Halbach Girder Fabrication Integration Meeting

CBETA

Attendees: S. Peggs, D. Trbojevic, S. Berg, G. Mahler, S. Brooks, S. Trabbochi, T. Roser, N. Tsoupas, J. Tuozzolo

Minutes 1/11/17 meeting

1. The permanent magnet material (PMM) blocks order was placed by procurement. Delivery is estimated as March 17, need an update from the vendor.
2. N. Tsoupas presented the corrector study results. It was agreed that the quad and dipole corrector specifications (slide 11) were adequate and provided reasonable margin. The quad corrector provides field adjustment if Halbach field shimming strength leveling does not meet its goal. The present plan is to build the correctors with quad windings; but, not to install quad power supplies until proved necessary by production Halbach magnet measurement results. This should be a project risk list item.
3. The dipole strength provides lattice tuning and correction capability. While the dipole strength was approved there are still some on-going lattice studies.
4. It was agreed that the dipoles and quads should be separate windings. There was extended discussion on the benefit of matching the resistance of the corrector types. It was noted by R. Lambiase that the higher power needed to drive the quad correction (6x dipole correction if the same wire size is used) would at least double the power supply cost.
5. The corrector's inside dimensions work well with the present Halbach design.
6. N. Tsoupas will do a final iteration on the coil winding design and provide the information to S. Trabocchi for engineering design. Schedule is tight the fabrication drawings for the steel are needed ASAP.
7. A thermal analysis needs to be done (S. Trabocchi) to provide a better estimate of the heat that will transferred from the correctors to the Halbach magnet. This is required to provide specifications to Cornell for the water stabilization system (heat load, flow rate, pressure drop).
8. G. Mahler presented the latest results (attached below) of the deflection analysis for the split Halbach magnet designs using a vertical split. The dipole (BD) had the largest displacement, .0051" (slide 23) because of the offset nature of the block installation. S. Brooks confirmed that was ok. The quad (QF) was not an issue because of the balanced frame thickness, deflection was <.0003" (slide 21).
9. George presented the latest results of the thermal analysis for temperature stabilizing of the Halbach permanent magnet material (PMM) for both QF and BD designs. The analysis is still very conservative assuming 100% of the heat from the corrector coils at max. current was on the surface of the frame. The analysis showed that water cooling could effectively stabilize the temperature of the permanent magnet material with optimized (reduced number) of water passages. The split frame clamping bolts need to be added to the model.
10. There was discussion on the PMM block shimming method to balance the magnet to magnet field strength. The present frame design allows for shimming the blocks by 0.1 to 0.8 mm (.004 to .031"). The PMM blocks for the preproduction magnets were purchased with 2% higher strength to put them in the middle of the shim range and within the 2% tolerance specification for the material. There was discussion on the method for same testing PPM for field strength. Methode will be needed for production material QA assistance testing and defining the shimming requirements.
11. Schedule is tight, George was tasked with developing a fabrication drawing for the aluminum frames ASAP. Starting without the water passages so material (aluminum plate) can be ordered and fabrication can be planned.

Critical Project Dates

Technical milestones (NYSERDA contract Table 2)

#	Milestone	Date	
	NYSERDA funding start date	2016 Oct 31	
1	Engineering design documentation complete	2017 Feb 1	
2	Prototype girder assembled	2017 May 1	
3	Magnet production approved	2017 July 1	
4	**Beam through Main Linac Cryomodule**	**2017 Sept 1**	**CRITICAL: Go/no go 1**
5	First arc production magnet tested	2018 Jan 1	
6	**Fractional Arc Test: beam through MLC & prototype girder**	**2018 May 1**	**CRITICAL: Go/no go 2**
7	Girder production run complete	2018 Dec 1	
8	Final assembly & pre-beam commissioning complete	2019 Mar 1	
9	Single pass beam energy scan	2019 July 1	
10	Single pass beam with energy recovery	2019 Nov 1	
11	Four pass beam with energy recovery (low current)	2020 Jan 1	
12	C-Beta commissioned and project complete	2020 May 1	

Engineering design documentation complete *Feb 1, 2017*

1st Article QF and QD Magnets assembled and tested May 1, 2017

Prototype Girder Assembled May 1, 2017

Magnet production plan April 1, 2017

Magnet production approved July 1, 2017

1st Halibach Priorities

Build and magnetically measure 8 preproduction halbach magnets w/8 correctors

1. **Order PMM for 5 + 5 magnets + 1+ 1 for margin.** S. Brooks, G. Mahler
2. **Design QF halbach split aluminum frames – Design, order. Mahler, Trabocchi**

   Deflection analysis complete. Mahler

   Water cooling/stabilization passages/thermal and analysis. Mahler

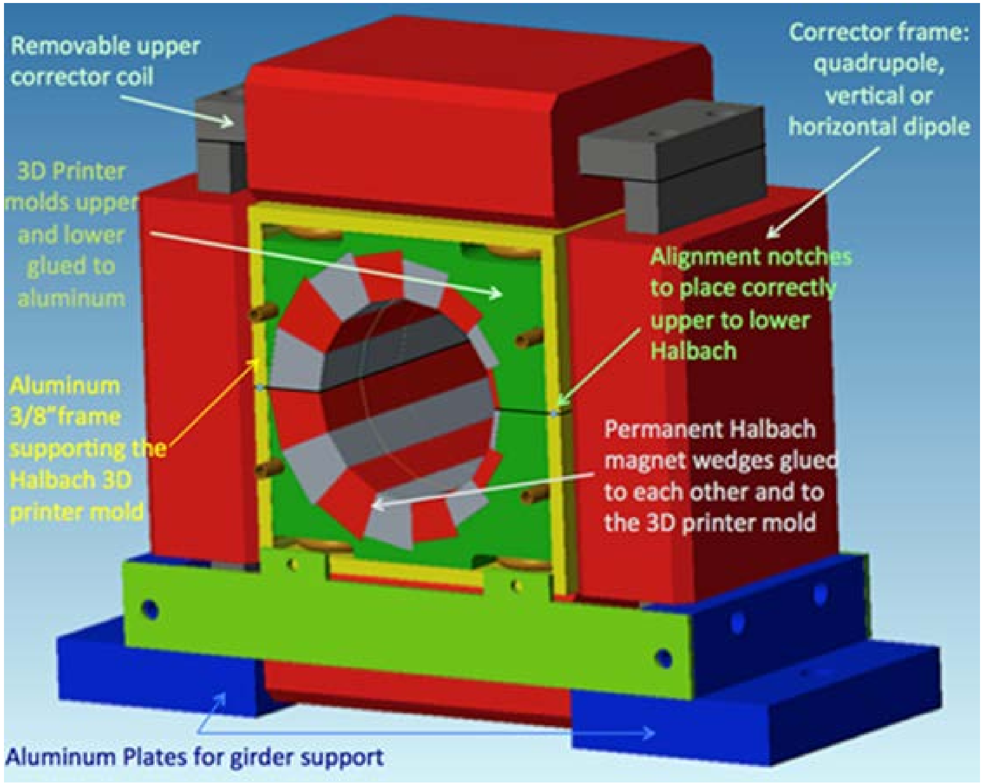
   Fabrication drawing, order. Mahler, designer?
3. **Magnetic strength shimming method. Mahler, Brooks**
4. **Define and design halbach inner tuning steel wire holder – order**

   Define Brooks, Design/Fab Mahler/Trabocchi
5. Test plan for permanent magnet material to determine magnetic strength and orientation: shimming dimension. Brooks
6. Repeat 1 through 4 for BD

1st Correctors Priorities

Build and magnetically measure 8 preproduction halbach magnets w/8 correctors

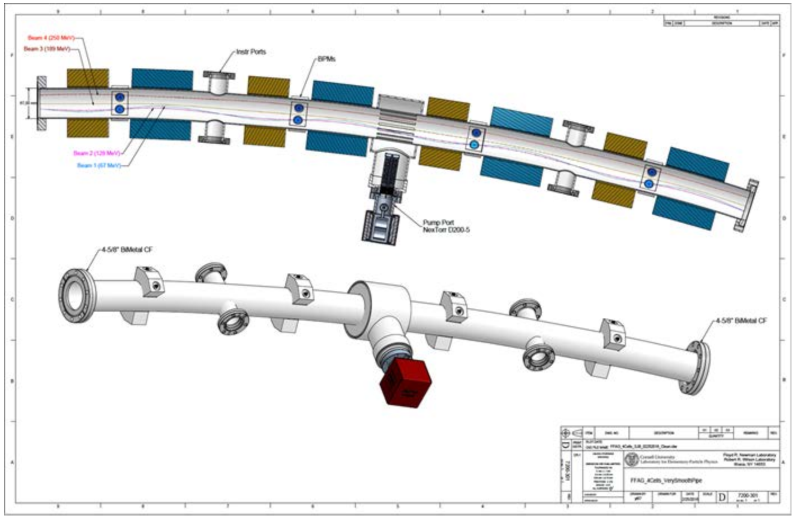
1. **Define and design correctors – order steel cores, wire.**
   Define Trbojevic/Tsoupis; Design/Fab Mahler/Trabocchi
   Quad and dipole corrector gradient and strength
   Separate coils for dipole and quadrupole
   Skew Quad?
   Power Supply interface



1st Girder Priorities

Build and magnetically measure 8 preproduction halbach magnets w/8 correctors

1. **Interface w/Cornell vac. group on vacuum chamber Yulin**
   Ion pump and NEG (horizontal)
2. **BPM configuration Michnoff**
3. Define and design table top Mahler/Trabocchi
   Alignment specifications
   Magnet mounts – hard pins/frame driven, shim and pin, jacking screws?
   Magnet mounts – separate mounts for Halbach and Corrector?
4. **Stand design**



