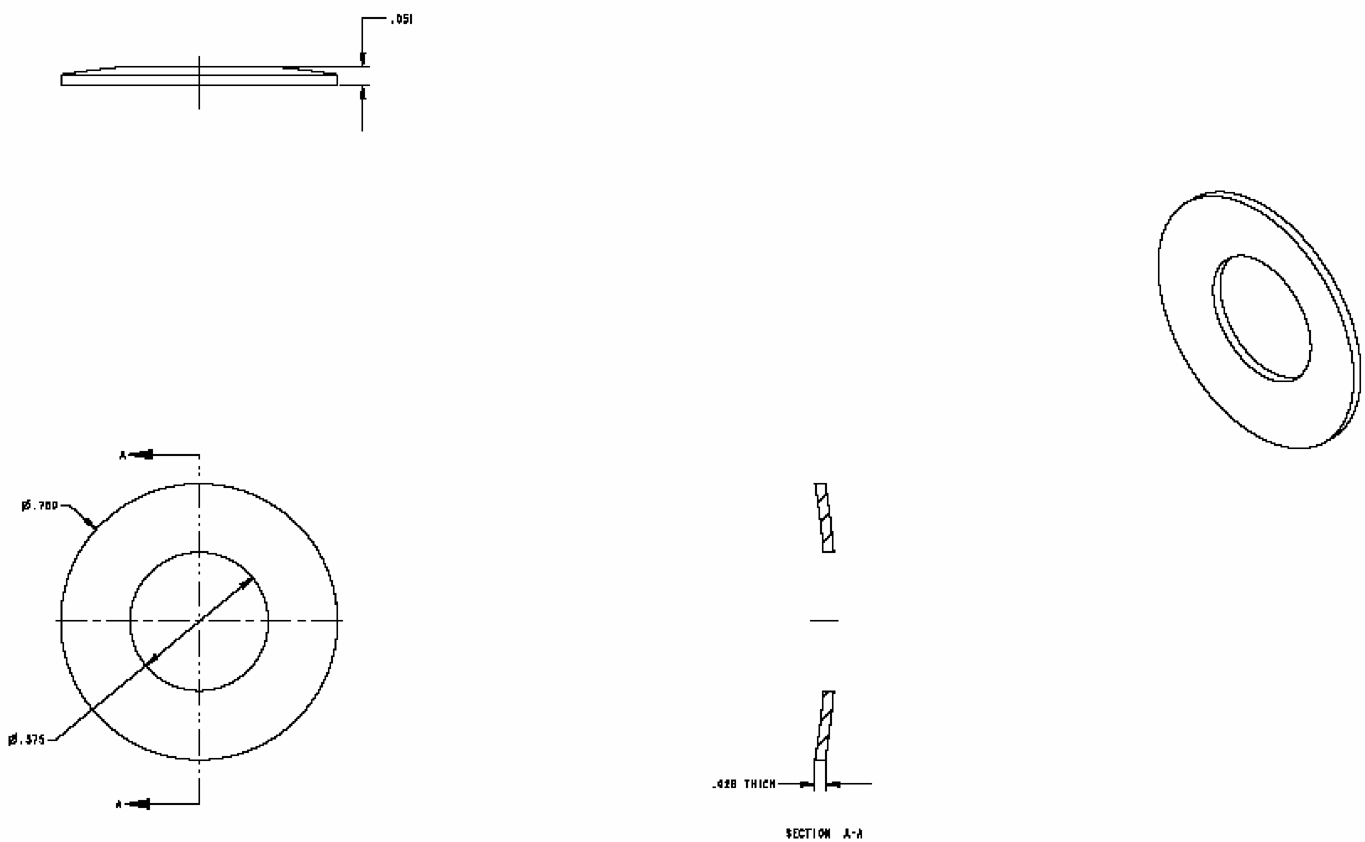
SE1405-257

P THIS DRAWING PRODUCED ON PRO-ENGINEER

NAME:PAUL DENNIS MILLER OBJECT:SE1405-258 DATE:16-Apr-04 11:09:18

NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M
2. DIMENSIONS ARE IN INCHES
3. DIMENSIONS APPLY AT ROOM TEMPERATURE. OPERATING TEMP 80 K
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART
6. SPRING CONSTANT K=7510 LBS/IN



	SE1405-258	WASHER, BELLEVILLE, 3/4 OD, 3/8 ID	316 STAINLESS STEEL	--	1
CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
NEXT ASSEMBLY		PARTS LIST			

P THIS DRAWING PRODUCED ON PRO-ENGINEER

SCALE NOTED

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NATIONAL COMPACT STELLARATOR EXPERIMENT

WASHER, BELLEVILLE, 3/4 OD, 3/8 ID

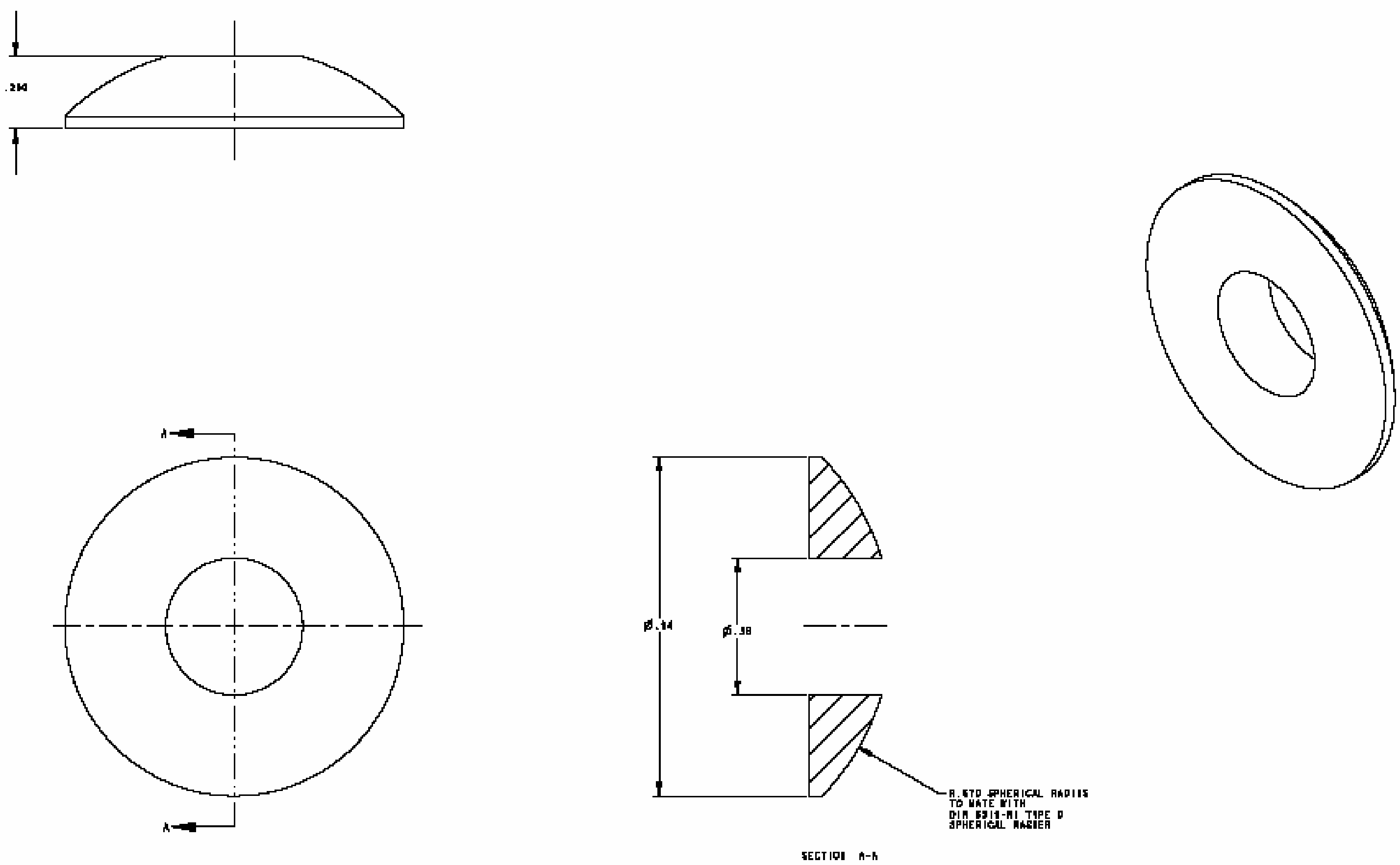
X-10 | 4700 | 3 | 1 | 1 | 3 | U

SE1405-258

NAME:PAUL DENNIS MILLER OBJECT:SE1405-259 DATE:16-Apr-04 11:09:02

NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M
2. DIMENSIONS ARE IN INCHES
3. DIMENSIONS APPLY AT ROOM TEMPERATURE, OPERATING TEMP 4K
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART



			SE1405-259	WASHER, SPHERICAL, TYPE C	316 STAINLESS STEEL	DIN 6319-N1	1
	SE1405-259	CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		NEXT ASSEMBLY		PARTS LIST			

P THIS DRAWING PRODUCED ON PRO-ENGINEER

SCALE NOTED

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PAUL MILLER

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NATIONAL COMPACT STELLARATOR EXPERIMENT

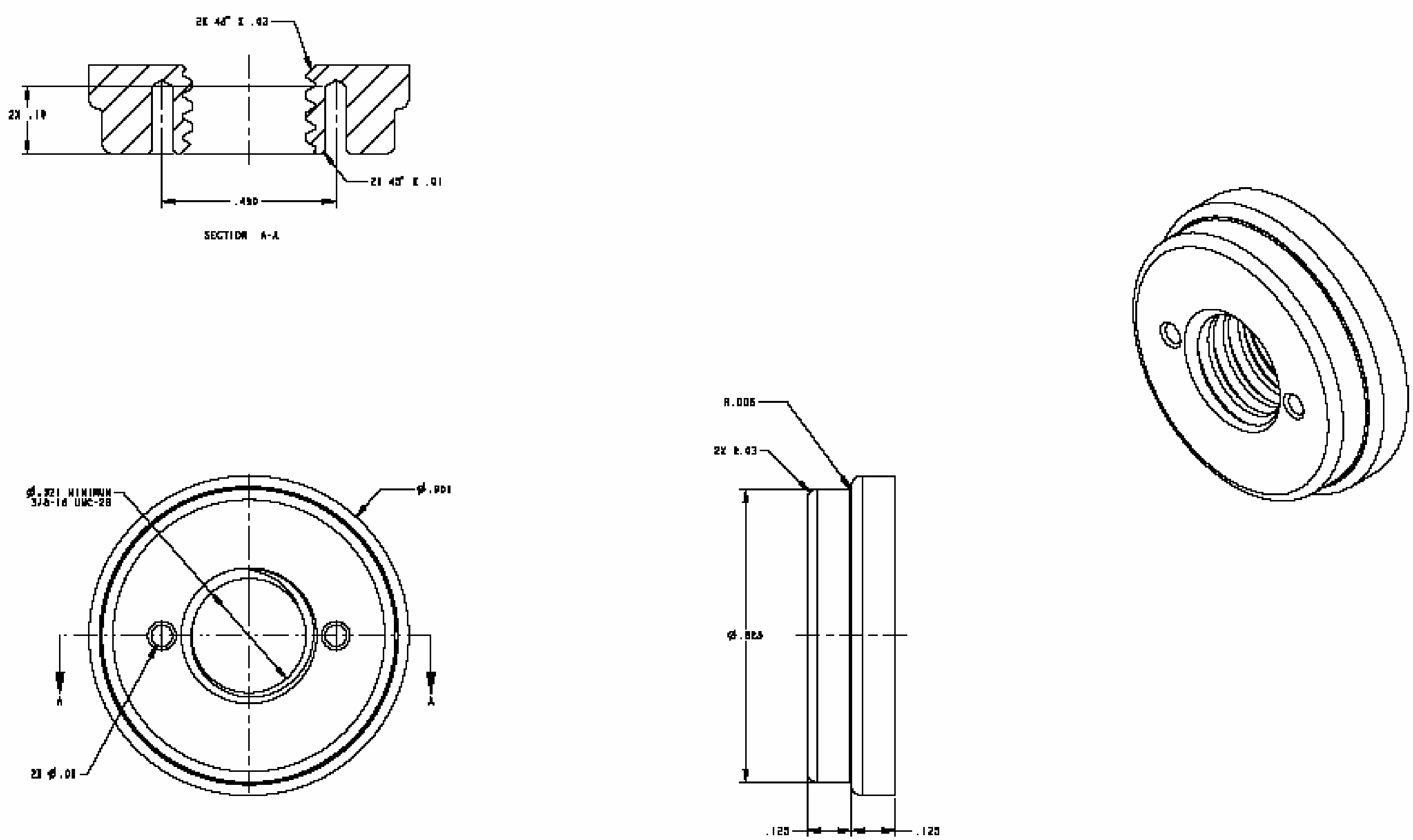
WASHER, SPHERICAL, TYPE C

PLANT X-10 | 5700 | 3 | 1 | 1 | 3 | U

SE1405-259

NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M
2. DIMENSIONS ARE IN INCHES
3. DIMENSIONS APPLY AT ROOM TEMPERATURE, OPERATING TEMP 80 K
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART



	SE1405-260	NUT, PIN DRIVE, 3/8-16 UNC-2B	316 STAINLESS STEEL	--	1
CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
NEXT ASSEMBLY		PARTS LIST			

