Collaboration meeting on DS 11T Dipole grounds

Sep. 21-23, 2015

C. Löffler

CERN Model assembly and sensitivity - Response FEM model 11T - composite coil material behaviour

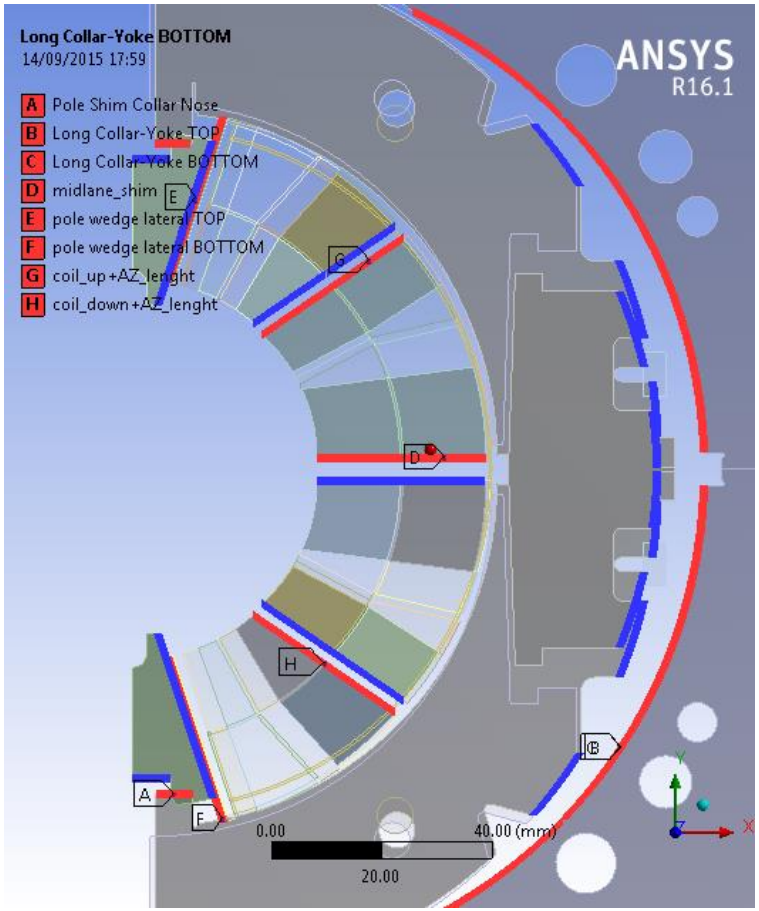
Goal

1. Influence of different geometrical parameters on coil stress levels
   - Keeping in mind the two goals of the loading
     - Not more than 150MPa in compression
     - At 11T no tension in the coil
2. The response of the system to the variation of the young modulus
3. Material behaviour linear vs. non-linear

Geometrical - Response analysis 11T-FEM model

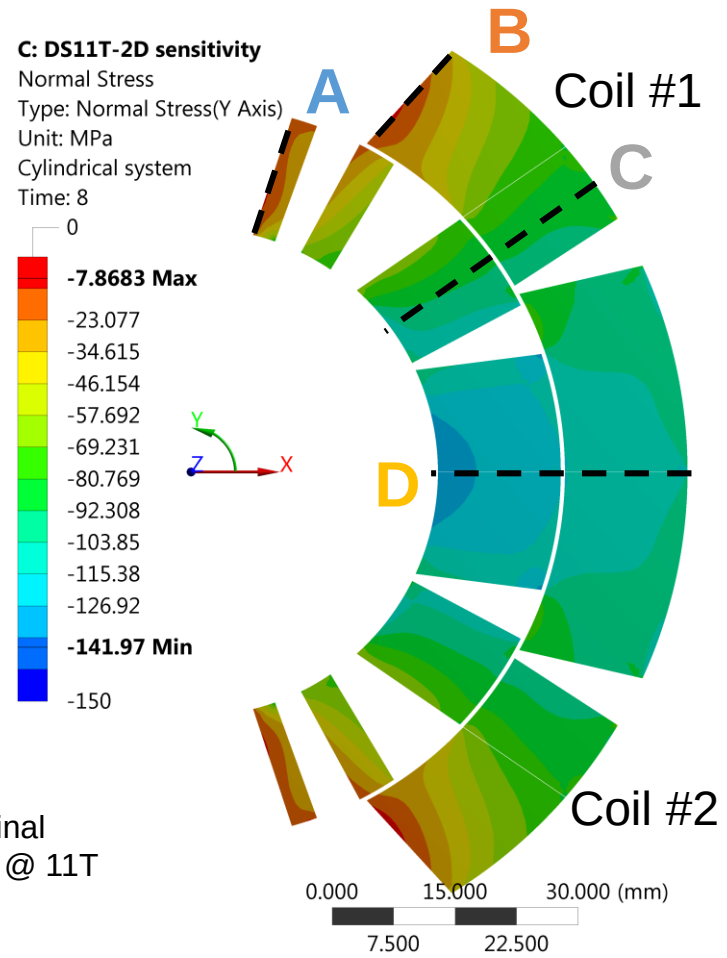
- Boundaries
  - Shimming/coil size as designed – nominal case
  - Response from four different locations in the coil, maximum and minimum

Input parameters

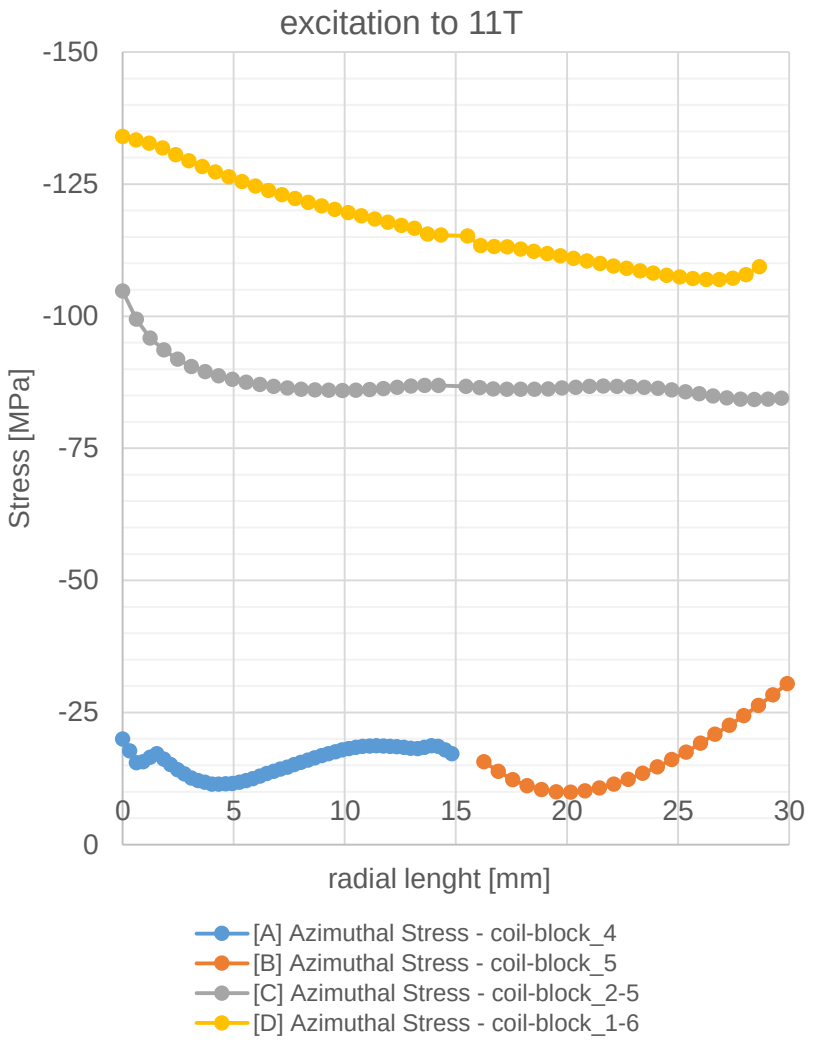


- **P718** - pole wedge lateral TOP Offset
- **P719** - pole wedge lateral BOTTOM Offset
- **P720** - coil_up+AZ_lenght Offset
- **P721** - coil_down+AZ_lenght Offset
- **P722** - midplane_shim Offset
- **P723** - Pole Shim Collar Nose Offset
- **P724** - Long Collar-Yoke TOP Offset
- **P725** - Long Collar-Yoke BOTTOM Offset

Output parameters – coil azimuthal stress – coil #1



Nominal case @ 11T

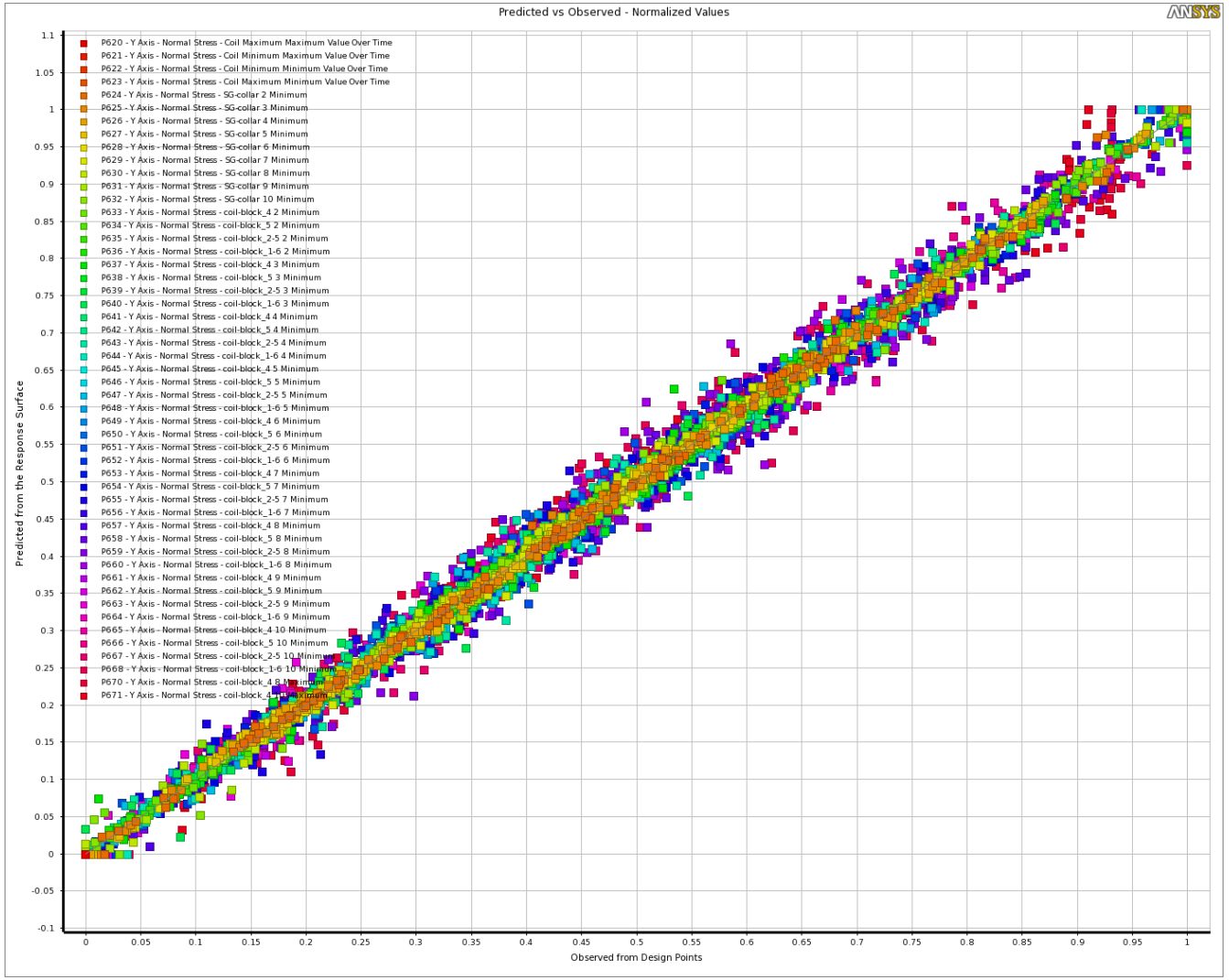


Input parameter variation -

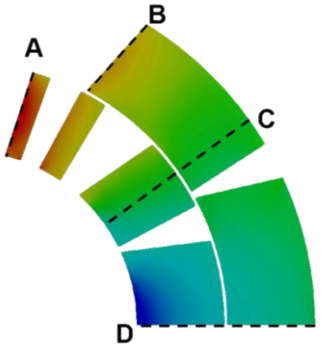
#	Parameter Name	Nom. [mm]	lower bound [mm]	upper bound [mm]
P718	Lateral #1	0.2	0.17	0.23
P719	Lateral #2	0.2	0.17	0.23
P720	Coil size #1	0.06	0.03	0.1
P721	Coil size #2	0.06	0.03	0.1
P722	Mid. shim	0.04	0.01	0.07
P723	Top pole shim	0.2	0.17	0.23
P724	Collar-Yoke #1	0.4	0.35	0.45
P725	Collar-Yoke #2	0.4	0.35	0.45

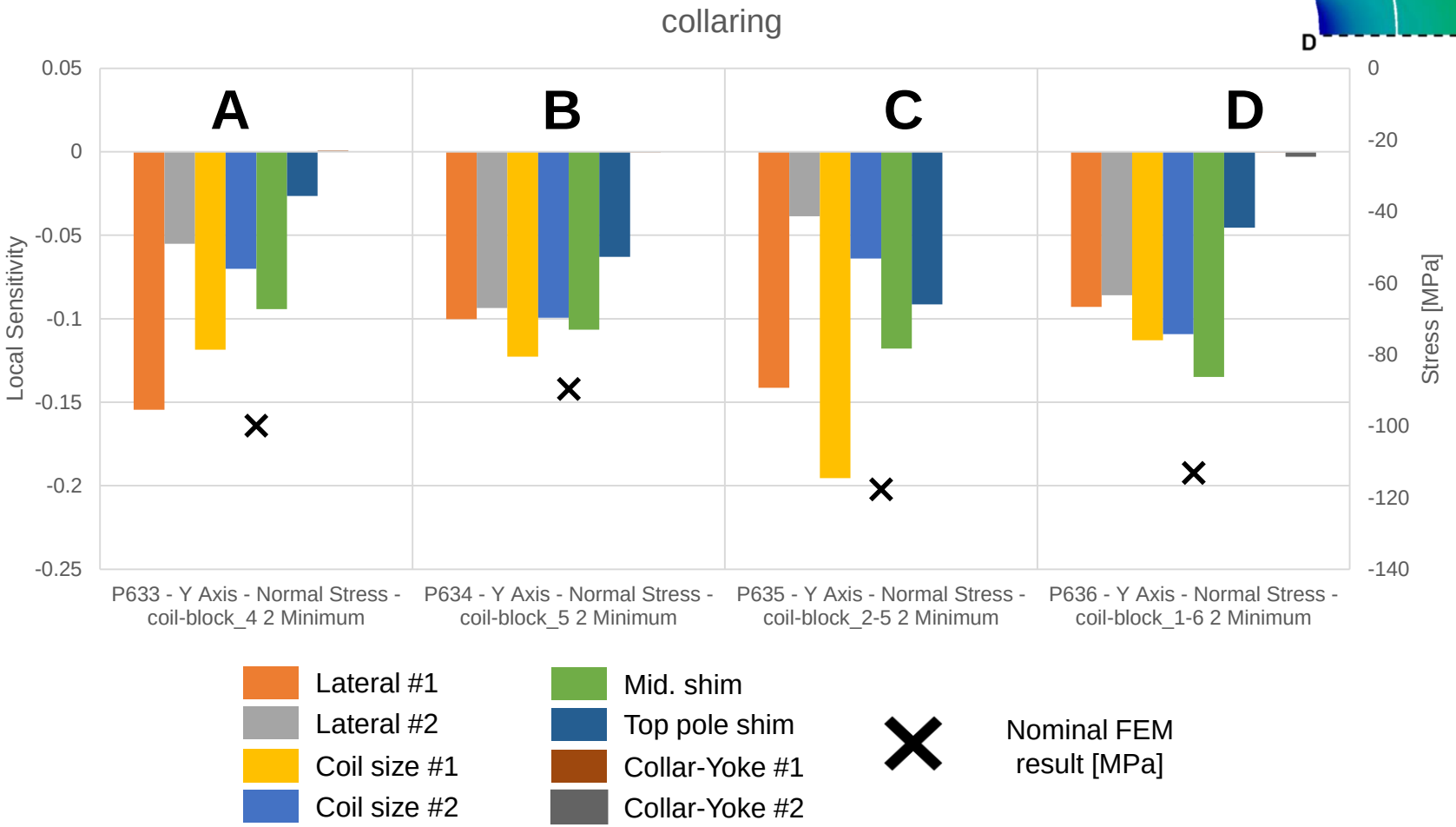
-Continuous parameters not discrete
-150 different runs
-central composite design