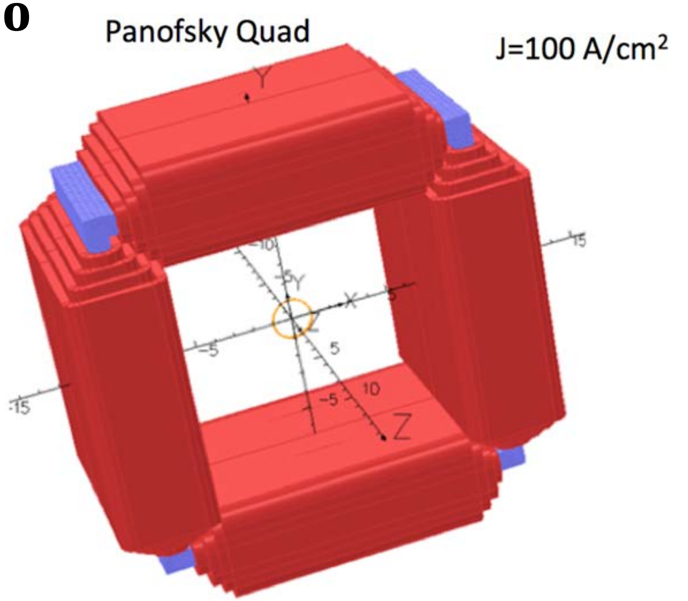
Halbach Production Plan

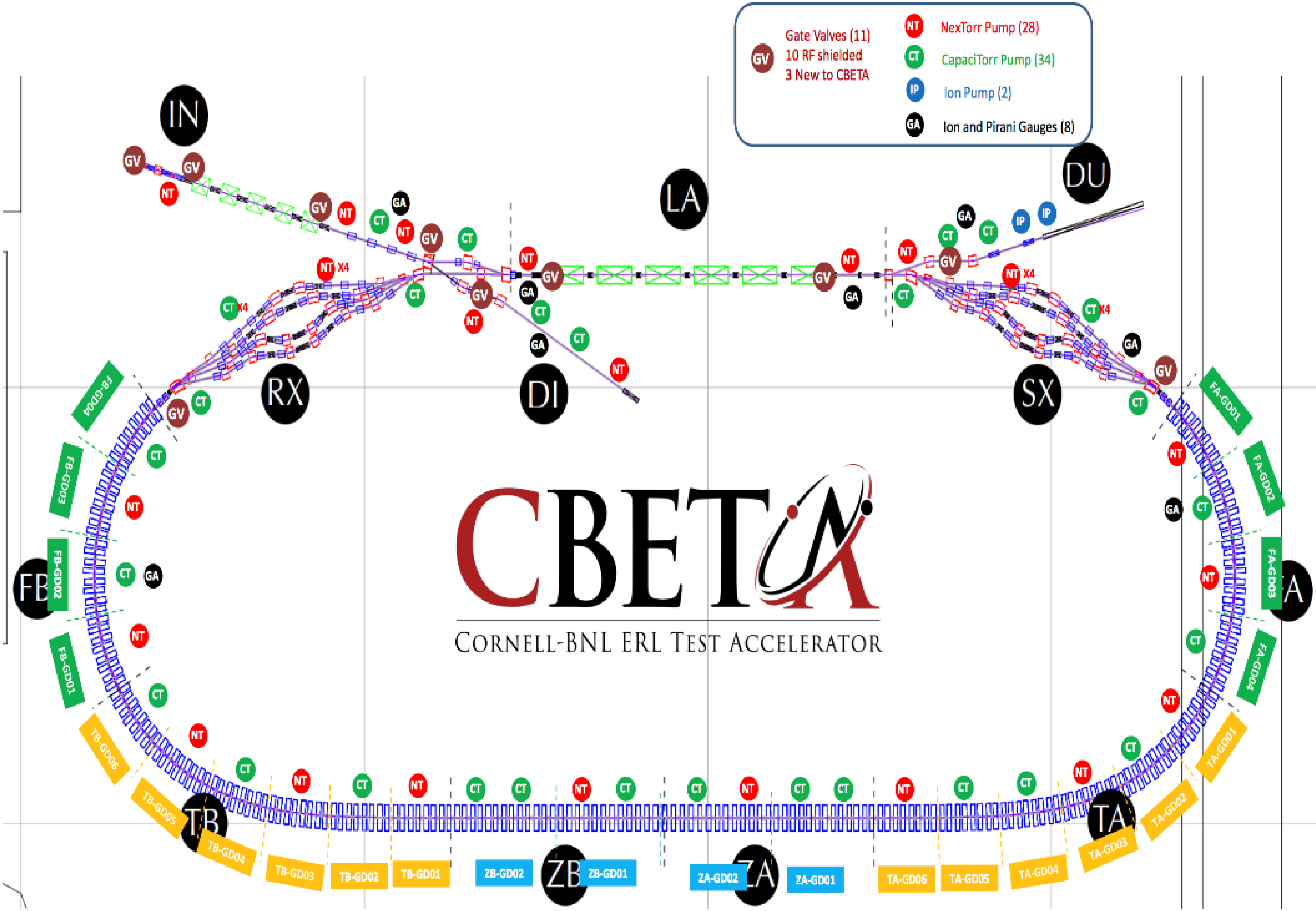
CBETA

- PMM block dimensions (tolerance), field strength (tolerance), field direction (tolerance). Document design list or drawing or specification
- Temperature stabilization specifications (+/- 5C ??)
- Split magnet frame fabrication method and deflection analysis.

Corrector details:

- Alternating horizontal and vertical corrections? **Yes** QF and QD
- Will BD and QF correctors be the same, interchangeable? **Yes**
- Quadrupole correction on all? **Yes** Skew quad? **No**
- **Are there a chosen power supplies?**
- **Has the method for winding for dipole field and quadrupole field been defined?**
- **Are separate windings needed?**





Gate Valves (11)
10 RF shielded
3 New to CBETA
NexTorr Pump (28)
CapaciTorr Pump (34)
Ion Pump (2)
Ion and Pirani Gauges (8)
IN
LA
DU
RX
DI
SX
FB
FA
TB
ZB
ZA
TA
CBETA
CORNELL-BNL ERL TEST ACCELERATOR
FB-GD04
FB-GD03
FB-GD02
FB-GD01
FA-GD01
FA-GD02
FA-GD03
FA-GD04
TB-GD06
TB-GD05
TB-GD04
TB-GD03
TB-GD02
TB-GD01
ZB-GD02
ZB-GD01
ZA-GD02
ZA-GD01
TA-GD06
TA-GD05
TA-GD04
TA-GD03
TA-GD02
TA-GD01