P THIS DRAWING PRODUCED ON PRO-ENGINEER

SCALE NOTED

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NATIONAL COMPACT STELLARATOR EXPERIMENT

NUT, PIN DRIVE, 3/8-16 UNC-2B

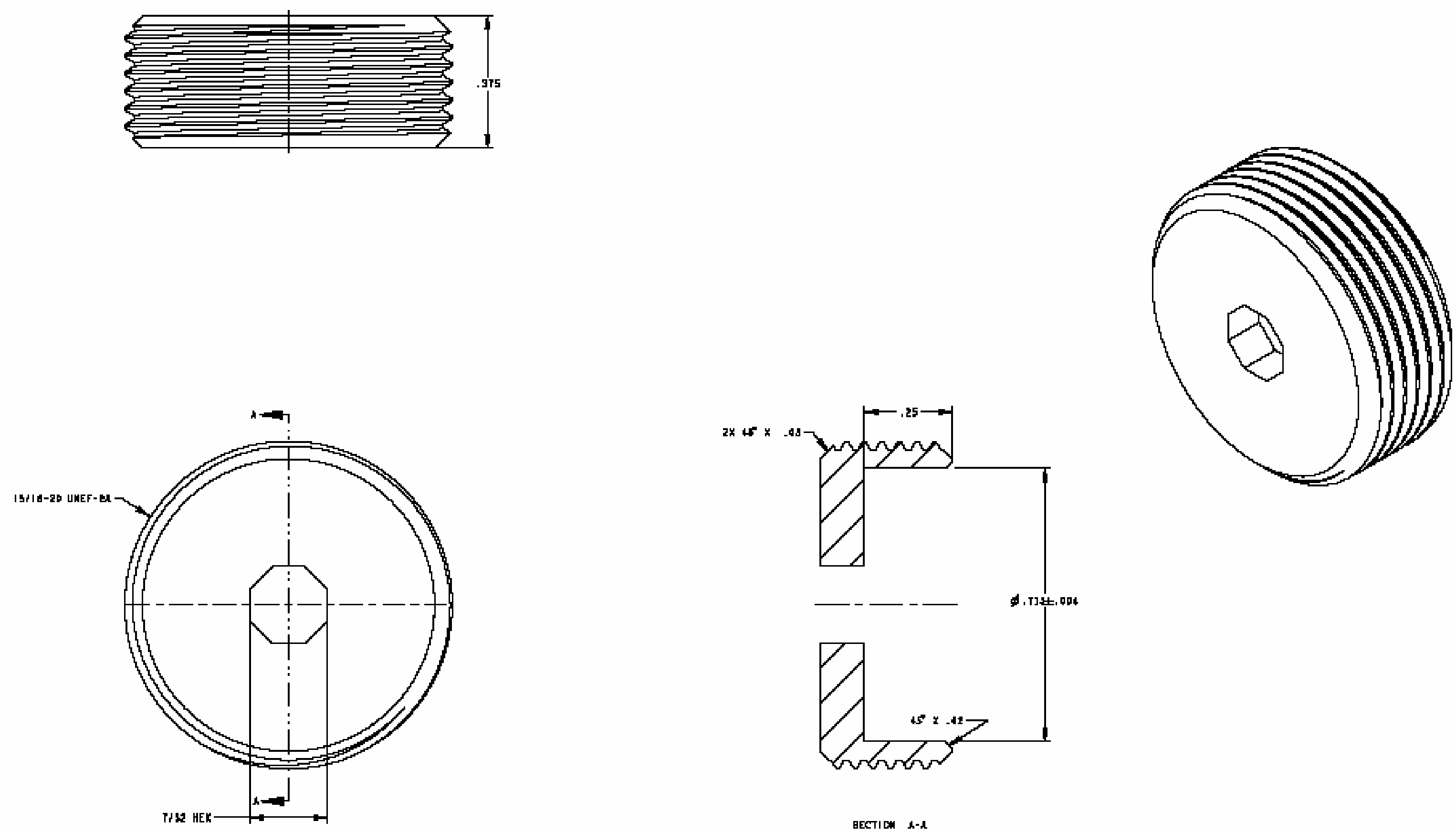
X-10 | 8700 | 3 | 1 | 1 | 3

SE1405-260

NAME:PAUL DENNIS MILLER OBJECT:SE1405-261 DATE:16-Apr-04 11:11:42

NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M
2. DIMENSIONS ARE IN INCHES
3. DIMENSIONS APPLY AT ROOM TEMPERATURE, OPERATING TEMP 4K ?
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART



			SE1405-261	SCREW, SET, 15/16-20 UNEF-2A X 3/8	316 STAINLESS STEEL	--	1
	SE1405-261	CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		NEXT ASSEMBLY			PARTS LIST		

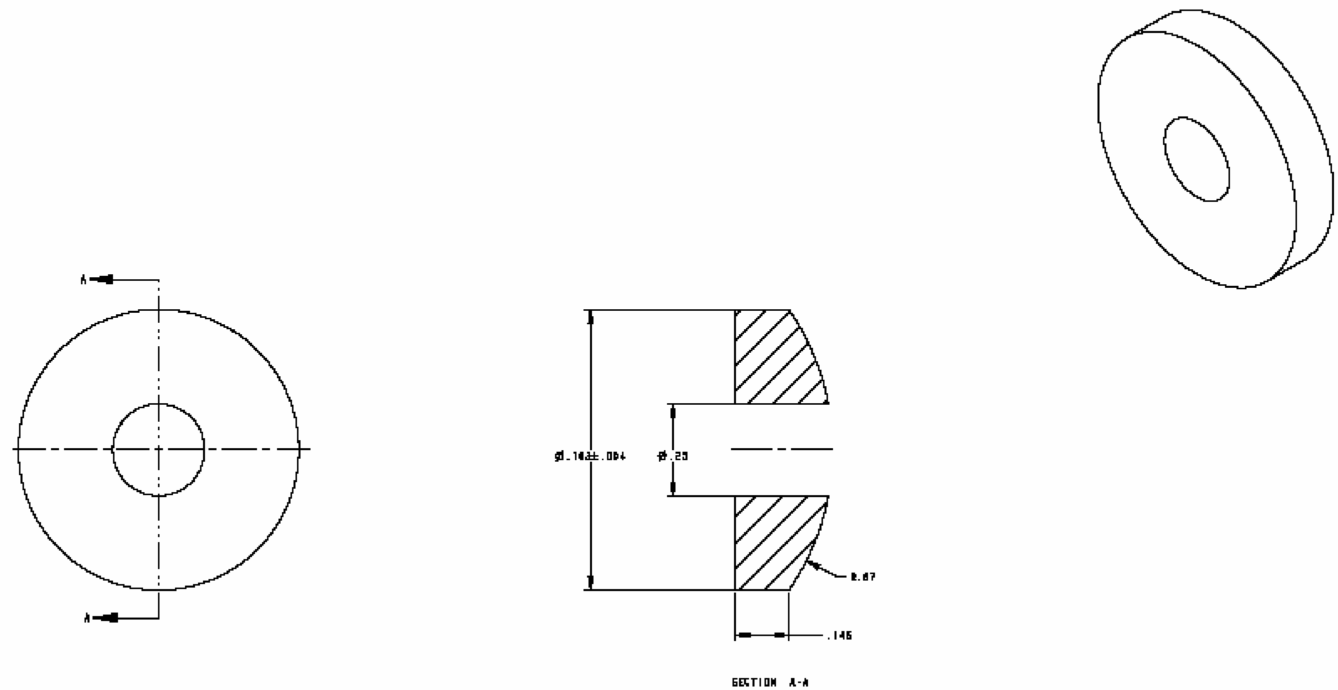
SE1405-261

P THIS DRAWING PRODUCED ON PRO-ENGINEER

SCALE NOTED	DRN PAUL MILLER		UT-BATTELLE Oak Ridge National Laboratory
	CHK PAUL MILLER		
FRACTIONS			NATIONAL COMPACT STELLARATOR EXPERIMENT
ANGLES			SCREW, SET, 15/16-20 UNEF-2A X 3/8
FINISH			PLANT X-10 · BLDG 5700 · SE1405-261

NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M
2. DIMENSIONS ARE IN INCHES
3. DIMENSIONS APPLY AT ROOM TEMPERATURE, OPERATING TEMP
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART



		SE1405-262	PISTON, SPHERICAL, 3/4 OD	316 STAINLESS STEEL	--	1
	CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
	NEXT ASSEMBLY			PARTS LIST		

P THIS DRAWING PRODUCED ON PRO-ENGINEER

SCALE NOTED

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PAUL MILLER

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NATIONAL COMPACT STELLARATOR EXPERIMENT

PISTON, SPHERICAL, 3/4 OD

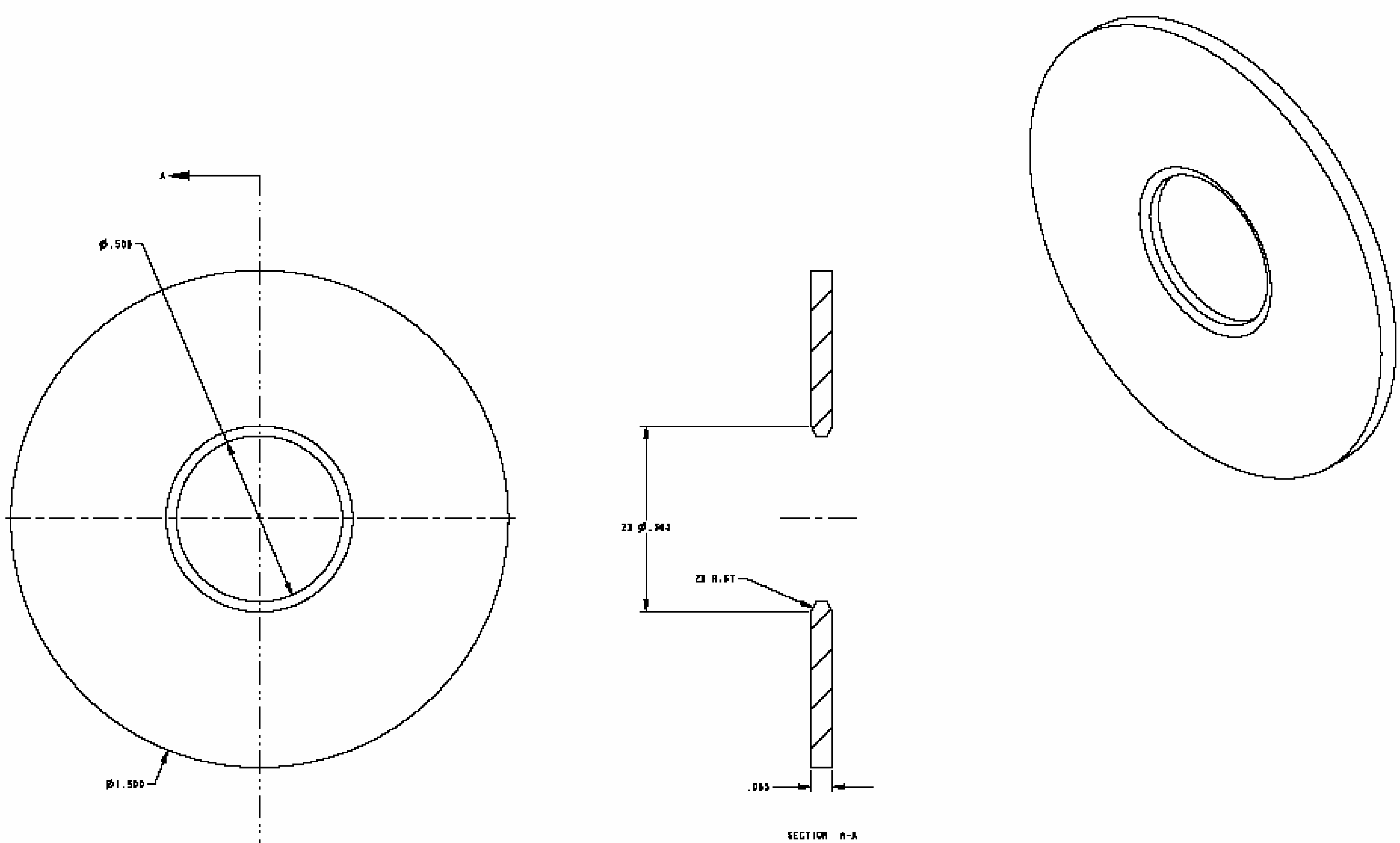
X-10 | 6700

SE1405-262

NAME:PAUL DENNIS MILLER OBJECT:SE1405-263 DATE:16-Apr-04 11:11:17

NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M
2. DIMENSIONS ARE IN INCHES
3. DIMENSIONS APPLY AT ROOM TEMPERATURE, OPERATING TEMP 80 K
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART



			SE1405-263	WASHER, FLAT, 3/4 OD, 3/8 ID	316 STAINLESS STEEL	--	1
		CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		NEXT ASSEMBLY		PARTS LIST			

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SCALE NOTED

DR PAUL MILLER

CHK PAUL MILLER

FRACTIONS

FINISH

UT-BATTELLE

Oak Ridge National Laboratory

NATIONAL COMPACT STELLARATOR EXPERIMENT

WASHER, FLAT, 3/4 OD, 3/8 ID

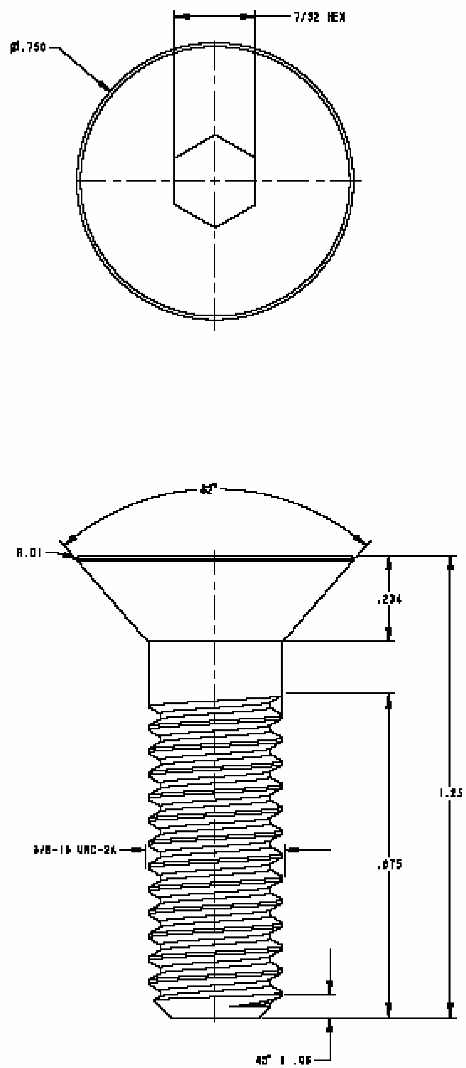
PLANT X-10 | BLDG 6700 | FL 3 | SHT 1 OF 1 | TYPE 3 | CLASS U

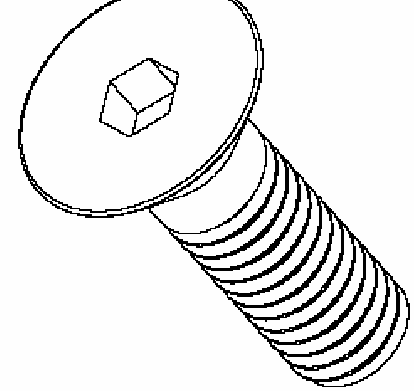
SE1405-263

NAME:PAUL DENNIS MILLER OBJECT:SE1405-264 DATE:16-Apr-04 11:11:01

NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M
2. DIMENSIONS ARE IN INCHES
3. DIMENSIONS APPLY AT ROOM TEMPERATURE. OPERATING TEMP 80 K
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART





	SE1405-264	SCREW, 3/8-16 UNC-2A X 1 1/4	316 STAINLESS STEEL	--	1
CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
NEXT ASSEMBLY		PARTS LIST			

SE1405-264

THIS DRAWING PRODUCED ON PRO-ENGINEER

SCALE NOTED

DR PAUL MILLER
DS PAUL MILLER

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NATIONAL COMPACT STELLARATOR EXPERIMENT

SCREW, 3/8-16 UNC-2A X 1 1/4

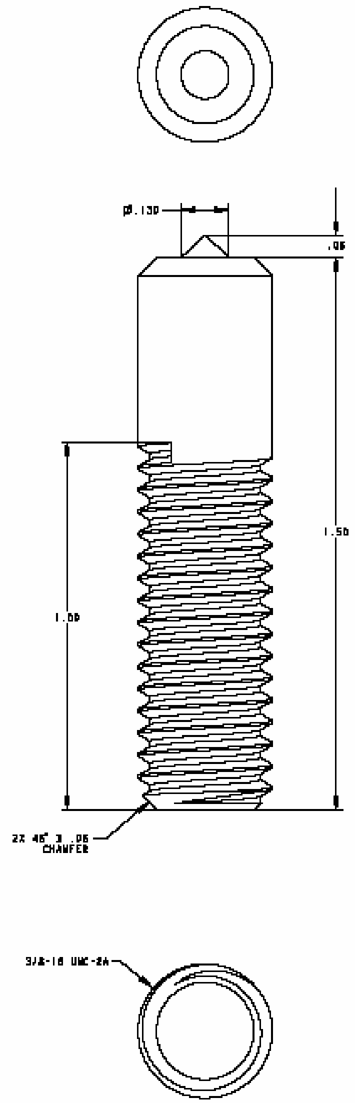
PLANT X-10 | BLDG 5700 | SIZE U

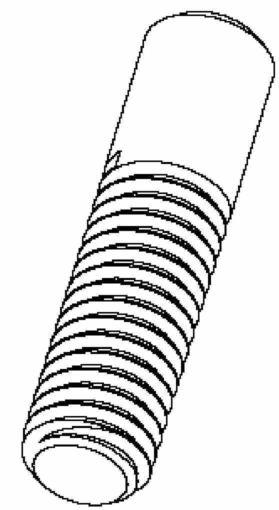
SE1405-264

NAME:PAUL DENNIS MILLER OBJECT:SE1405-265 DATE:16-Apr-04 11:10:42

NOTES:

1. INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M
2. DIMENSIONS ARE IN INCHES
3. DIMENSIONS APPLY AT ROOM TEMPERATURE. OPERATING TEMP 80 K
4. GEOMETRY IS DEFINED IN PRO ENGINEER CAD MODELS/FILES
5. DRAWING AND MODELS COMBINED DEFINE FINISHED MACHINED PART





			SE1405-265	STUD, WELD, 3/8-16 UNC-2A	316 STAINLESS STEEL	--	1
		CAGE CODE	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		NEXT ASSEMBLY		PARTS LIST			

P THIS DRAWING PRODUCED ON PRO-ENGINEER

SCALE	NOTED
DRN	PAUL MILLER
DSGN	PAUL MILLER
FRACTIONS	
FINISH	
	DRAWING APPROVALS / DATE

UT-BATTELLE — Oak Ridge National Laboratory

NATIONAL COMPACT STELLARATOR EXPERIMENT

STUD, WELD, 3/8-16 UNC-2A

	PLANT	BLDG	FL	SHT OF	TYPE	CLASS
	X-10	8700	3	1 1	3	U

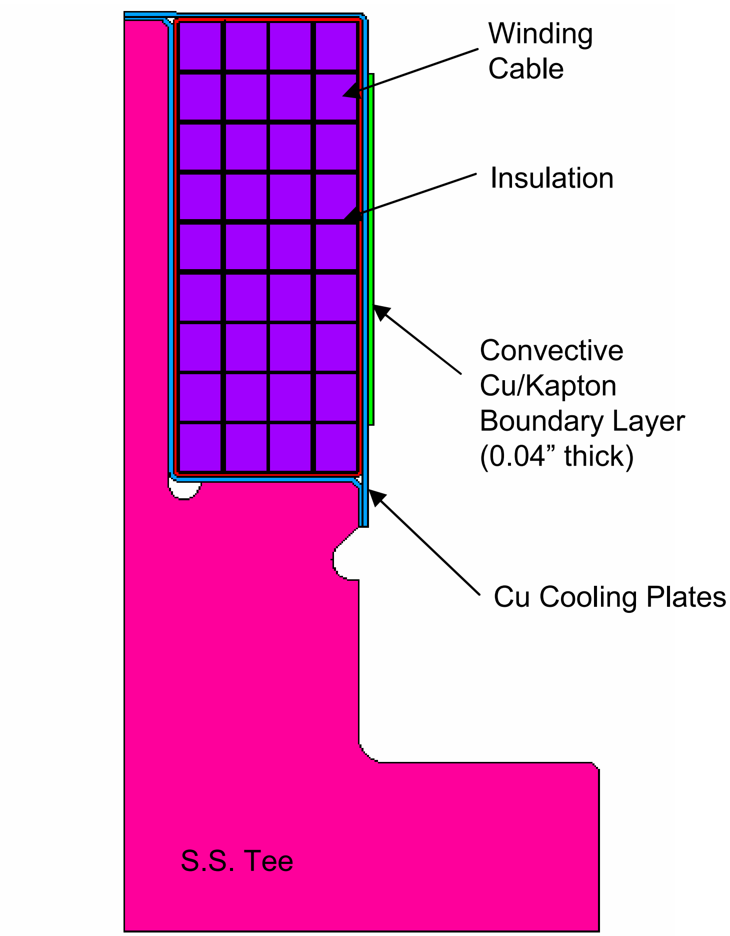
SE1405-265

SE1405-265

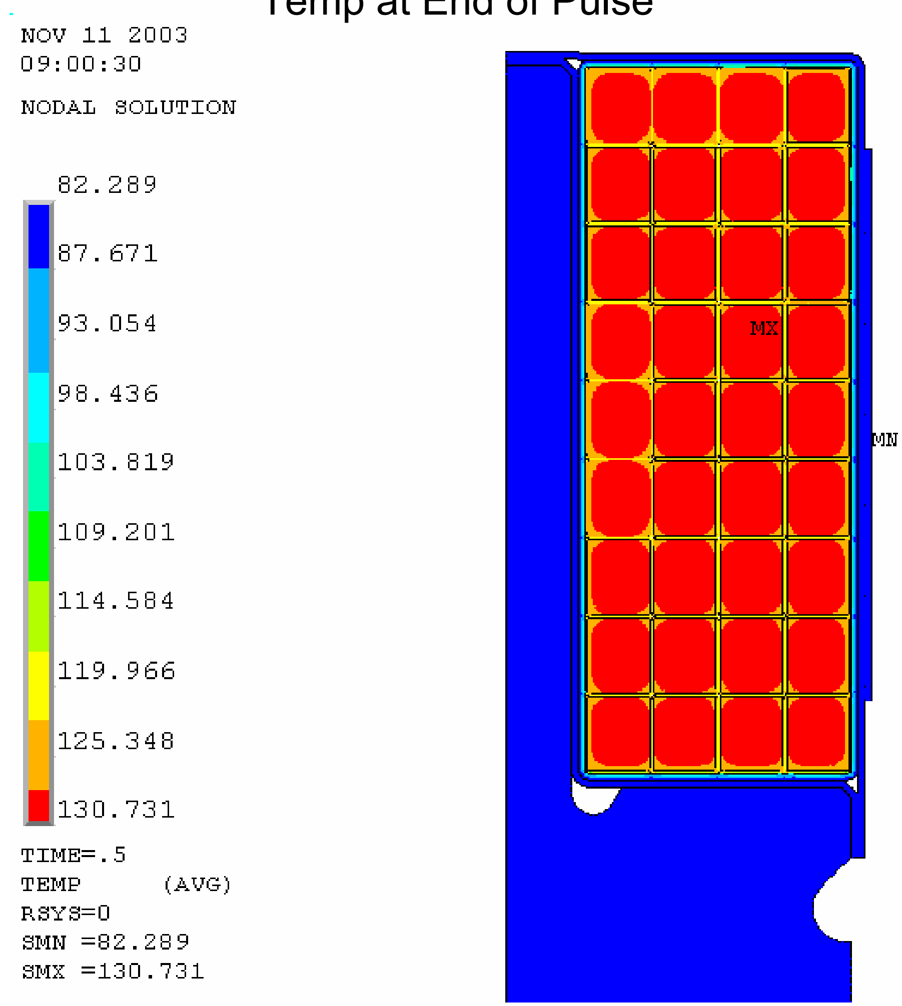
Thermal Performance

- Transient conduction/convection model has been updated for four-in-hand winding