Predicted vs. Observed output values

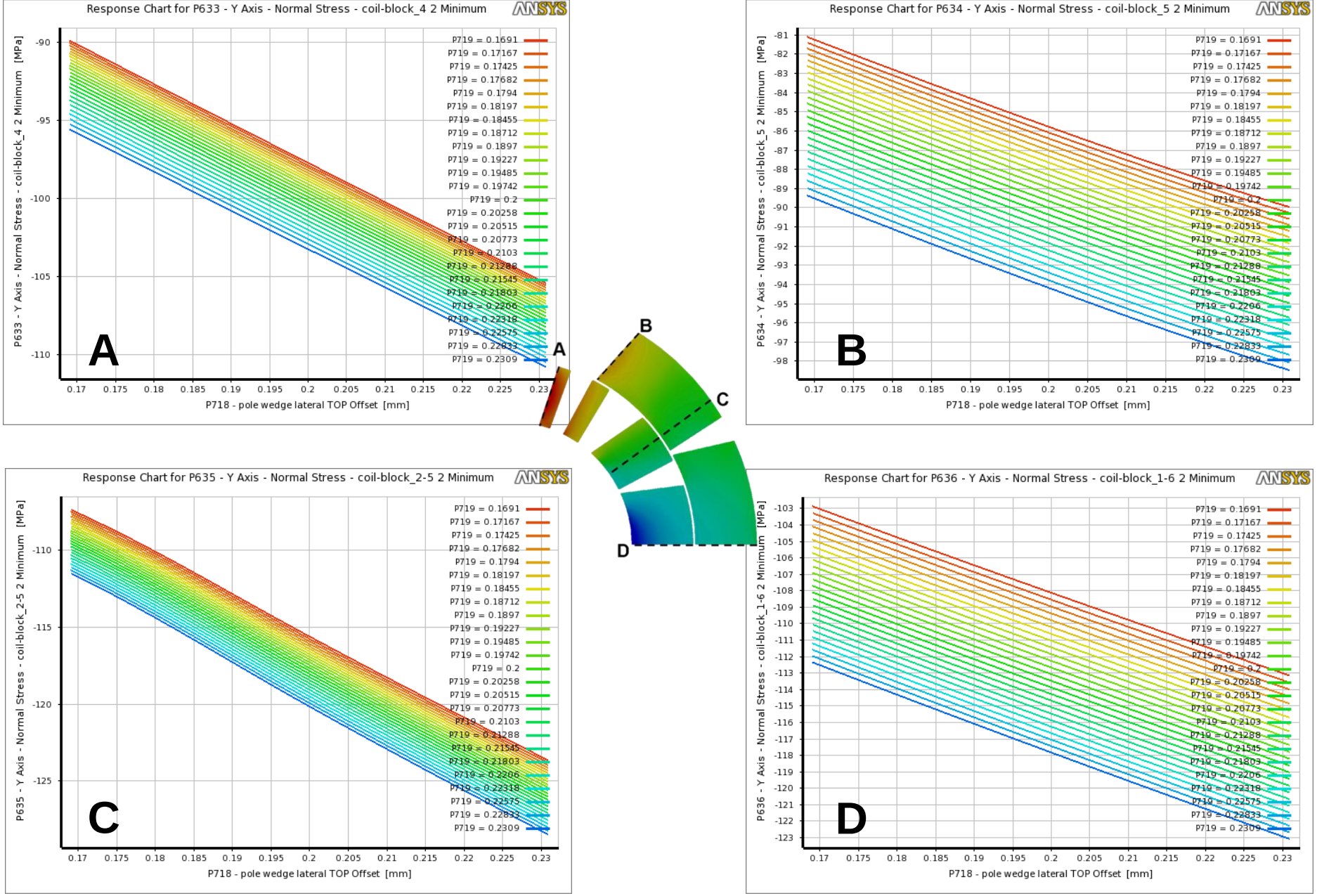


Local sensitivity – max. compression stress





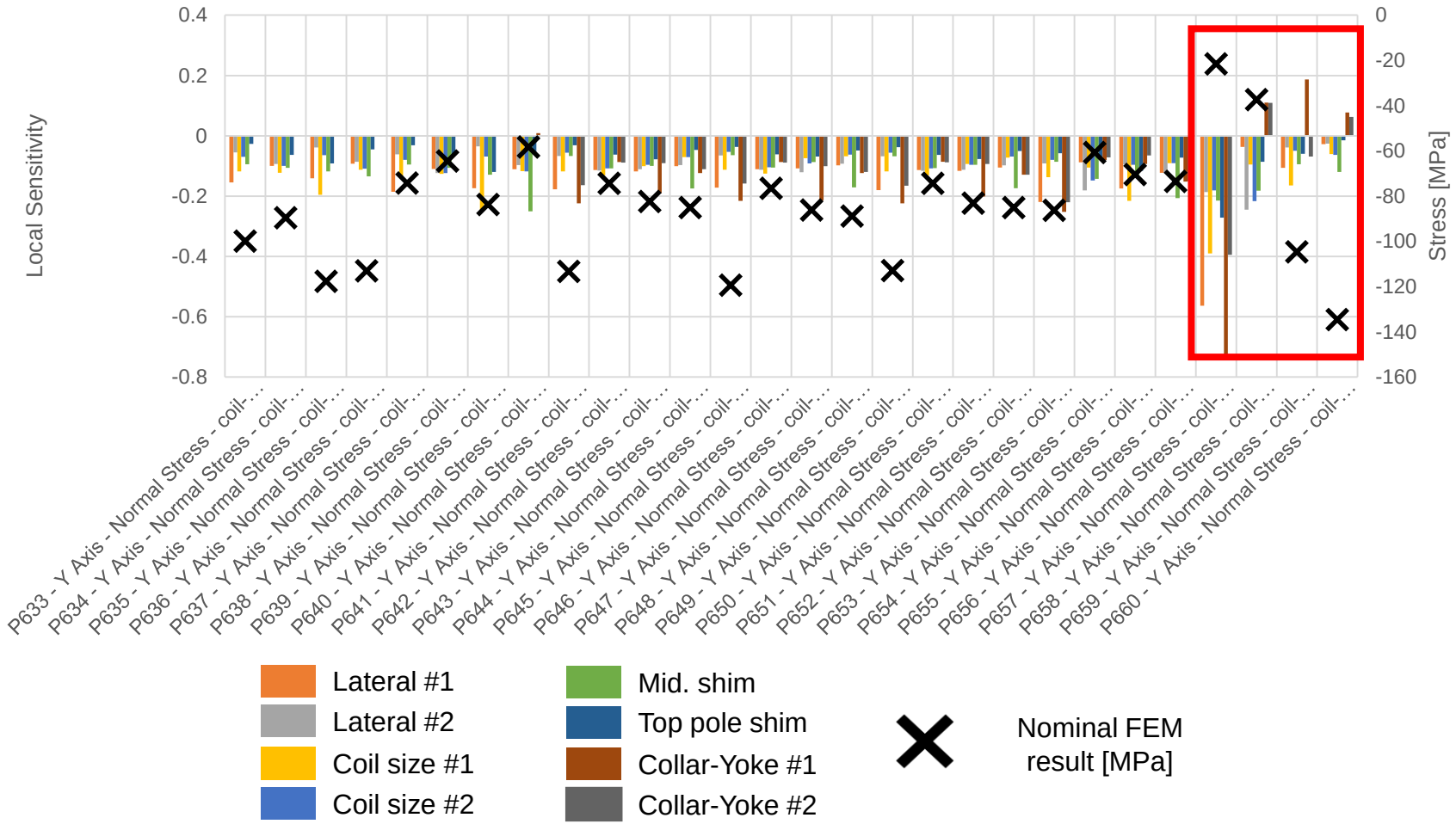
LS = f(input) = Max(OP)-Min(OP)/Avg(OP)
If OP increases while IP increases, the sign is positive, otherwise its negative.



collaring – resp. lateral pole shim

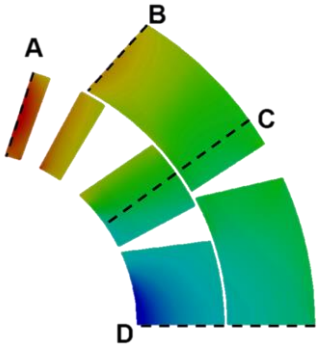
Local sensitivity – all outputs

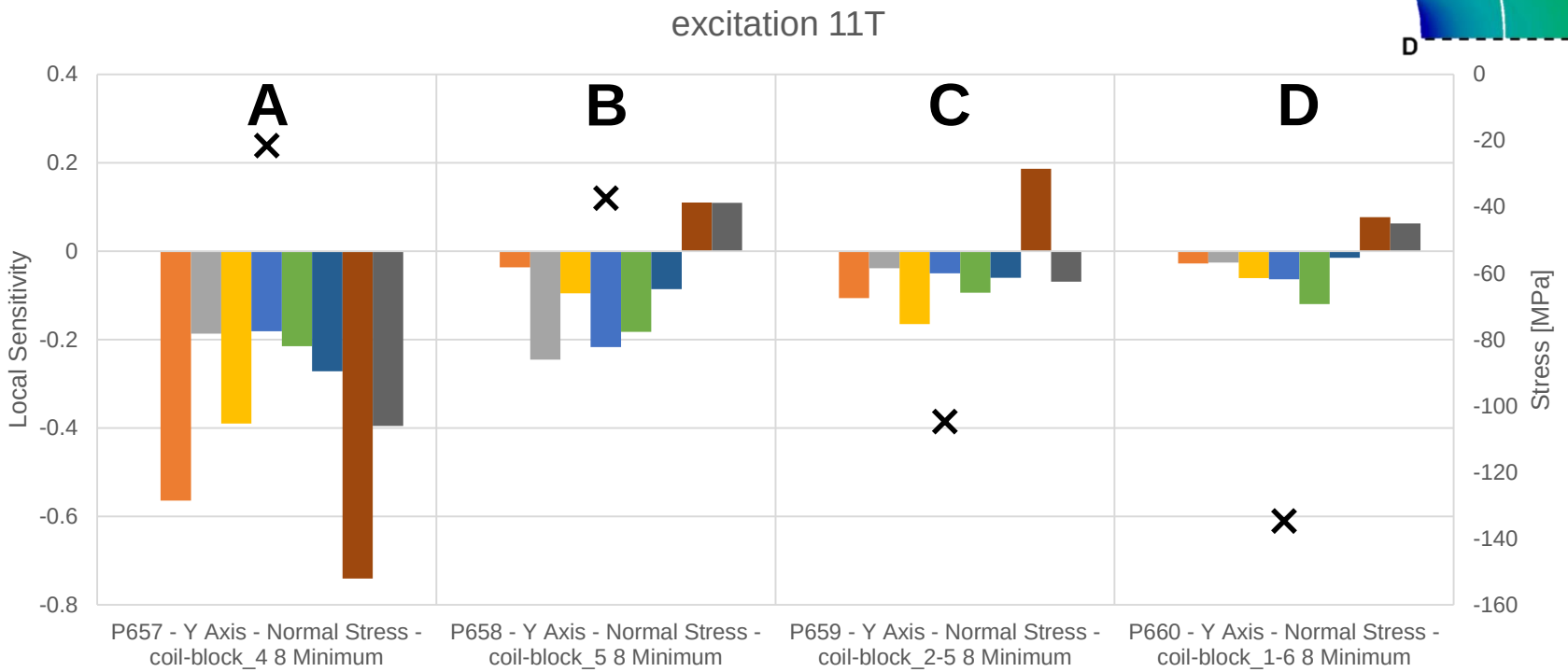
Excitation phase
of most interest



LS = f(input) = Max(OP)-Min(OP)/Avg(OP)
If OP increases while IP increases,
the sign is positive, otherwise its negative.

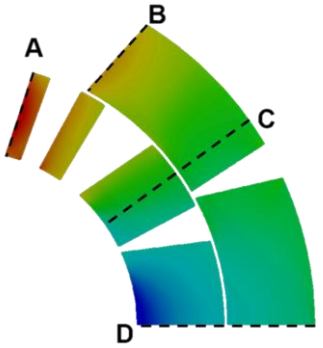
Local sensitivity – max. compression stress

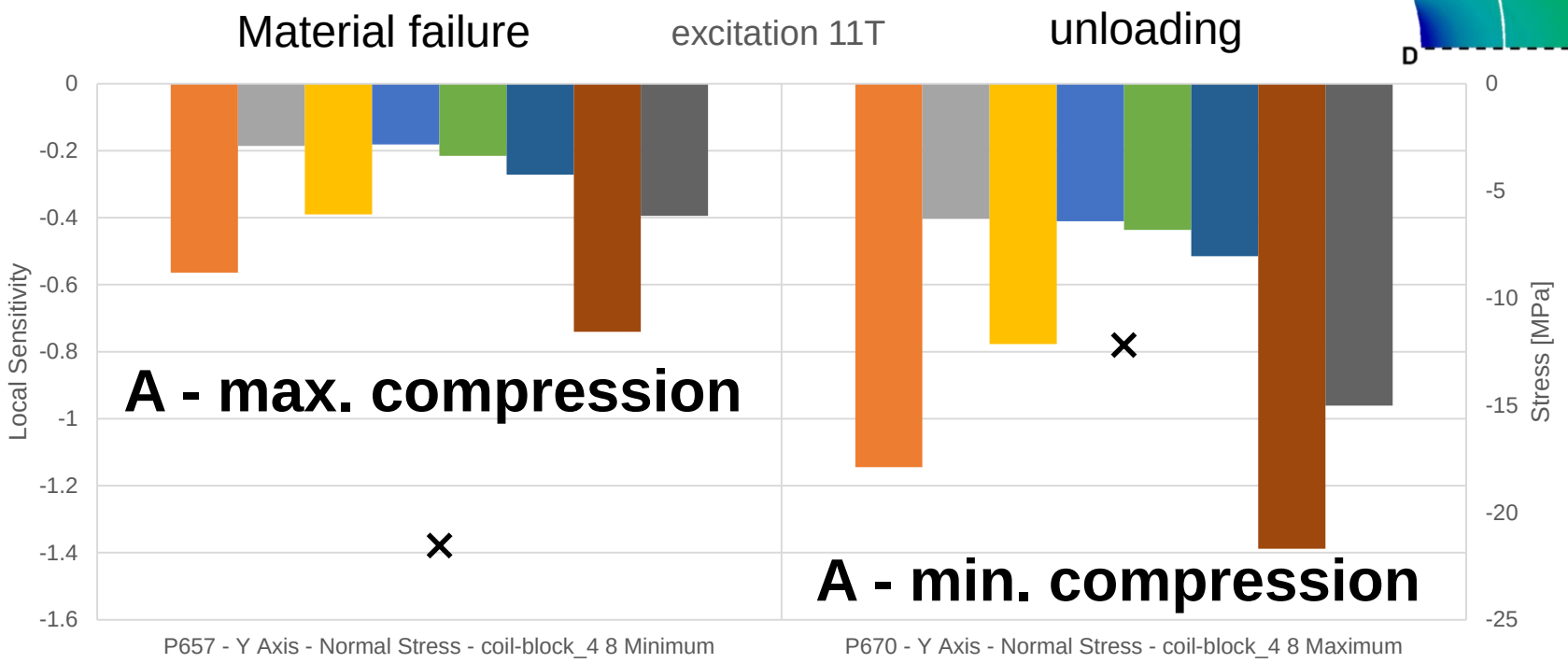




LS = f(input) = Max(OP)-Min(OP)/Avg(OP)
If OP increases while IP increases, the sign is positive, otherwise its negative.

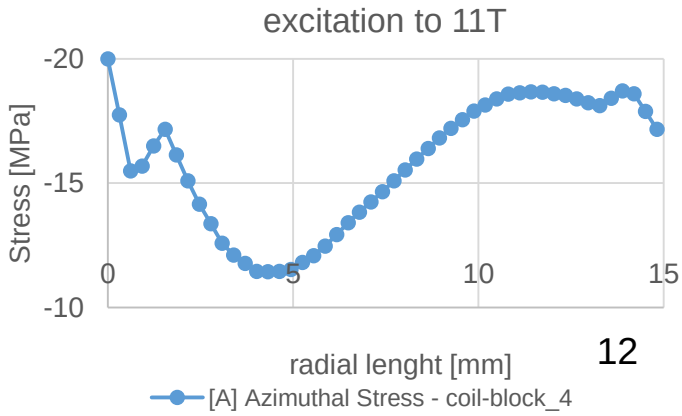
Local sensitivity

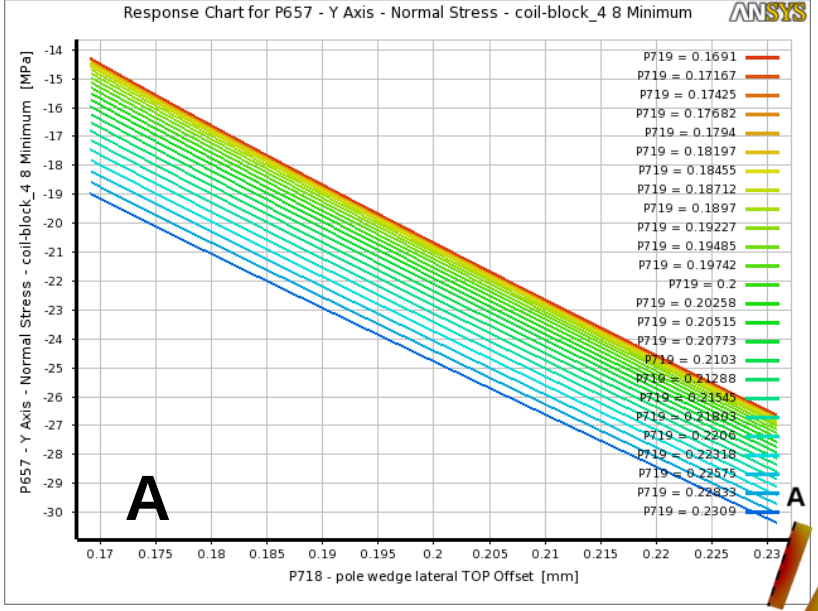


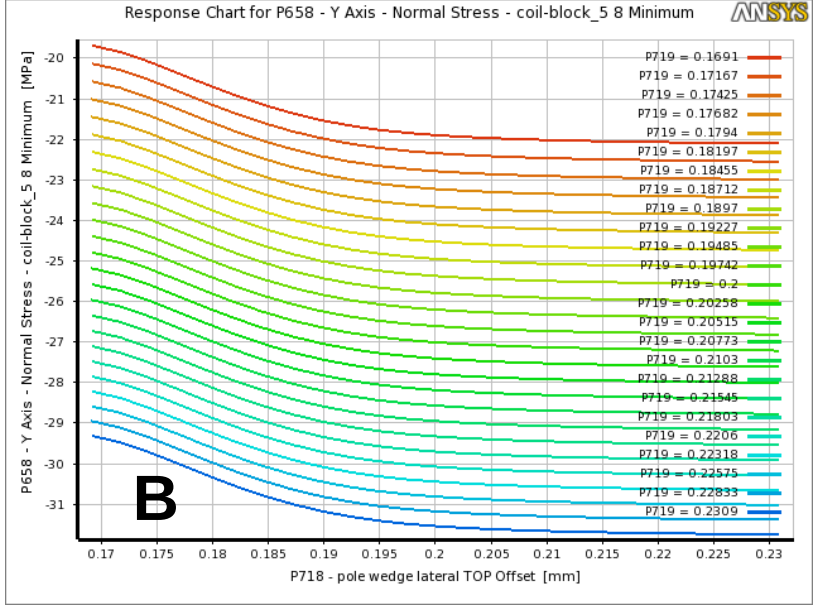


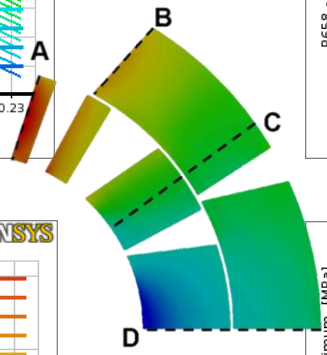
- Lateral #1
- Lateral #2
- Coil size #1
- Coil size #2
- Mid. shim
- Top pole shim
- Collar-Yoke #1
- Collar-Yoke #2

