U.S. MAGNET DEVELOPMENT PROGRAM

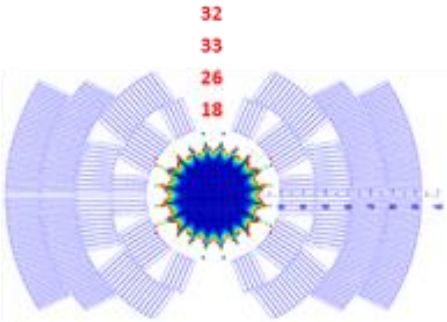
15 T cos-theta dipole demonstrator status

MDP meeting, July 19, 2017

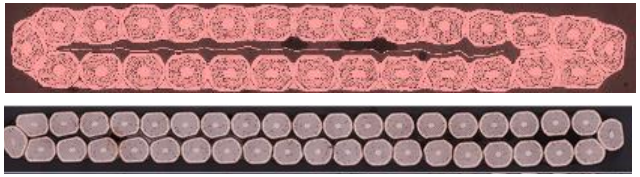
Alexander Zlobin
US Magnet Development Program
Fermi National Accelerator Laboratory

MDP High Field Dipole Demonstrator design

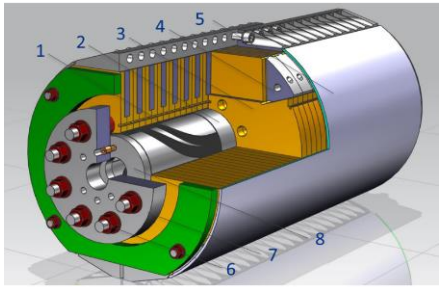
- Coil:
  - 60-mm aperture
  - 4-layer graded coil
  - W_{sc} = 68 kg/m/aperture

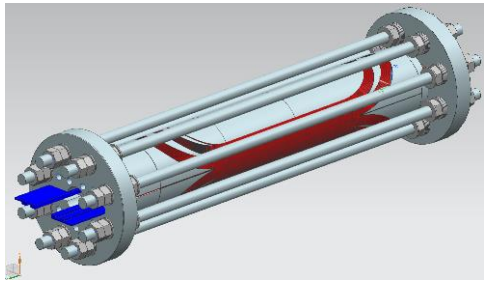


- Cable:
  - L1-L2: 28 strands, 1 mm RRP150/169
  - L3-L4: 40 strands, 0.7 mm RRP108/127
  - SS core
  - Insulation: E-glass tape



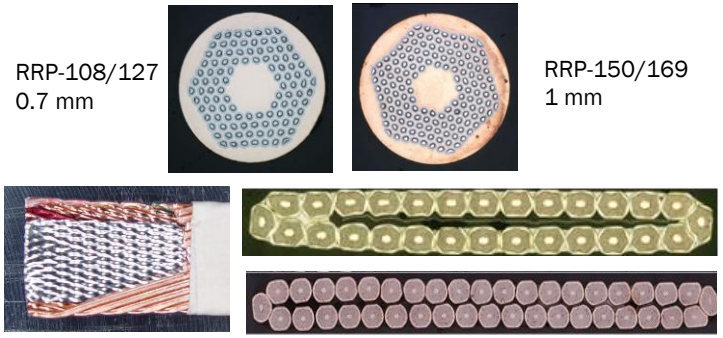
- Mechanical structure:
  - Thin StSt coil-yoke spacer
  - Vertically split iron laminations
  - Aluminum I-clamps
  - 12-mm thick StSt skin
  - thick end plates and StSt rods
  - Cold mass OD<610 mm (VMTF Dewar limit)

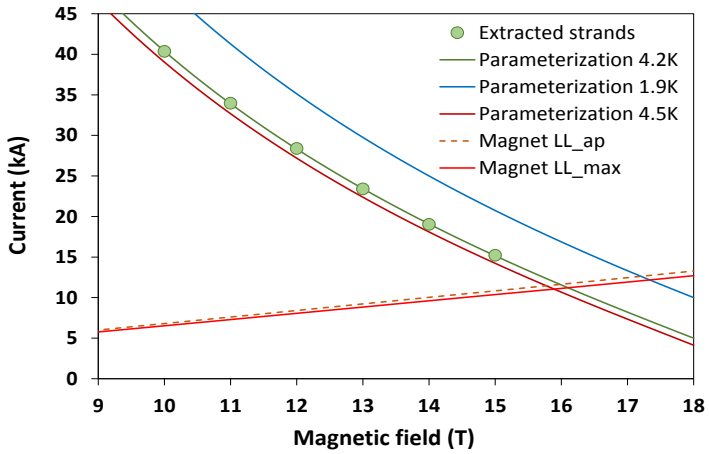




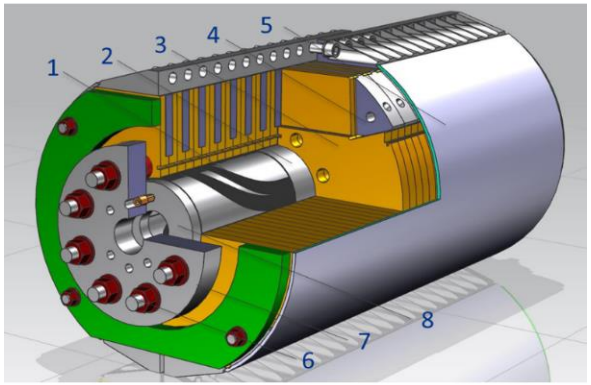
SC strand and cable

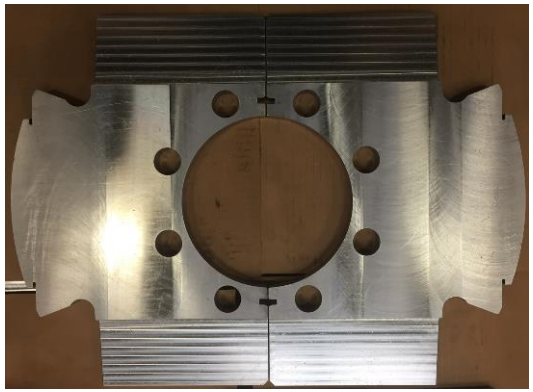
- Cable parameters
  - L1-L2: 28 strands, 1 mm RRP150/169
  - L3-L4: 40 strands, 0.7 mm RRP108/127
  - 0.025 mm by 11 mm SS core
- Magnet SSL estimated based on the cable test data:
  - 11.05 kA (B_{ap}=15.3 T) at 4.5 K
  - 12.2 kA (B_{ap}=16.7 T) at 1.9 K.



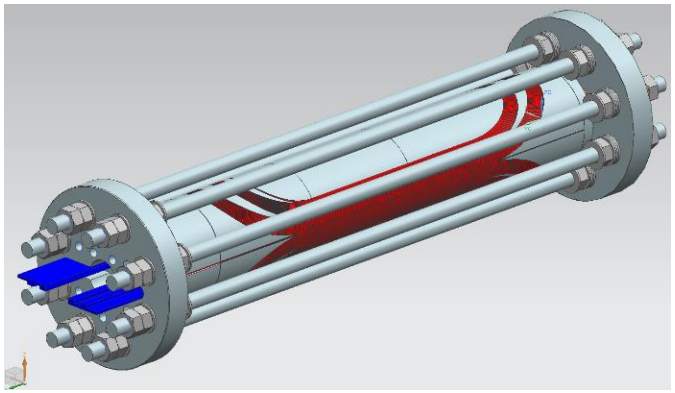


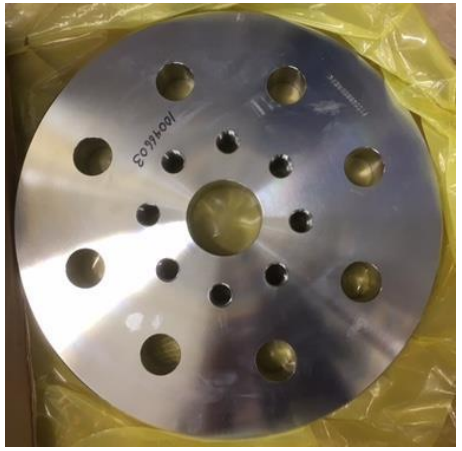
Procurement: Mechanical stricture





Procurement: Axial support structure



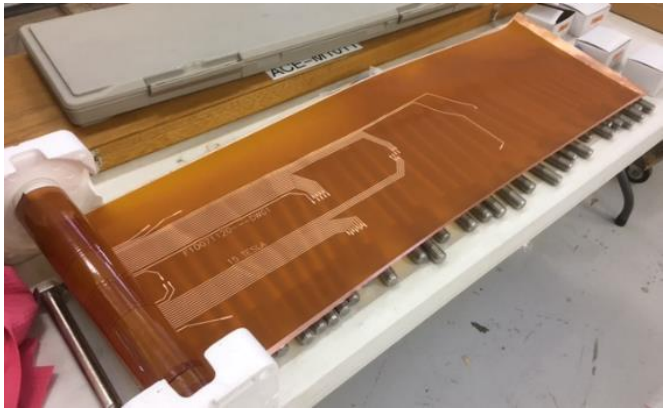


Procurement: Coil components

Cable (FNAL)

- 420 m of 28-strand cable
- 350 m of 40-strand cable + leftover from the 11 T program

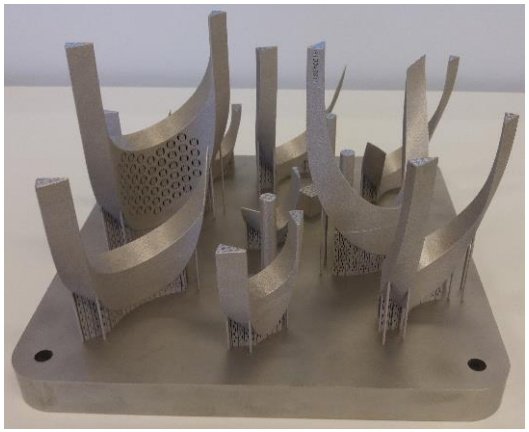
Traces (FNAL)



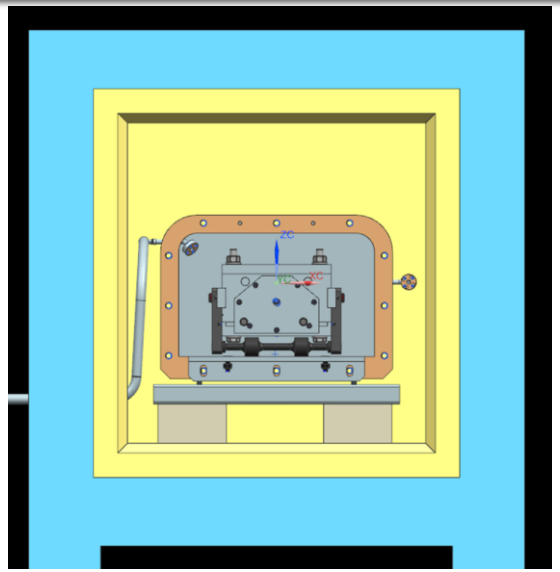
L3/4 parts (FNAL)