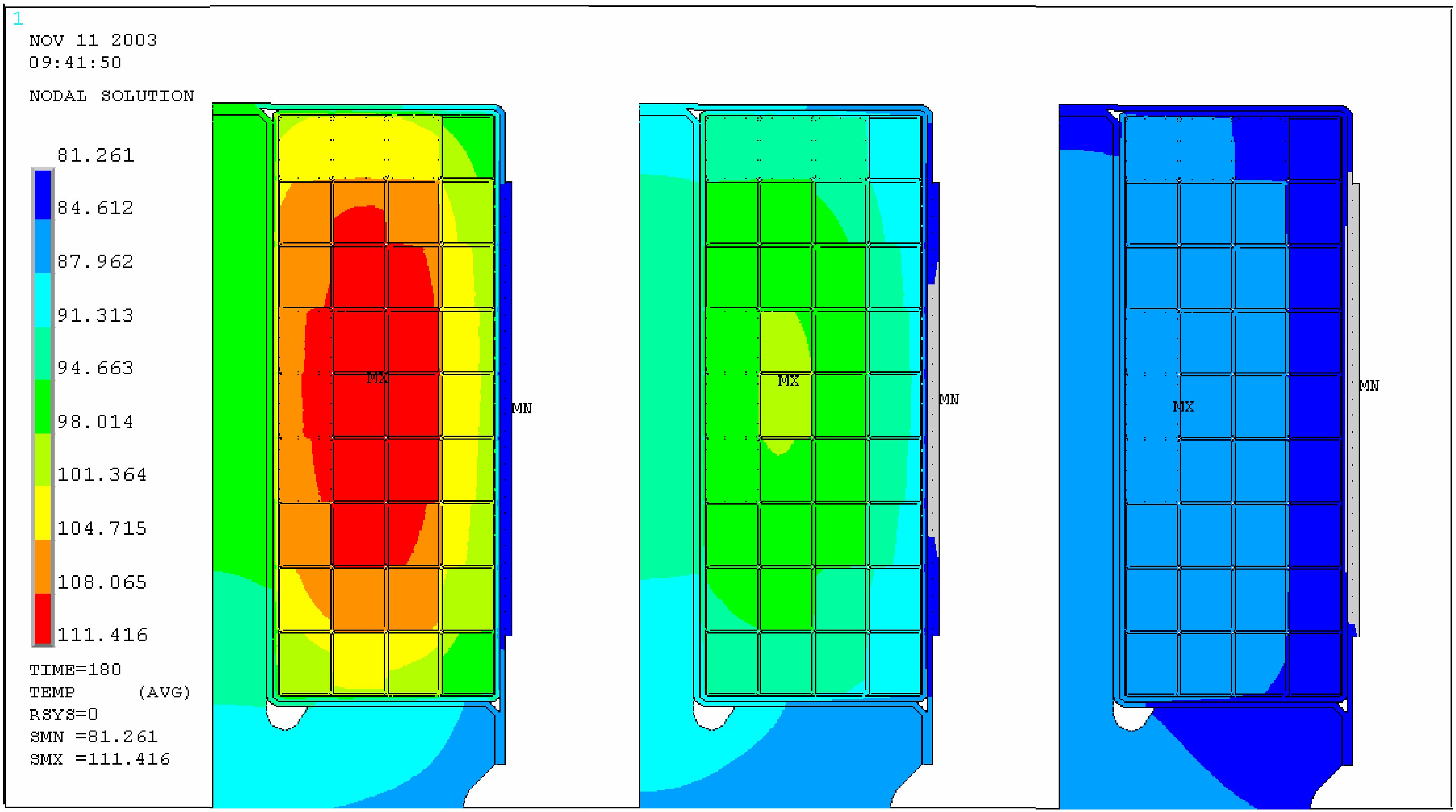
Analysis Model



Temp at End of Pulse

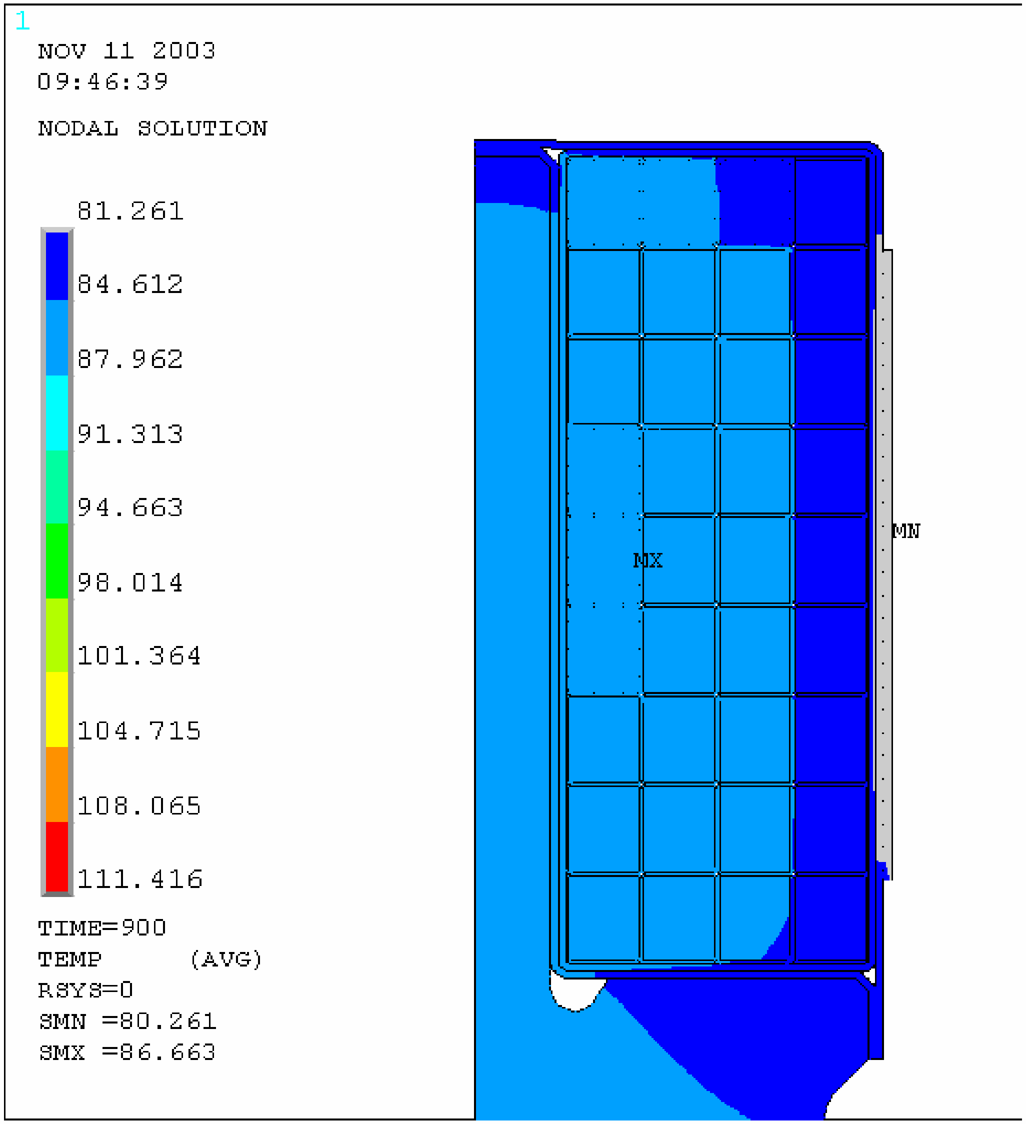


Temperature During Cooldown

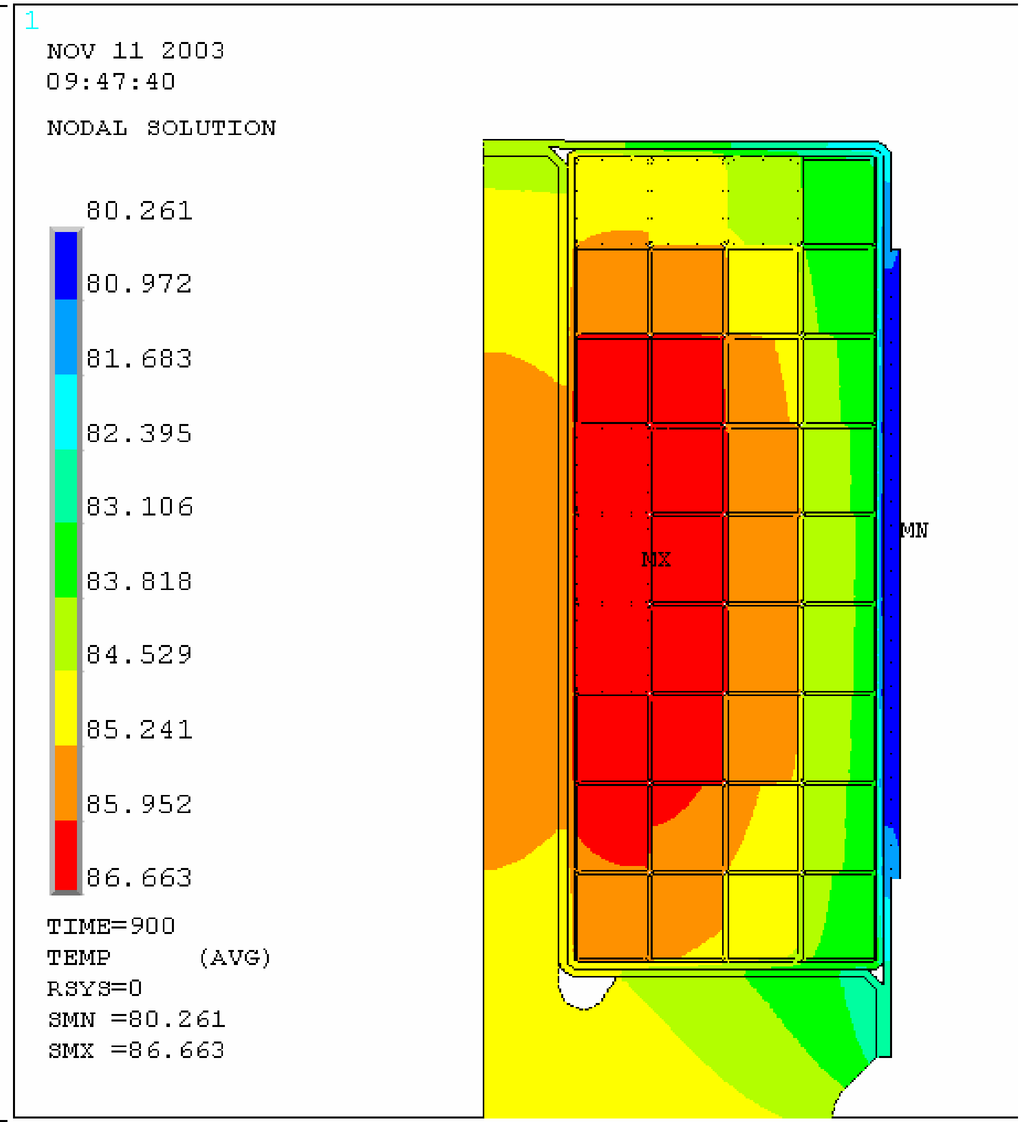


3 minutes 7 minutes 15 minutes

Temperature At 15-Min

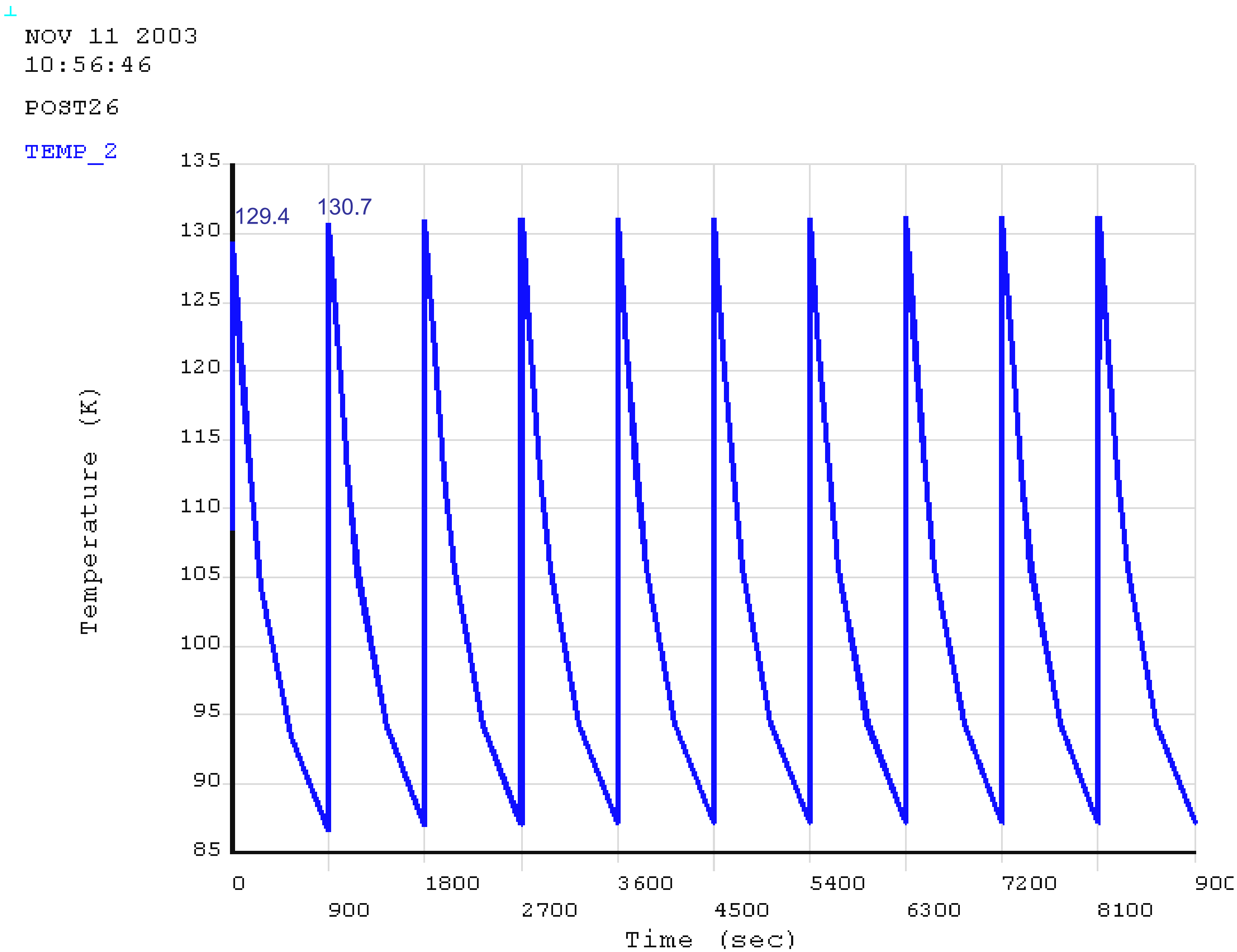


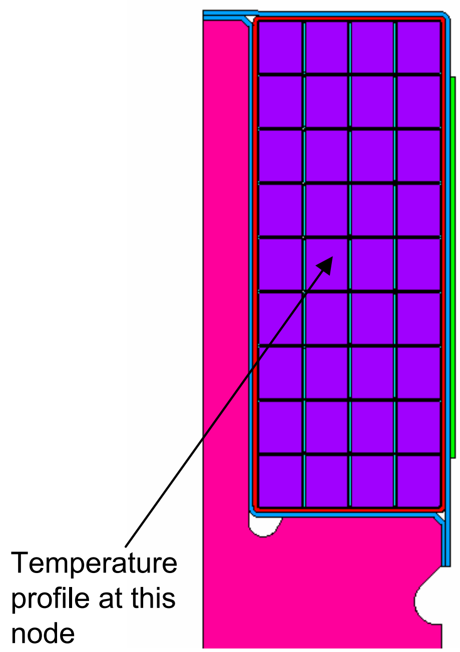
Same Scale as above cases at 15 mins

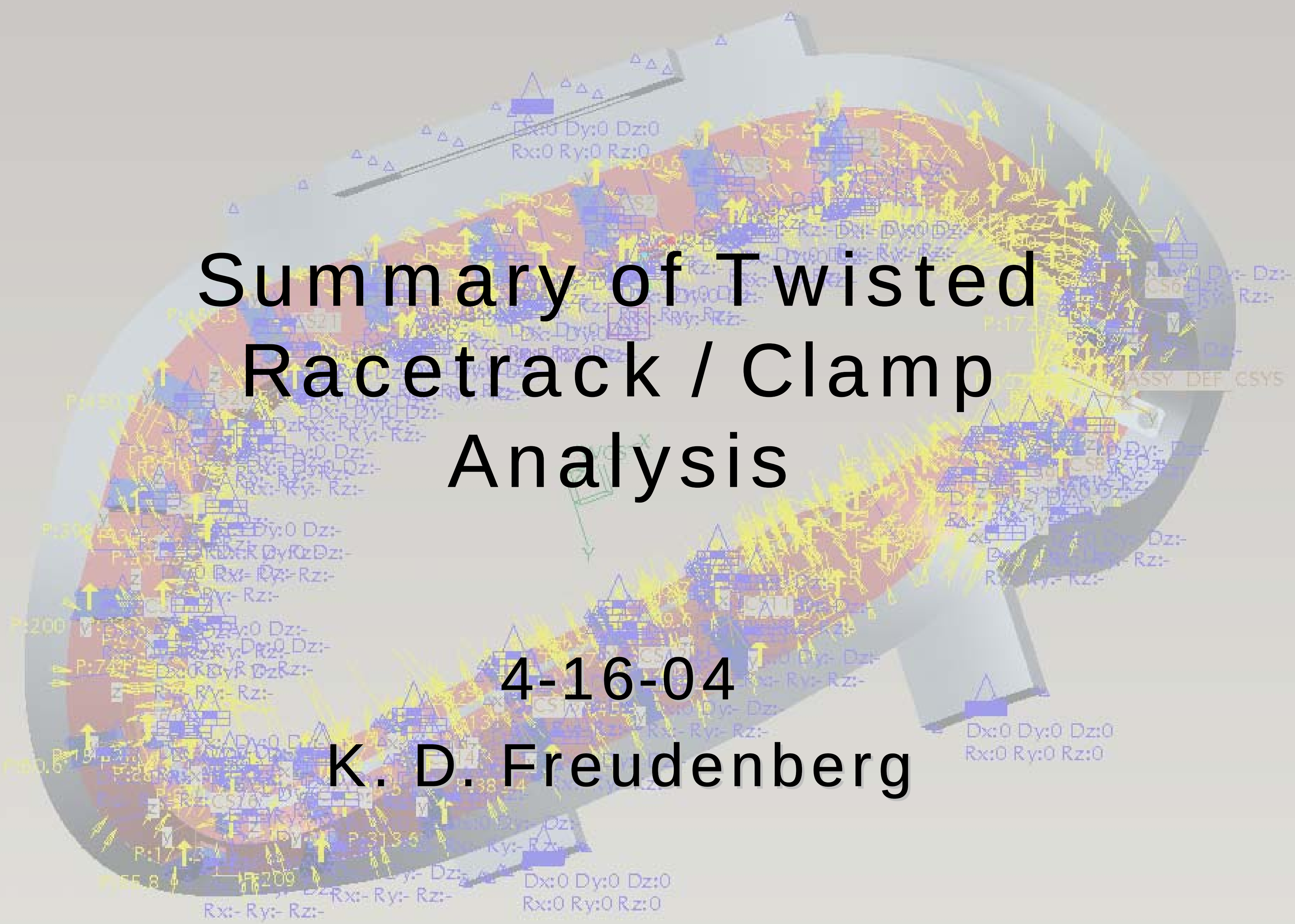


Automatic Scale at 15 mins

Temperature After 10 Cycles





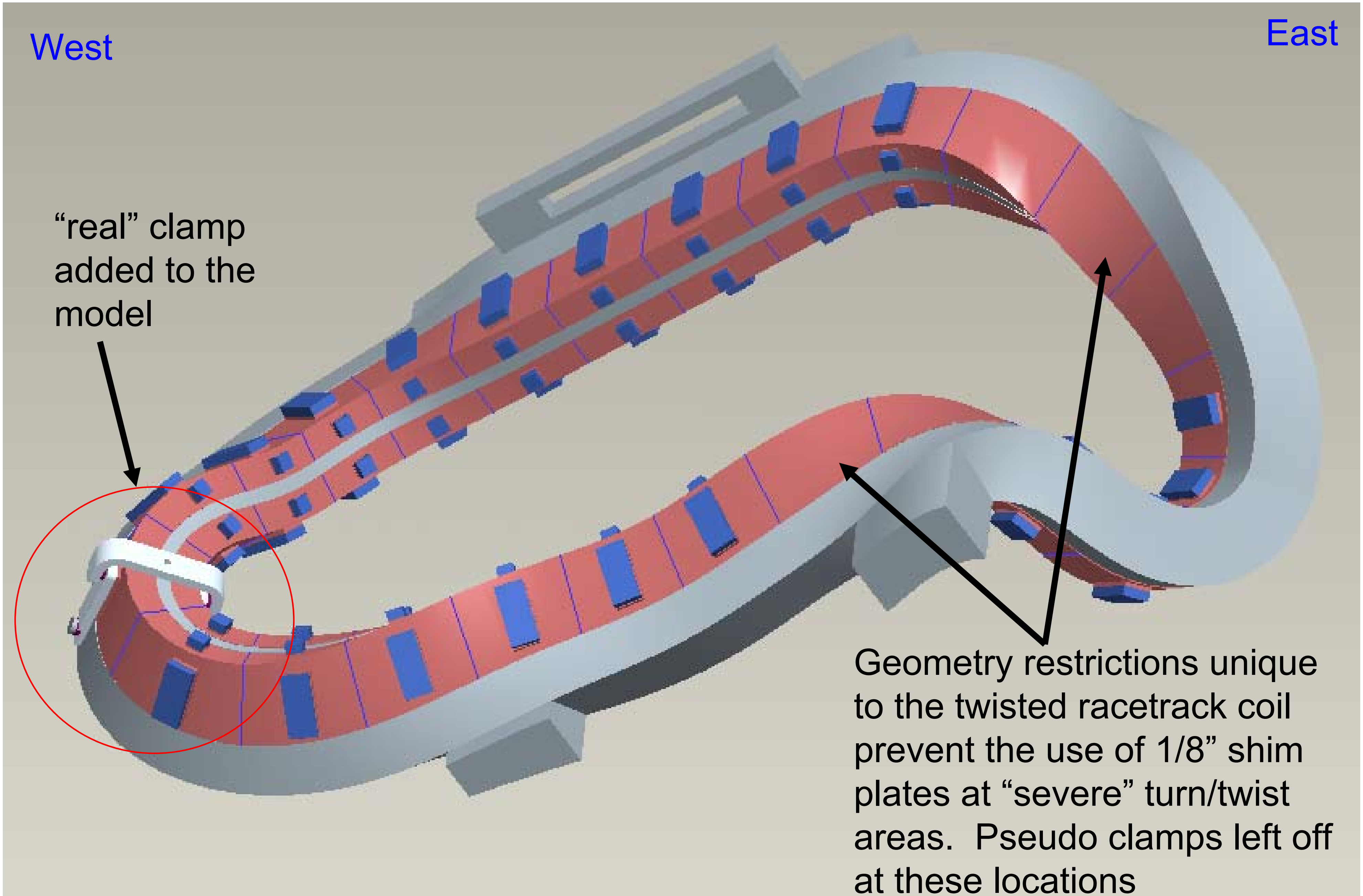


Summary of Twisted Racetrack / Clamp Analysis

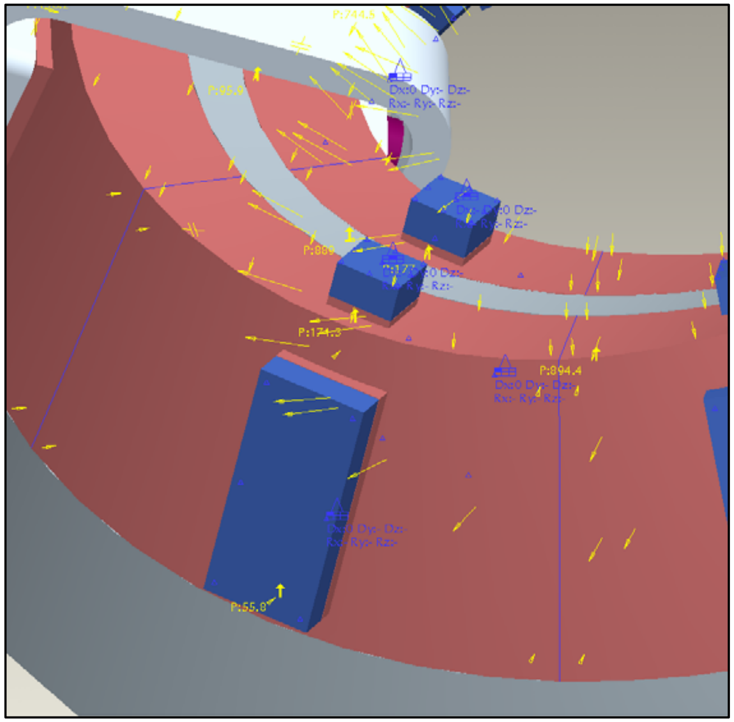
4-16-04

K. D. Freudenberg

Twisted Racetrack FEA Mechanica Model



Restraints and loads



- Winding is broken into regions (between blue lines) on which the magnetic pressure loads are applied, pressures correspond to **I=42-kA/electrical turn**.
- Max EM Running Loads:
  Radial: 1819 lb/in.
  Lateral: 3946 lb/in.
- Pseudo clamps are restrained in their respective normal directions to simulate real clamp behavior.

- Contact surfaces are used between the clamp winding and the tee.
- Thermal growth is imposed on the winding by utilizing the cte property and by applying a known strain over a given temperature change.