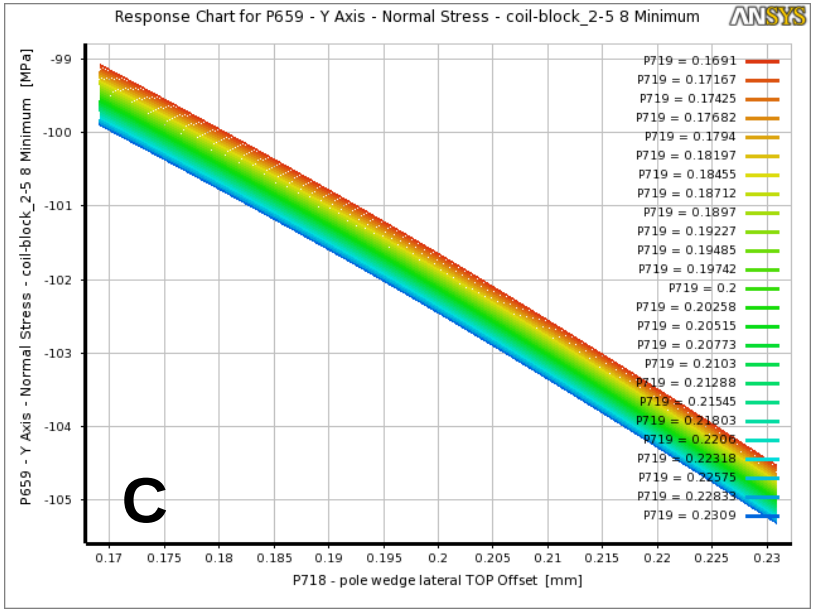
× Nominal FEM result [MPa]

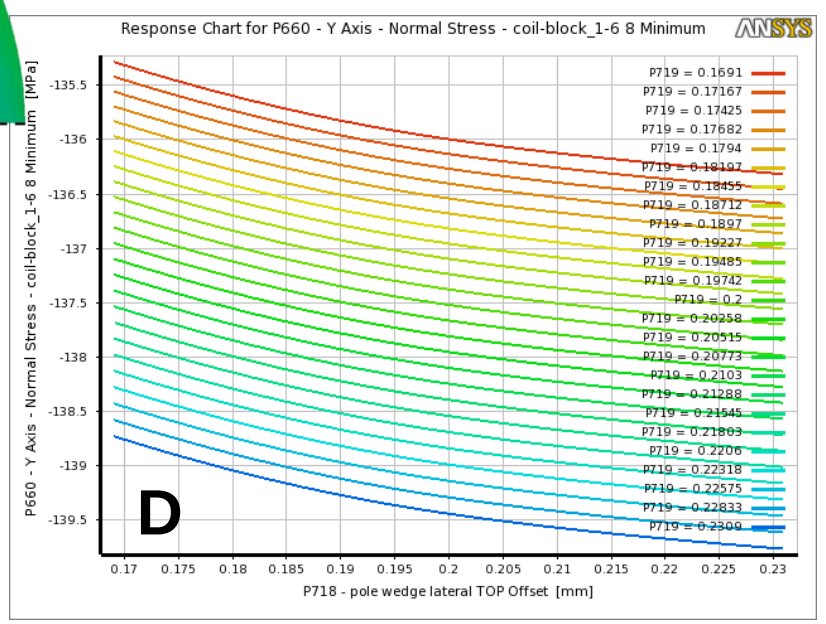


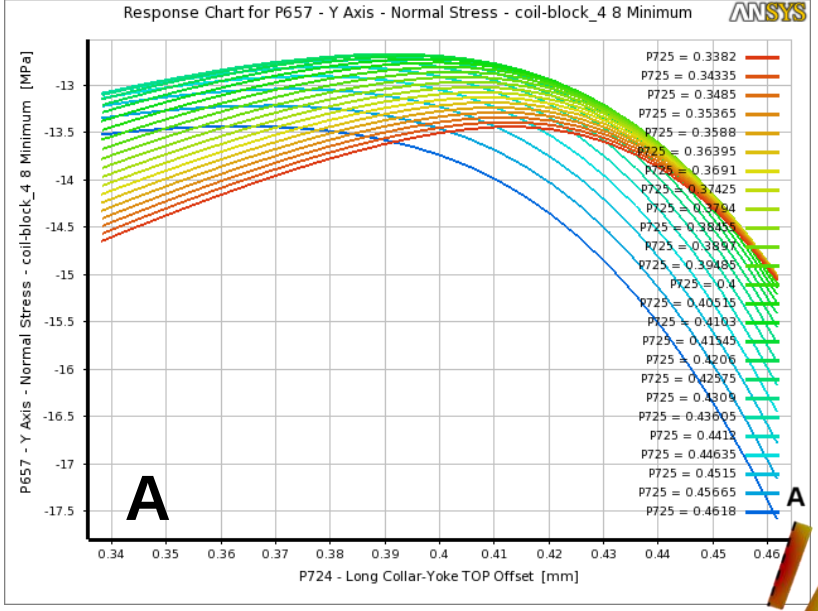

Response Chart for P657 - Y Axis - Normal Stress - coil-block_4 8 Minimum
ANSYS
P657 - Y Axis - Normal Stress - coil-block_4 8 Minimum [MPa]
P718 - pole wedge lateral TOP Offset [mm]
P719 = 0.1691
P719 = 0.17167
P719 = 0.17425
P719 = 0.17682
P719 = 0.1794
P719 = 0.18197
P719 = 0.18455
P719 = 0.18712
P719 = 0.1897
P719 = 0.19227
P719 = 0.19485
P719 = 0.19742
P719 = 0.2
P719 = 0.20258
P719 = 0.20515
P719 = 0.20773
P719 = 0.2103
P719 = 0.21288
P719 = 0.21545
P719 = 0.21803
P719 = 0.2206
P719 = 0.22318
P719 = 0.22575
P719 = 0.22833
P719 = 0.2309
A

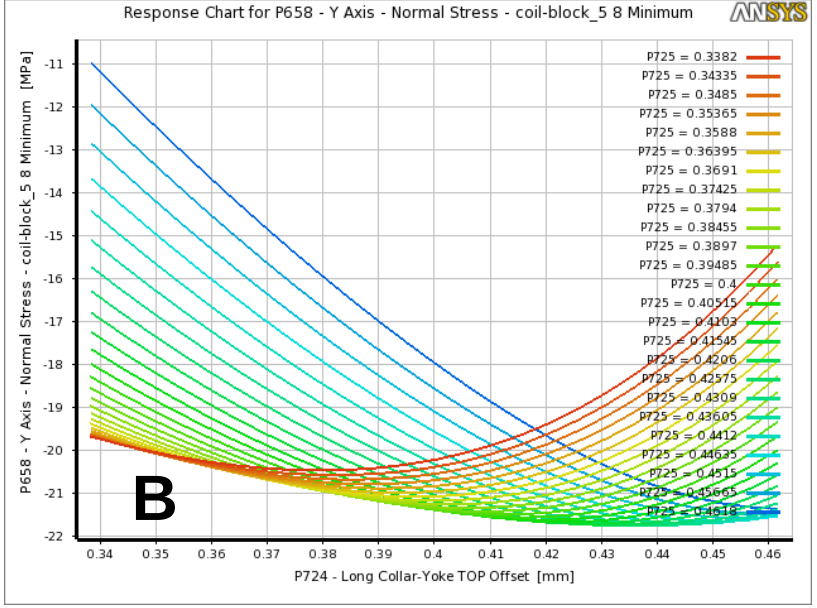

Response Chart for P658 - Y Axis - Normal Stress - coil-block_5 8 Minimum
ANSYS
P658 - Y Axis - Normal Stress - coil-block_5 8 Minimum [MPa]
P718 - pole wedge lateral TOP Offset [mm]
P719 = 0.1691
P719 = 0.17167
P719 = 0.17425
P719 = 0.17682
P719 = 0.1794
P719 = 0.18197
P719 = 0.18455
P719 = 0.18712
P719 = 0.1897
P719 = 0.19227
P719 = 0.19485
P719 = 0.19742
P719 = 0.2
P719 = 0.20258
P719 = 0.20515
P719 = 0.20773
P719 = 0.2103
P719 = 0.21288
P719 = 0.21545
P719 = 0.21803
P719 = 0.2206
P719 = 0.22318
P719 = 0.22575
P719 = 0.22833
P719 = 0.2309
B

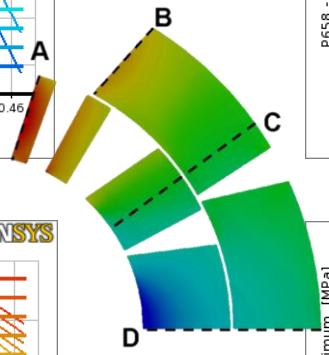

A
B
C
D

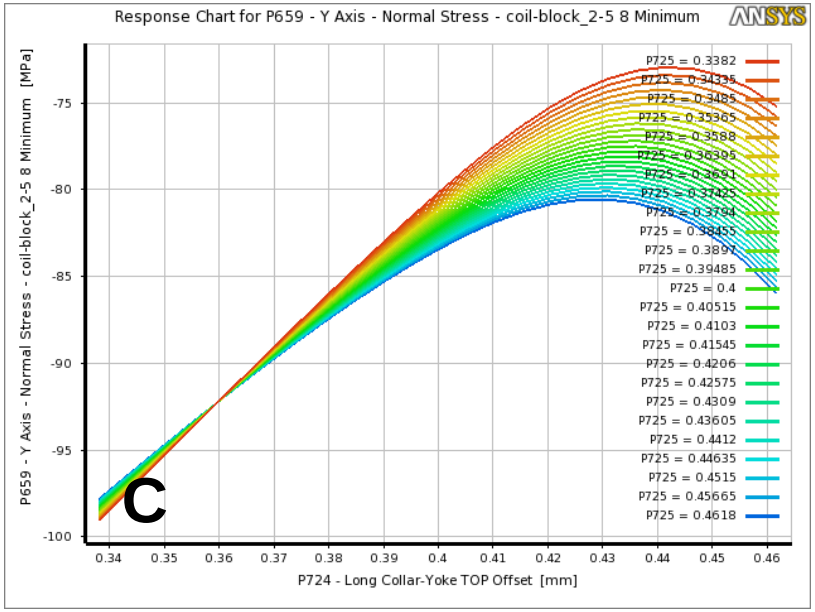

Response Chart for P659 - Y Axis - Normal Stress - coil-block_2-5 8 Minimum
ANSYS
P659 - Y Axis - Normal Stress - coil-block_2-5 8 Minimum [MPa]
P718 - pole wedge lateral TOP Offset [mm]
P719 = 0.1691
P719 = 0.17167
P719 = 0.17425
P719 = 0.17682
P719 = 0.1794
P719 = 0.18197
P719 = 0.18455
P719 = 0.18712
P719 = 0.1897
P719 = 0.19227
P719 = 0.19485
P719 = 0.19742
P719 = 0.2
P719 = 0.20258
P719 = 0.20515
P719 = 0.20773
P719 = 0.2103
P719 = 0.21288
P719 = 0.21545
P719 = 0.21803
P719 = 0.2206
P719 = 0.22318
P719 = 0.22575
P719 = 0.22833
P719 = 0.2309
C

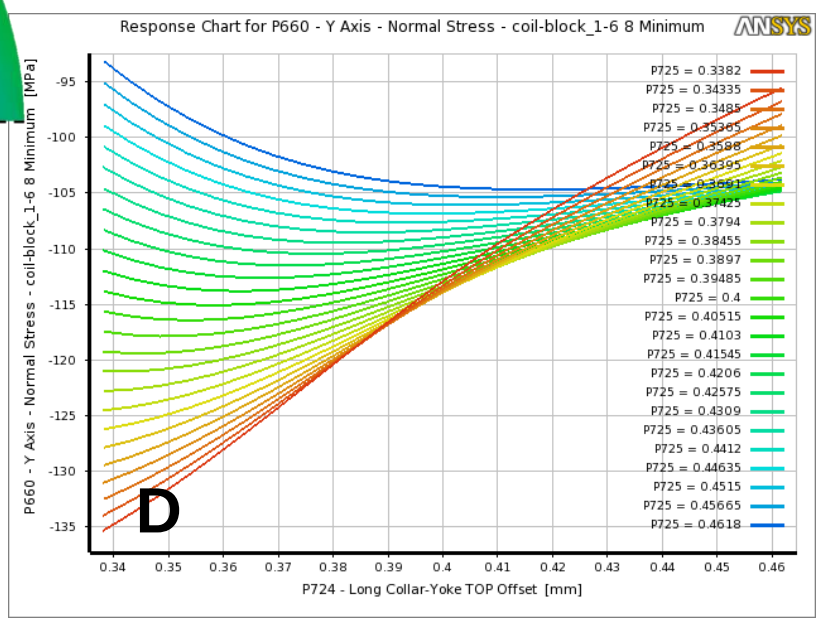

Response Chart for P660 - Y Axis - Normal Stress - coil-block_1-6 8 Minimum
ANSYS
P660 - Y Axis - Normal Stress - coil-block_1-6 8 Minimum [MPa]
P718 - pole wedge lateral TOP Offset [mm]
P719 = 0.1691
P719 = 0.17167
P719 = 0.17425
P719 = 0.17682
P719 = 0.1794
P719 = 0.18197
P719 = 0.18455
P719 = 0.18712
P719 = 0.1897
P719 = 0.19227
P719 = 0.19485
P719 = 0.19742
P719 = 0.2
P719 = 0.20258
P719 = 0.20515
P719 = 0.20773
P719 = 0.2103
P719 = 0.21288
P719 = 0.21545
P719 = 0.21803
P719 = 0.2206
P719 = 0.22318
P719 = 0.22575
P719 = 0.22833
P719 = 0.2309
D











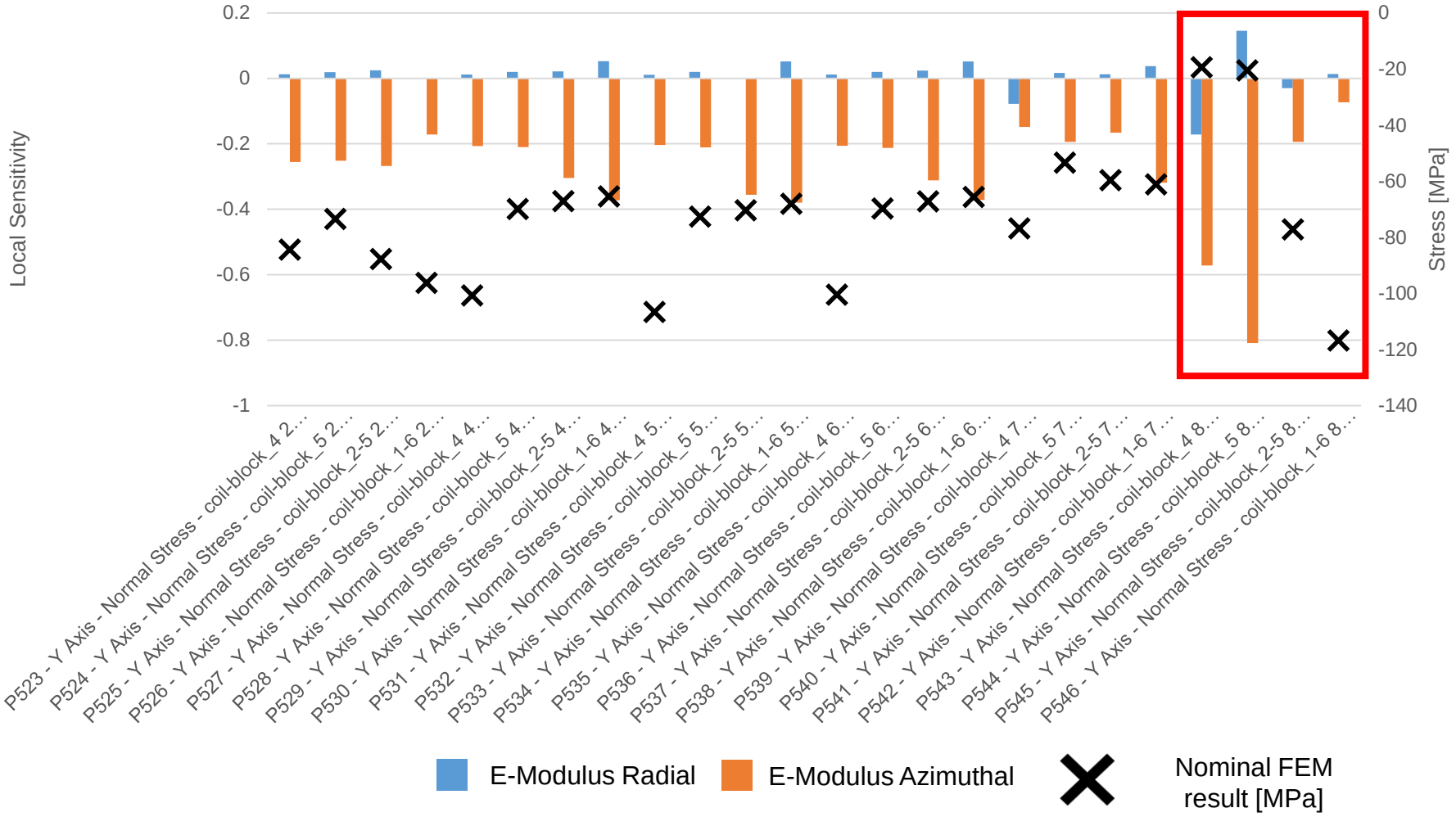
Excitation to 11T – resp. yoke-collared coil shim

E-modulus - Response analysis 11T-FEM model

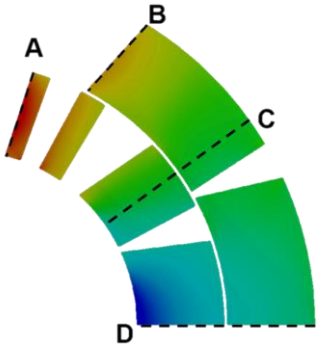
- Variation of elastic modulus
  - Over Radial and Azimuthal direction
  - Mean 25GPa (293K) variation from 30 to 20GPa
    - At 1.9K 10% higher then during RT
- Material characterisation test have shown much lower values (22GPa) then expected (33-40GPa) [1,2,3], after massaging.