Power Supplies for Correctors

Calculations by N. Tsoupas

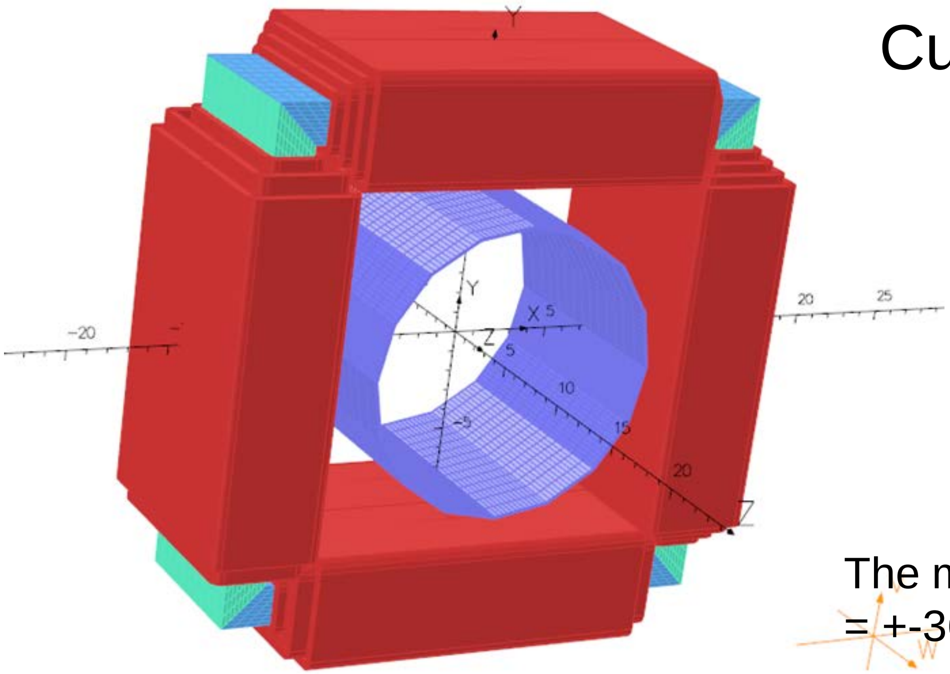
3D Calculations

Length of Iron along beam direction=8cm

Inner aperture of WINDOW-frame=10.7 cm

Current Density in coil =1 A/mm^2

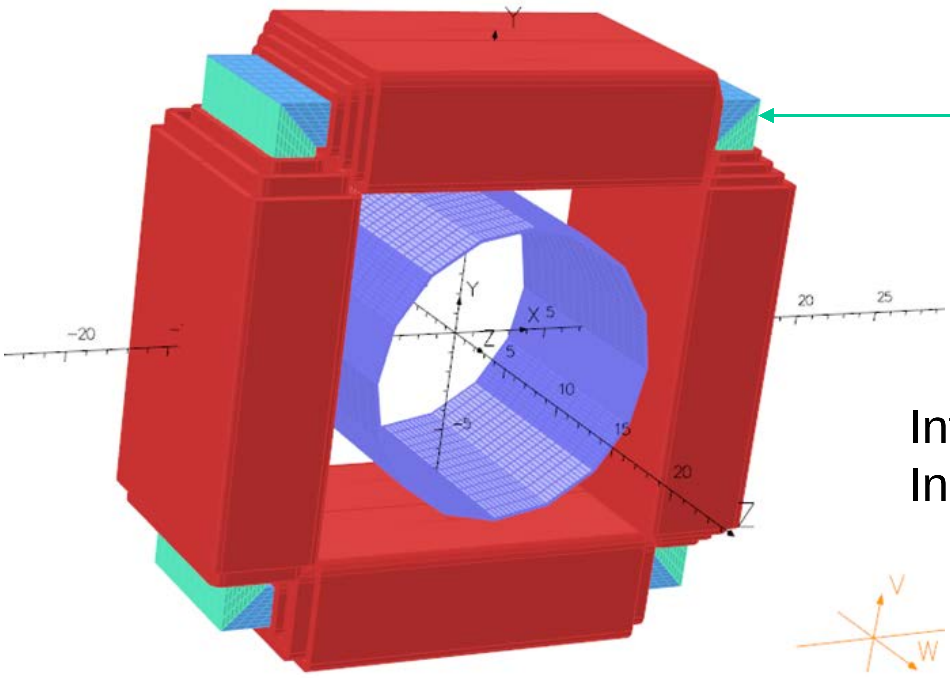
Total Coil Width of coil=1.8 cm



The magnet provides an integral quadrupole field = +-365 Gauss

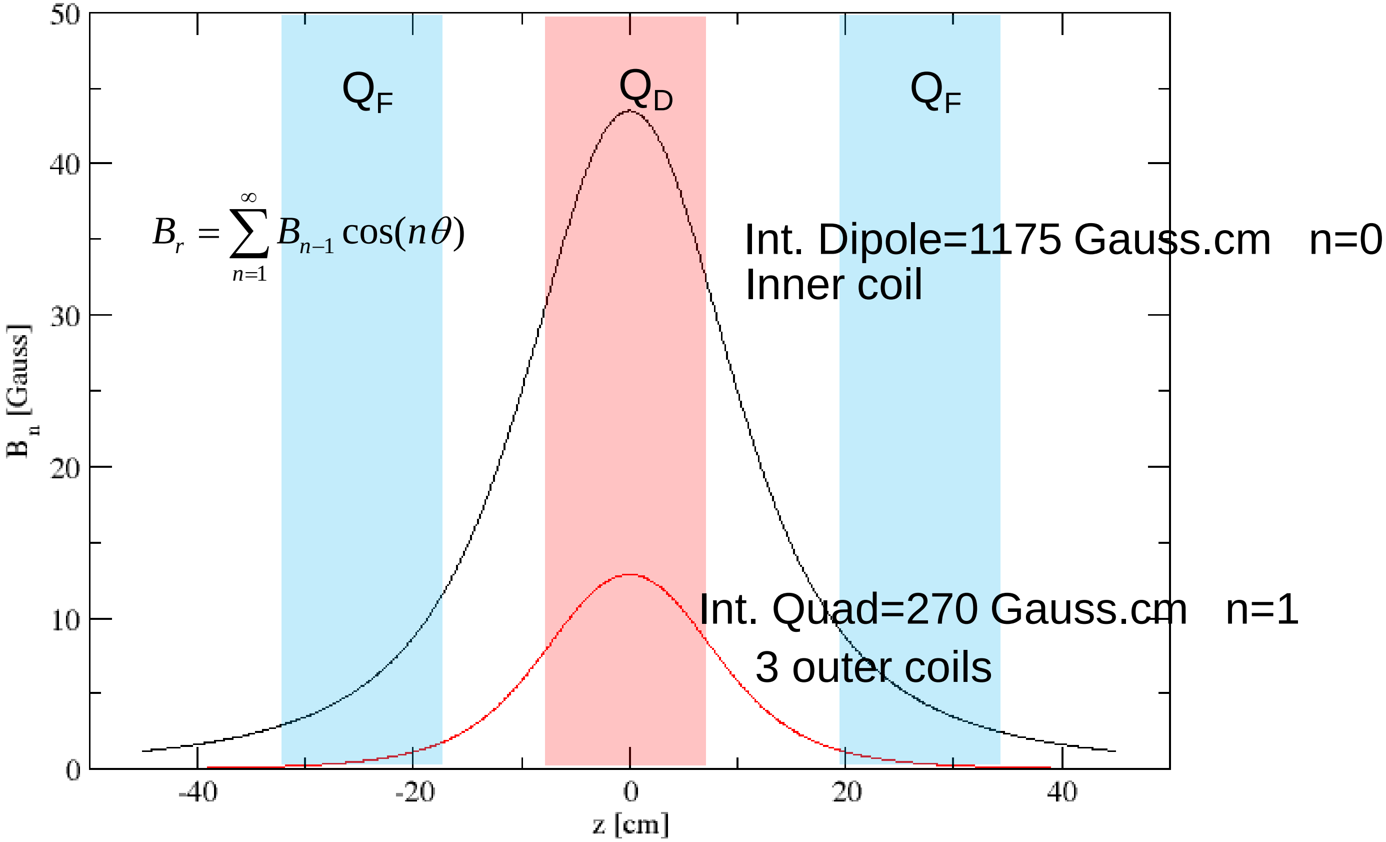
The integrated field of the FFAG quadrupole is
10T/m*12cm=10T/m*0.12m=100000*0.12 Gauss=12000 Gauss.
The +-2% corrector should have an integral quadrupole field = +-240 Gauss

Field inside iron <400 Gauss



Integrated Quad=365 Gauss
Insignificantly small other multipoles

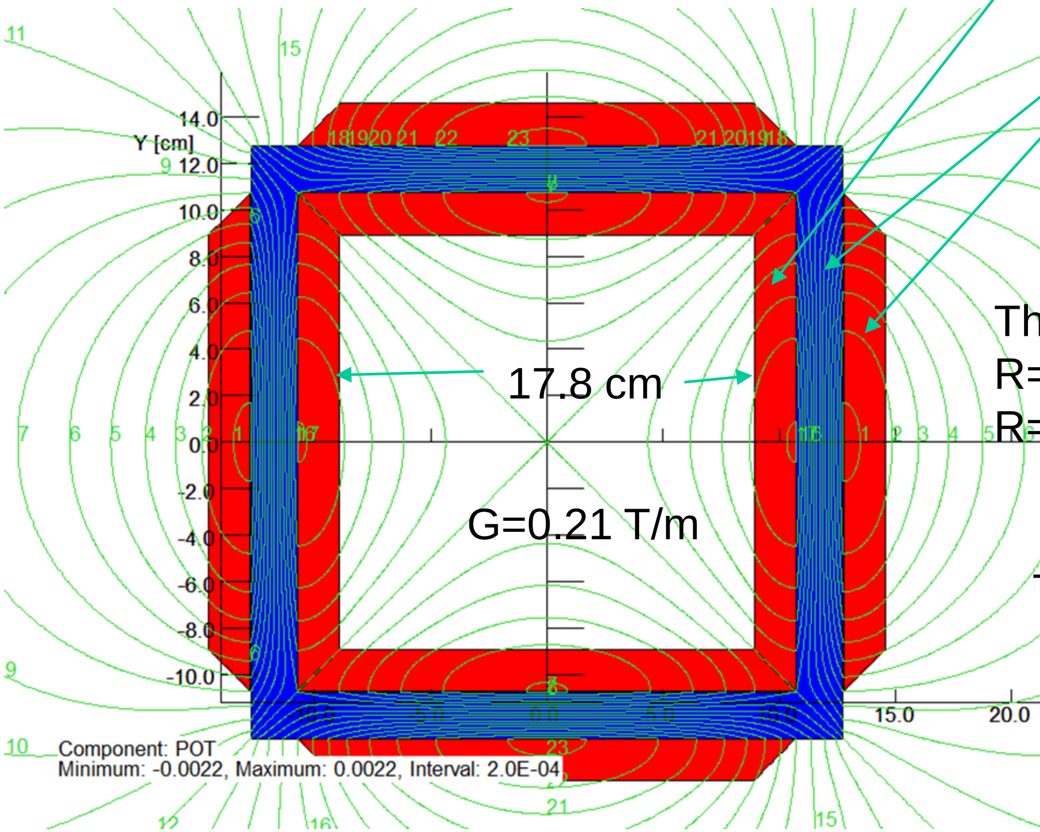
Multipoles from the correctors at R=1 cm



Correctors	Coil connection	Int. Dipole [Gauss.cm]	Int. N-Quad [Gauss.cm]	J [A/mm^2]
N-Quad+N-Dipole	Right-Inner-coil + Left-Inner-coil for N-Dipole Three-outer-coils from (R, L, T, B) for N-Quad	1200 (Normal)	275	1.0
N-Quad+S-Dipole	Top-Inner-coil + Bottom-Inner-coil for N-Dipole Three-outer-coils from (R, L, T, B) for N-Quad	1200 (Skew)	275	1.0

wire Gauge	Wire Cross Sect [mm^2]	Area [mm^2]	Number of wires	Length of Magnet Iron [cm]	Length of wire per turn [m]	Total length of wire per coil [m]	Resistance of coper wire per coil [Ohm]	Current in wire [A]	Voltage across Quad-coil 4-coils [V]	Voltage across Dipole-coil 2-coils [V]	Quad-Power [W]	Dipole-Power [W]	Inductance [H]
14	2.08	3528	1696	8	0.25	424.04	3.42	2.08	28.50	14.25	59.27	29.64	0.0800
11	4.17	3528	846	8	0.25	211.51	0.85	4.17	14.21	7.11	59.27	29.64	0.0199
9	6.63	3528	532	8	0.25	133.03	0.34	6.63	8.94	4.47	59.27	29.64	0.0079

THE RESISTANCE DOES NOT INCLUDE THE RESISTANCE OF THE WIRES FROM THE POWER SUPPLY TO THE MAGNET.



In this area ~18mmx196 mm will be 1696 #14 AWG wires.

The magnet iron is ~8cm.

The length of each wire turn is ~25 cm.

The length of the wire in each of the four coils is L=25cm*1696=425 m.