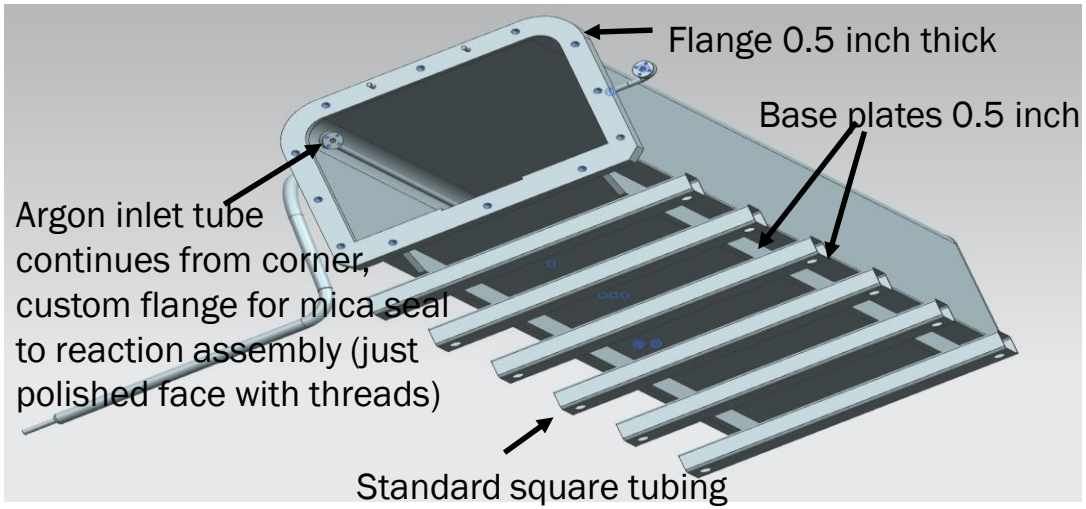
L1/2 parts (CERN)

	Pre-series	Series (availability at CERN)
Saddle	20 March 2017 (all parts accepted, except part 54822)	Parts will be produced until 30/05/2017, company will also do QC, for-crosschecking some parts will be already QC before that date at CERN
Pole	19 May 2017	
Wedge Ti	No pre-series	30/05/2017 (+2 weeks for measurement at CERN)
Wedge Discup	No pre-series	30/05/2017 (+2 weeks for measurement at CERN)
End spacers	-First set of end spacers (non-conform) shipped (arrival at FNAL ~15/03/2017) -Second set measured and accepted (27/03/2017)	All parts are produced, some will be measured (9 parts), ~3 weeks for measurements



Procurement: Coil reaction retort





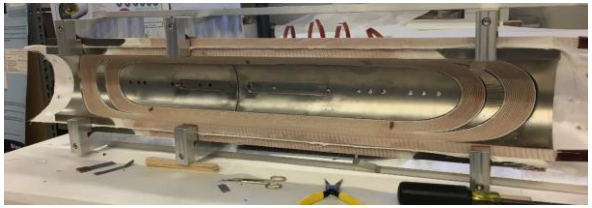
Coil fabrication status: L3/4

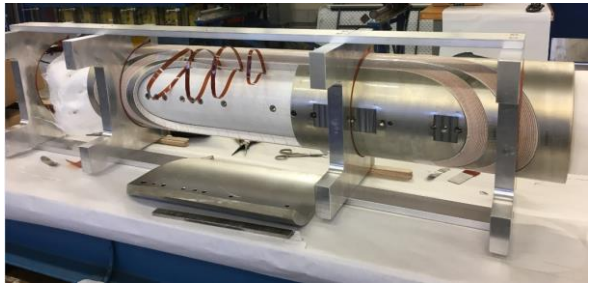
Coil #1

- Coil reaction is complete
- 8 witness samples have been tested

Coil #2

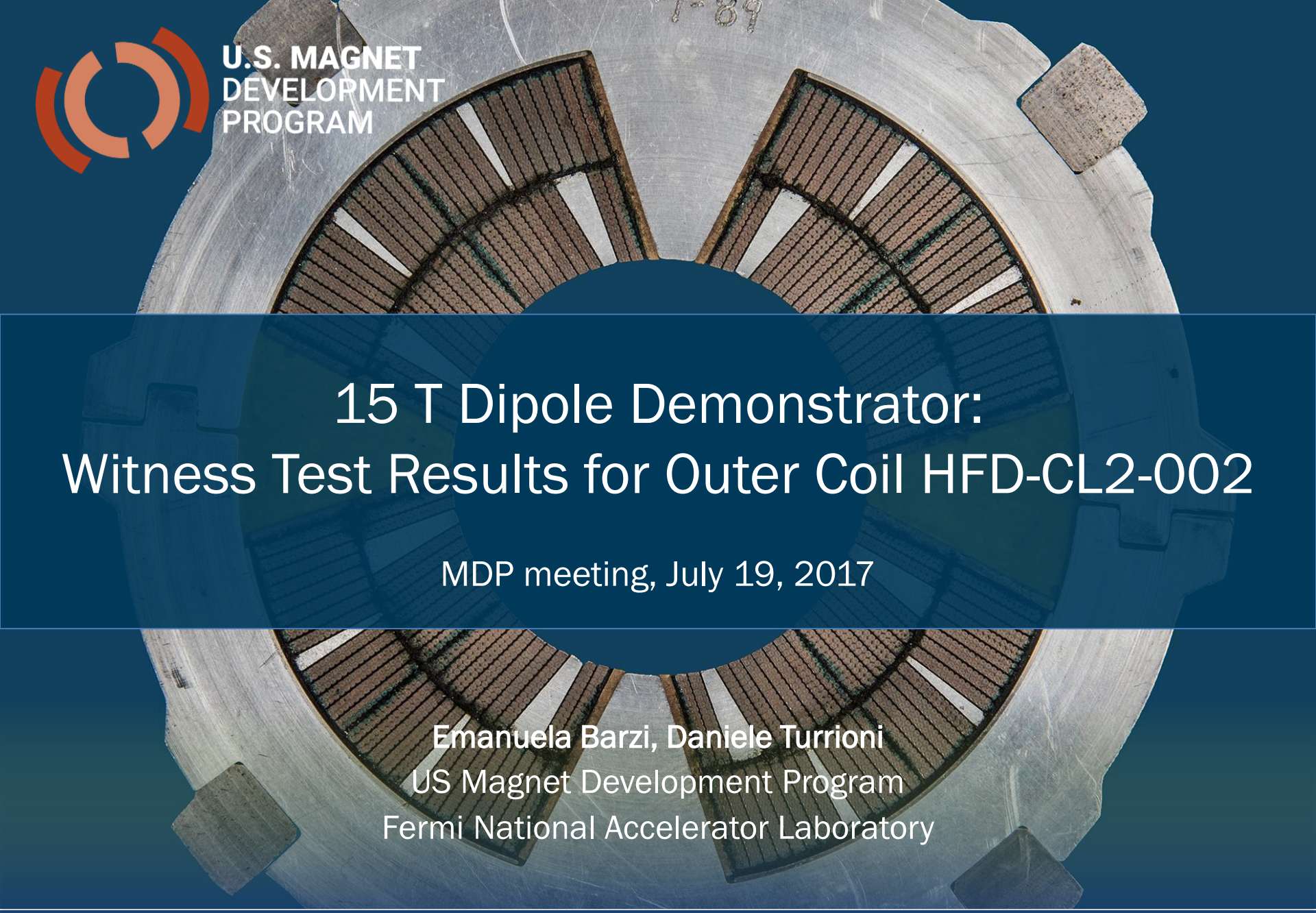
- Coil winding and curing is complete
- Short in the transition cable has been found and fixed
- Will be used as a spare coil





Coil #3

- Inner layer was wound and cured
- Outer layer winding is in progress



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15 T Dipole Demonstrator: Witness Test Results for Outer Coil HFD-CL2-002

MDP meeting, July 19, 2017

Emanuela Barzi, Daniele Turrioni
US Magnet Development Program
Fermi National Accelerator Laboratory

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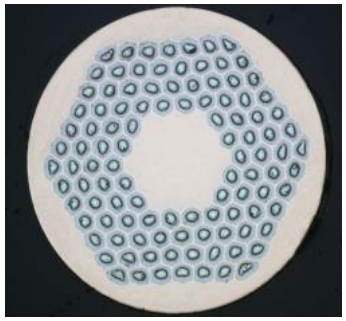
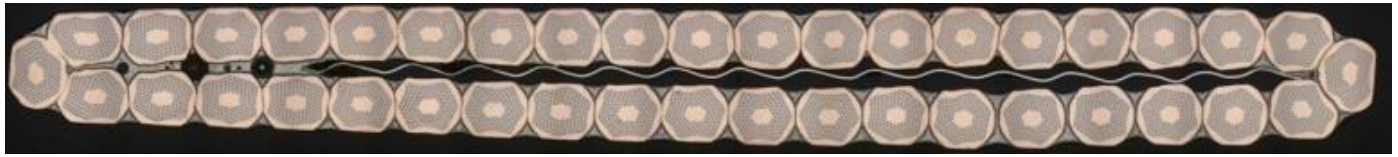
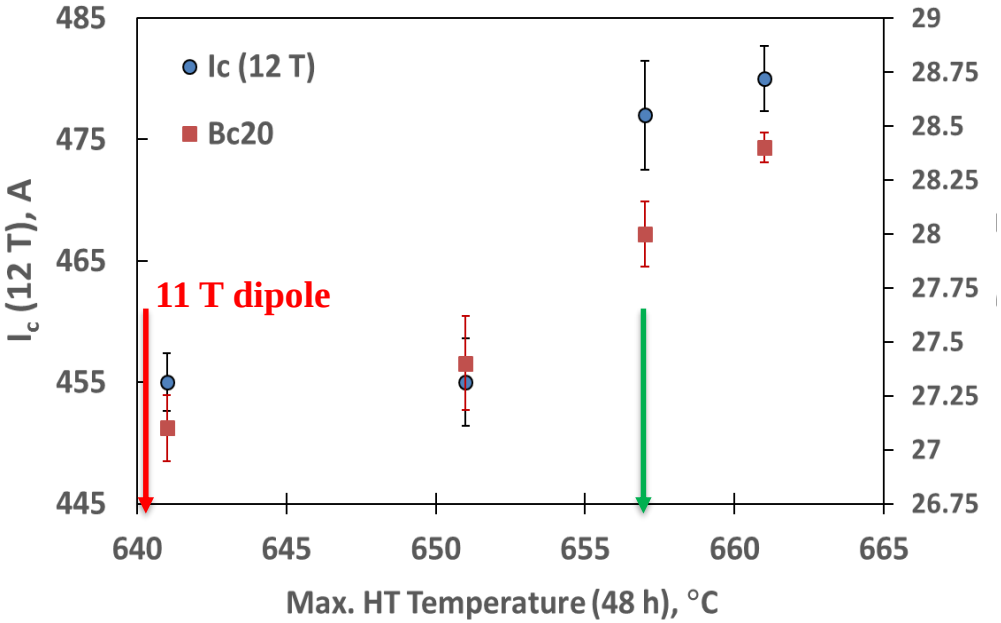
Heat Treatment Optimization for 15 T outer coil