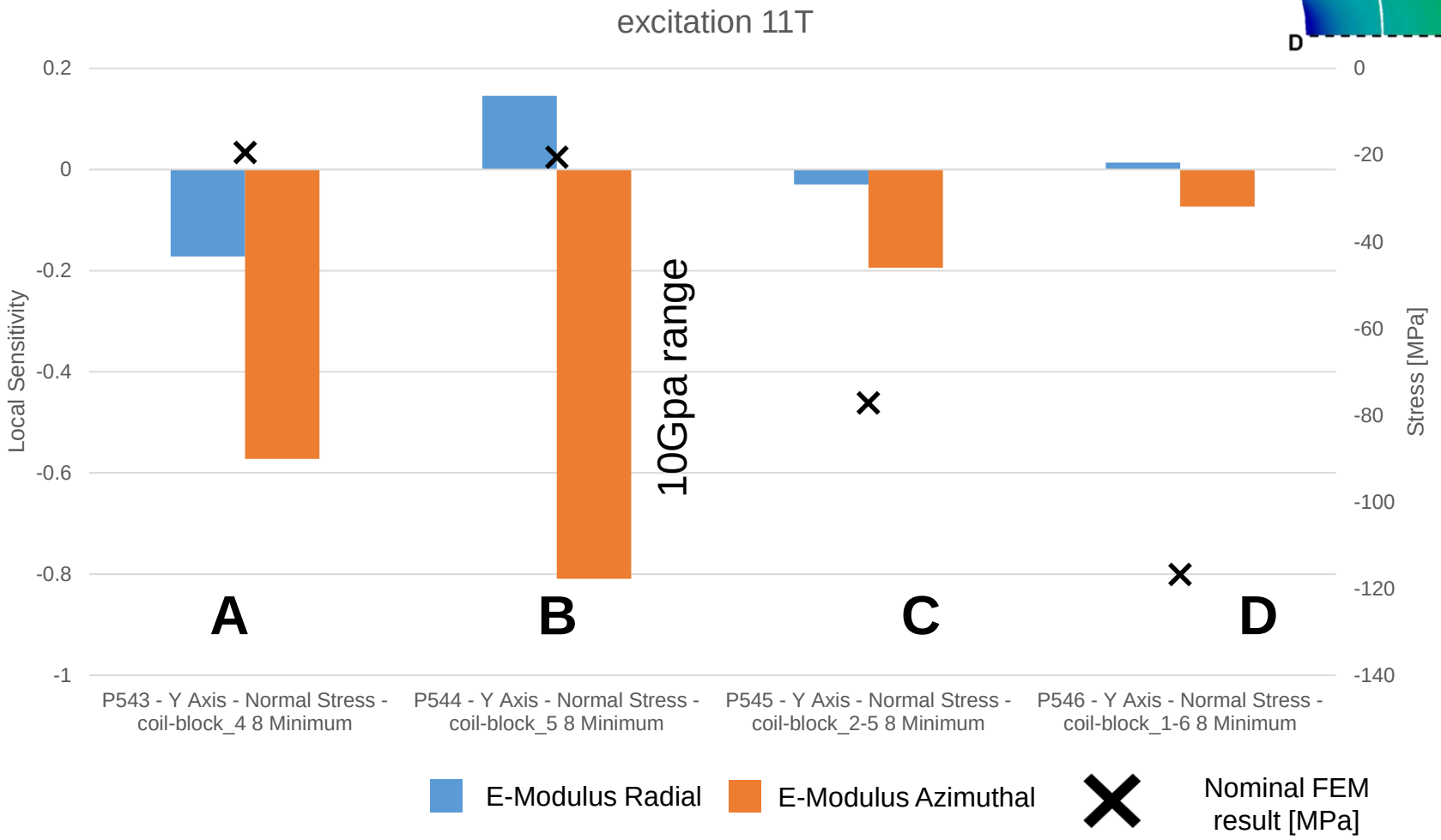
Local sensitivity – Modulus +-5GPa – max. compression stress

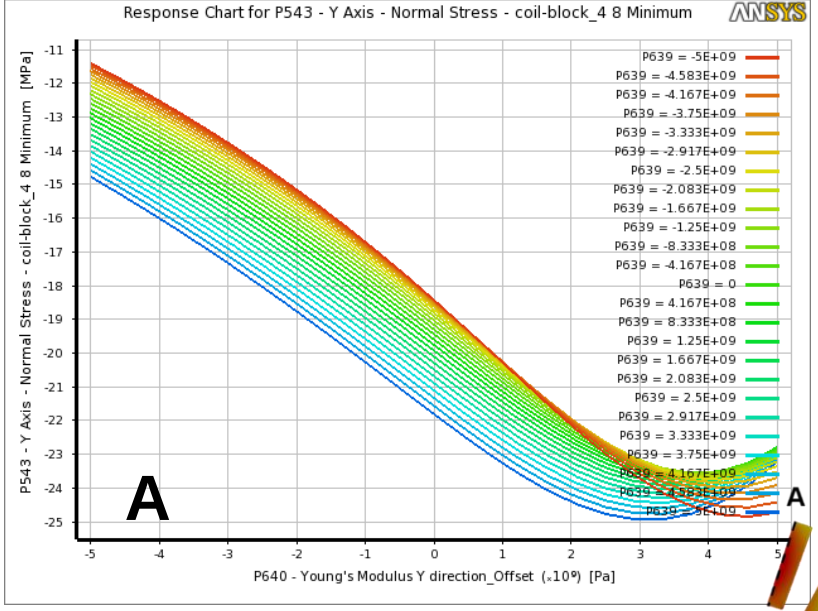
Excitation phase of most interest

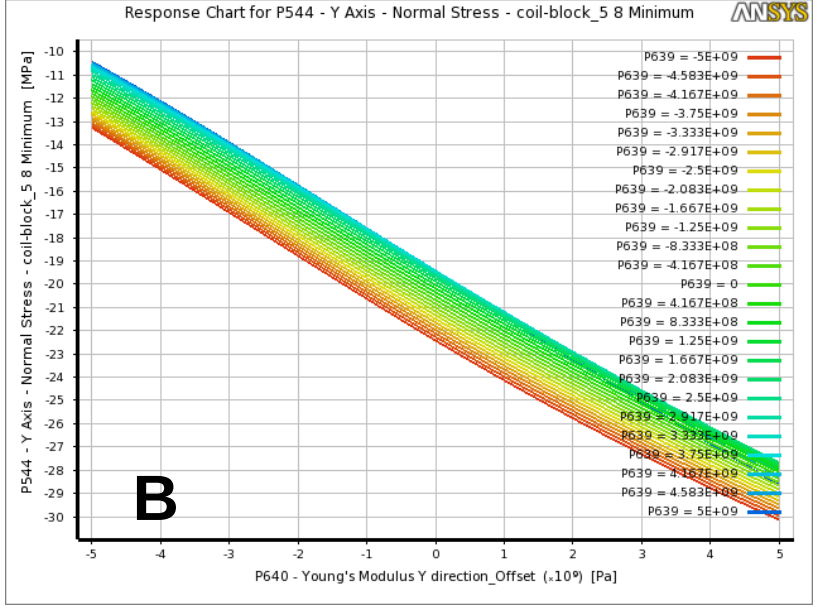


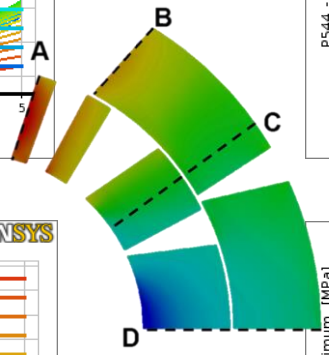
Local sensitivity – Modulus +-5GPa – max. compression stress

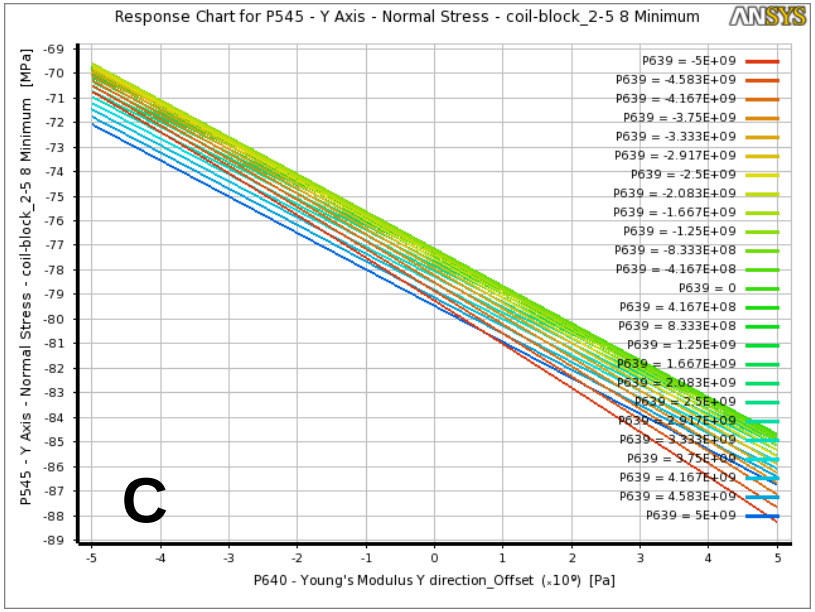


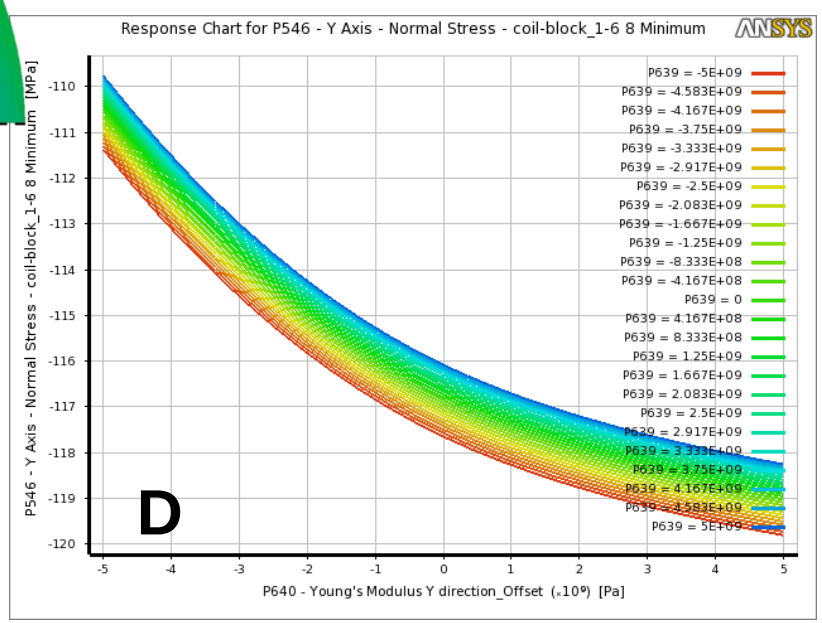










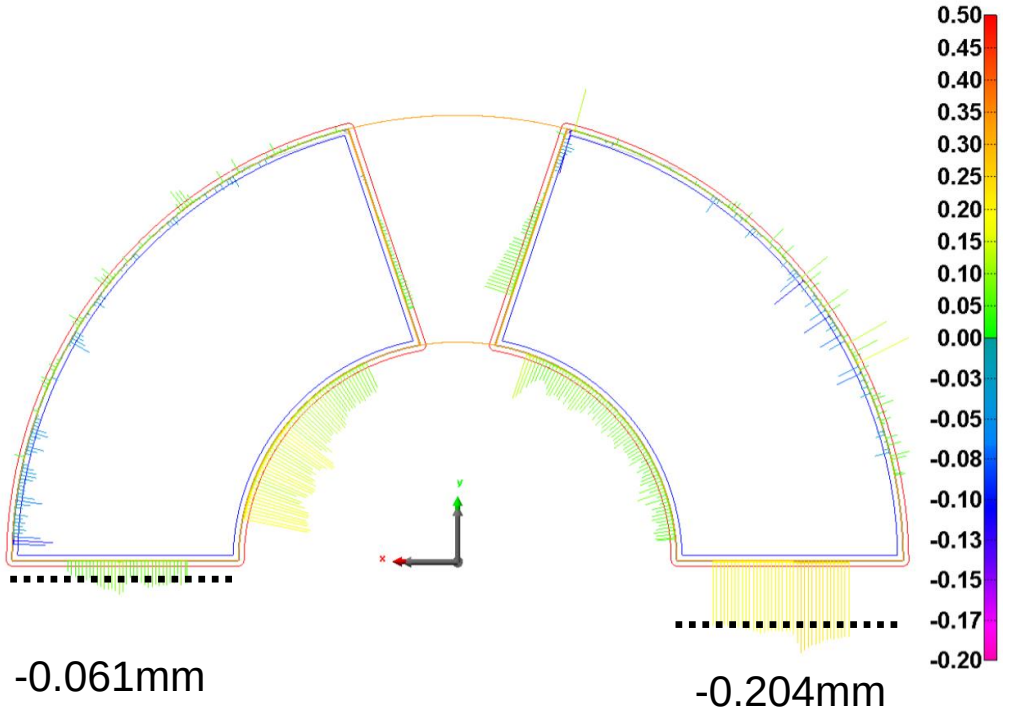


Excitation to 11T – X/Y elastic modulus coil

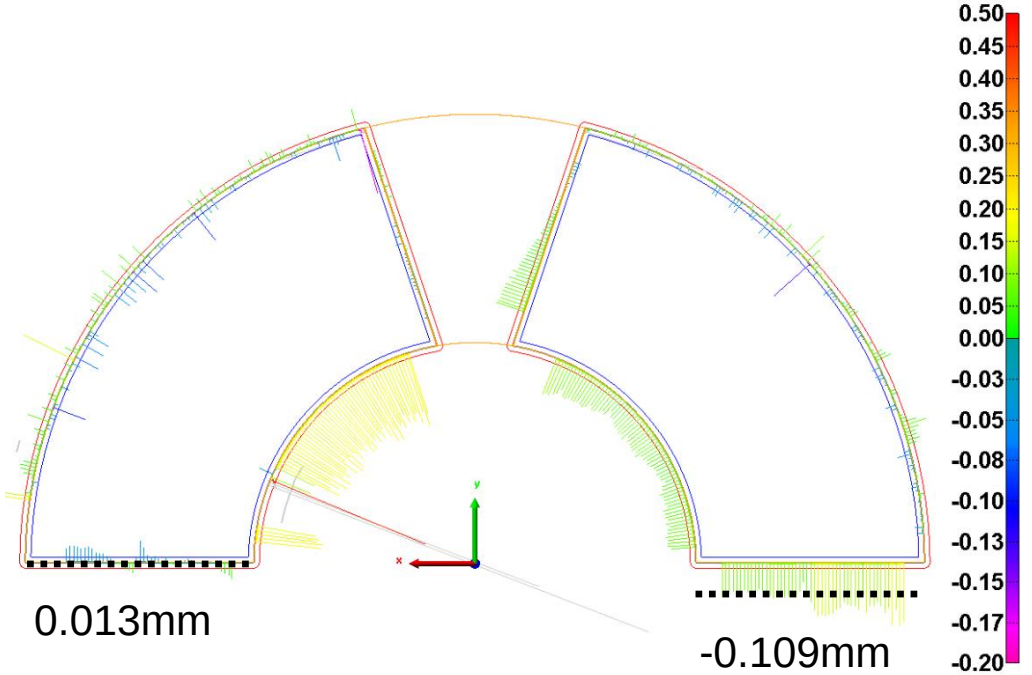
Elastic vs. elastic-plastic - Response analysis 11T-FEM model

- Why?
- Coil deformation during assembly and testing
- Hysteretic behaviour of 10-Stack compression test measurements
- Unpredicted quenches, with the elastic FEM-model, in the straight section of MBHSP102, which might be explained by lack of compression

Permanent deformation in 11T coil 107



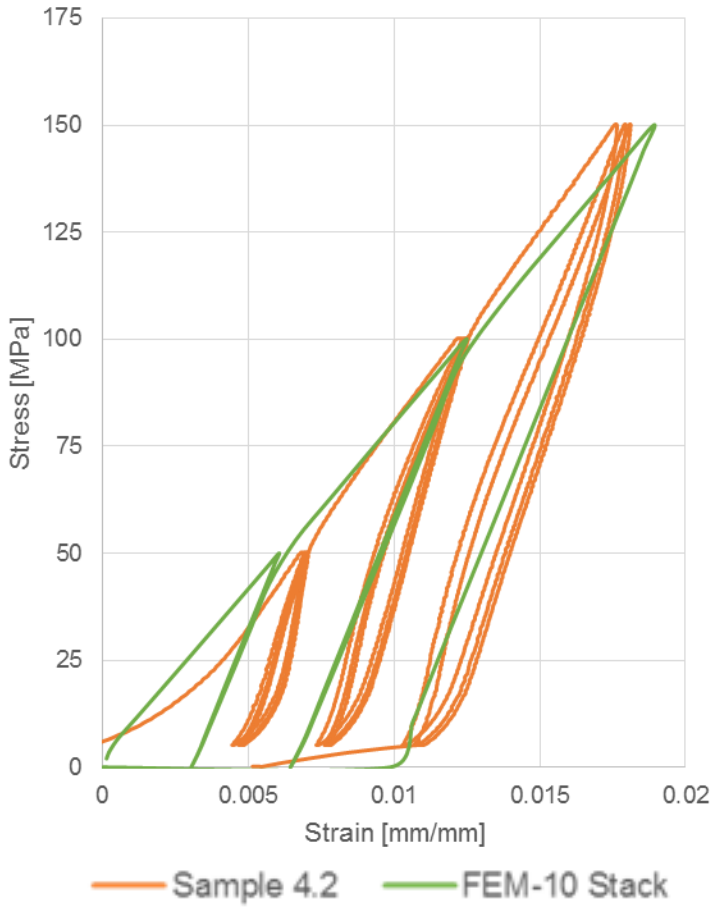
Coil 107 after manufacturing – virgin state