The resistance of each coil is:

$R=\rho*(L/Area)=1.68\times10^{-8}(425/2.08\times10^{-6})$ Ohm

R=3.4 Ohm

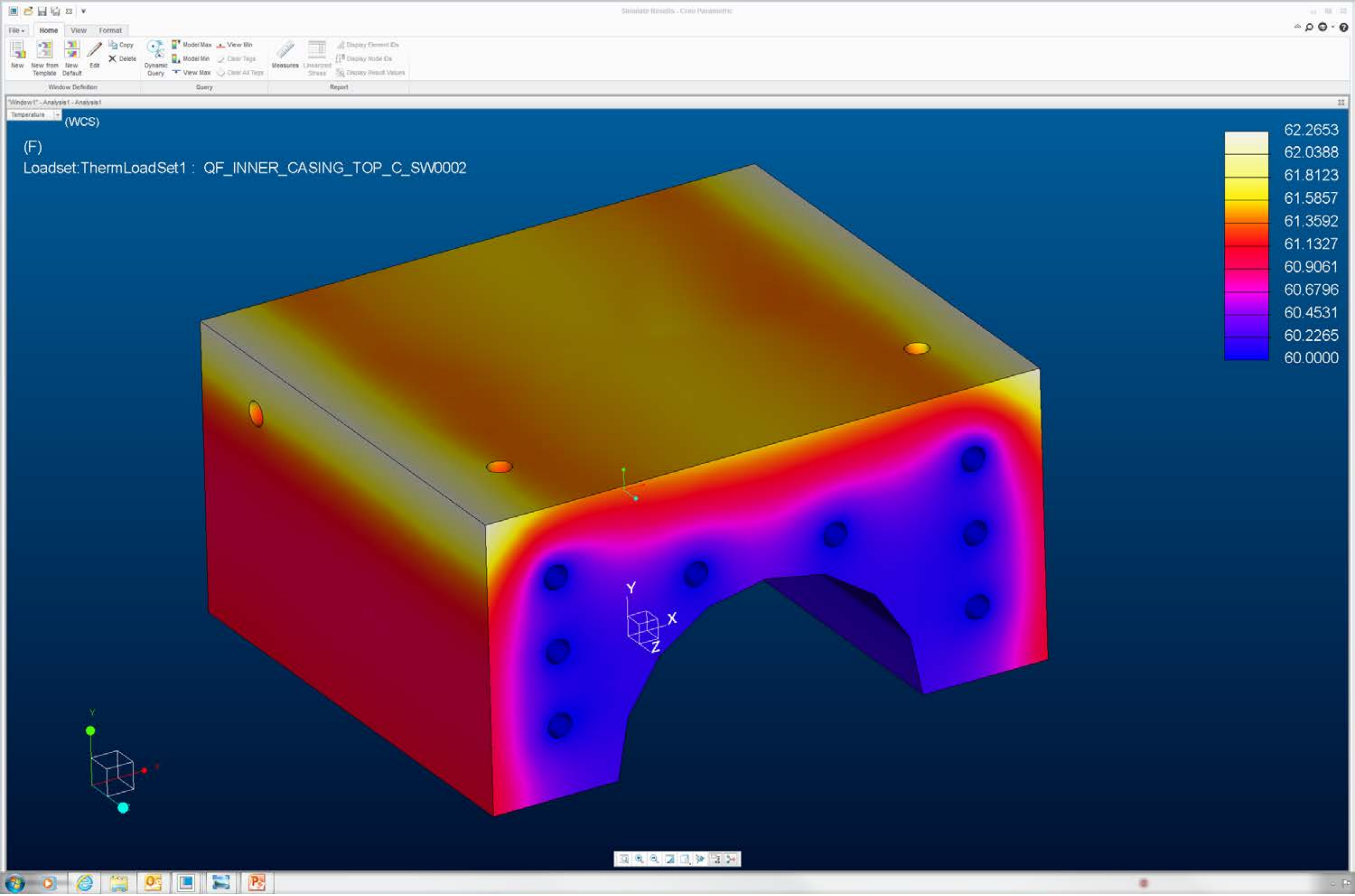
The current per wire I=2.08A

The voltage for Quad Corr=I*(4*R)~28.5 V

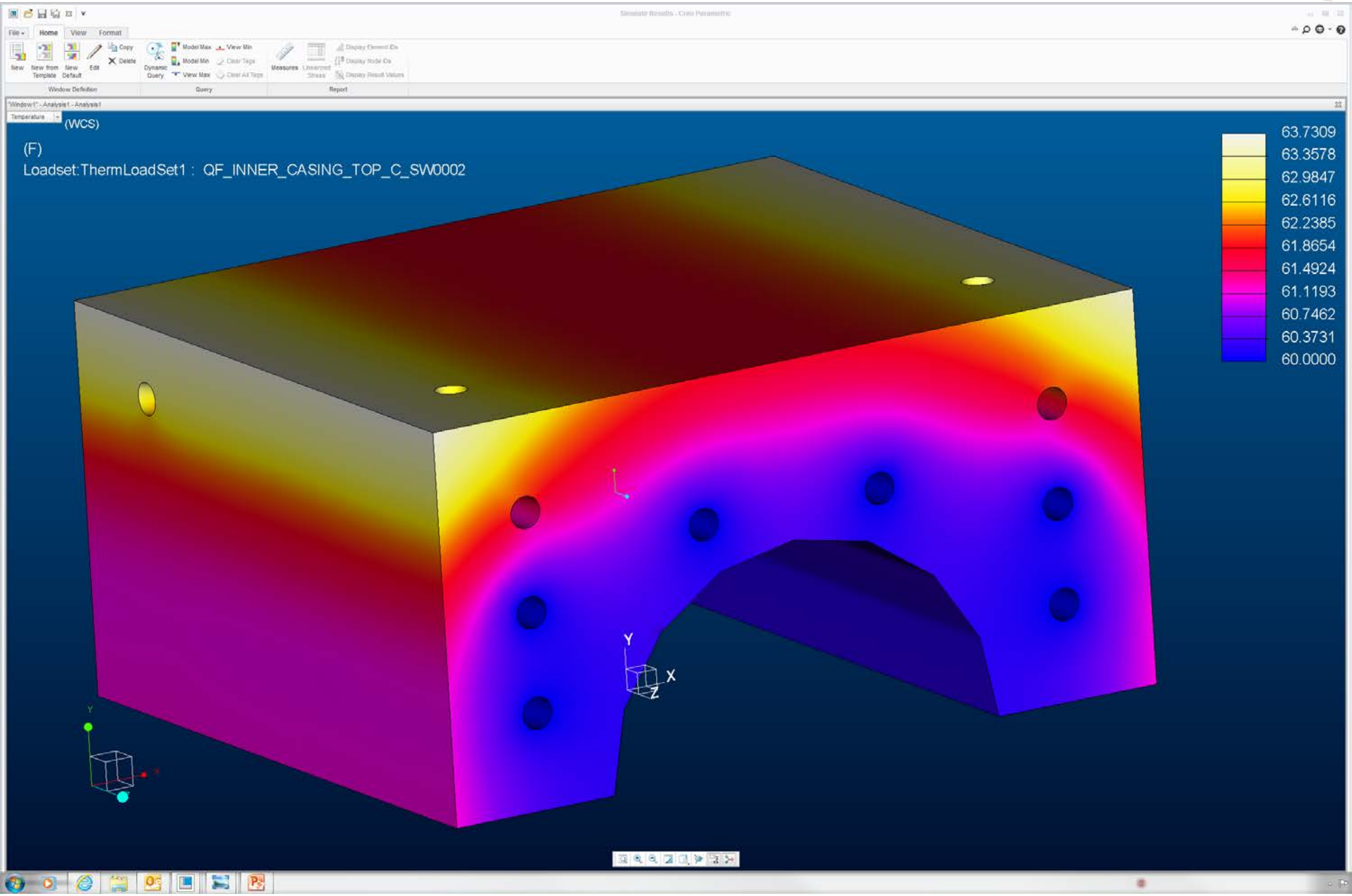
Total Power/cm in four coils ~6.5 W/cm