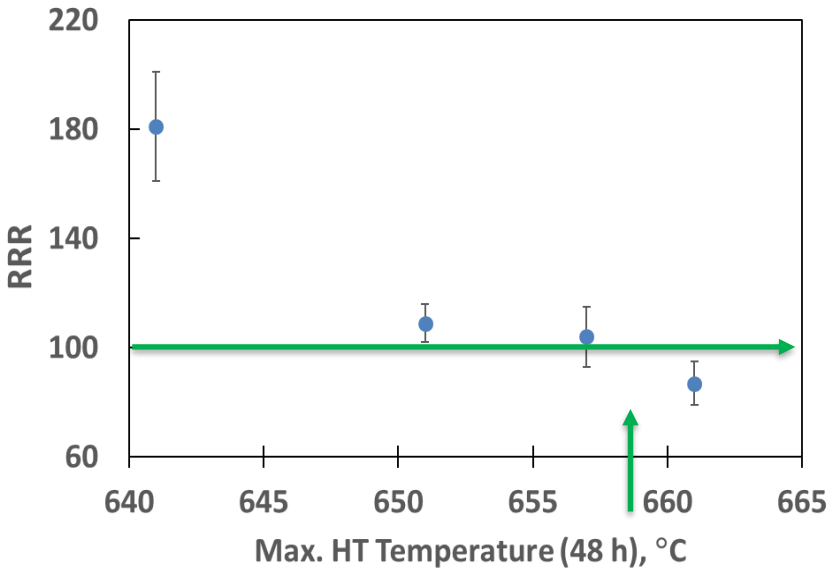


0.7 mm RRP108/127
40-strand cable with SS core



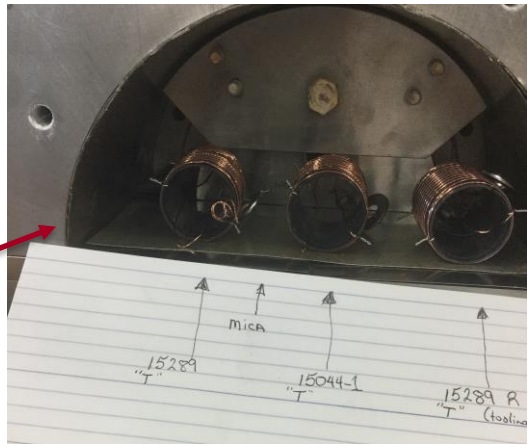
Studies performed on extracted strands





Witness Sample Location

Pure Argon is fed from the bottle to the coil and tooling first, and to the retort next.

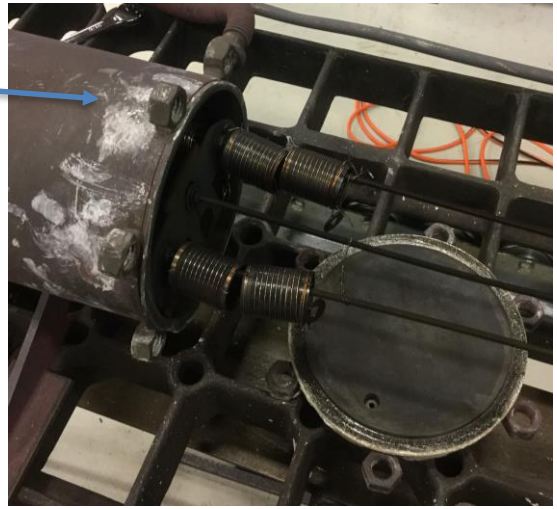


TOOLING

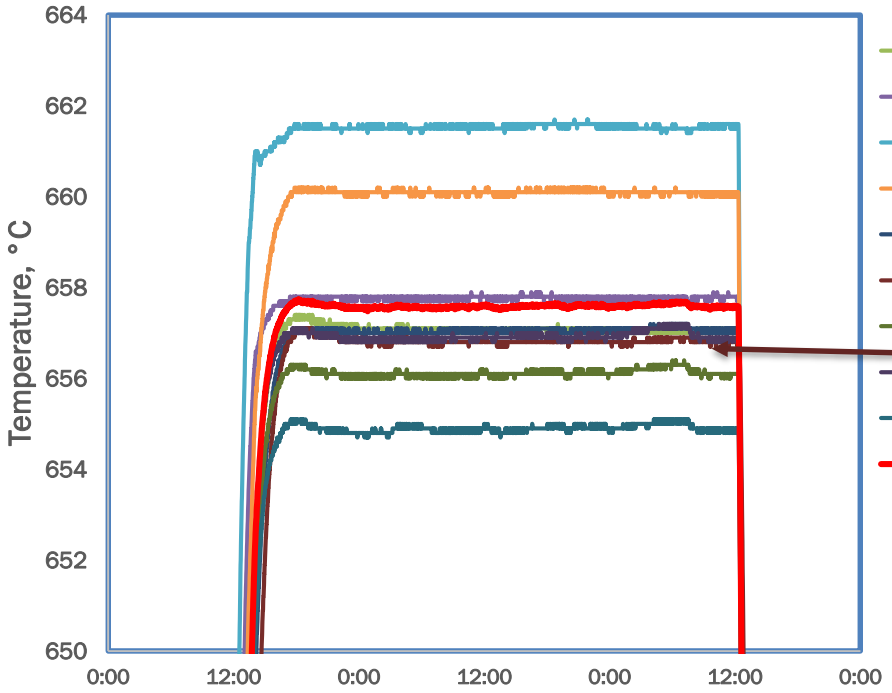
4 samples (1 round + 3 extracted) were placed in a central position with respect to the coil cross section, i.e. where temperature is the lowest.

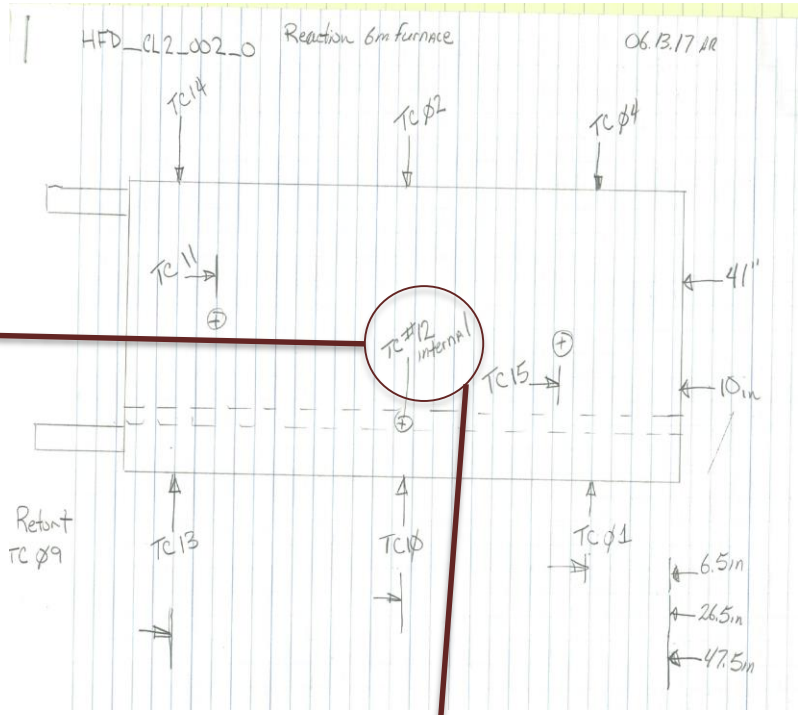
RETORT

8 samples (2 round + 6 extracted) were placed along the retort.



Heat Treatment Obtained





Nominal desired on coil: 72 hr @ 210°C, 48 hr @400°C, 48 hr @ 657°C

Average obtained: 72 hr @ 208°C, 48 hr @400°C, 48 hr @ 658°C

Internal TC #12 obtained: 72 hr @ 208°C, 48 hr @399°C, 48 hr @ 657°C

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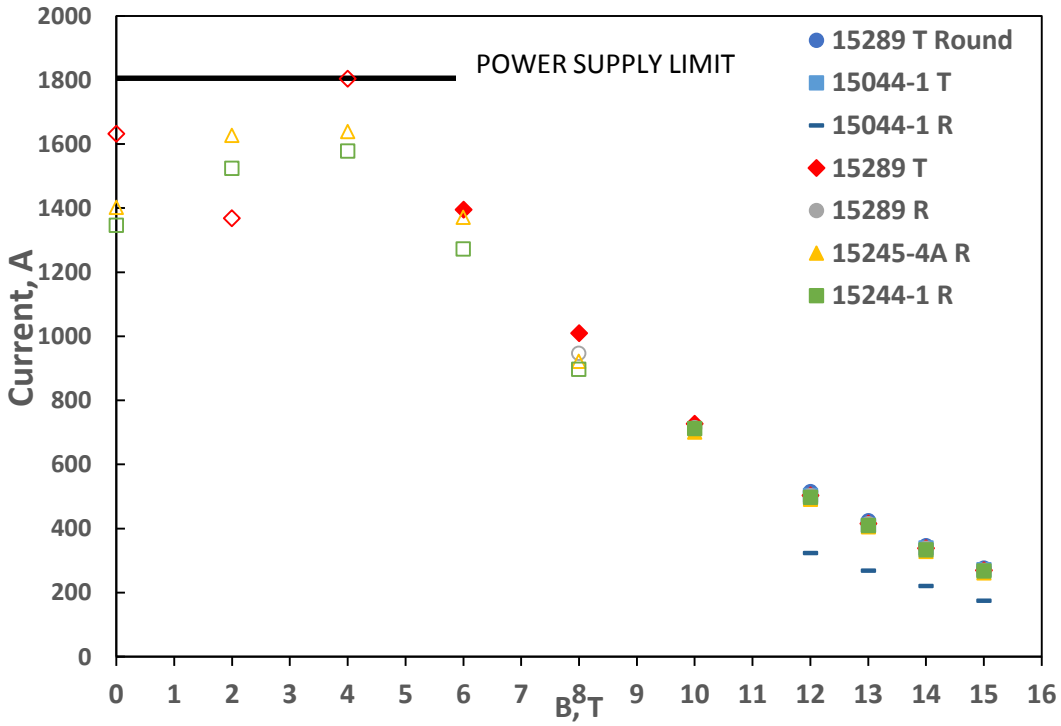
Test Results (8 samples tested so far)

EXTRACTED	15044-1				15289				15245-4A		15244-1	
	Tooling		Retort		Tooling		Retort		Retort		Retort	
	Ic, A	Jc, A/mm^2	Ic, A	Jc, A/mm^2	Ic, A	Jc, A/mm^2	Ic, A	Jc, A/mm^2	Ic, A	Jc, A/mm^2	Ic, A	Jc, A/mm^2
15 T Field	272	1536	175	991	270	1509	270	1511	262	1488	268	1513
12 T Field	(504)	2847	324	1830	504	2816	504	2817	492	2797	498	2813
n-value (15 T)	(38)		18		(40)		(45)		(42)		-	
RRR	86		56, 60		130		90, 97		49, 84		69, 84	