Coil 107 after testing in MBHP101

11T_model-coil_metrology #107
EDMS 1541563 v.1

Stress Strain curve – 10-Stack measurements

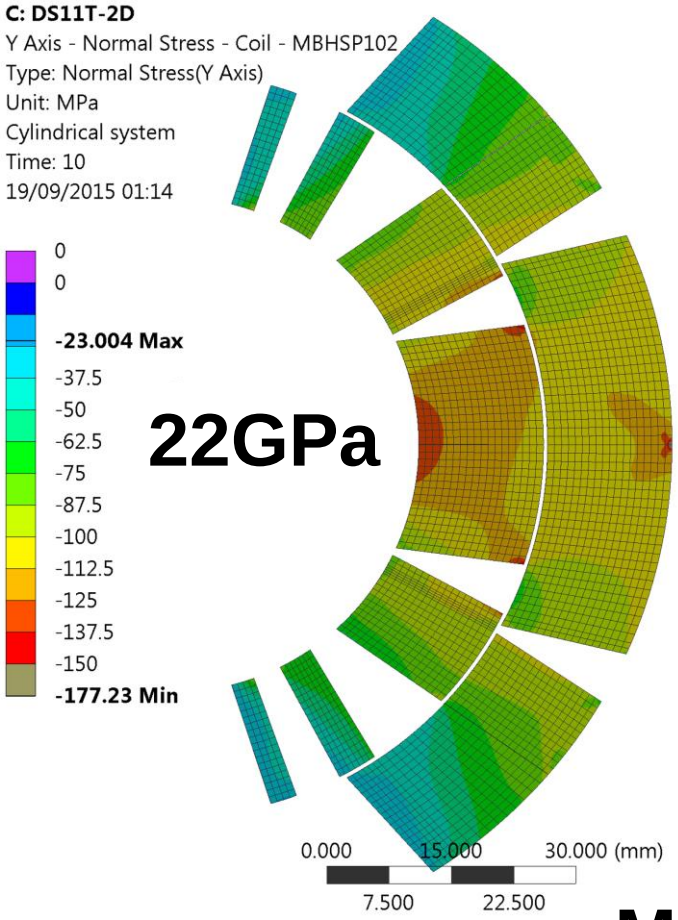


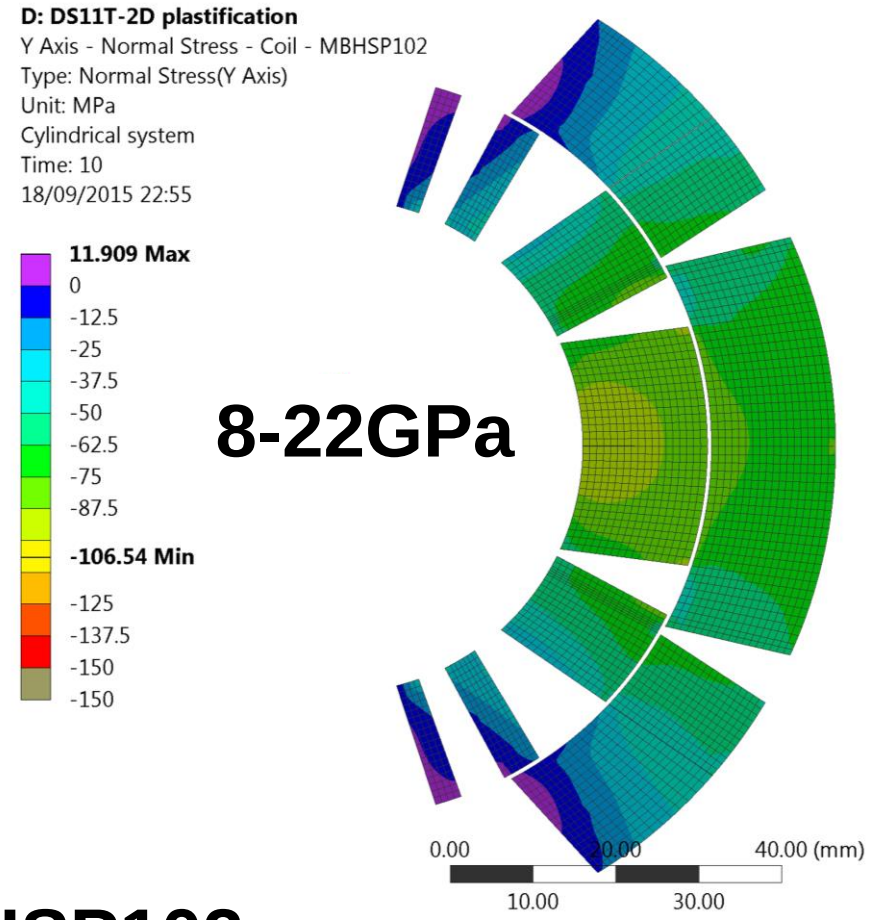
- 10-Stack are showing a hysteresis behaviour
- Influence on theoretical model?
- Use of bilinear isotropic hardening material parameters
- Need to linearize the strain-stress curve

Measured coil deformation after assembly

- Coil azimuthal length (conductors only) **40mm**
  - Permanent azimuthal deformation on average over the straight section 0.08mm
  - *0.2%* of permanent deformation
- 10-Stack **15mm**
  - Permanent deformation 0.04mm after compressive test to 100MPa
  - *0.26%* of permanent deformation

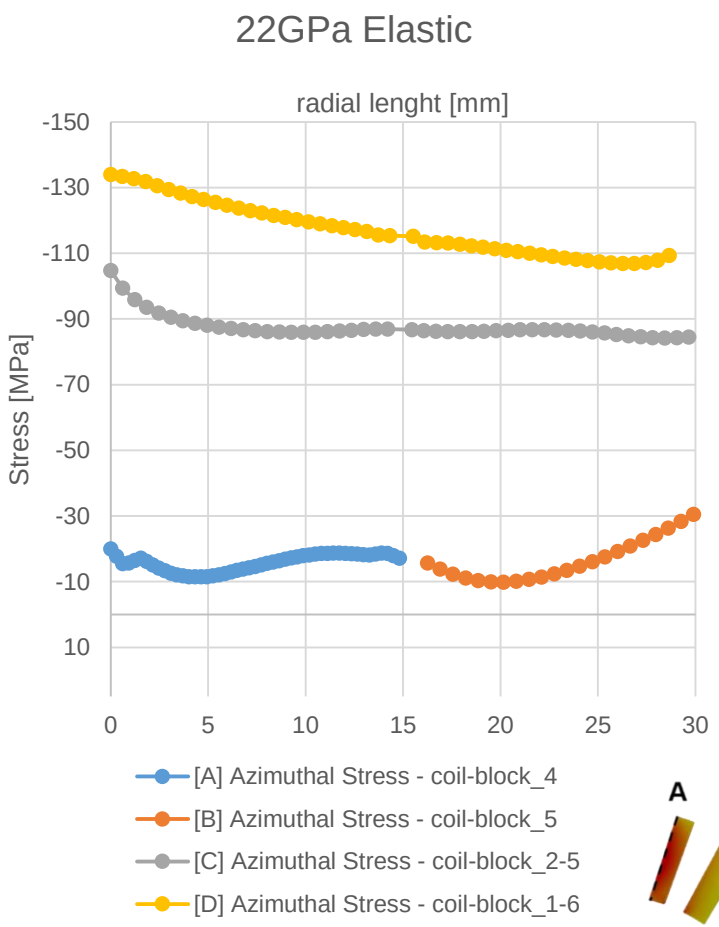
Comparison between perfect elastic (left) and perfect elastic-plastic (right) material parameters

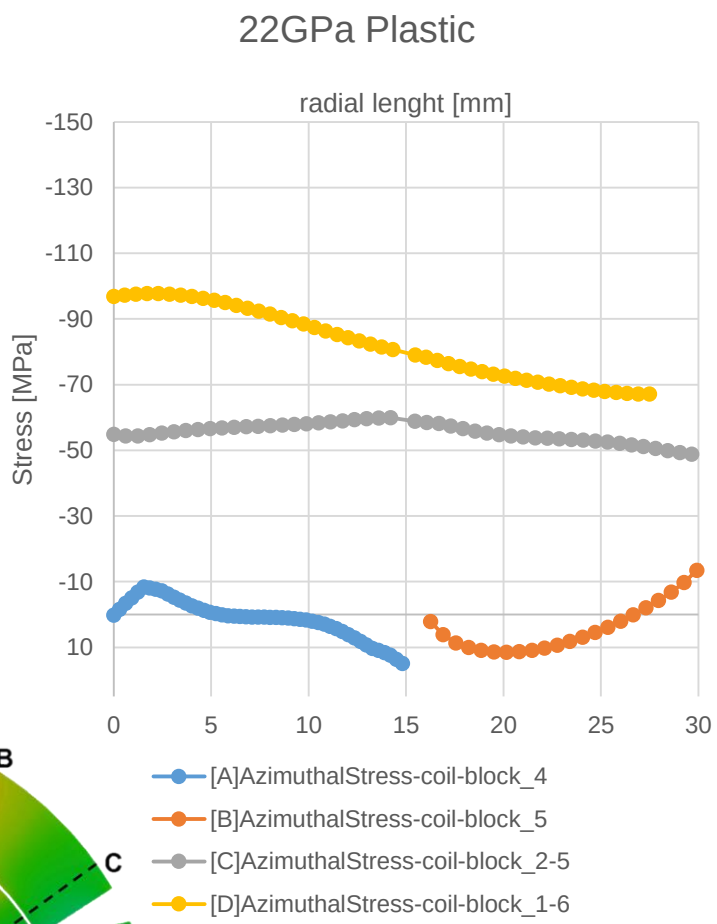


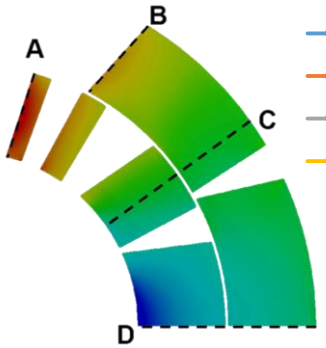


MBHSP102-Excitation to 11T

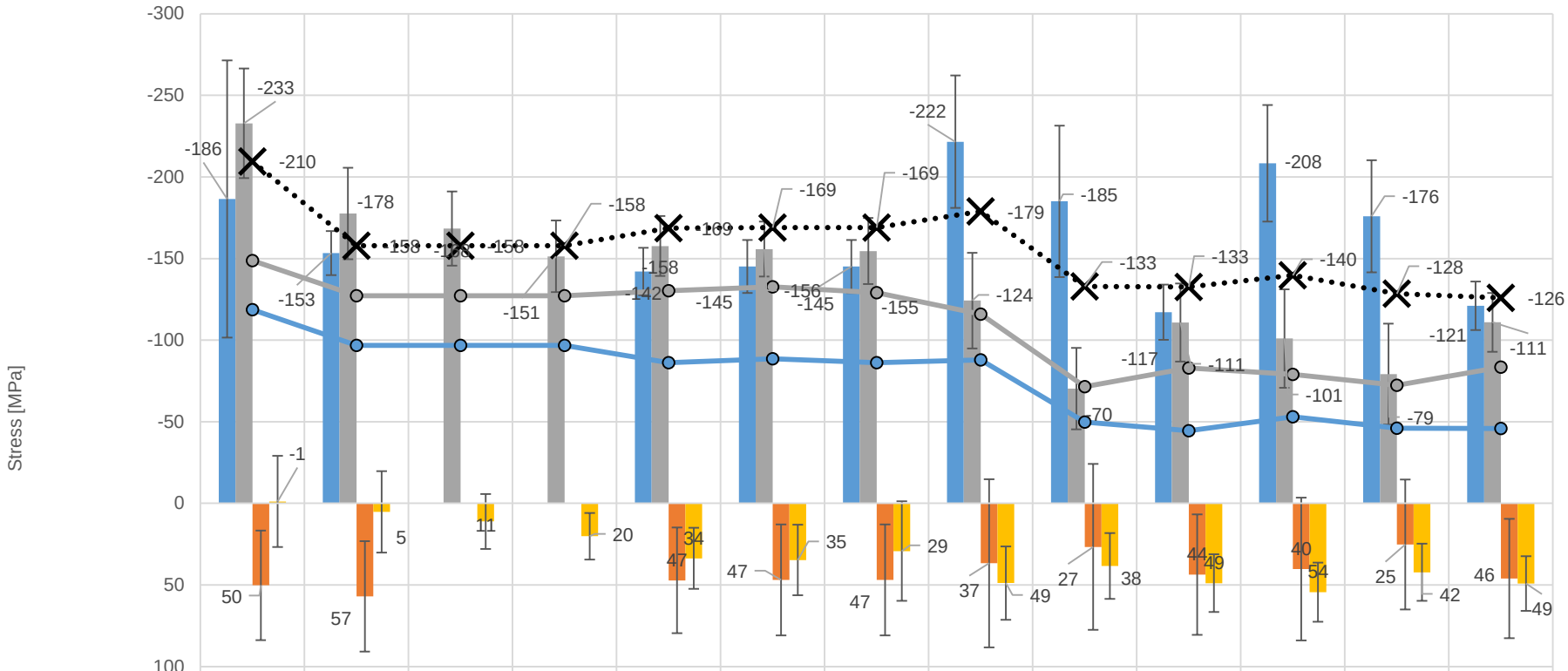
Comparison between perfect elastic and perfect elastic-plastic material parameters







MBHSP101&102 // Stress collar-nose (error +-1 stdev)

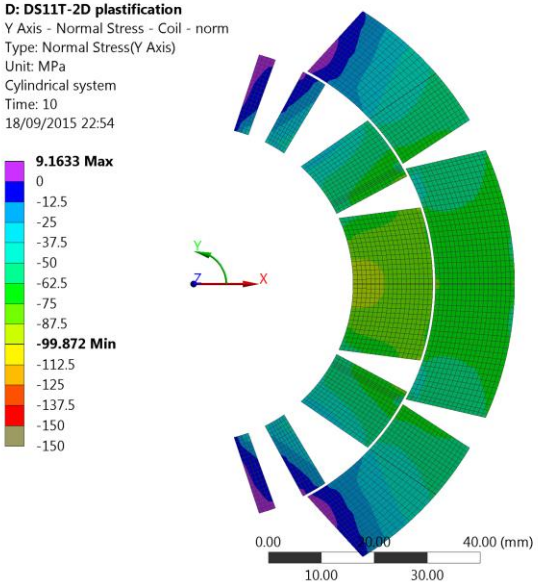


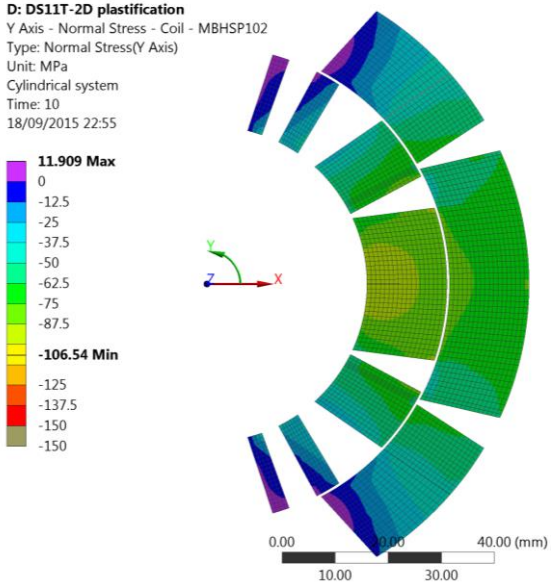
	Collaring - 34MN of force	Collaring - Keys inserted	Check before transport	Welding press - no load	Before shell welding under press	After shell welding	293K at SM18	1.9K	1.9K after Q7	293K	1.9K	1.9K after Q16	293K
AV. Traction 101	-186	-153			-142	-145	-145	-222	-185	-117	-208	-176	-121
AV. Traction 102	-233	-178	-168	-151	-158	-156	-155	-124	-70	-111	-101	-79	-111
AV. Bending 101	50	57			47	47	47	37	27	44	40	25	46
AV. Bending 102	-1	5	11	20	34	35	29	49	38	49	54	42	49
FEM-Traction 33GPa	-210	-158	-158	-158	-169	-169	-169	-179	-133	-133	-140	-128	-126
FEM 101 8-22Gpa	-119	-97	-97	-97	-86	-89	-86	-88	-50	-44	-53	-46	-46
FEM 102 8-22GPa	-149	-127	-127	-127	-130	-133	-129	-116	-71	-83	-79	-72	-83

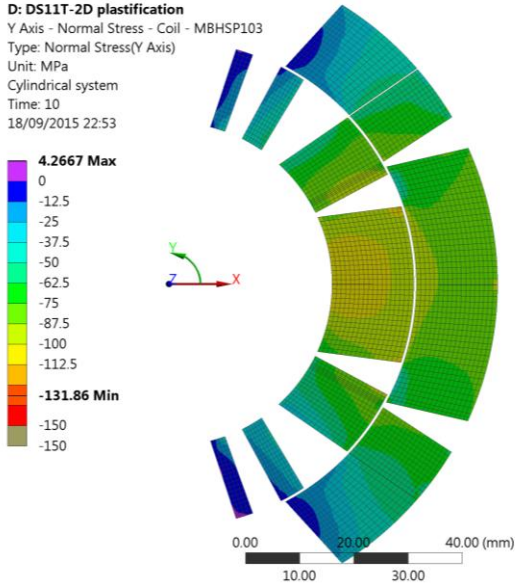
Comparison between perfect elastic and perfect elastic-plastic material parameters