Halibach Frame Analyses

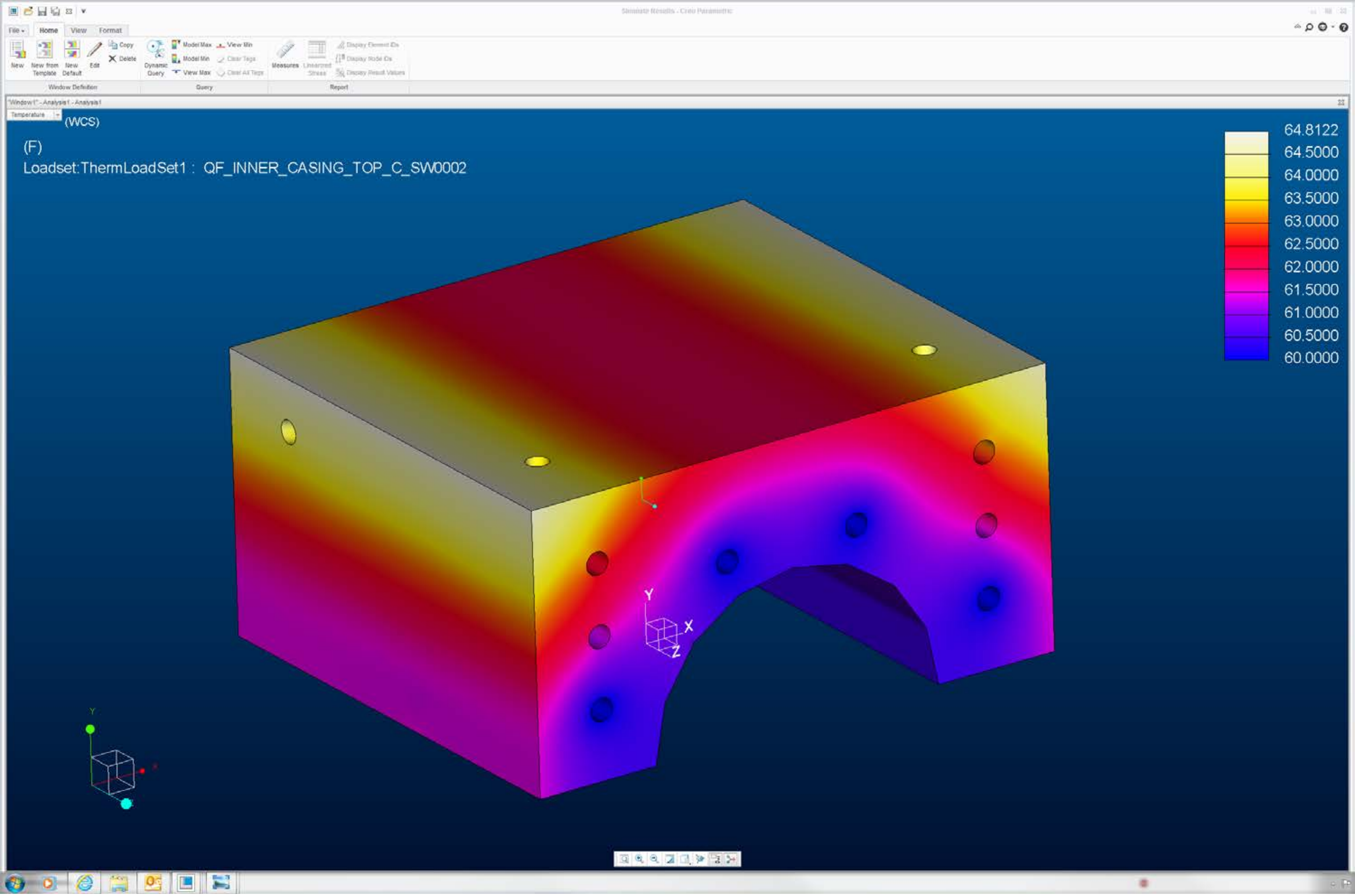
- Split magnet designs
- G. Mahler



60 F water temp, 5 W/m^2 convection coefficient, 100 Watts top, 50 Watts each side



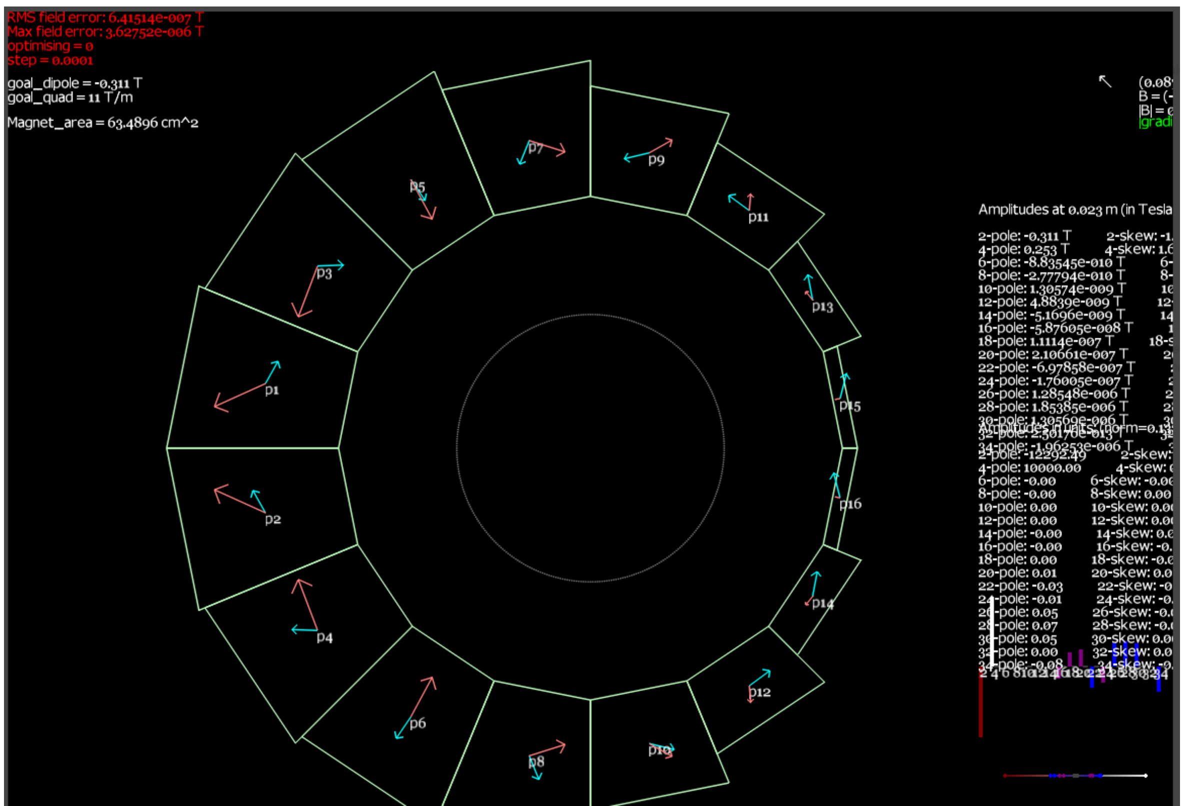
60 F water temp, 5 W/m^2 convection coefficient, 100 Watts top, 50 Watts each side