Ic (12 T)_Extracted - GOAL = (477 ± 5) A

RRR_Extracted - GOAL = 104 ± 11

Ic (12 T)_Extracted (Tooling) = 504 A

Ic (12 T)_Extracted (Retort) = (498 ± 3) A

RRR_Extracted (Tooling) = 108 ± 22

RRR_Extracted (Retort) = 74 ± 6

ROUND	15289			
	Tooling		Retort	
	Ic, A	Jc, A/mm^2	Ic, A	Jc, A/mm^2
15 T Field	277	1550		
12 T Field	516	2882		
n-value (15 T)	(51)			
RRR	175		132, 159	

U.S. MAGNET DEVELOPMENT PROGRAM

15 T Dipole Demonstrator: Mechanical Model

MDP meeting, July 19, 2017

Igor Novitski, Charles Orozco
US Magnet Development Program
Fermi National Accelerator Laboratory

U.S. DEPARTMENT OF ENERGY | Office of Science

Mechanical Model

MM design:

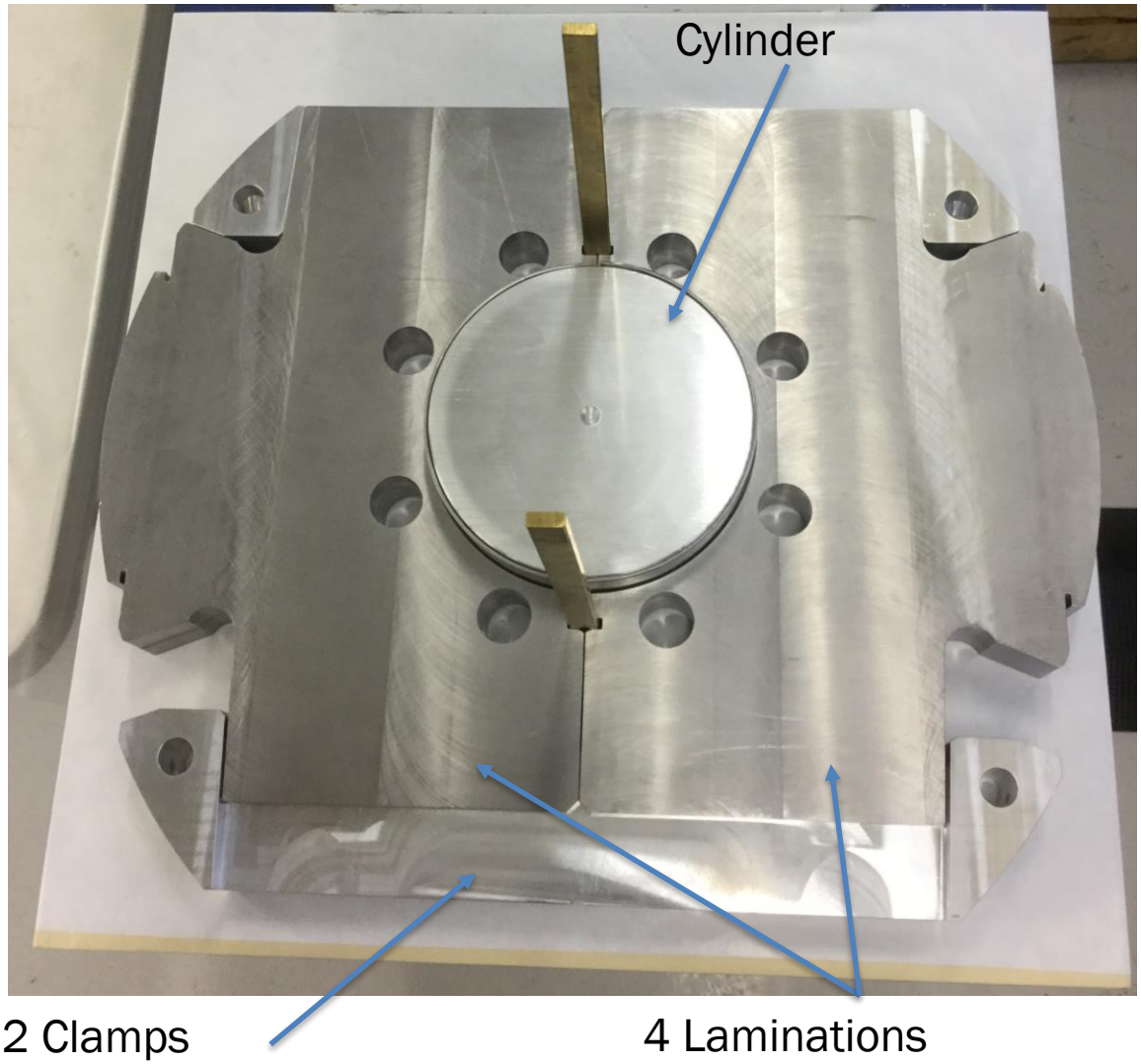
- iron laminations
- Al I-clamps
- coil-yoke shim
- instrumented “dummy” Al coils (short and full-size)

Goals:

- Test assembly tooling and main components of the mechanical structure
- Develop coil assembly plan and prestress targets
- Compare experimental data with the FEA

Short Mechanical Model

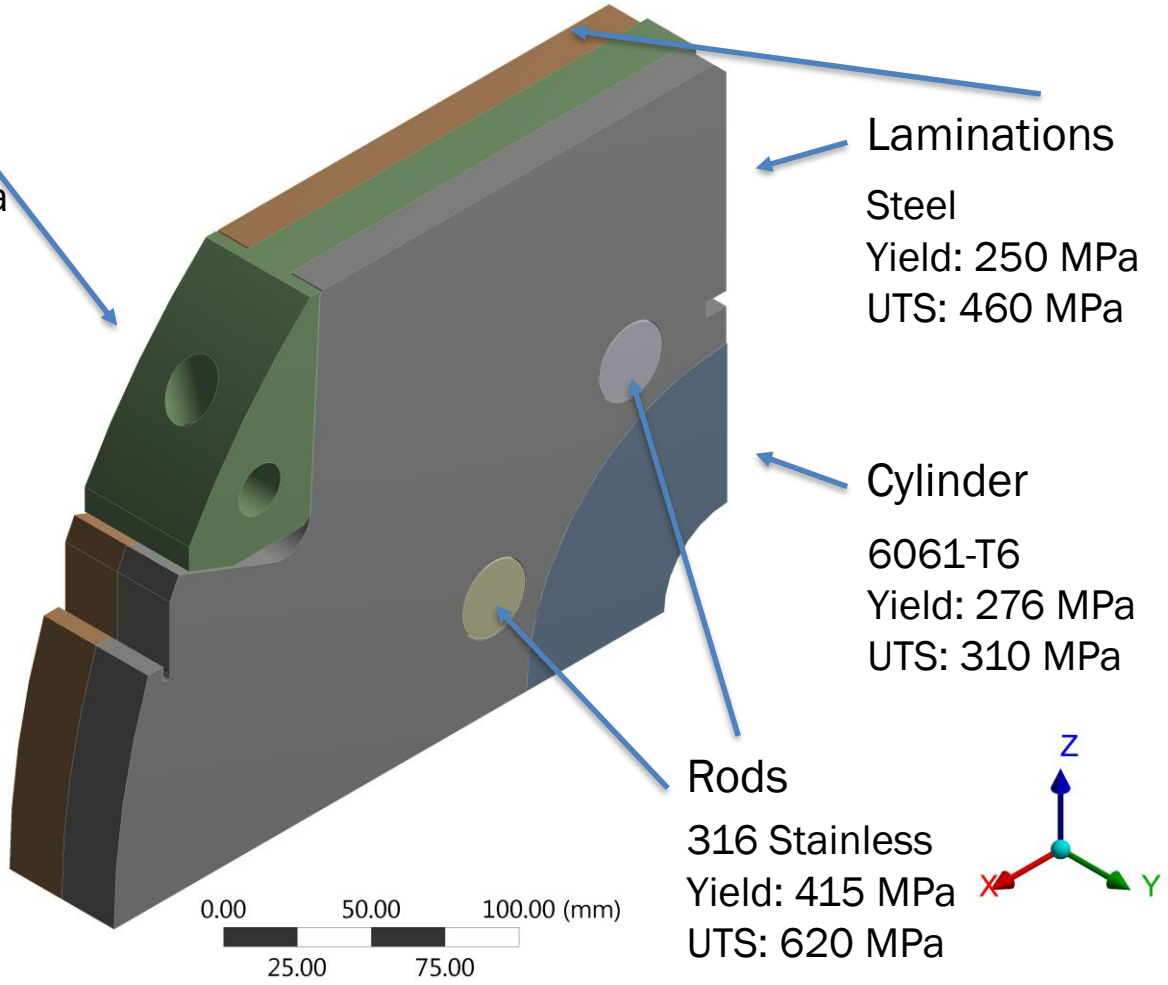
- 2’’-long for Cold Test
  - FEA Results Verification
  - Material Cold Test (Stress and Displacements vs Rad-Shim)
  - Instrumentation Location



Geometry

Clamp

7075-T6
Yield: 503 MPa
UTS: 572 MPa



Laminations

Steel
Yield: 250 MPa
UTS: 460 MPa

Cylinder

6061-T6
Yield: 276 MPa
UTS: 310 MPa

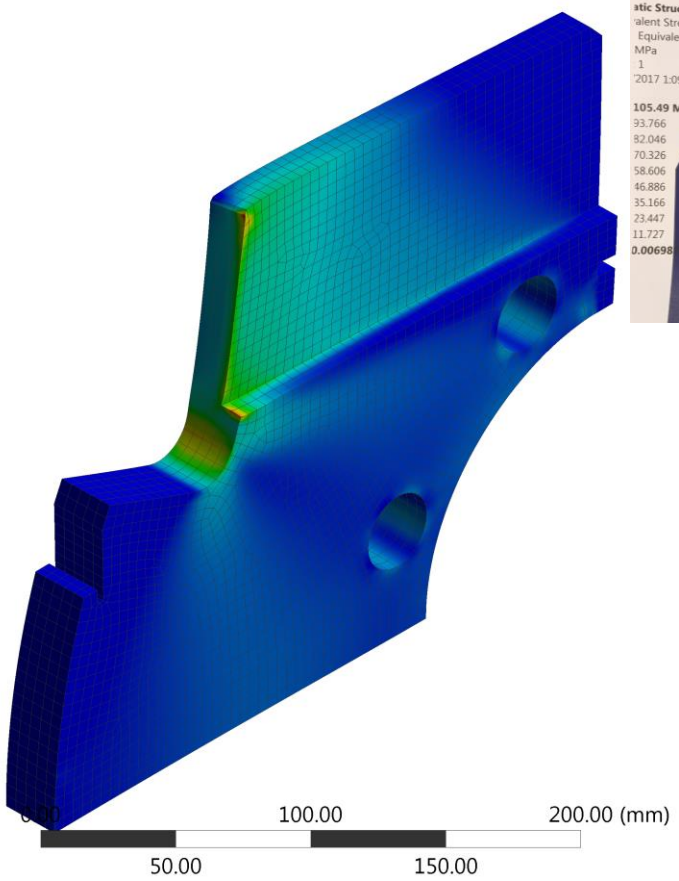
Rods

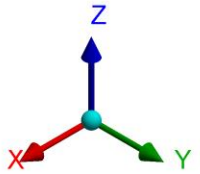
316 Stainless
Yield: 415 MPa
UTS: 620 MPa