Example: strain = -800με , arbitrary temp difference = 72 F. Therefore,

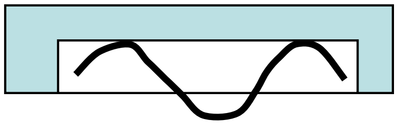
Winging cte = -800με /72 F = = 1.11E-5 /F

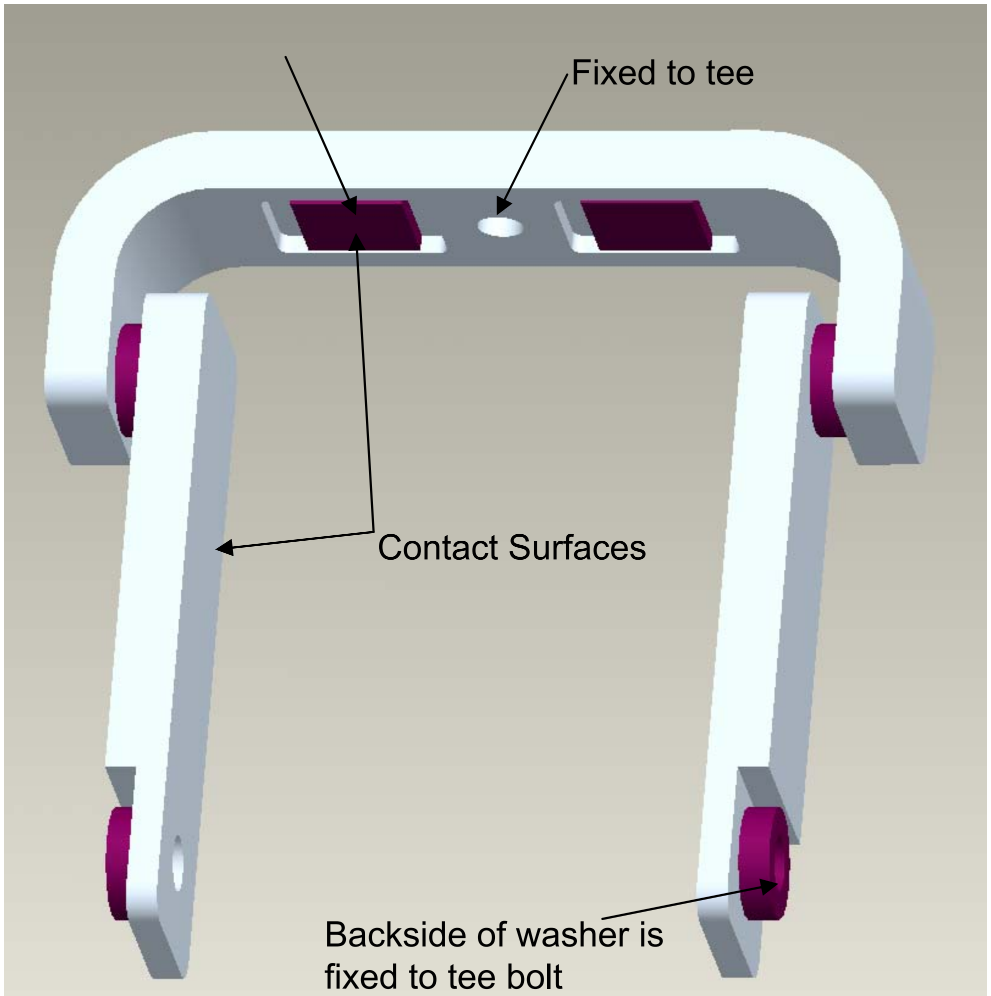
Tee cte = 0

The latest data indicates essentially no cure shrinkage of the winding. Therefore, the -800*με* used in this analysis should be tailored down to -400*με* to account only for the cool-down shrinkage between the tee and winding (4-10-2004).

Clamp modeling

Wave spring in clamp pocket





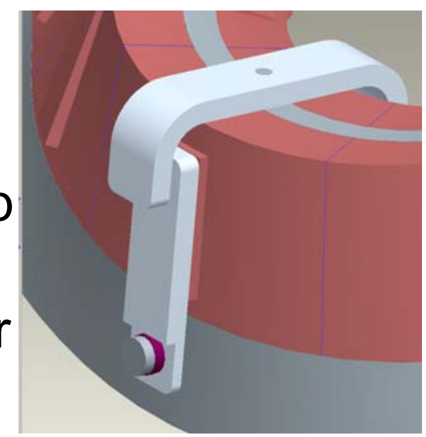
Contact Surfaces are used between the clamp and the winding.

-Modulus of washers is tailored to represent the spring constant of the belleville washers. Example: k = 26,000 lb/in, A_{washer} = 0.81in^2, $Depth_{washer}$ = 0.15 in^2. Therefore: E= k*depth/A = 4814 psi

- The cte of the washer is used to impose a preload on the clamp and winding. *Assume 0.1 in/in strain Therefore: cte = 0.1 / -72 F = -0.00138 /F and preload for "hard" springs is 2600 lbs, and 1000 for "soft" springs*

- All washers have the same spring constant but have different modulus values.

-The clamp is fixed to the tee by a stud at the top of the clamp and a representative bolt head on the lower end.