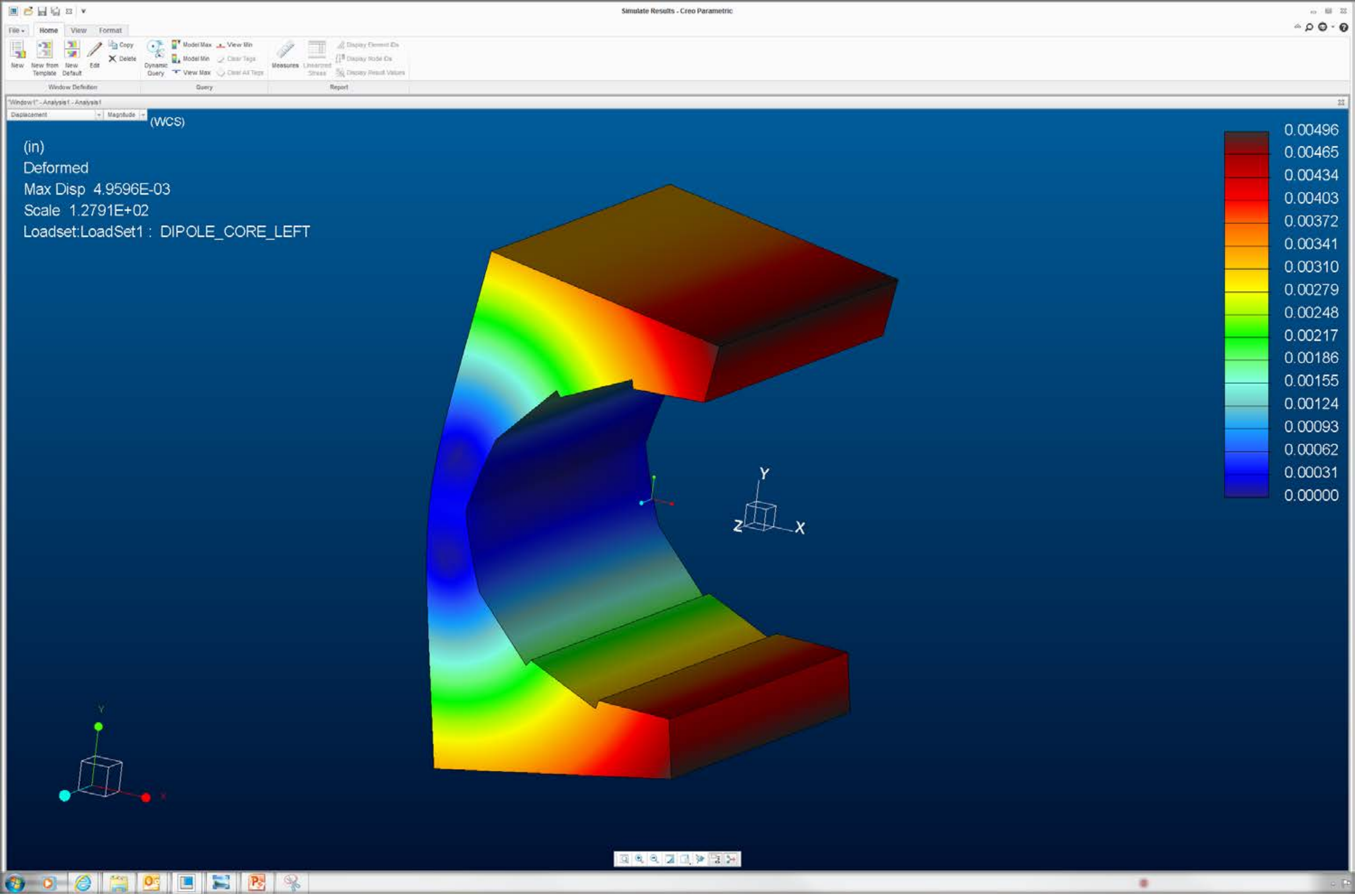


60 F water temp, 5 W/m^2 convection coefficient, 100 Watts top, 50 Watts each side

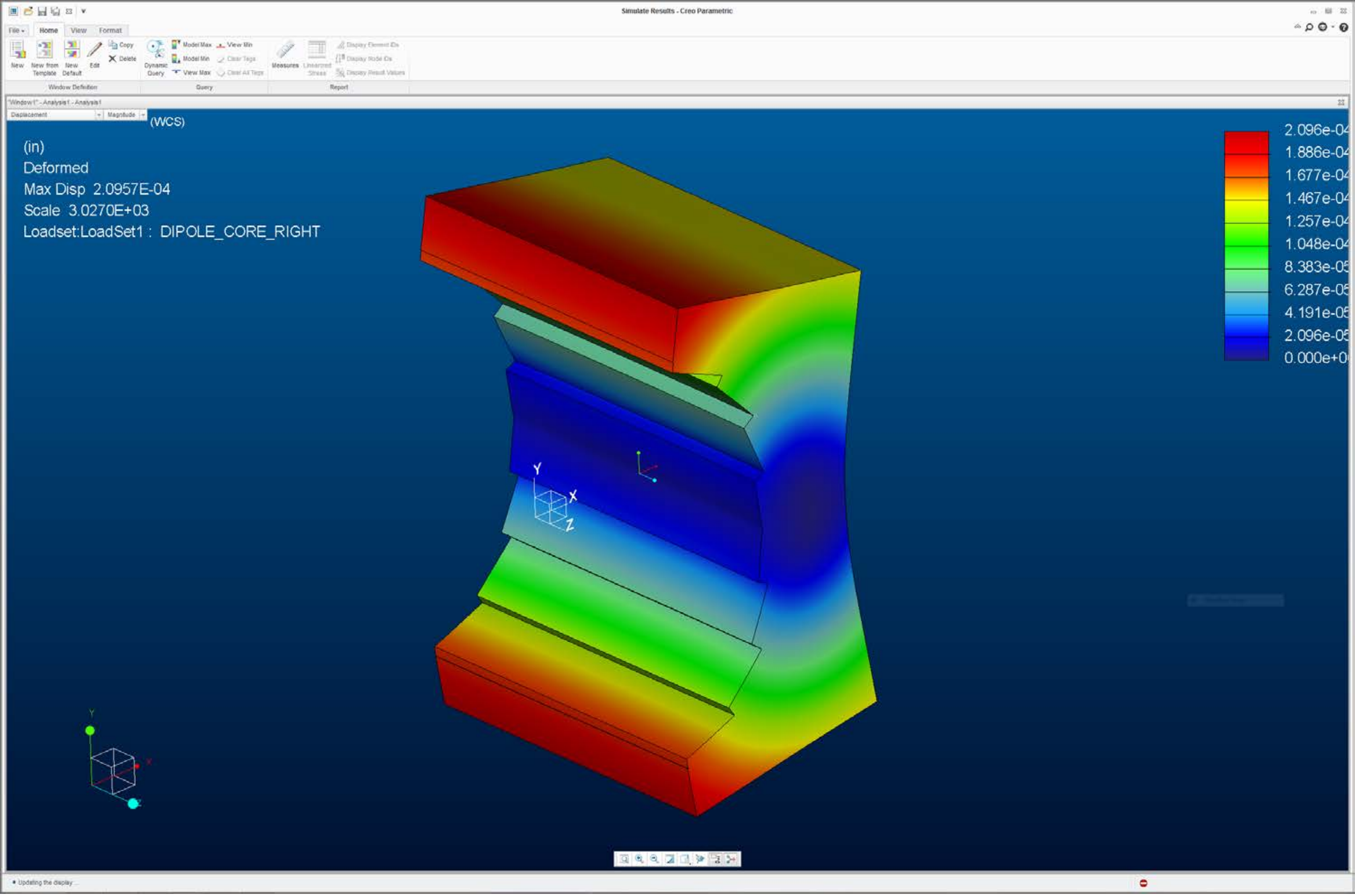
Sheet1

Piece	Fx (N/m)	Fy (N/m)	Fx (N)	Fy (N)	Fx (lbf)	Fy (lbf) (for nominal length 0.1217m)	
p1	-8763.96633	-3966.86394	-1066.5747	-482.767341	-239.775531	-108.530416	
p2	-8763.96633	3966.86394	-1066.5747	482.767341	-239.775531	108.530416	
p3	-3330.09713	-8774.88275	-405.272821	-1067.90323	-91.1089545	-240.074197	
p4	-3330.09713	8774.88275	-405.272821	1067.90323	-91.1089545	240.074197	
p5	3695.36607	-6845.16327	449.72605	-833.05637	101.102438	-187.278522	
p6	3695.36607	6845.16327	449.72605	833.05637	101.102438	187.278522	
p7	6136.75709	-1937.06225	746.843338	-235.740476	167.897061	-52.9965673	
p8	6136.75709	1937.06225	746.843338	235.740476	167.897061	52.9965673	
p9	3909.27642	2198.57361	475.75894	267.566408	106.954865	60.1513214	
p10	3909.27642	-2198.57361	475.75894	-267.566408	106.954865	-60.1513214	
p11	240.982639	2846.22359	29.3275871	346.385411	6.59310387	77.870538	
p12	240.982639	-2846.22359	29.3275871	-346.385411	6.59310387	-77.870538	
p13	-1170.22008	1438.05793	-142.415783	175.011651	-32.0163417	39.3441842	
p14	-1170.22008	-1438.05793	-142.415783	-175.011651	-32.0163417	-39.3441842	
p15	-806.348861	-138.855496	-98.1326563	-16.8987139	-22.0610988	-3.79898202	
p16	-806.348861	138.855496	-98.1326563	16.8987139	-22.0610988	3.79898202	
Top half	-88.2501751	-15179.9726	-10.7400463	-1847.40266	-2.41445846	-415.31264	
Bottom half	-88.2501751	15179.9726	-10.7400463	1847.40266	-2.41445846	415.31264	

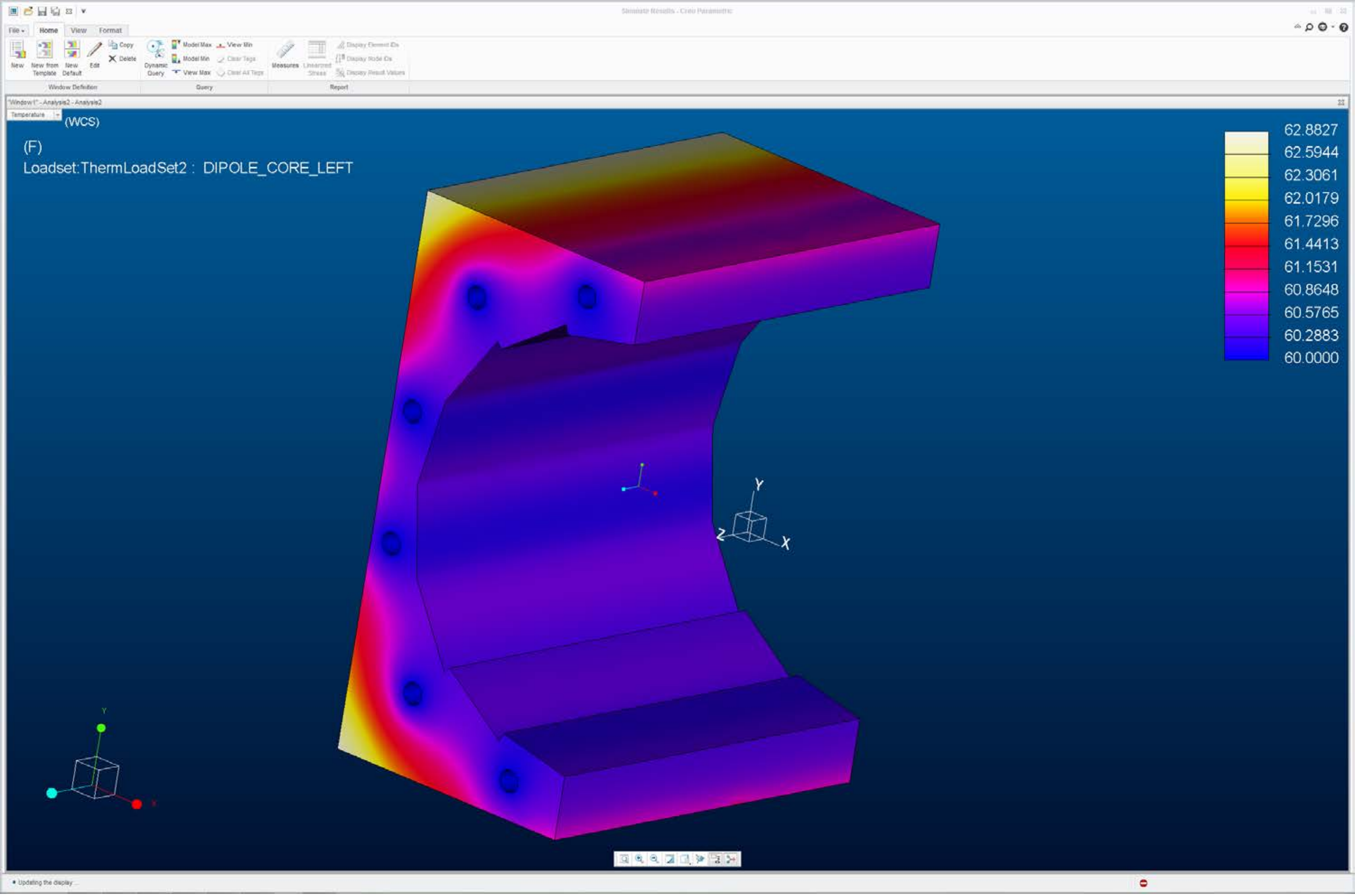



Simulate Results - Creo Parametric
(WCS)
(in)
Deformed
Max Disp 4.9596E-03
Scale 1.2791E+02
Loadset:LoadSet1 : DIPOLE_CORE_LEFT
0.00496
0.00465
0.00434
0.00403
0.00372
0.00341
0.00310
0.00279
0.00248
0.00217
0.00186
0.00155
0.00124
0.00093
0.00062
0.00031
0.00000