- Applying elastic-plastic parameters on built models

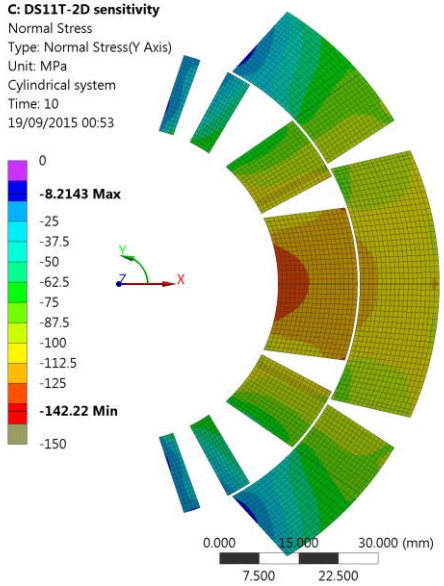
elastic-plastic 8-22GPa

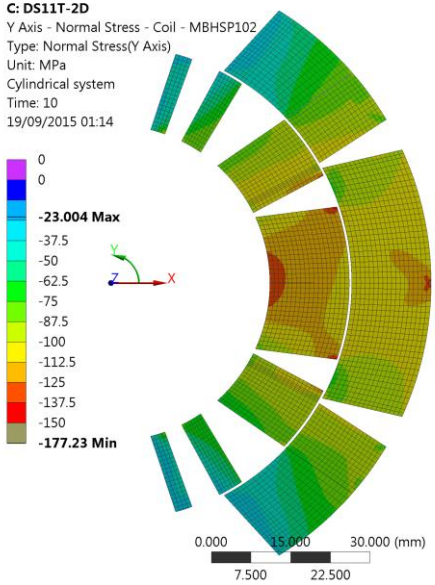


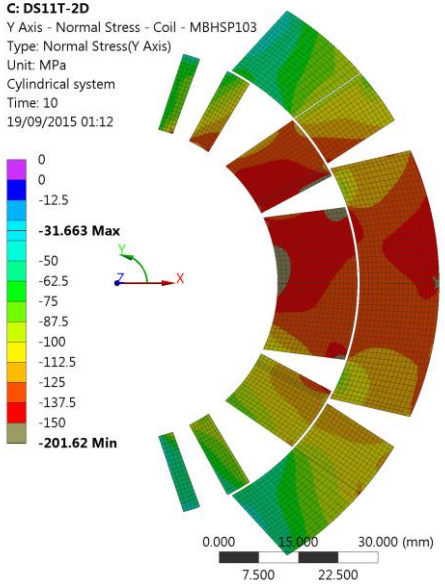




elastic 22GPa







nominal

MBHSP102

MBHSP103

conclusion

- Influence of shimming is more important during excitation then during assembly.
- E-Modulus influences the coil uniformly during assembly. This is no longer true during powering. High impact on the pole turns.
- The coil size after testing corresponds to the FEM-model.
- The behaviour of the previous MBHSP-magnets can be explained with an E-Modulus of 22GPa and elastic-plastic behaviour.

Topics for discussion

- Is a non-linear coil material the only way to simulate impregnated coils correctly?
- How to predict long term cycling fatigue?
- What is the driving factor for the hysteresis behaviour?

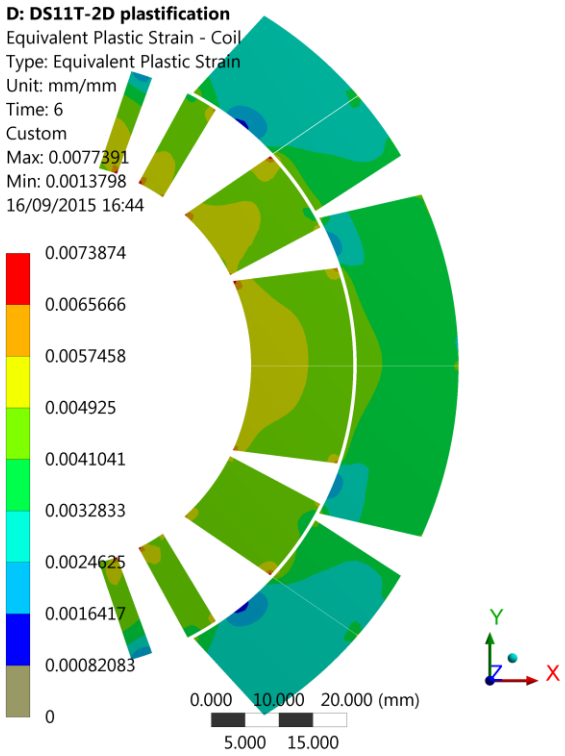
Literature

- **[1] Recent Progress and Tests of Radiation Resistant Impregnation Materials for Nb3Sn Coils** - R. Bossert, S. Krave, G. Ambrosio, N. Andreev, G. Chlachidze, A. Nobrega, I. Novitski, M. Yu and A.V. Zlobin
- **[2] NIOBIUM-TIN MAGNET TECHNOLOGY DEVELOPMENT AT FERMILAB** - D.R. Chichili+, T.T. Arkan, I. Terechkine, Fermilab, Batavia, IL, USA - J.A. Rice, Composite Technology Development Inc., Lafayette, CO, USA
- **[3] D.Del'Orco et al., "Fabrication and Component Testing Results for a Nb3Sn Dipole Magnet"**, IEEE Trans. of Applied - Superconductivity, Vol. 5 (1995).

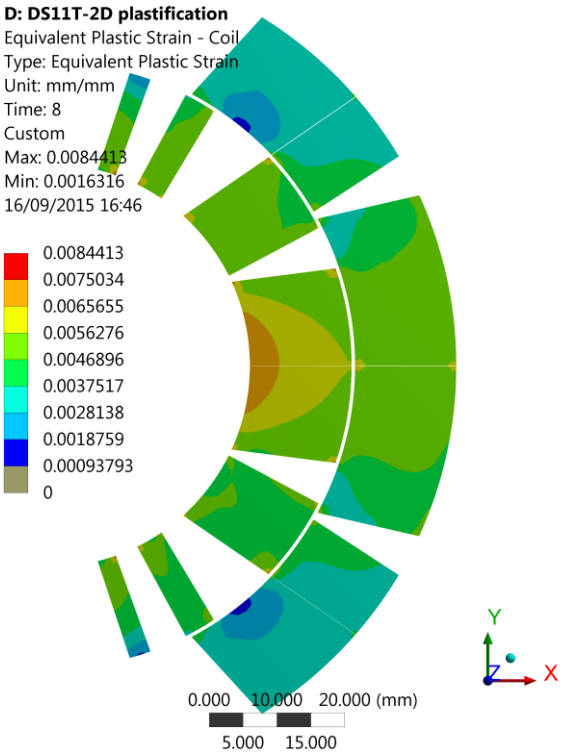

CERN

Back Up

Permanent plastic strain in the coil after excitation

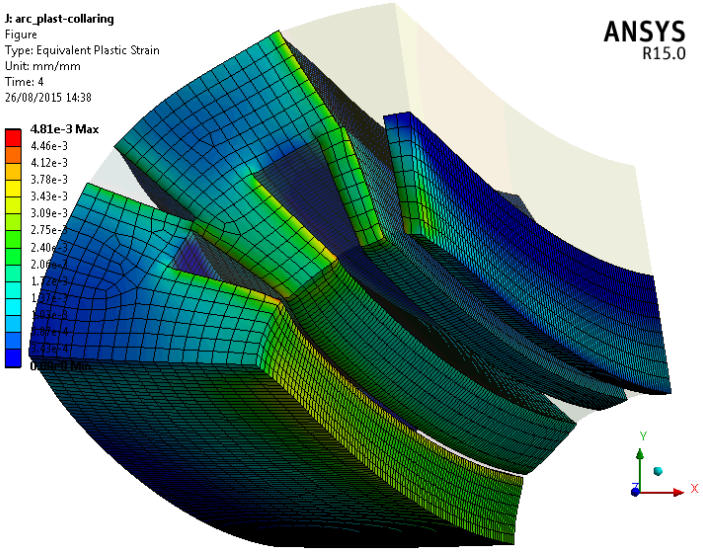


After assembly

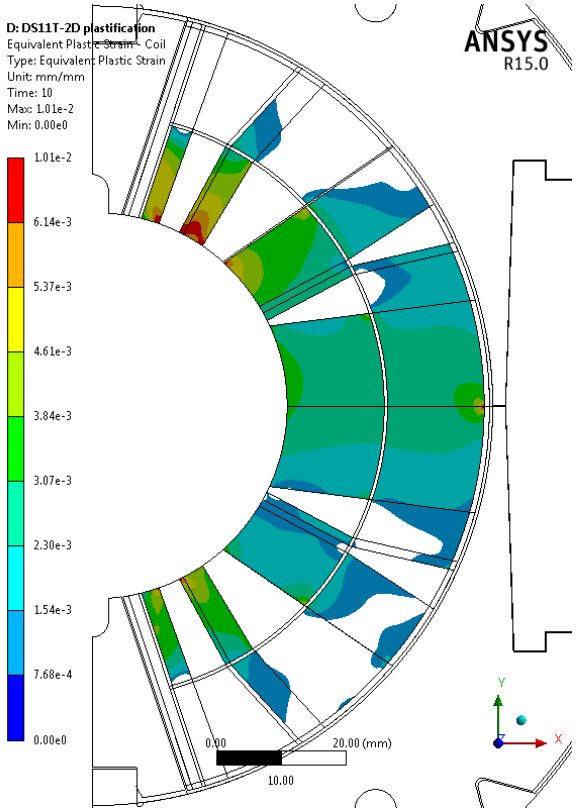


After testing

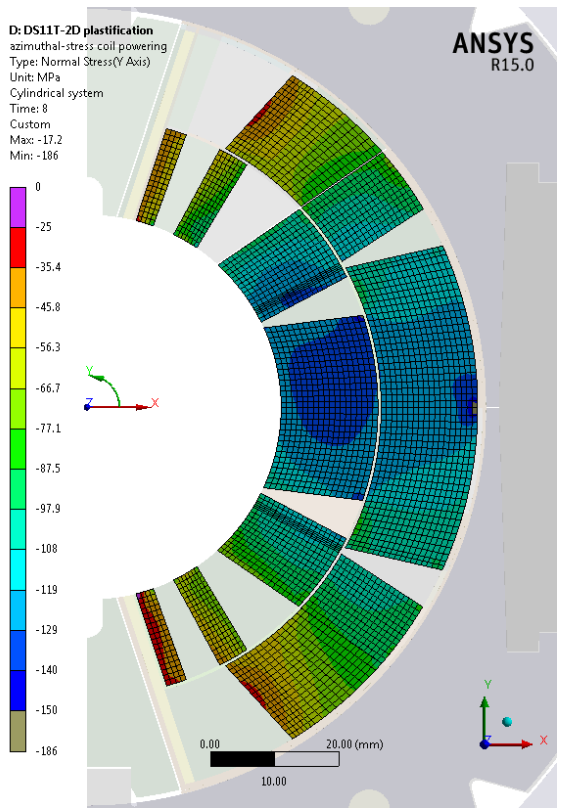
FEM-11T



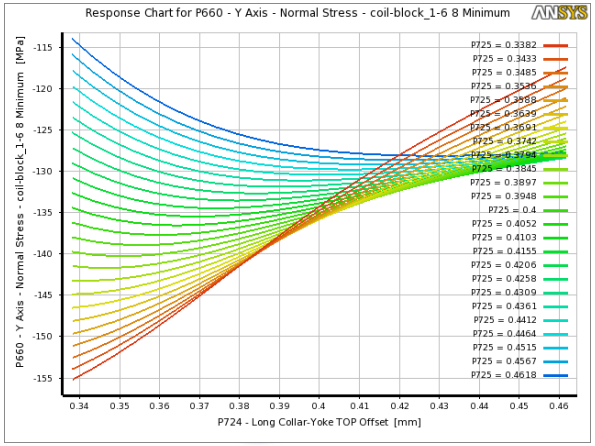
Non-linear material parameters (plast. def.) explain observed behaviour of the coils. Shrinkage and bending after assembly and testing.



Plastification of the conductor blocks after testing

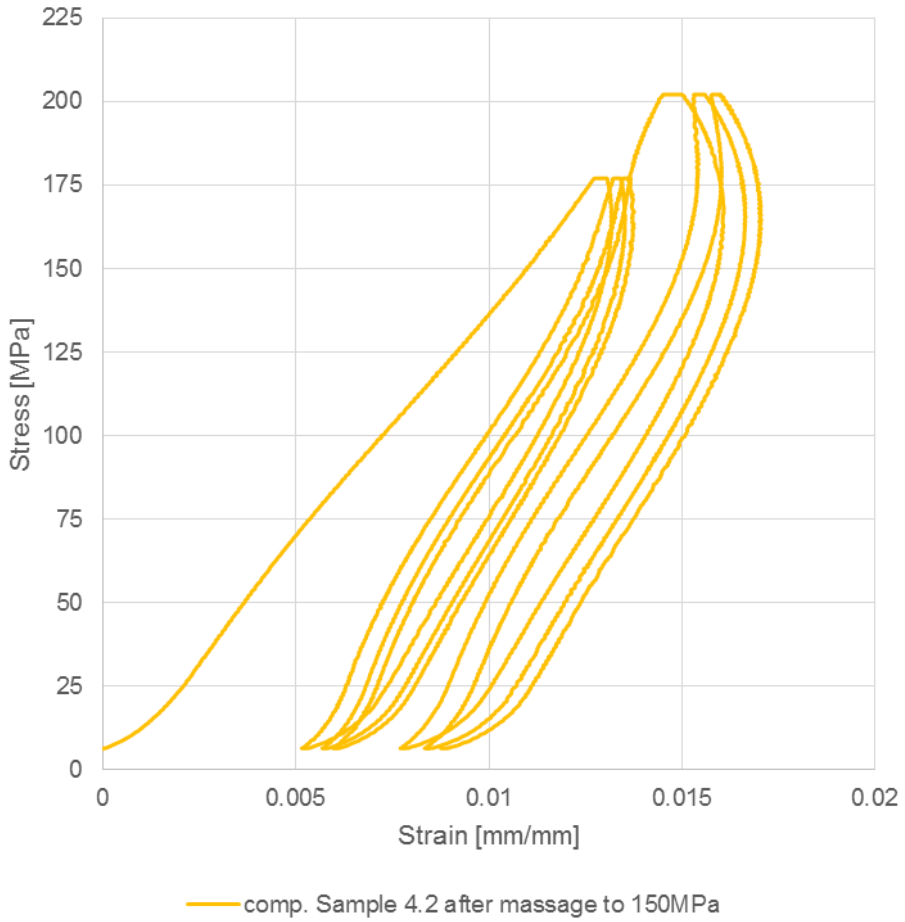


Influence on stress of different coil geometries



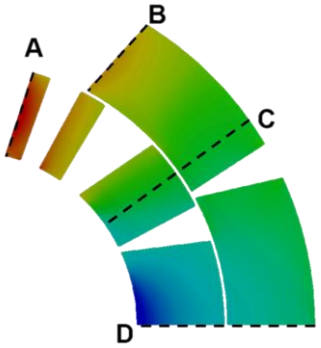
The magnets mechanical response to geometrical changes/ friction is analysed.