Sample Results Images $(\delta_{clamp} = 0.3mm, \delta_{cylinder} = 0mm)$

H: Mechanical Model
Lam 2 Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
2/24/2017 1:39 PM

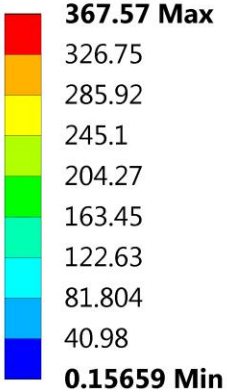
360.41 Max
320.37
280.32
240.28
200.24
160.19
120.15
80.108
40.065
0.021575 Min

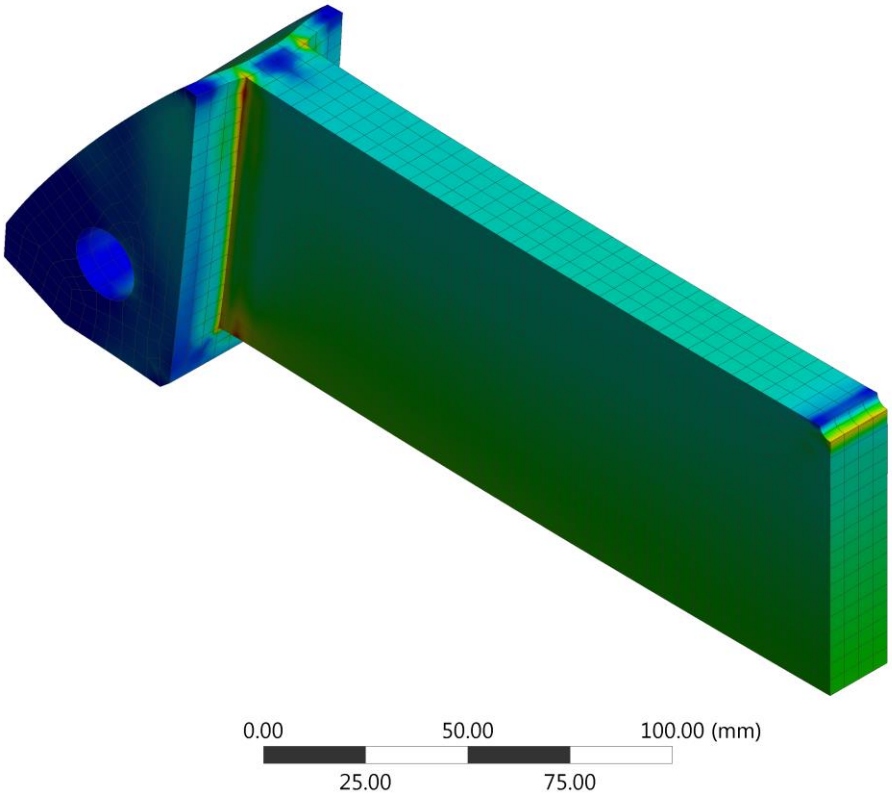


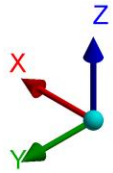


Sample Results Images ($\delta_{clamp} = 0.3mm, \delta_{cylinder} = 0mm$)

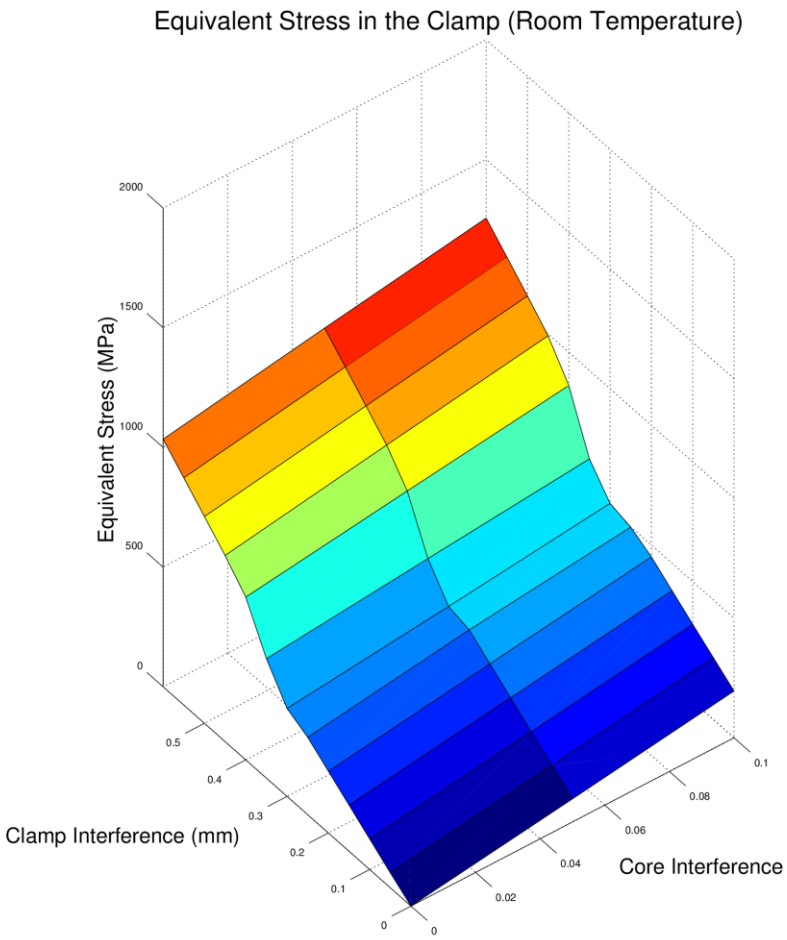
H: Mechanical Model
Clamp Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
2/24/2017 1:38 PM