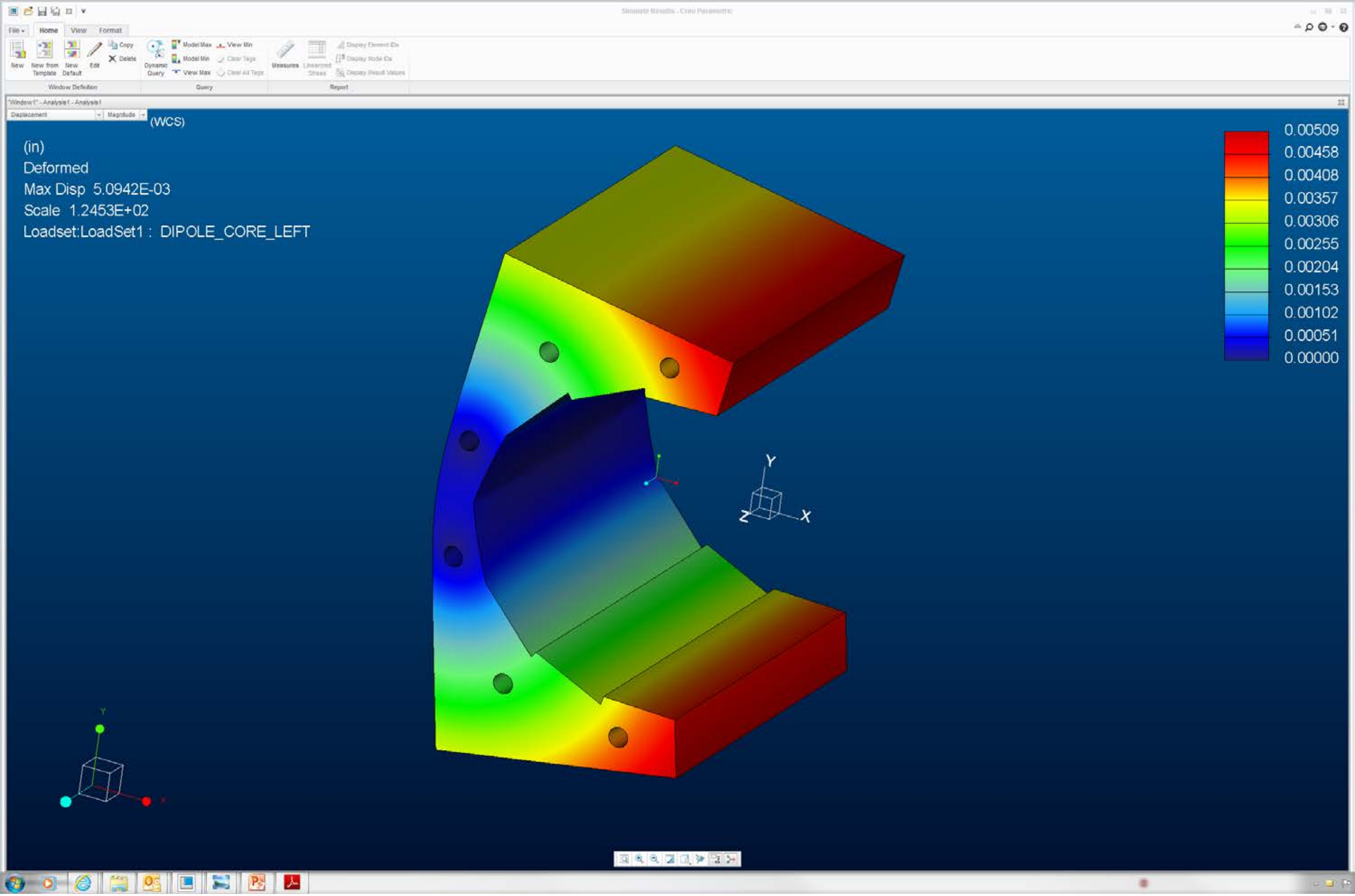
“Left side”


Simulate Results - Creo Parametric
(WCS)
(in)
Deformed
Max Disp 2.0957E-04
Scale 3.0270E+03
Loadset:LoadSet1 : DIPOLE_CORE_RIGHT
2.096e-04
1.886e-04
1.677e-04
1.467e-04
1.257e-04
1.048e-04
8.383e-05
6.287e-05
4.191e-05
2.096e-05
0.000e+00

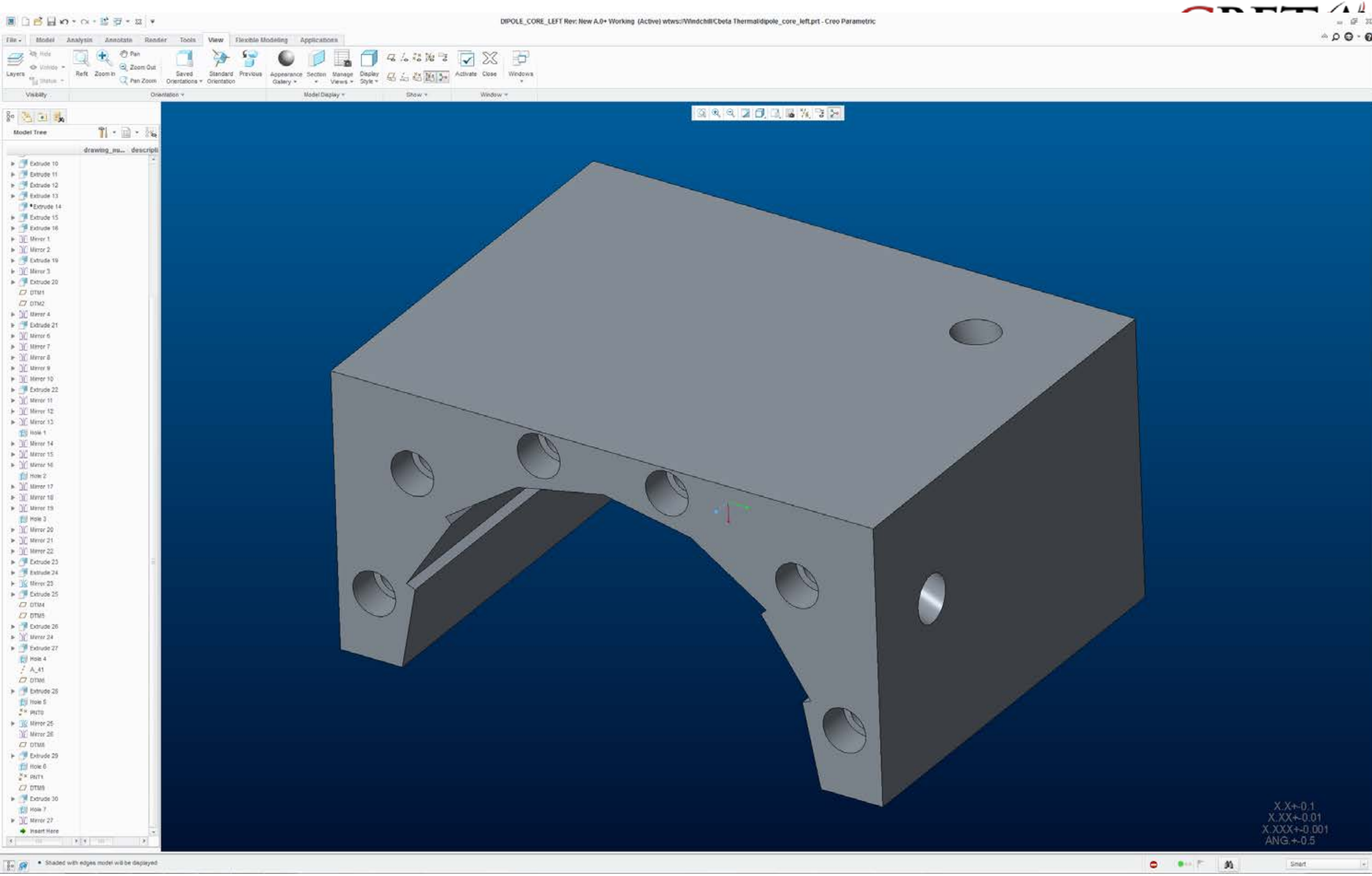
“right side”