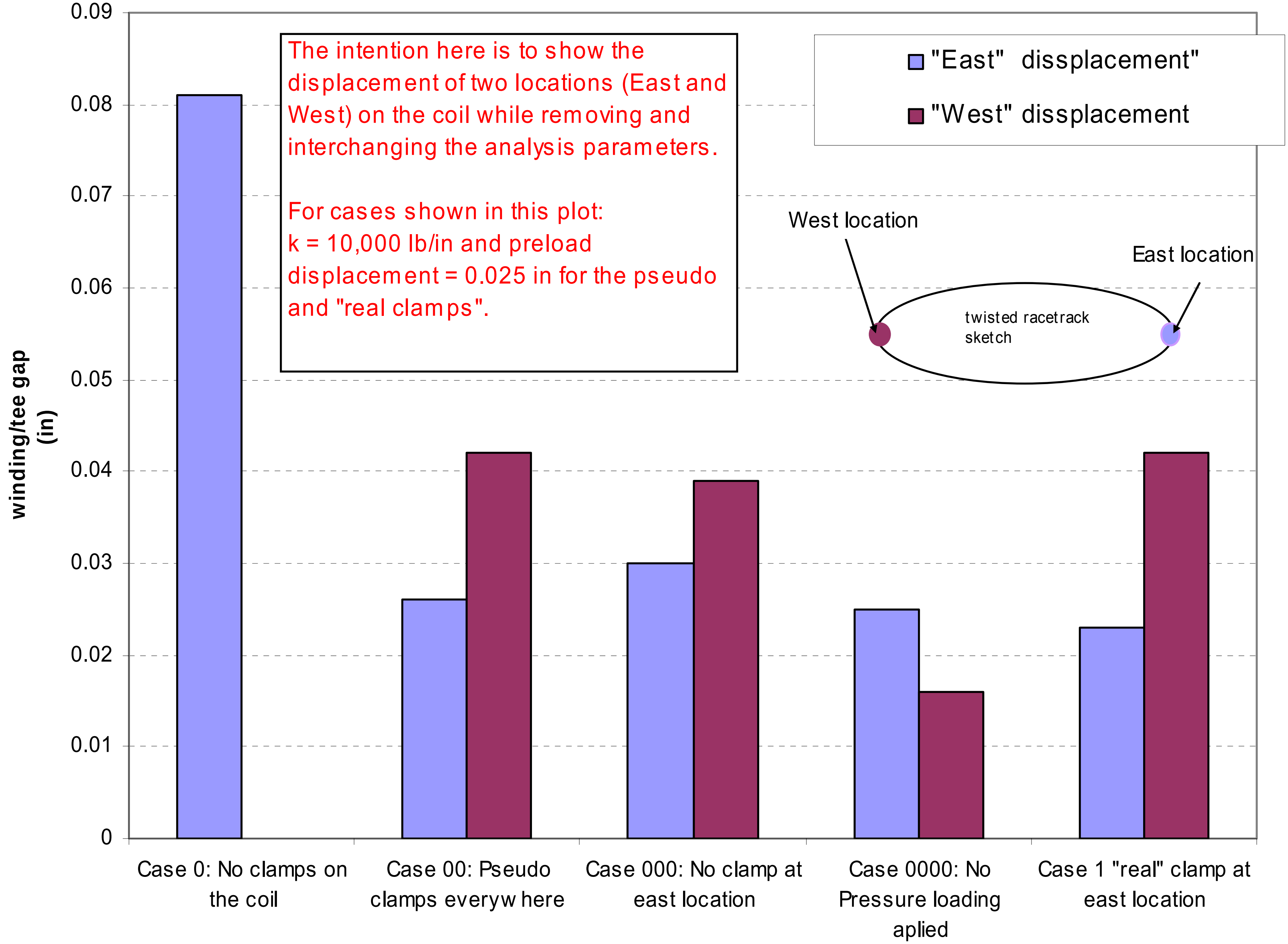


Clamp Design Iterations

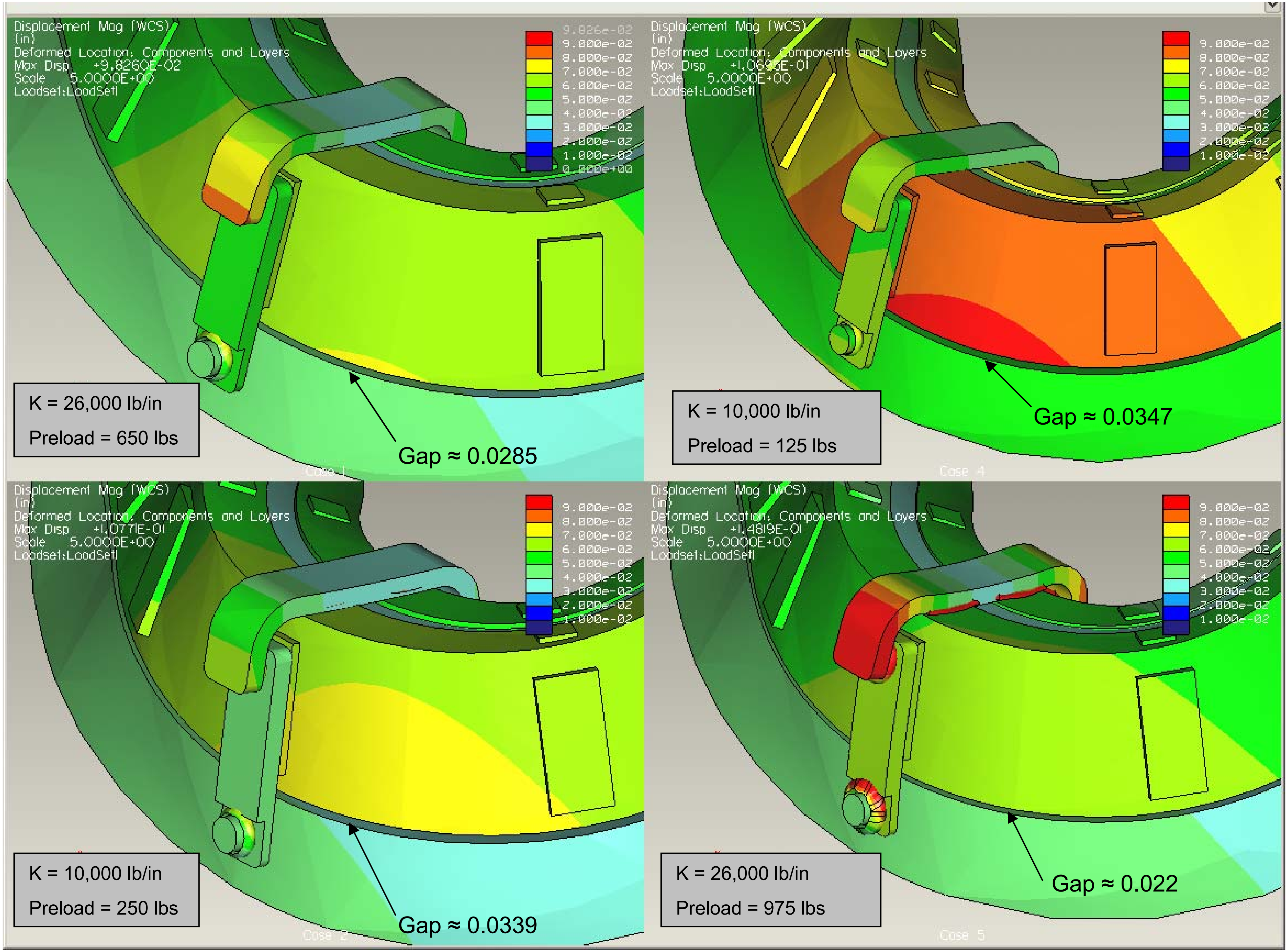
	Case 0: No clamps on the coil	**Case 00:** Faux clamps everywhere	**Case 000:** No Pressure loading aplied	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**
Washer k (lb/in)	-	10,000	10,000	10,000	5,000	20,000	2,500	10,000	10,000	10,000
Washer Preload (in)	-	0.025	0.025	0.025	0.025	0.025	0.025	0.05	0.01	0
Washer Preload (lb)	-	250	250	250	125	500	62.5	500	100	0
Winding E (psi)	9.50E+06	9.50E+06	9.50E+06	9.50E+06	9.50E+06	9.50E+06	9.50E+06	9.50E+06	9.50E+06	9.50E+06
Approximate Winding Dissplacement off Tee [west] (in)	**0.081**	0.026	0.025	0.023	0.023	0.022	0.021	0.02	0.025	0.026
Winding Dissplacement [East] (in)	**0**	0.042	0.016	0.042	0.047	0.032	0.054	0.038	0.045	0.046
Max Von Mises Stress in winding (psi)	**22,000**	10,700	3,500	11,500	10,200	12,200	9,500	11,500	10,500	10,500
Max Von Mises Stress Clamp (psi)	-	-	63,000 (39,000)	48,000 (28,000)	29,000 (15,000)	78,000 (46,800)	6,600 (4,200)	91,000 (54,000)	31,800 (11,400)	24,000 (3,800)

Multiple case have been run to determine what the correct design parameters should be for the clamps and corresponding Belleville washers. Cases 1–7 have one “real clamp” on board at west location and the rest are pseudo clamps.