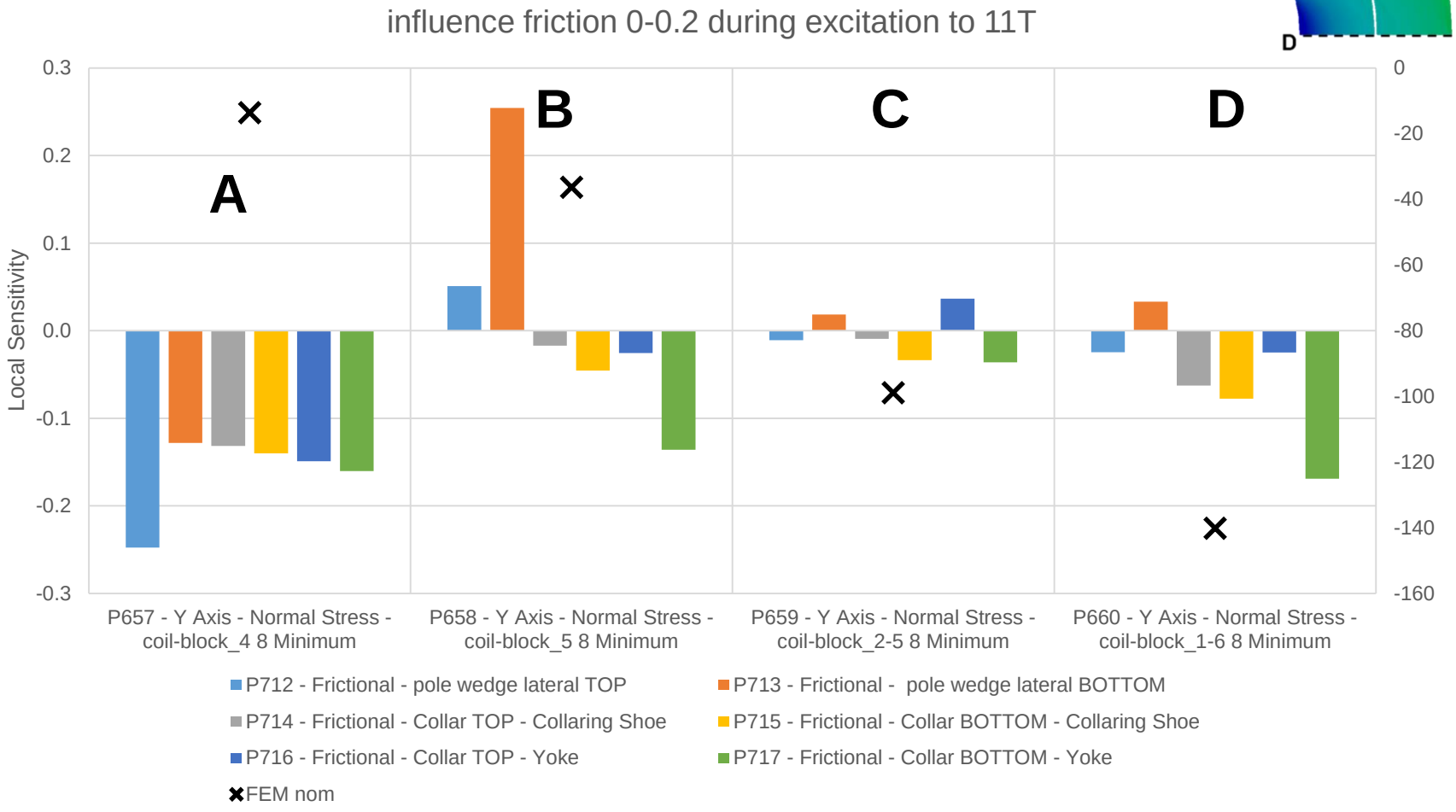
Stress-Strain curve +150MPa



- Increase of strain at stable stress
- Ratcheting due to cycling

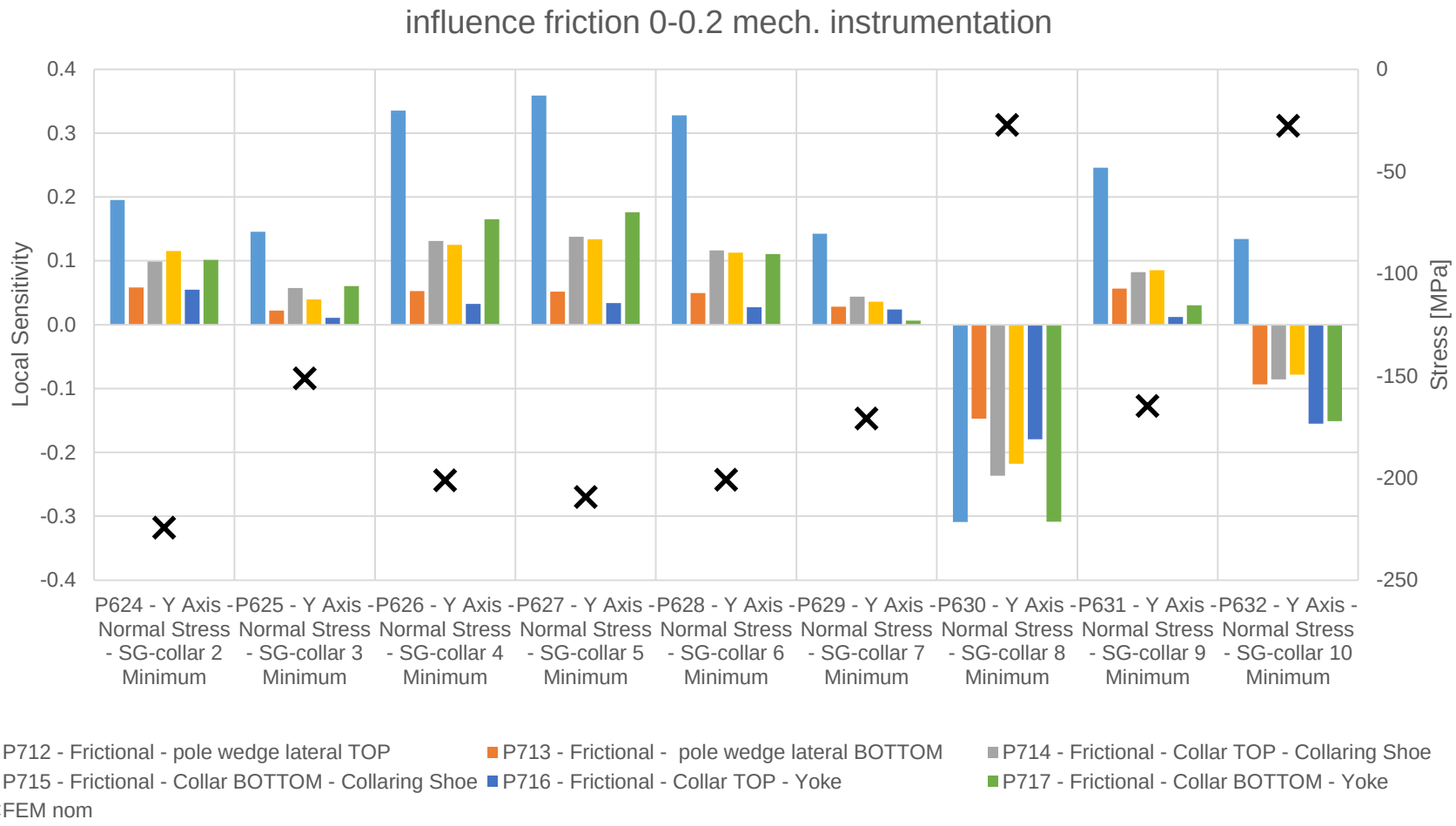
Local sensitivity – max. compression stress



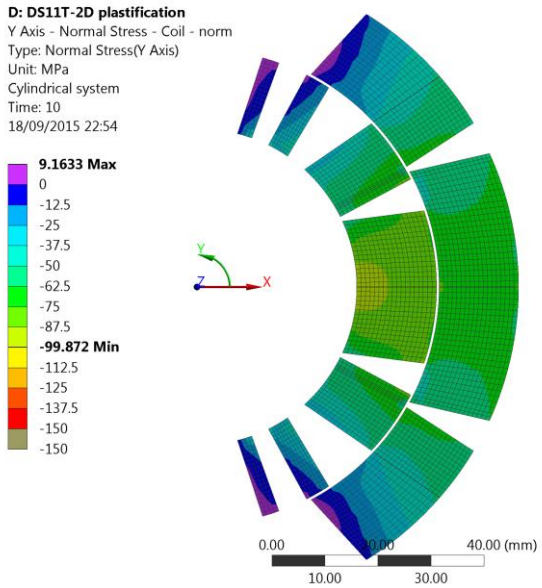


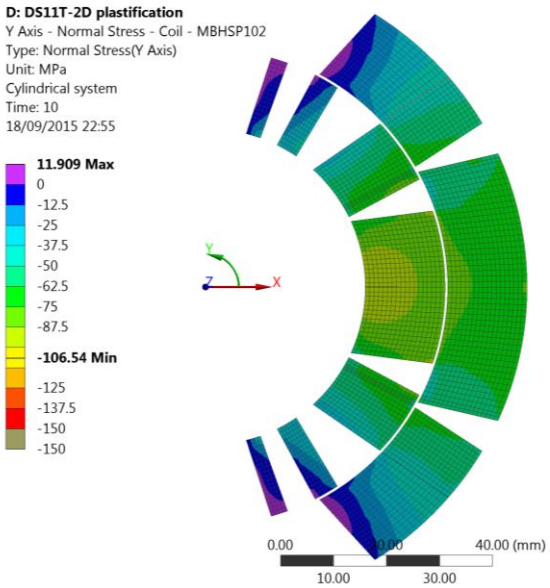
LS = f(input) = Max(OP)-Min(OP)/Avg(OP)
If OP increases while IP increases,
the sign is positive, otherwise its negative.

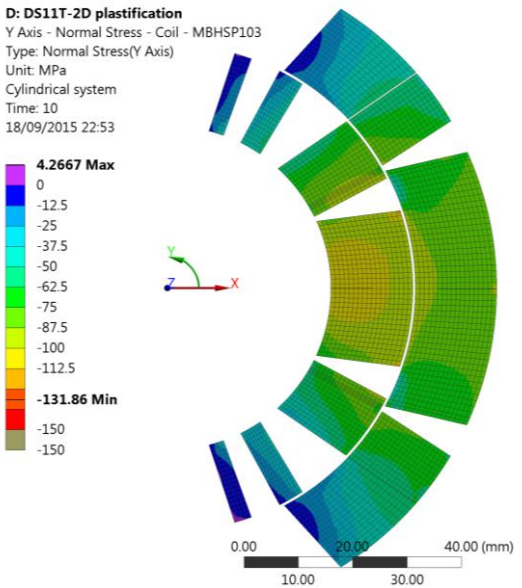
Local sensitivity – max. compression stress

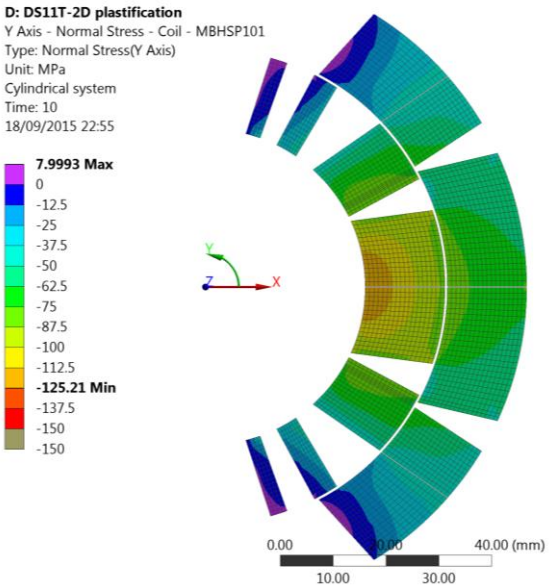


LS = f(input) = Max(OP)-Min(OP)/Avg(OP)
If OP increases while IP increases,
the sign is positive, otherwise its negative.



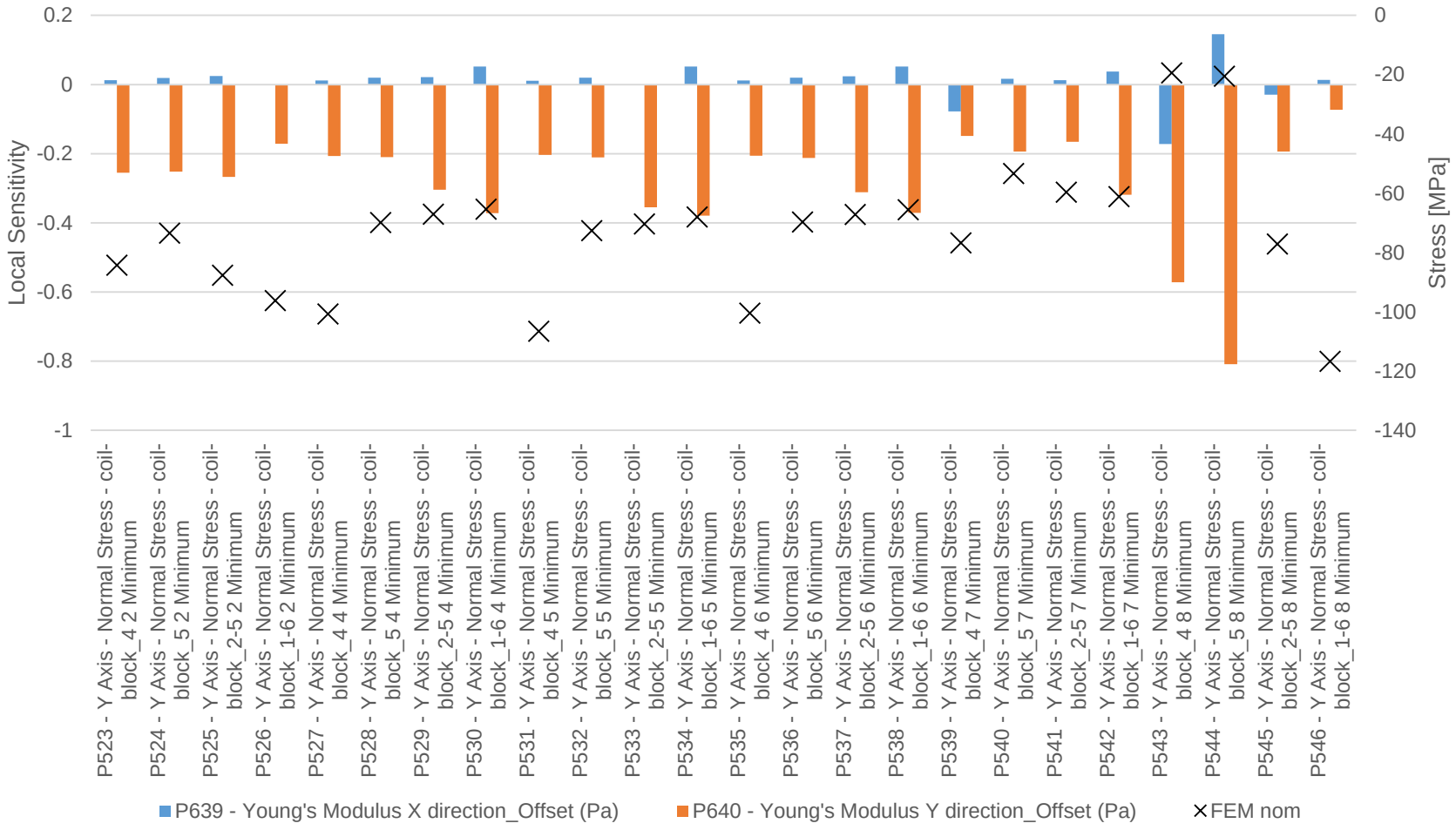




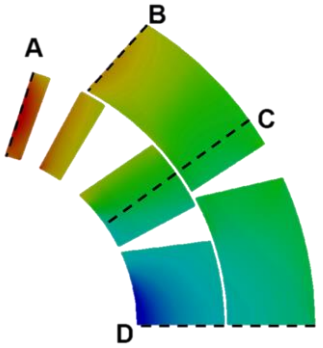


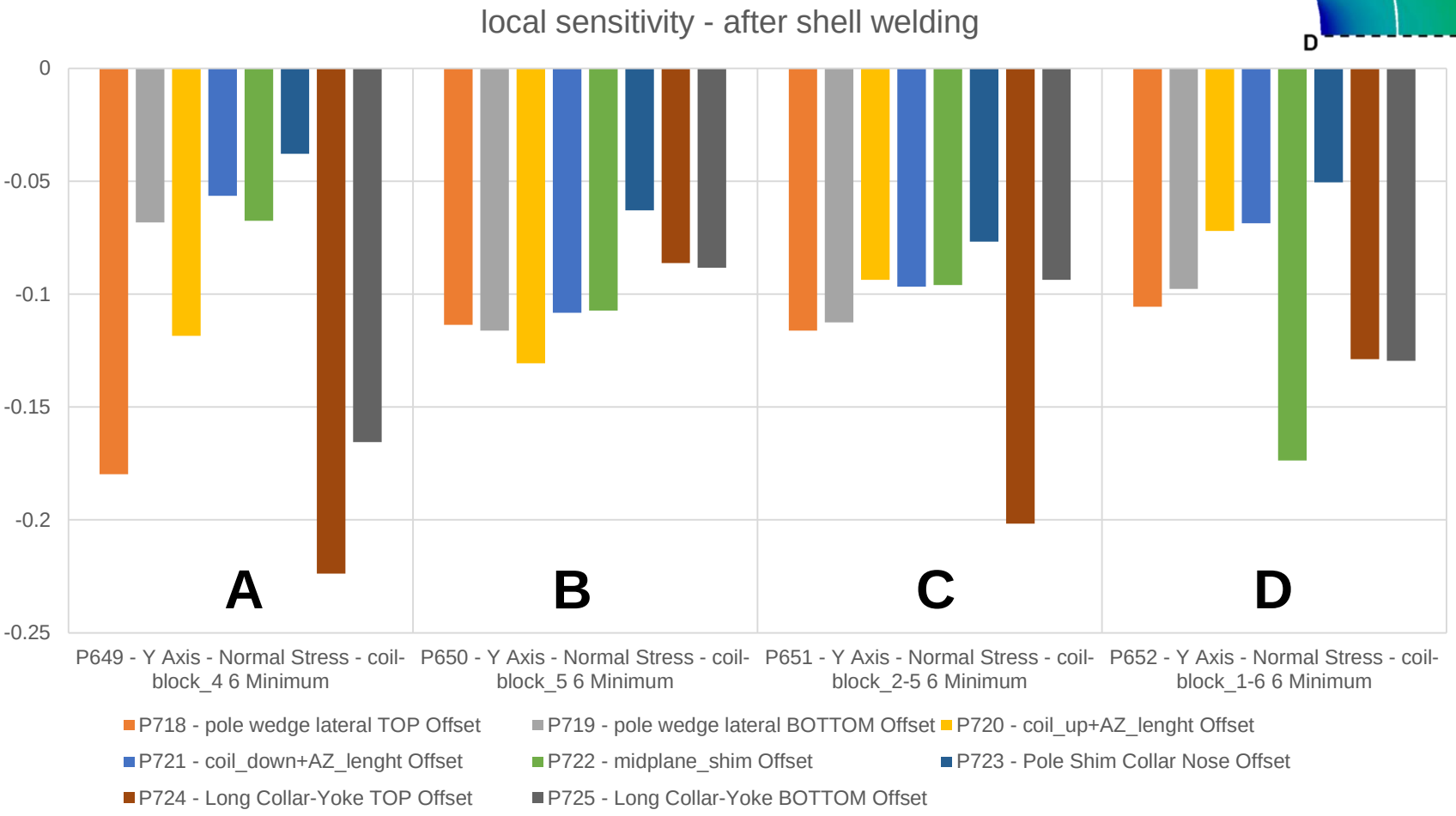
Nominal, MBHSP101,2,3 with 9 to 22GPa coil modulus