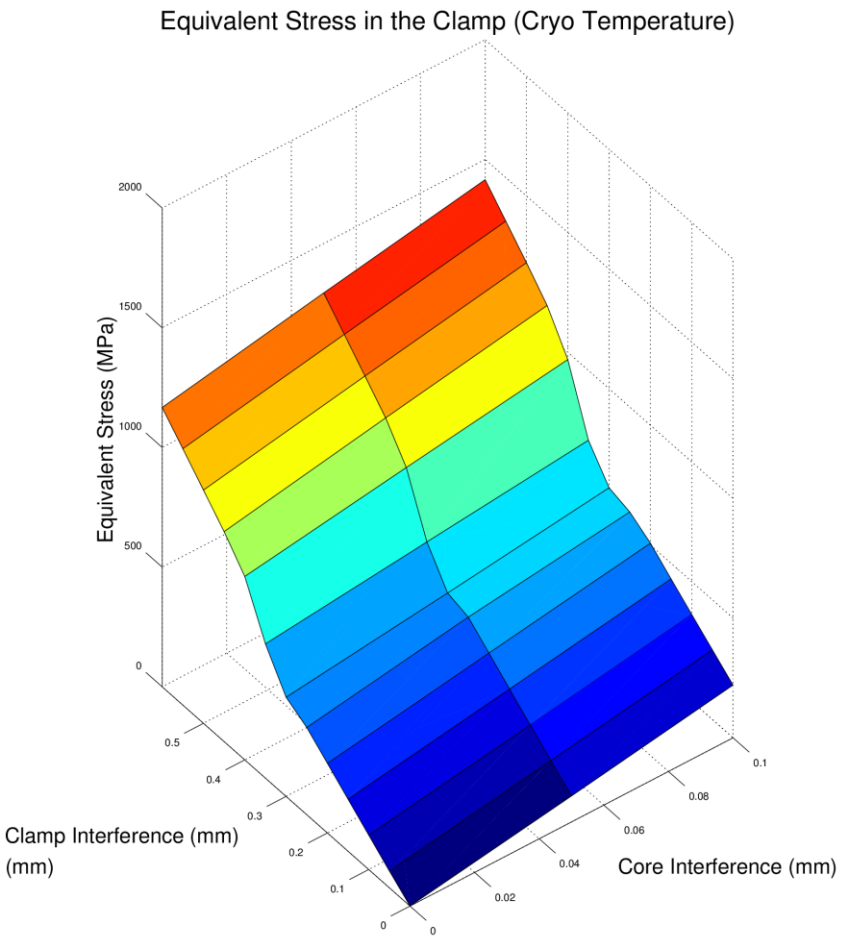




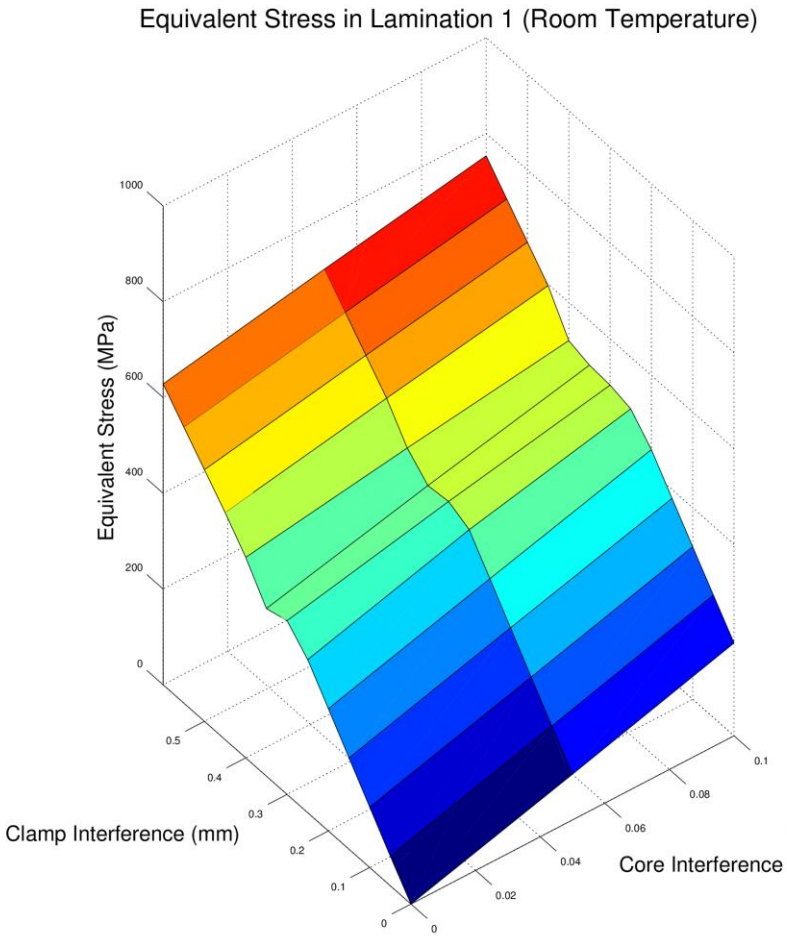


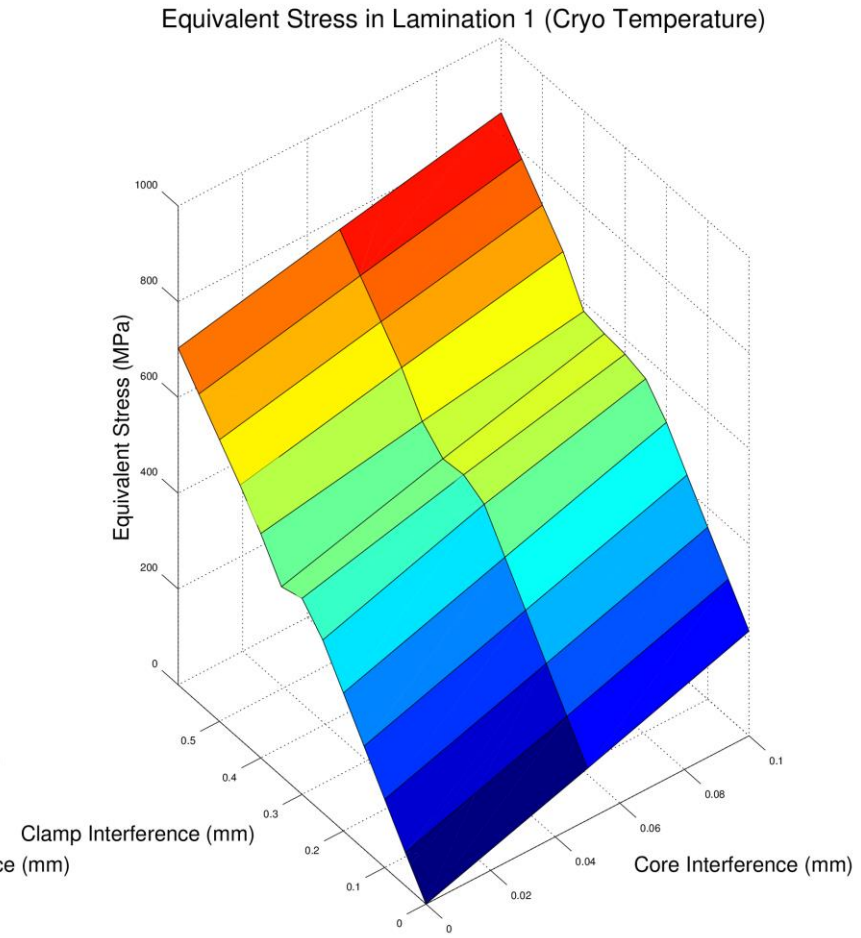
Clamp


Equivalent Stress in the Clamp (Room Temperature)
Equivalent Stress (MPa)
2000
1500
1000
500
0
Clamp Interference (mm)
0.5
0.4
0.3
0.2
0.1
0
Core Interference (mm)
0
0.02
0.04
0.06
0.08
0.1

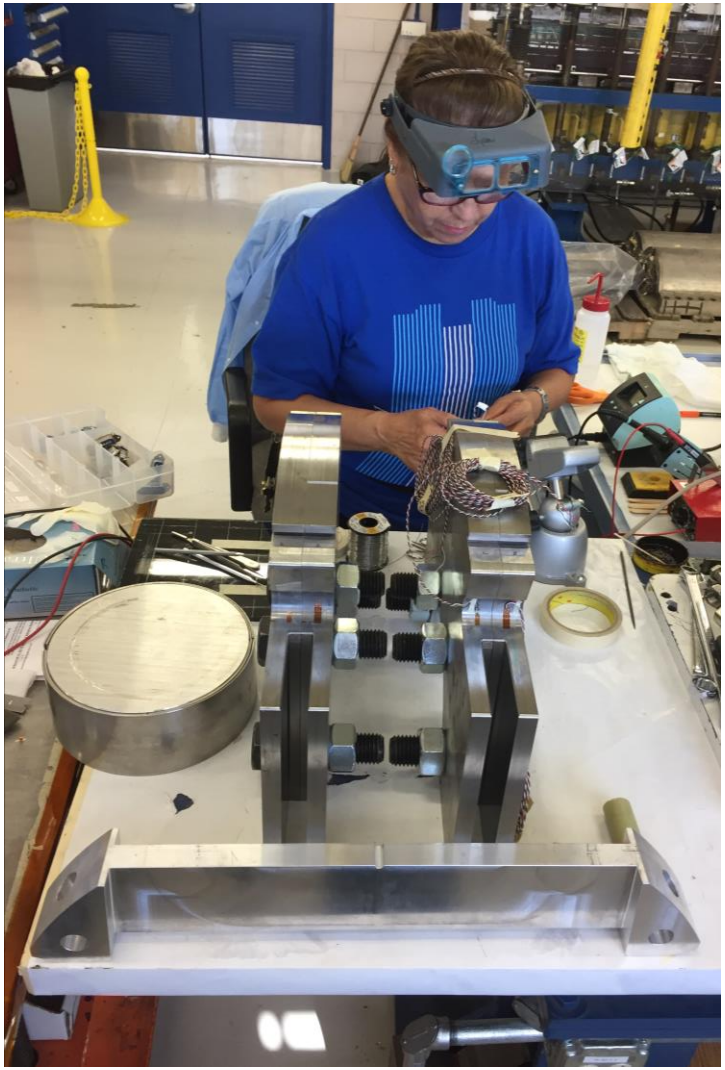

Equivalent Stress in the Clamp (Cryo Temperature)
Equivalent Stress (MPa)
2000
1500
1000
500
0
Clamp Interference (mm)
0.5
0.4
0.3
0.2
0.1
0
Core Interference (mm)
0
0.02
0.04
0.06
0.08
0.1