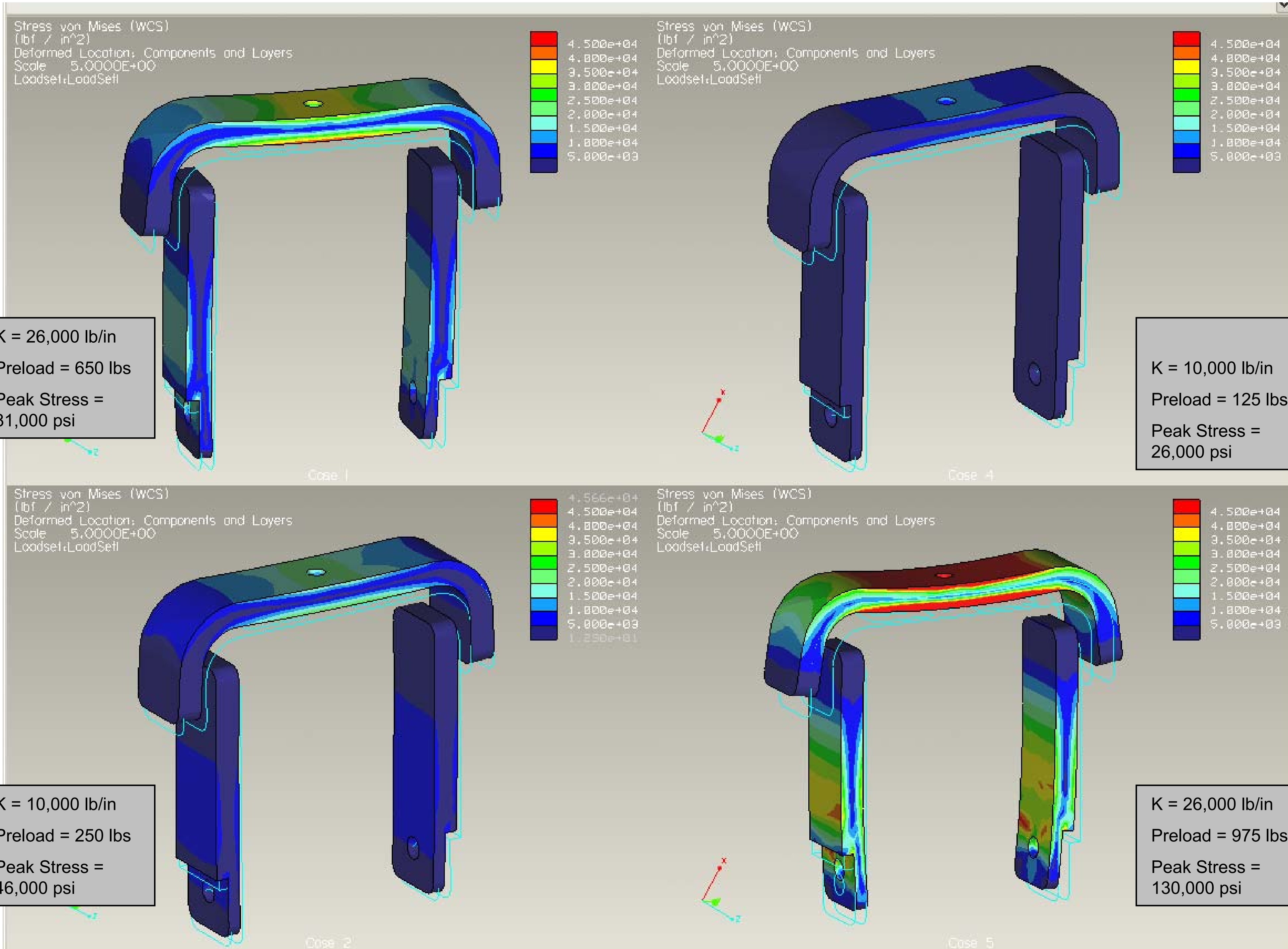
Displacement Comparison



How are Displacements from Tee Measured



Clamp Stresses



K = 26,000 lb/in

Preload = 650 lbs

Peak Stress = 81,000 psi

K = 10,000 lb/in

Preload = 125 lbs

Peak Stress = 26,000 psi

K = 10,000 lb/in

Preload = 250 lbs

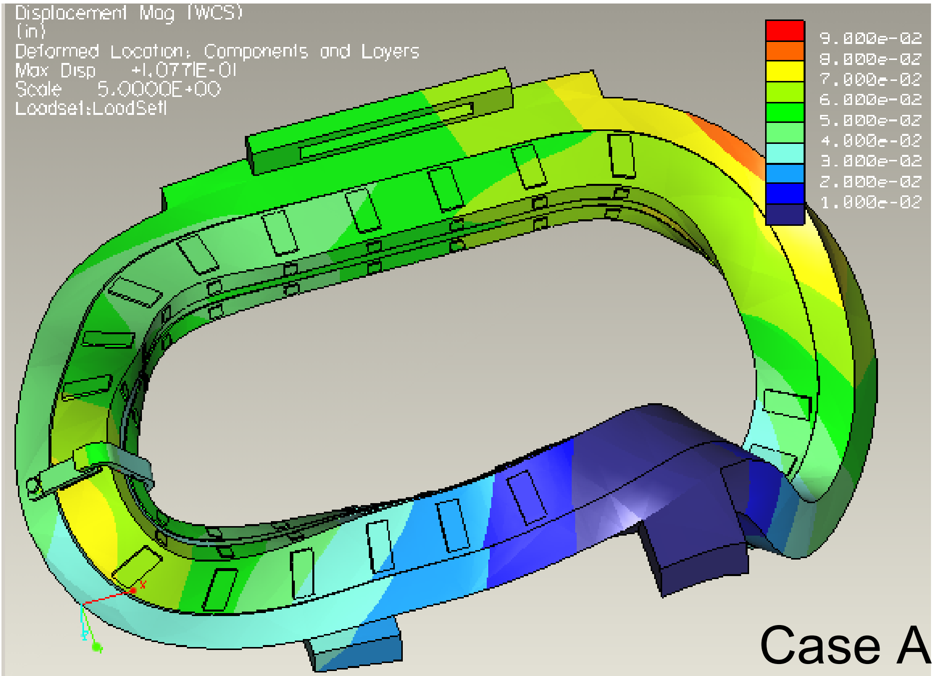
Peak Stress = 46,000 psi

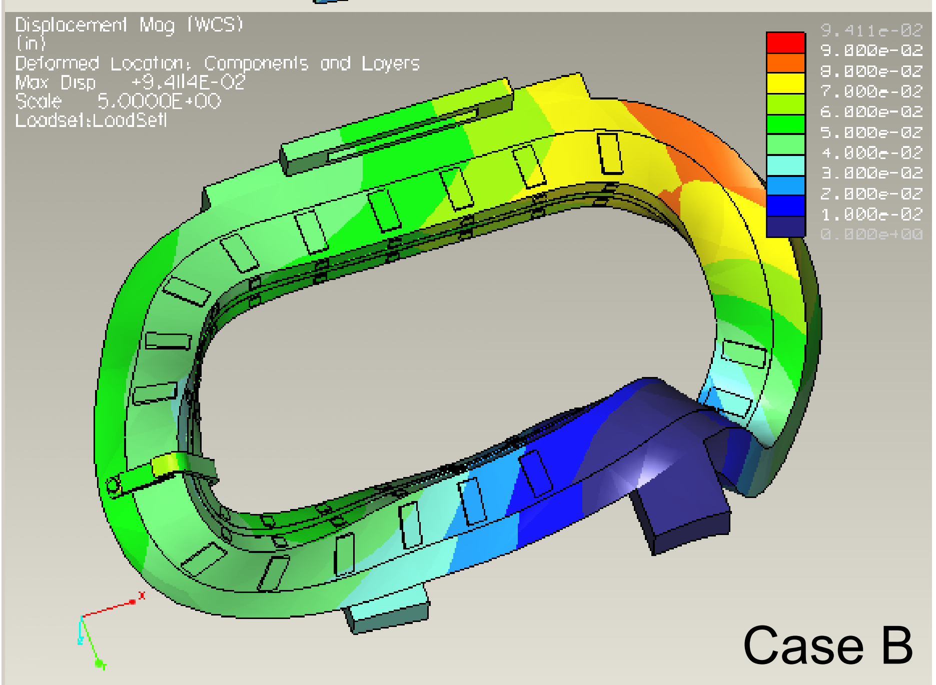
K = 26,000 lb/in

Preload = 975 lbs

Peak Stress = 130,000 psi

Winding Modulus Comparison Deformation



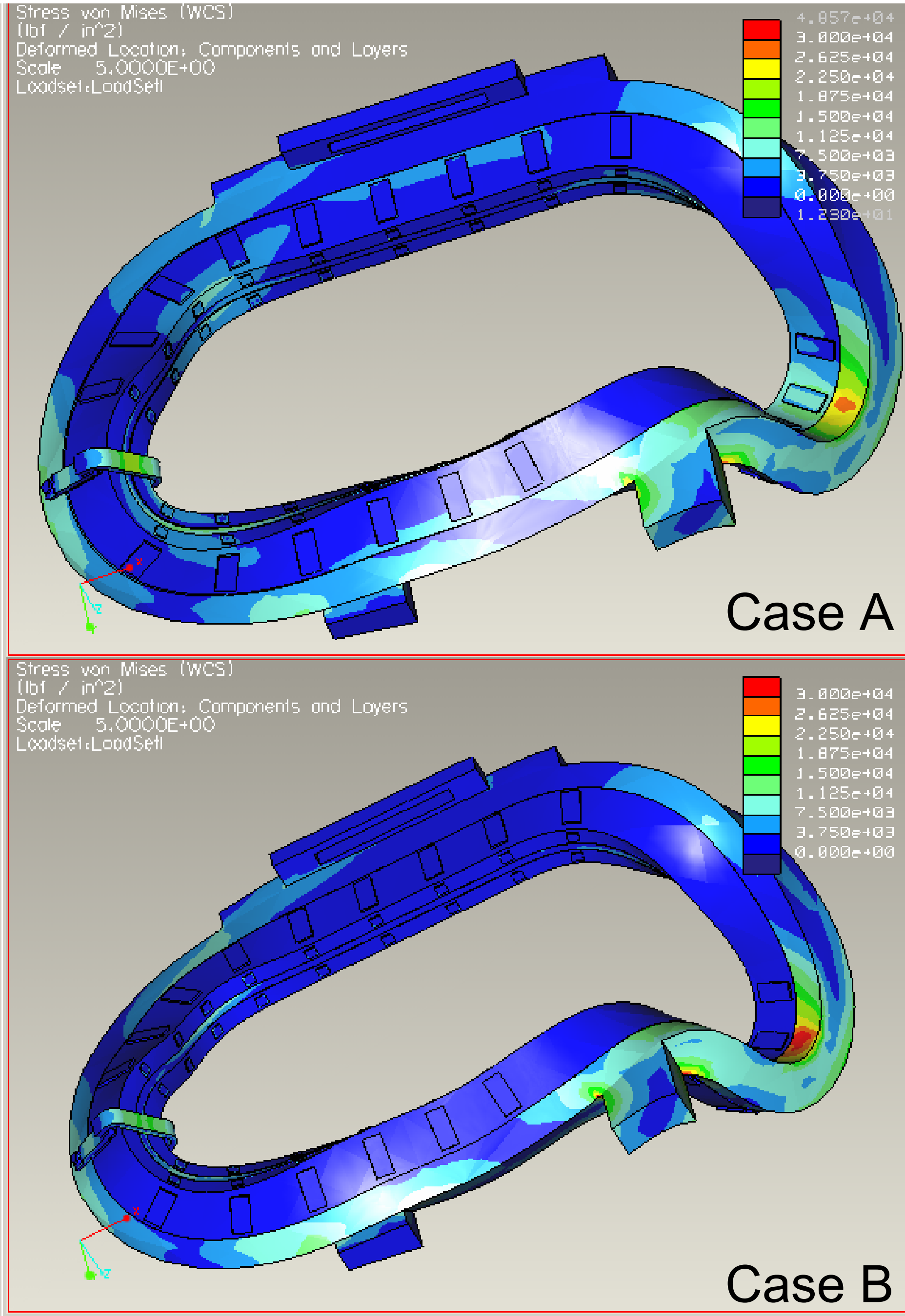


Points:

- **The modulus of the winding is a big player in determining the deflection of the coil.**
- **The deformation decreases with the lower modulus coil.**

Parameter	CASE A	CASE B
Spring stiffness (lb/in)	10,000	10,000
Winding Modulous (psi)	9.50E+06	1.00E+06
Pre-load deflection (in)	0.1	0.1

Winding Modulus Comparison Stress



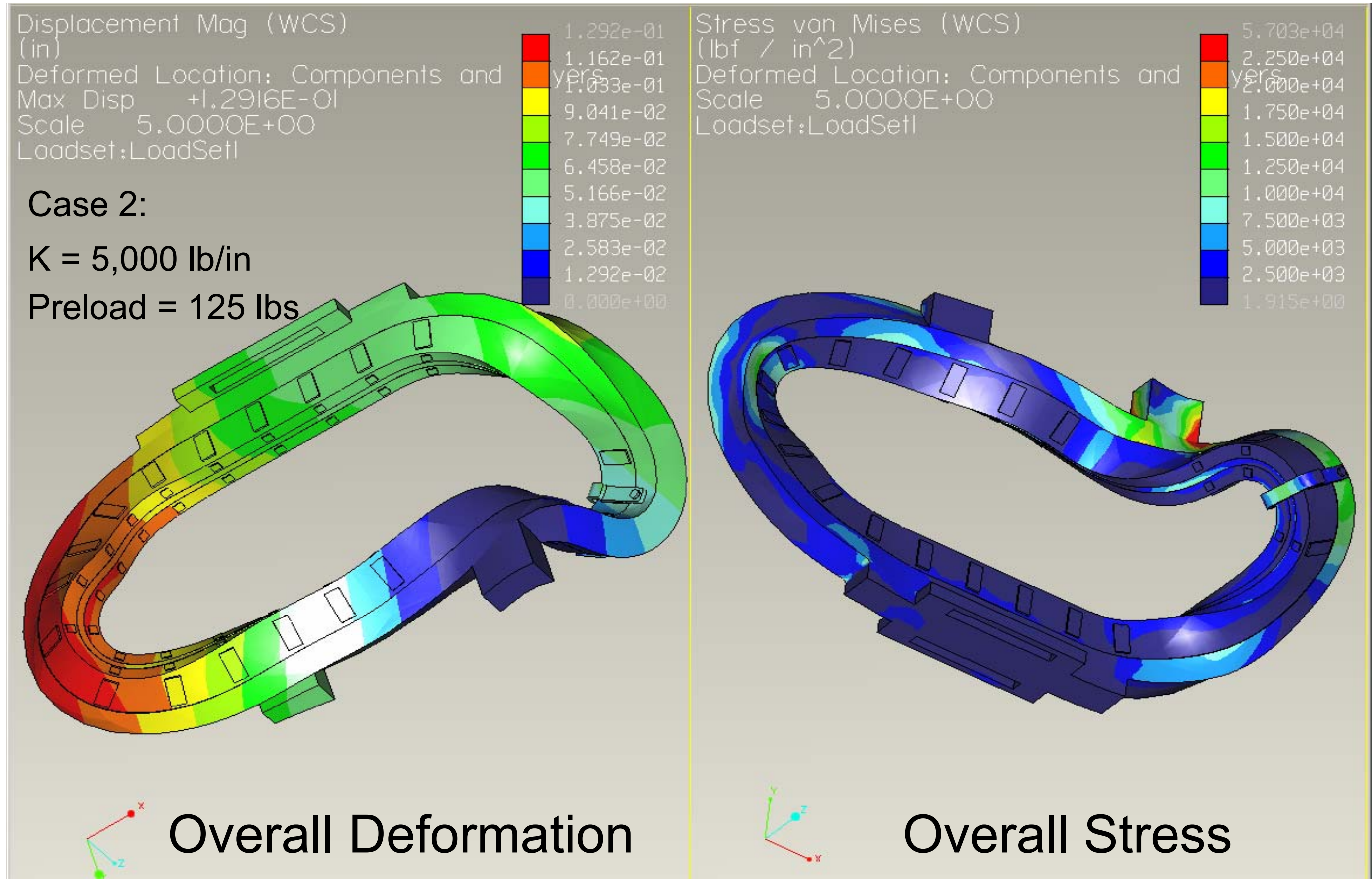
Points:

- **Stress in tee is higher for the less stiff winding.**
- **Winding stress decreases as winding modulus is lowered.**
- **Clamp Stress is relatively the same. Clamp is dominated by preloaded springs**

Parameter	CASE A	CASE B
Spring stiffness (lb/in)	10,000	10,000
Winding Modulous (psi)	9.50E+06	1.00E+06
Pre-load deflection (in)	0.1	0.1

Case 2 (Revisited 4-10-2004)

- Case 2 produced the best fit in terms of gap deflection, winding stress and clamp stress.
- Rerunning the case with the new cure shrinkage data produces the following results.



	Approximate Dissplacement Off Tee (in)	Faux Clamp Dissplacment (in)	Max Von Mises Stress in Winding (psi)	Max Von Mises Stress Clamp (psi)
0.04 % cure shrinkage (1-10-2004)	0.023	0.047	10,200	29,000 (15,000)
No Cure Shrinkage (4-12-2004)	0.007	0.019	8,400	25,000 (14,000)

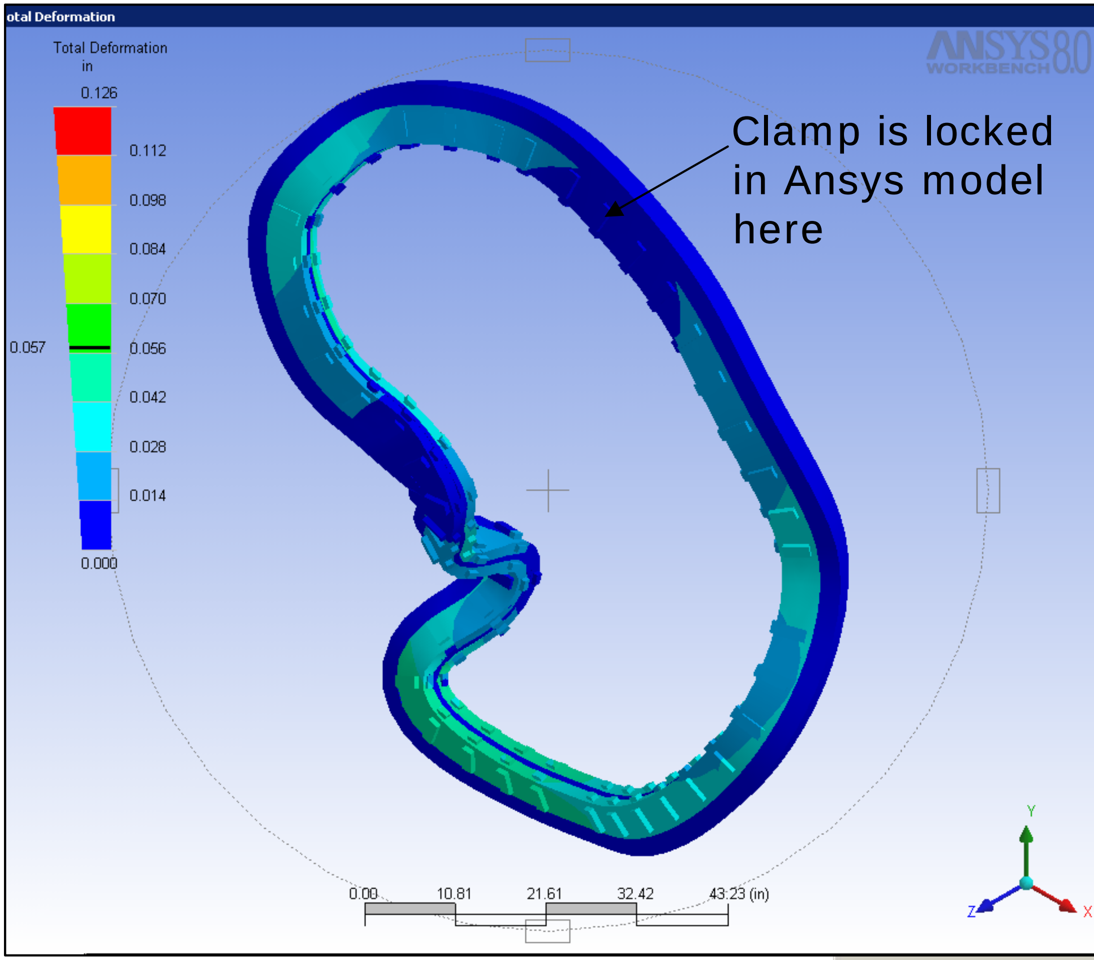
Obviously, the new data, if genuine, is encouraging.

Considering the 4 Operating States (Case 2, No Cure Shrinkage)

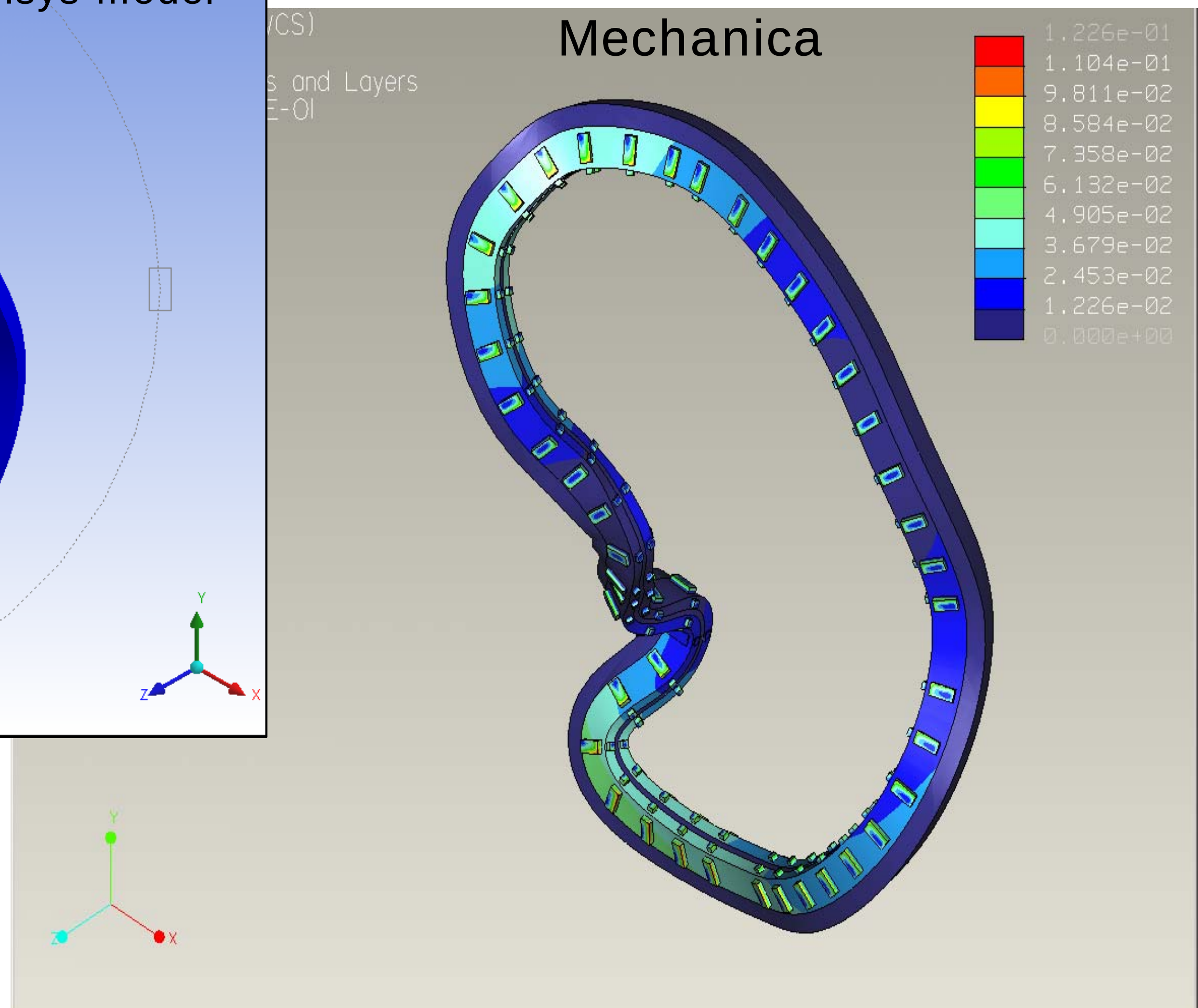
1. **Immediately after cool down.** -0.04 % relative strain between winding and tee due to thermal expansion.
2. **Beginning of Pulse.** Magnetic loading applied with thermal expansion.
3. **End of pulse**. Magnetic loading applied without thermal expansion, heating of coil has resulted in a relative +0.04 % strain difference between the winding and tee. (strain value is only coincidentally equal to the cool down strain difference).
4. **Post Pulse.** No magnetic loading, no thermal expansion (at rest state, coil will then cool back to state 1)