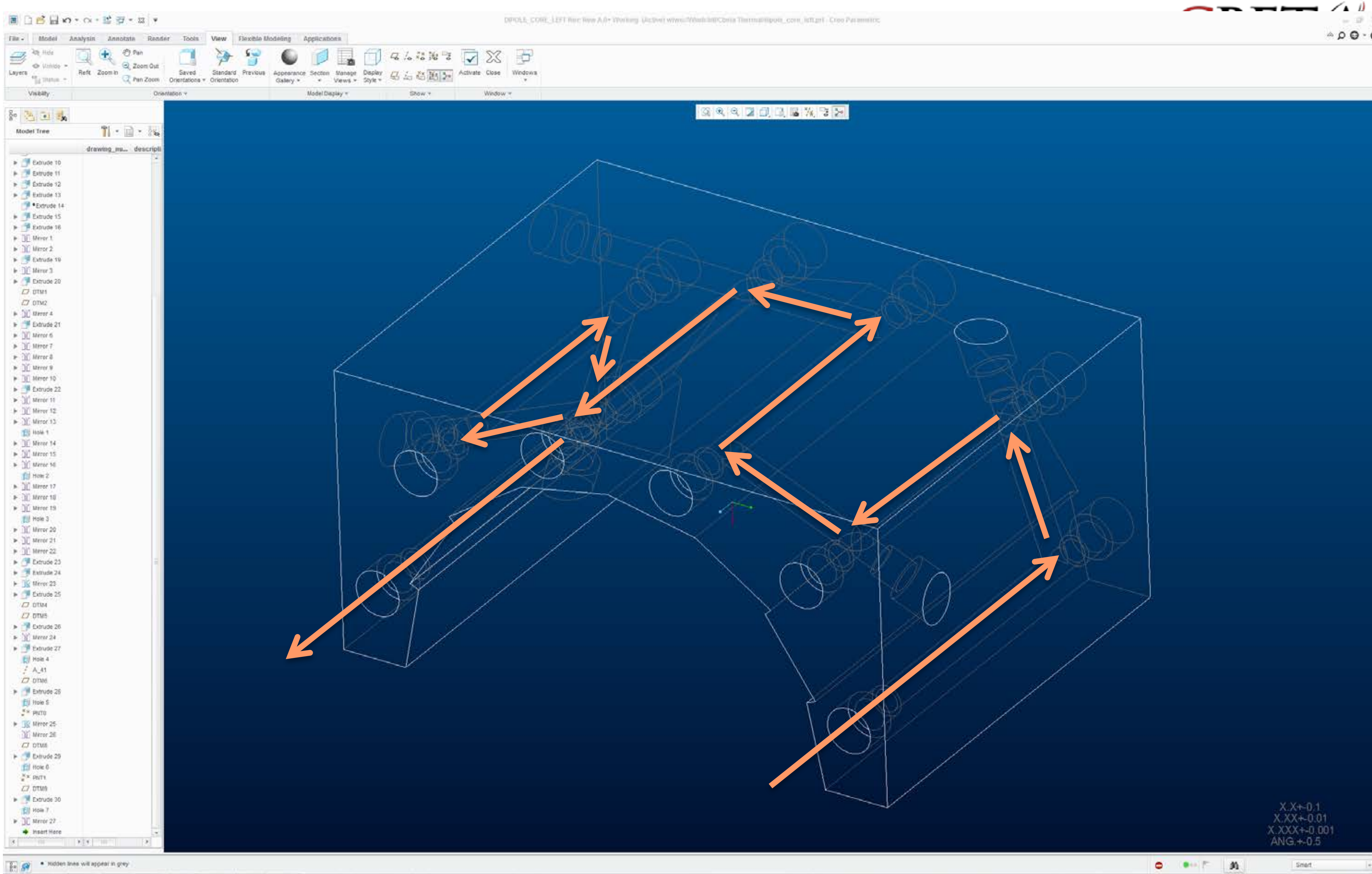


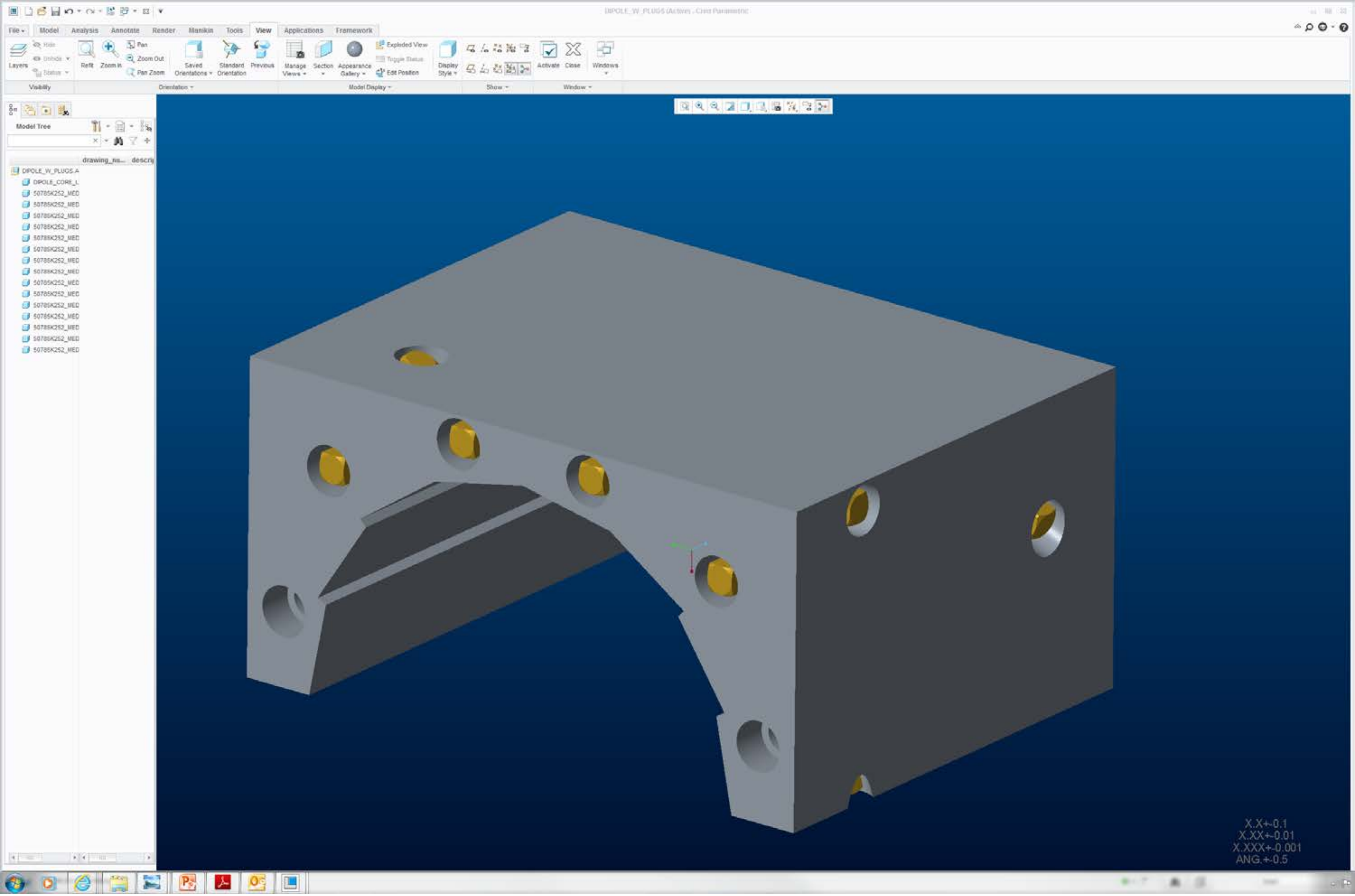
60 F water temp, 5 W/m^2 convection coefficient, 100 Watts top, 50 Watts each side



Slight increase in deflection because of holes


DIPOLE_CORE_LEFT Rev: New A.0+ Working (Active) wtws://Windchill/Cbeta Thermal/dipole_core_left.prt - Creo Parametric
File
Model
Analysis
Annotate
Render
Tools
View
Flexible Modeling
Applications
Layers
Refit
Zoom In
Pan
Zoom Out
Pan Zoom
Saved Orientations
Standard Orientation
Previous
Appearance Gallery
Section
Manage Views
Display Style
Activate
Close
Windows
Visibility
Orientation
Model Display
Show
Window
Model Tree
drawing_nu...
descripti
Insert Here
X.X+-0.1
X.XX+-0.01
X.XXX+-0.001
ANG.+-0.5
Shaded with edges model will be displayed
Smart


File
Model
Analysis
Annotate
Render
Tools
View
Flexible Modeling
Applications
Model Tree
X.X+-0.1
X.XX+-0.01
X.XXX+-0.001
ANG.+-0.5
Hidden lines will appear in grey



File
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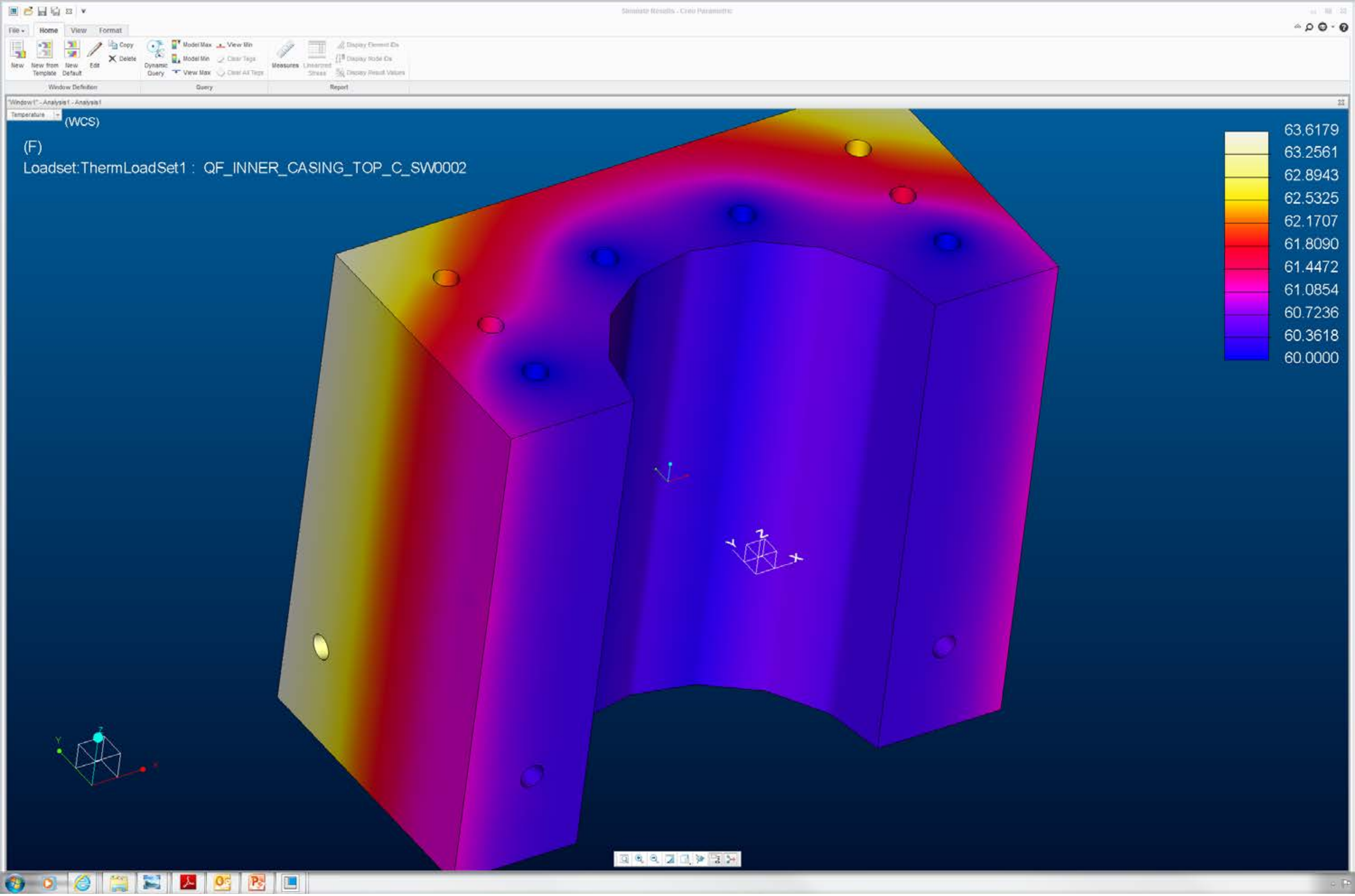
X.X+-0.1
X.XX+-0.01
X.XXX+-0.001
ANG.+-0.5



60 F water temp, 5 W/m^2 convection coefficient, 75 Watts top, 37.5 Watts each side