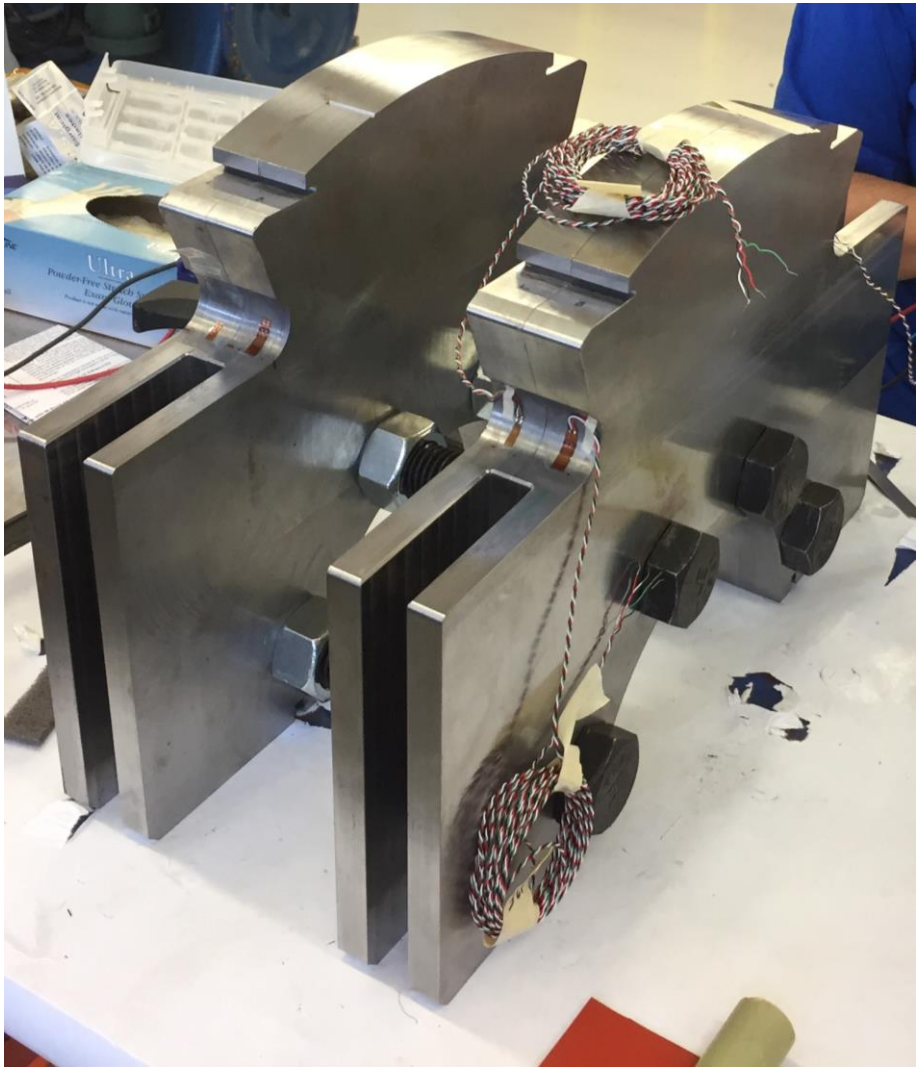
Laminations





Model Assembly and Instrumentation

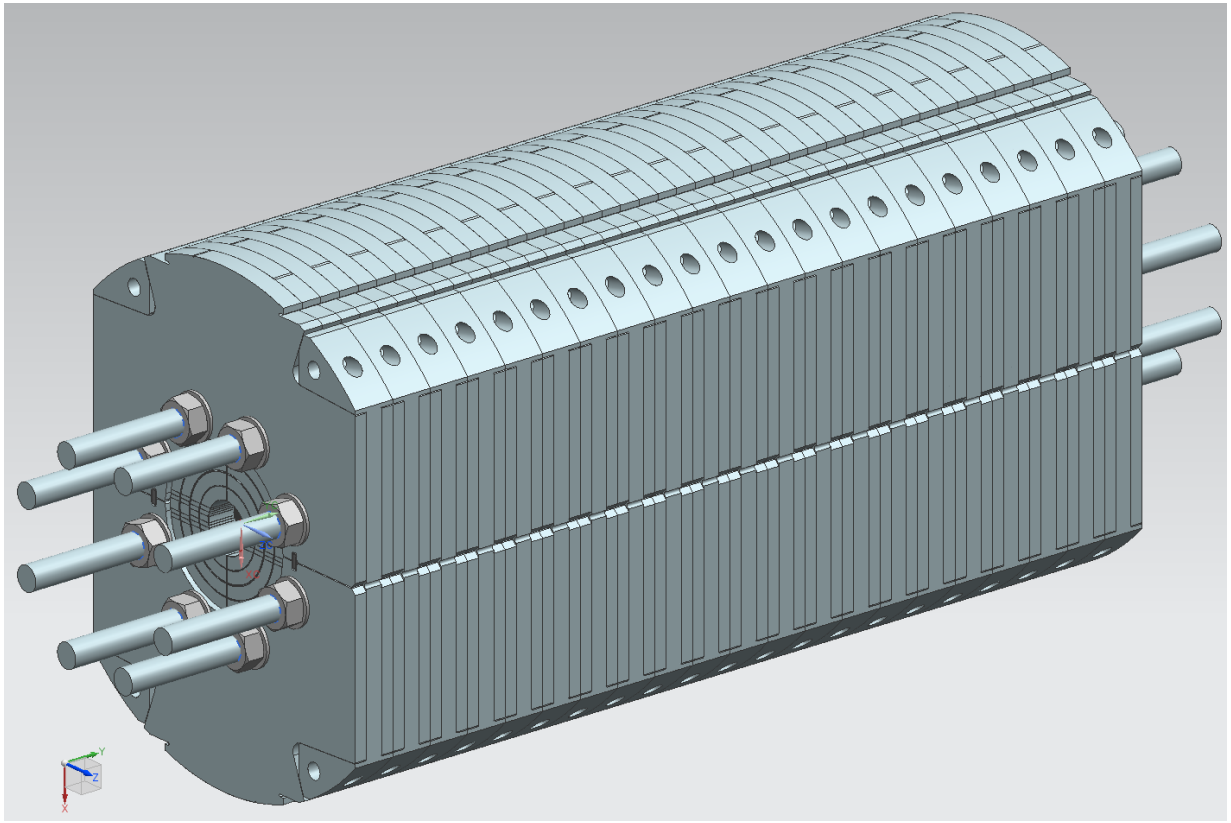




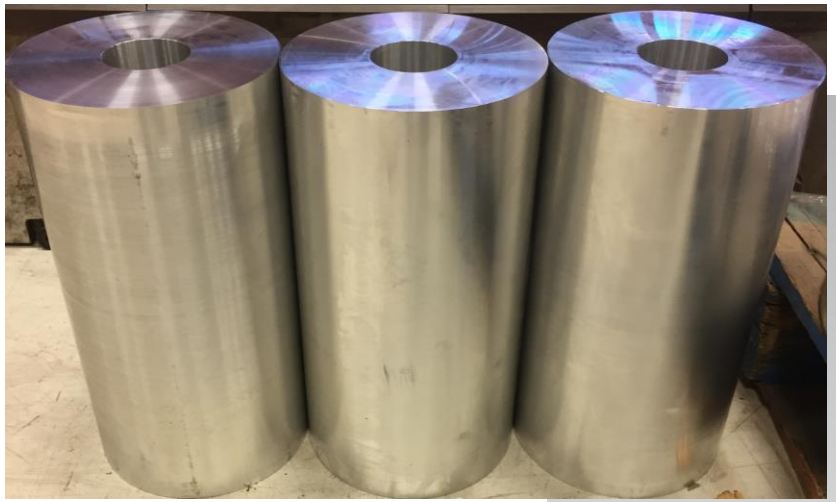
Long Mechanical Model

43’’-long model

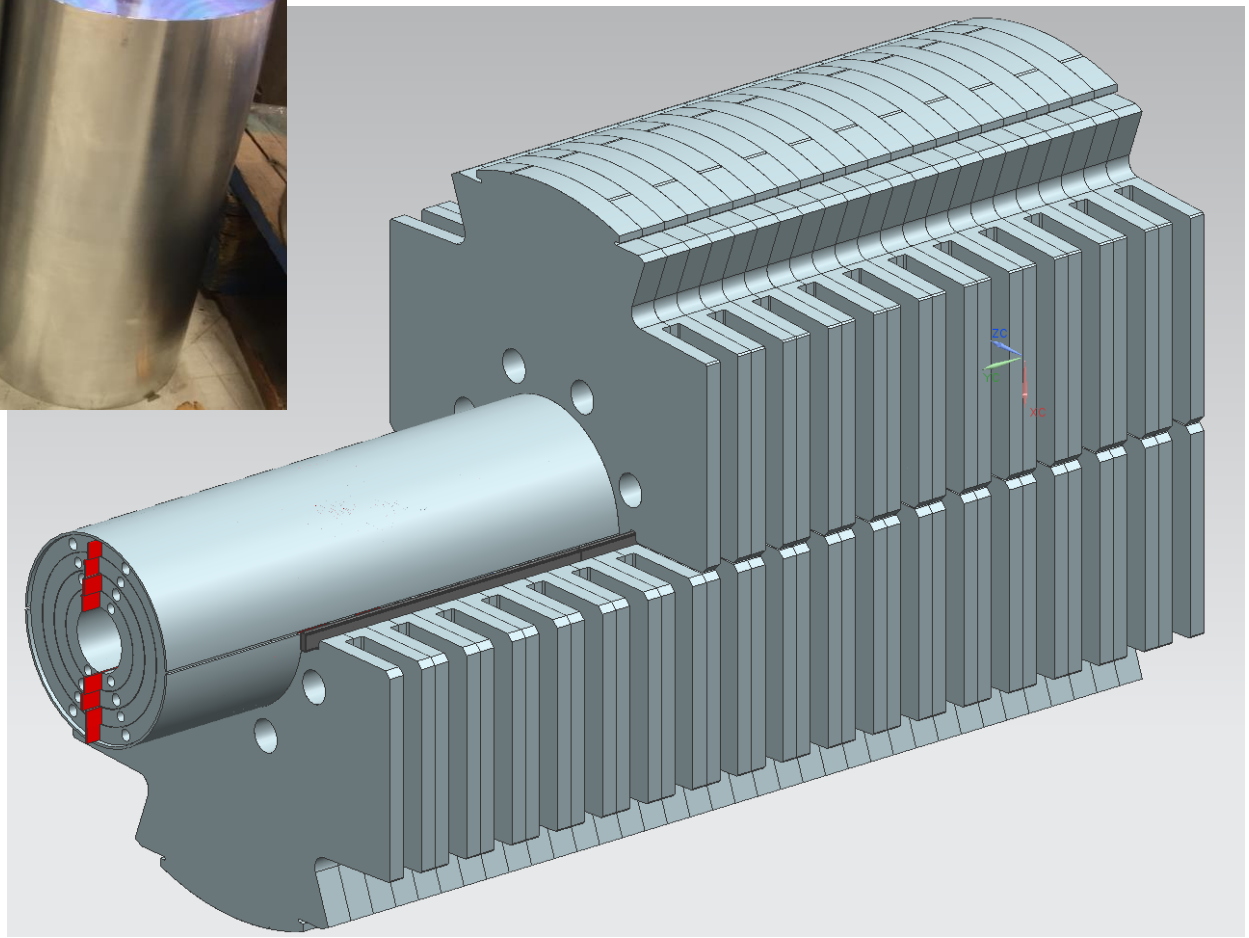
- FEA Data Verification (Shim Plan)
- Clamping Tooling and Procedure Test
- Instrumentation