Operating State	Approximate Dissplacement Off Tee (in)	Faux Clamp Dissplacment (in)	Max Von Mises Stress in Winding (psi)	Max Von Mises Stress in Tee (psi)	Max Von Mises Stress Clamp (psi)
1	0.014	0.008	4,000	14,000	23,000 (12,000)
2	0.007	0.019	8,400	22,800	24,000 (14,000)
3	0	0.0002	7,350	35,285	23,000 (11,000)
4	-	-	-	-	24,000 (12,000)

Is Mechanica Accurate, Can It Be Trusted For Non-Linear Contact Analysis ?

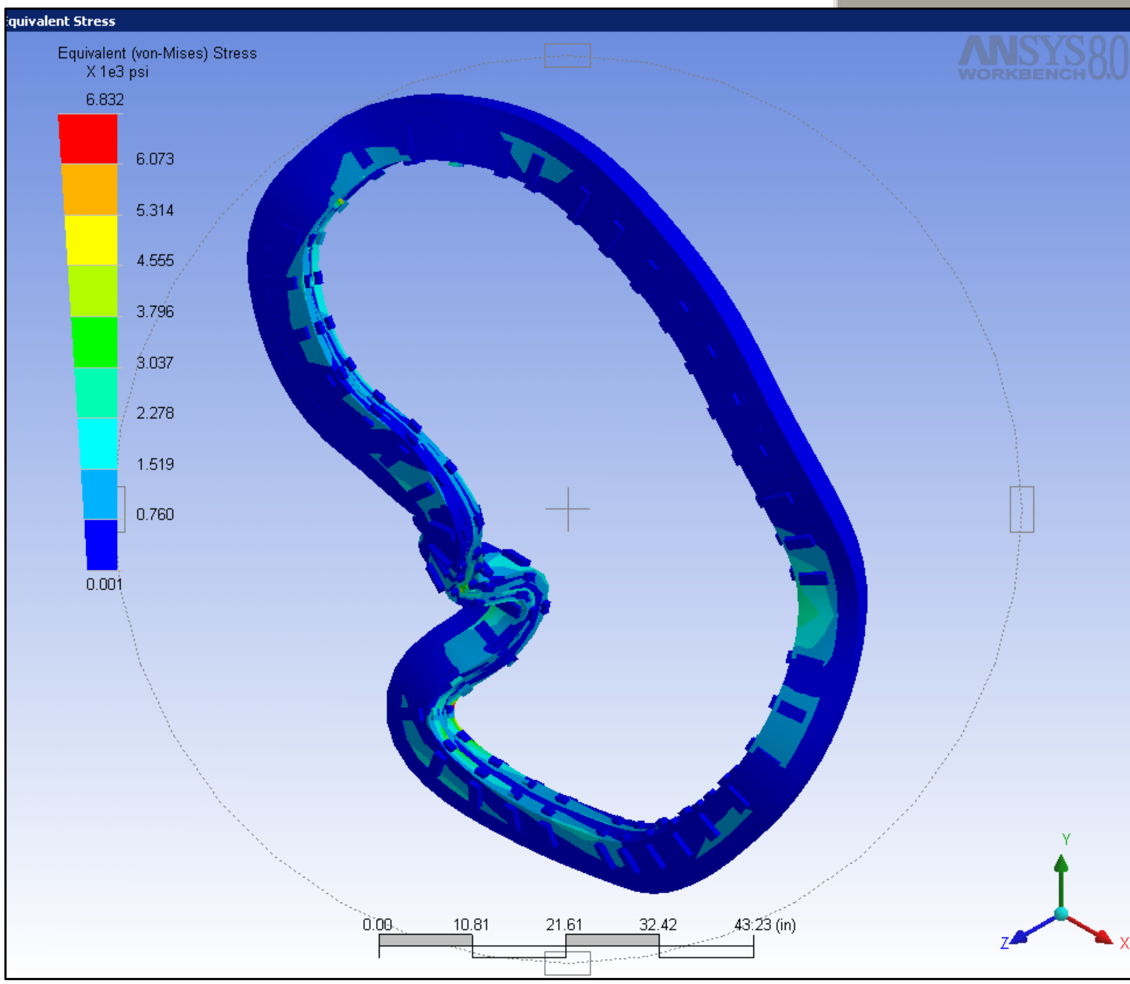


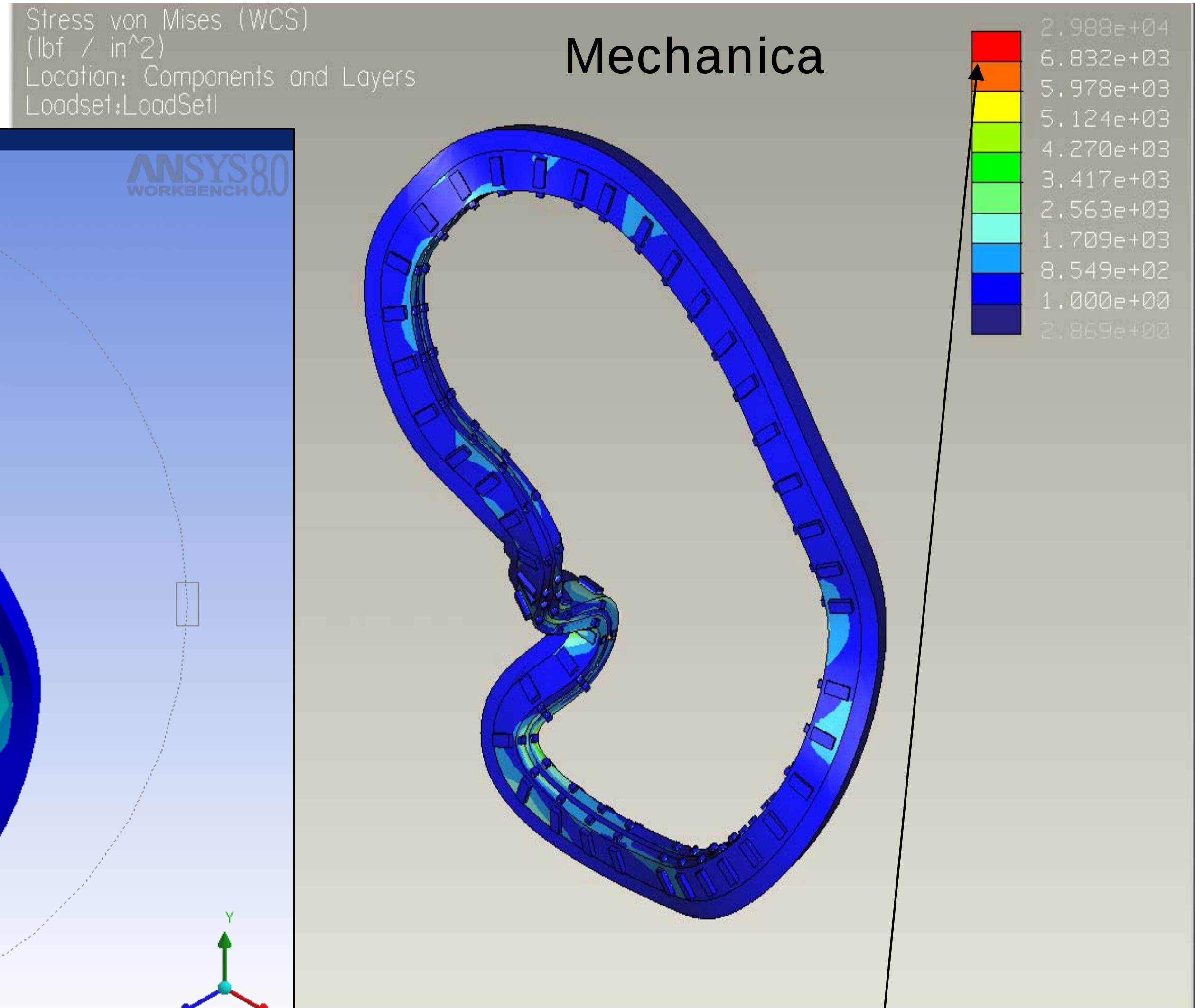
A comparison study has been worked in Ansys for modular coil 2.



No Preload on clamp pads in Ansys version

Comparison Between Mechanica and Ansys (Von Mises Stress)





Is Mechanica Accurate? Yes, It agrees well with Ansys

The high stress is in the pin connecting the clamp which the Ansys model does not have.

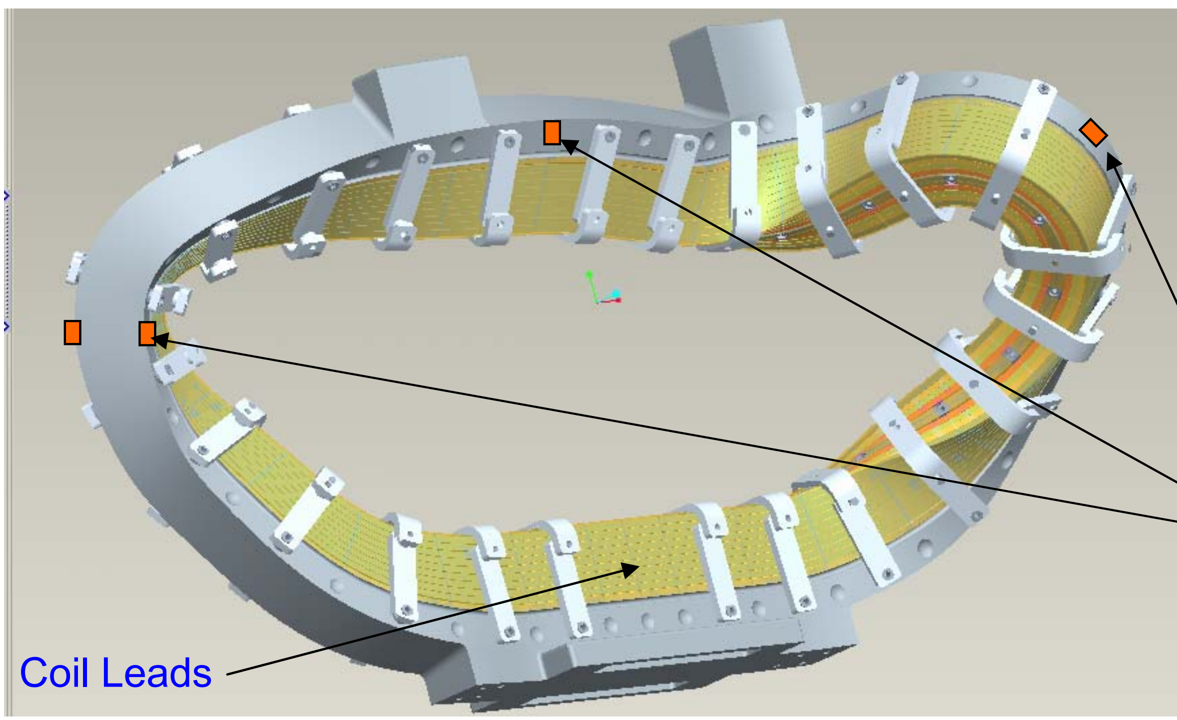
Summary

- Iterations show that Belleville washers should be designed with a stiffness of 5,000 - 10,000 lb/in and a preload of 100 – 125 lbs. This corresponds to case 2 and case 6.
- Clamp Stresses depends mostly on preload.
- Soft windings stick to the tee better, but do raise stress in the tee.
- Using no clamps, results in larger displacements and gaps, but this effect is less for the stiff winding pack.
- Mechanica and Ansys give the same answers for non-linear contact analysis.

Future Work

- Modify Winding Stiffness based on results of ongoing tension and compression tests at PPPL.
- Provide a table for predicted strain values at experimental strain gage locations for the four loading states.
- Perform a detailed analysis of the actual clamp design (with all features) based on the max deflections measured in this analysis.

“Actual” clamp design



Strain Gauge Locations (ends and middle of winding form) ?

Work to be done

Design tasks -

- Complete pattern drawings for inner plate (cladding)
- Issue clamp detail drawings for fabrication
- Finalize patterns for chill plate and cooling tubes, develop drawings

Schedule -

			May				Jun					Jul				Aug				Sep				
Week #	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Issue cladding and clamp detail drawings	X																							
Issue chill plate / cooling detail drawings		X																						
Fabricate / procure hardware		X	X	X	X	X	X																	
Wind coil								X	X	X	X	X												
Mold and VPI													X	X	X									
Setup and test																X	X	X	X					

Begin winding prototype coil

The twisted racetrack coil is prototypical

- complex winding surface
- actual conductor and insulation
- prototypical clamps and chill plates
- utilizes production winding facility

Test objectives have been defined

All models / drawings are not final, but should be released in stages asap to improve schedule