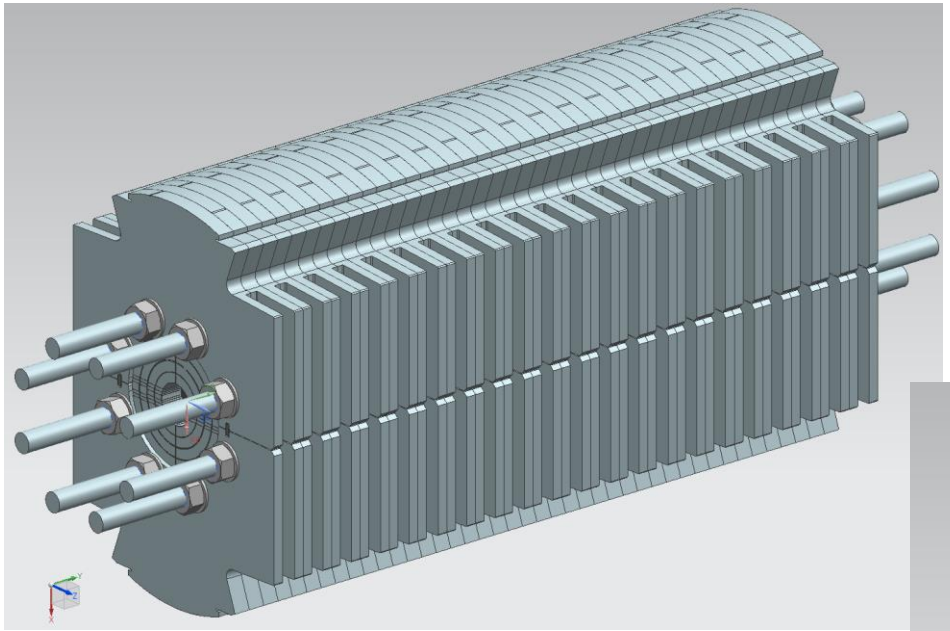
Coil-Yoke assembly

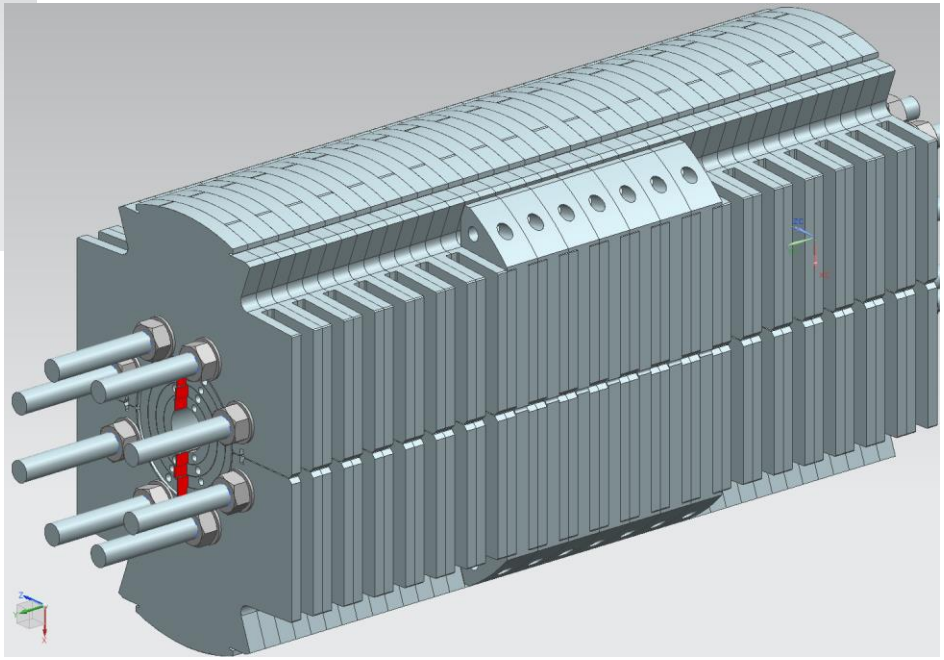


AL Cylinders

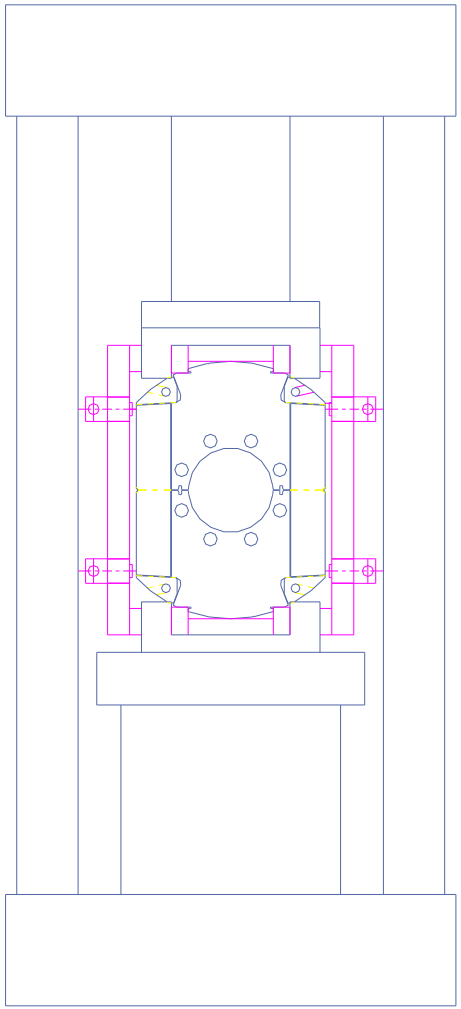


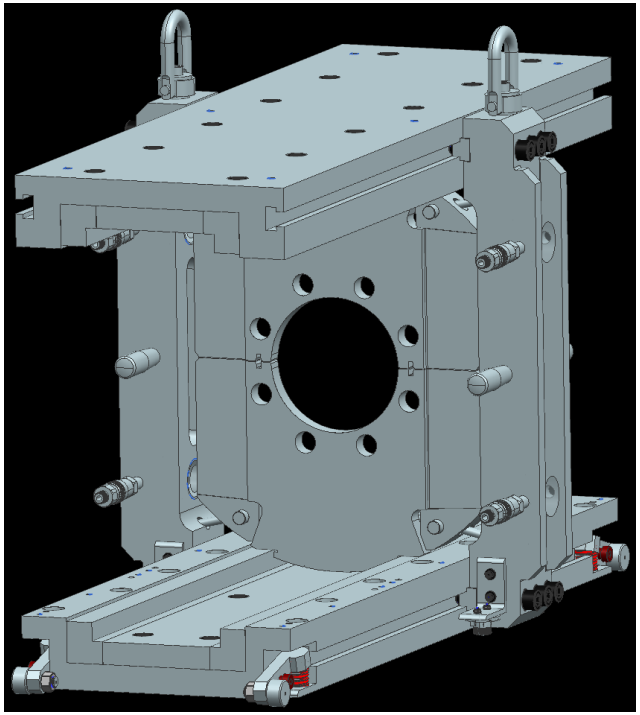
Yoke Clamping



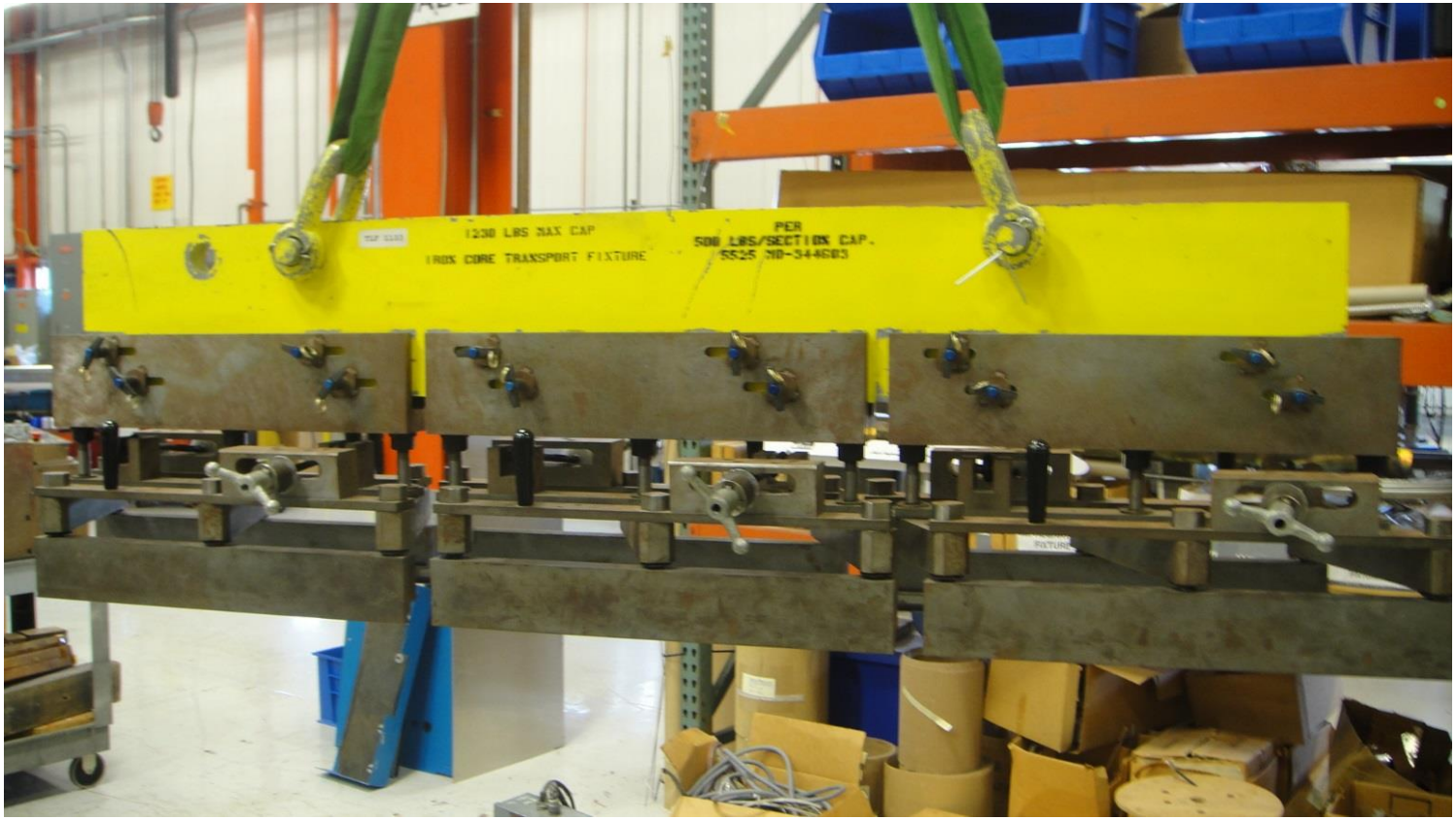


Clamping Tooling



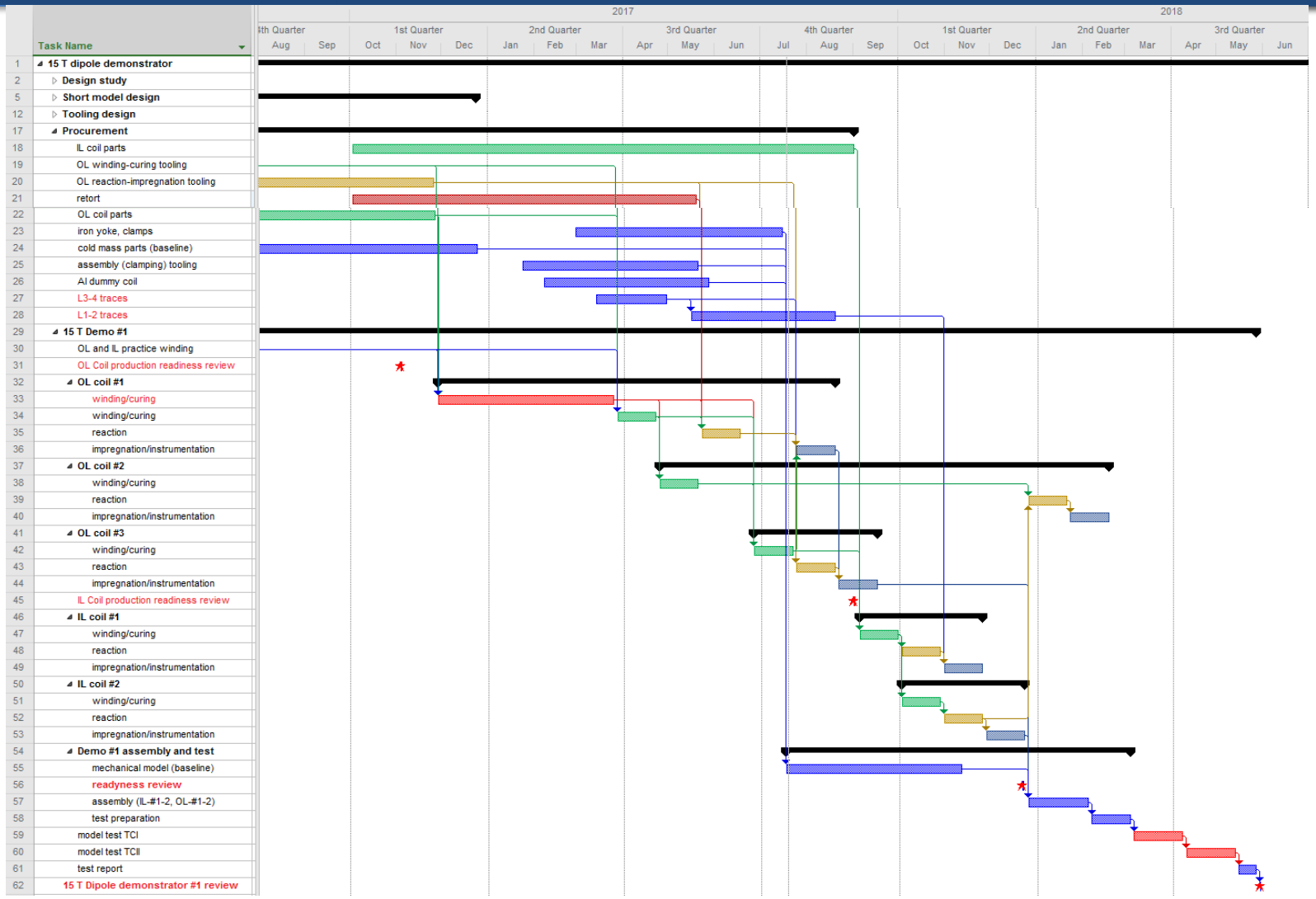


Lifting Fixture



U.S. MAGNET DEVELOPMENT PROGRAM

15 T dipole schedule



	Task Name
1	15 T dipole demonstrator
2	Design study
5	Short model design
12	Tooling design
17	Procurement
18	IL coil parts
19	OL winding-curing tooling
20	OL reaction-impregnation tooling
21	retort
22	OL coil parts
23	iron yoke, clamps
24	cold mass parts (baseline)
25	assembly (clamping) tooling
26	Al dummy coil
27	L3-4 traces
28	L1-2 traces
29	15 T Demo #1
30	OL and IL practice winding
31	OL Coil production readiness review
32	OL coil #1
33	winding/curing
34	winding/curing
35	reaction
36	impregnation/instrumentation
37	OL coil #2
38	winding/curing
39	reaction
40	impregnation/instrumentation
41	OL coil #3
42	winding/curing
43	reaction
44	impregnation/instrumentation
45	IL Coil production readiness review
46	IL coil #1
47	winding/curing
48	reaction
49	impregnation/instrumentation
50	IL coil #2
51	winding/curing
52	reaction
53	impregnation/instrumentation
54	Demo #1 assembly and test
55	mechanical model (baseline)
56	readyness review
57	assembly (IL-#1-2, OL-#1-2)
58	test preparation
59	model test TCI
60	model test TCII
61	test report
62	15 T Dipole demonstrator #1 review