Variation Modulus in radial and azimuthal +- 5GPa - coil azimuthal stress

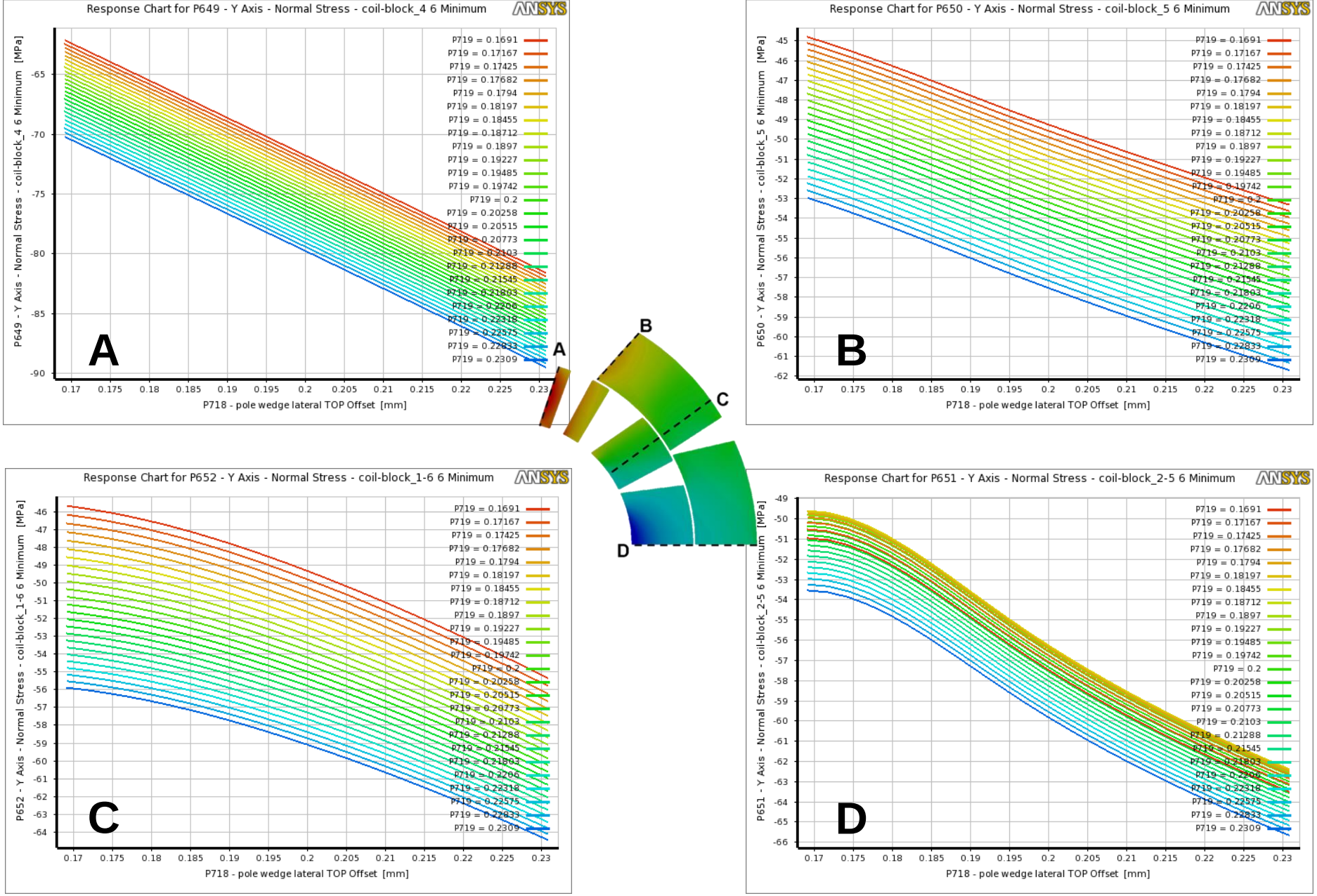


Local sensitivity – max. compression stress

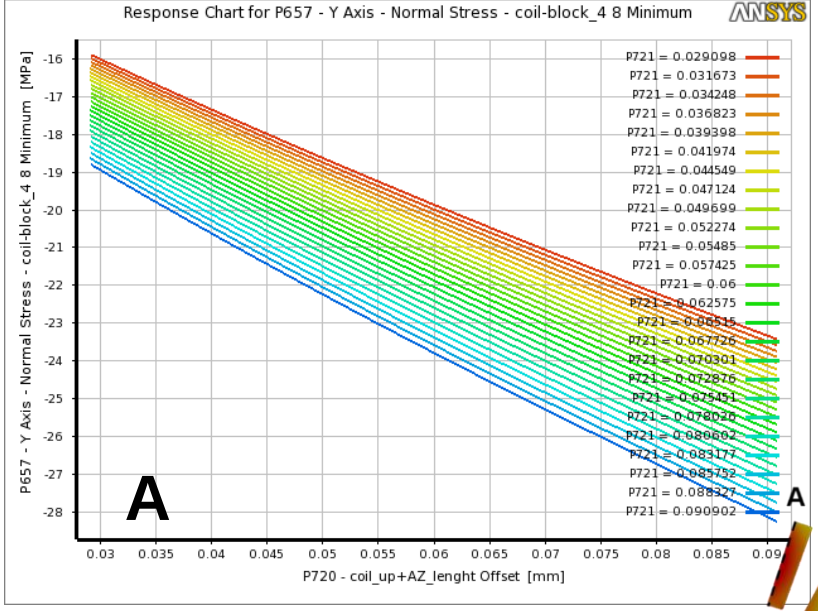


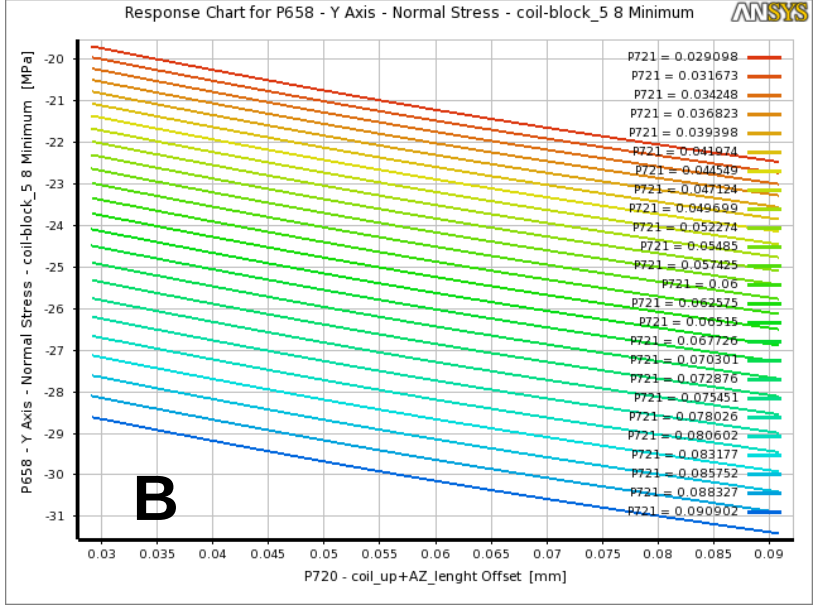


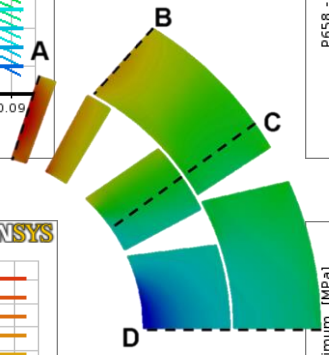
LS = f(input) = Max(OP)-Min(OP)/Avg(OP)
If OP increases while IP increases,
the sign is positive, otherwise its negative.

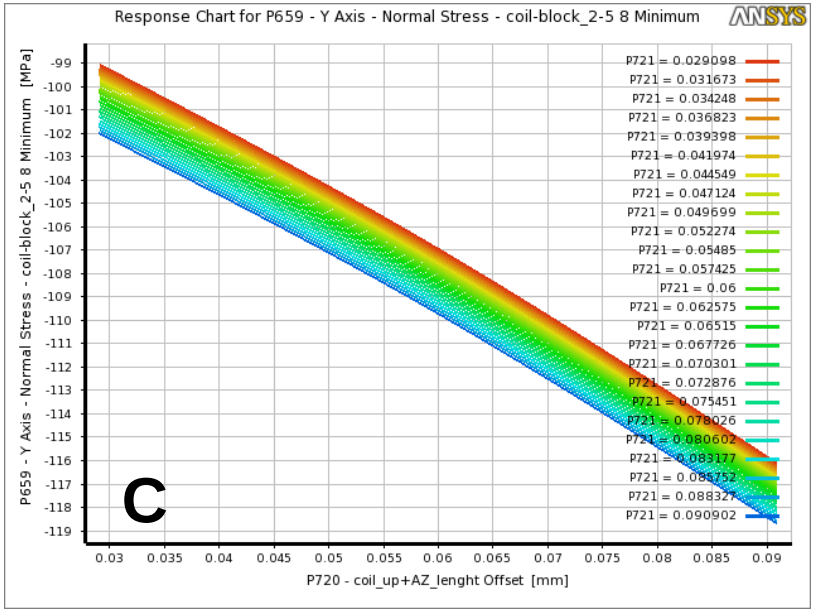


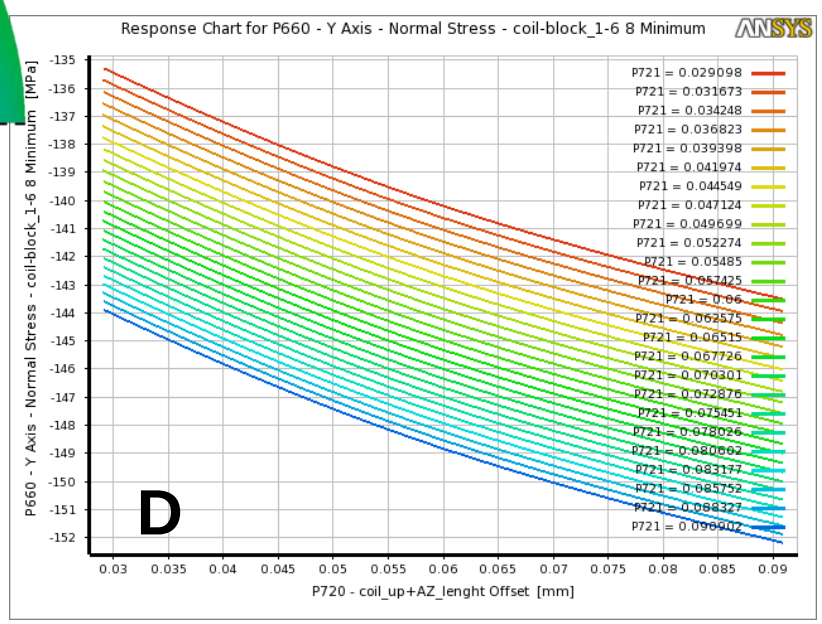
Cold mass at RT – resp. lateral pole shim

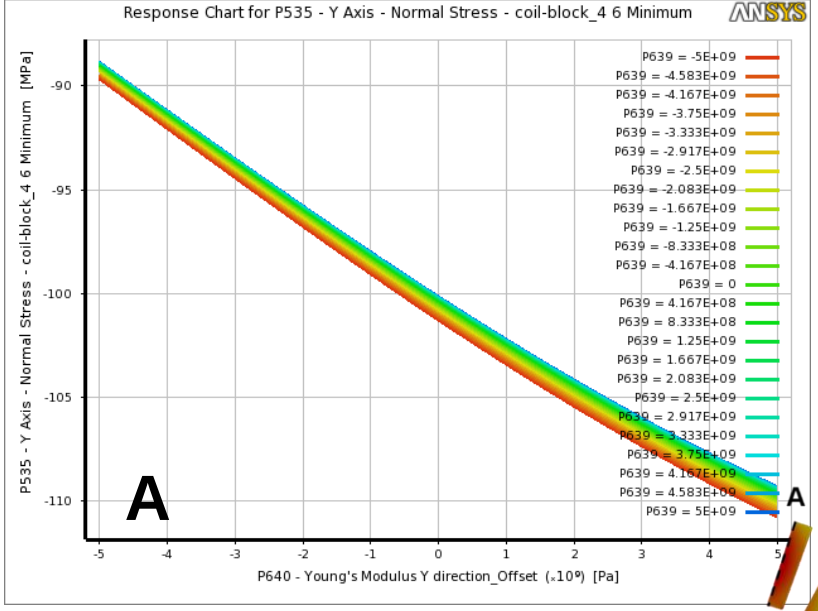

Response Chart for P657 - Y Axis - Normal Stress - coil-block_4 8 Minimum
ANSYS
P657 - Y Axis - Normal Stress - coil-block_4 8 Minimum [MPa]
P720 - coil_up+AZ_lenght Offset [mm]
P721 = 0.029098
P721 = 0.031673
P721 = 0.034248
P721 = 0.036823
P721 = 0.039398
P721 = 0.041974
P721 = 0.044549
P721 = 0.047124
P721 = 0.049699
P721 = 0.052274
P721 = 0.05485
P721 = 0.057425
P721 = 0.06
P721 = 0.062575
P721 = 0.06515
P721 = 0.067726
P721 = 0.070301
P721 = 0.072876
P721 = 0.075451
P721 = 0.078026
P721 = 0.080602
P721 = 0.083177
P721 = 0.085752
P721 = 0.088327
P721 = 0.090902
A

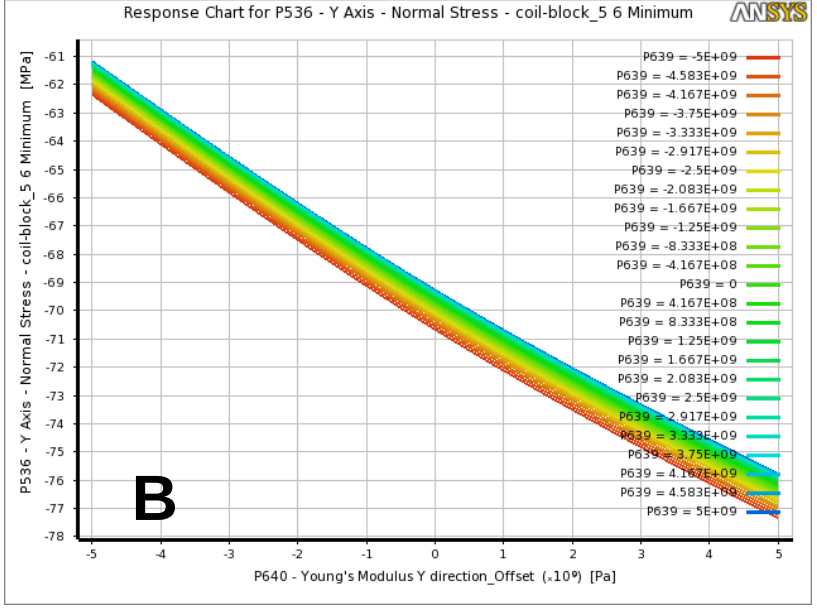

Response Chart for P658 - Y Axis - Normal Stress - coil-block_5 8 Minimum
ANSYS
P658 - Y Axis - Normal Stress - coil-block_5 8 Minimum [MPa]
P720 - coil_up+AZ_lenght Offset [mm]
P721 = 0.029098
P721 = 0.031673
P721 = 0.034248
P721 = 0.036823
P721 = 0.039398
P721 = 0.041974
P721 = 0.044549
P721 = 0.047124
P721 = 0.049699
P721 = 0.052274
P721 = 0.05485
P721 = 0.057425
P721 = 0.06
P721 = 0.062575
P721 = 0.06515
P721 = 0.067726
P721 = 0.070301
P721 = 0.072876
P721 = 0.075451
P721 = 0.078026
P721 = 0.080602
P721 = 0.083177
P721 = 0.085752
P721 = 0.088327
P721 = 0.090902
B

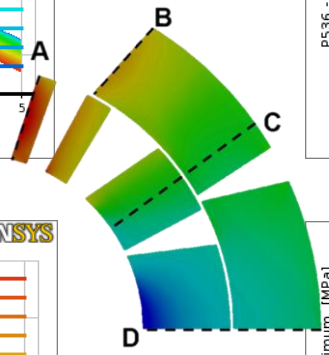

A
B
C
D

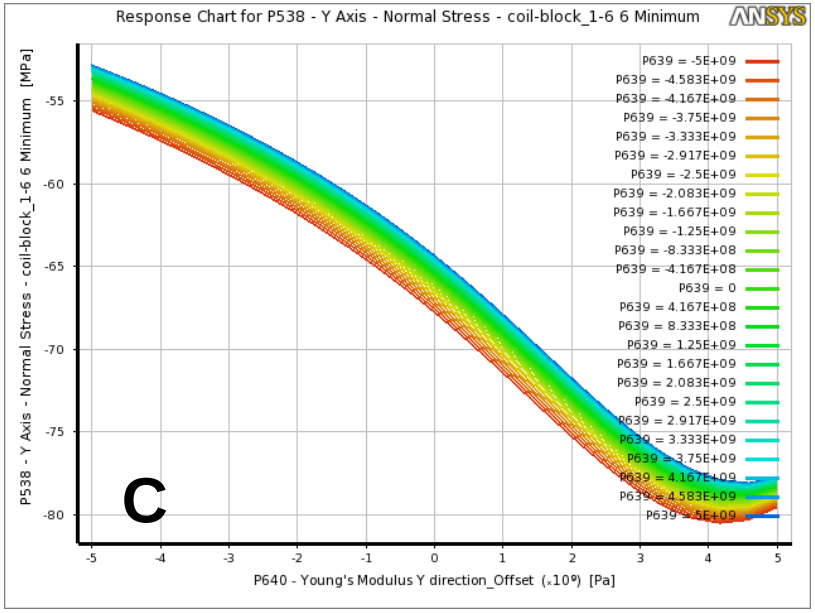

Response Chart for P659 - Y Axis - Normal Stress - coil-block_2-5 8 Minimum
ANSYS
P659 - Y Axis - Normal Stress - coil-block_2-5 8 Minimum [MPa]
P720 - coil_up+AZ_lenght Offset [mm]
P721 = 0.029098
P721 = 0.031673
P721 = 0.034248
P721 = 0.036823
P721 = 0.039398
P721 = 0.041974
P721 = 0.044549
P721 = 0.047124
P721 = 0.049699
P721 = 0.052274
P721 = 0.05485
P721 = 0.057425
P721 = 0.06
P721 = 0.062575
P721 = 0.06515
P721 = 0.067726
P721 = 0.070301
P721 = 0.072876
P721 = 0.075451
P721 = 0.078026
P721 = 0.080602
P721 = 0.083177
P721 = 0.085752
P721 = 0.088327
P721 = 0.090902
C

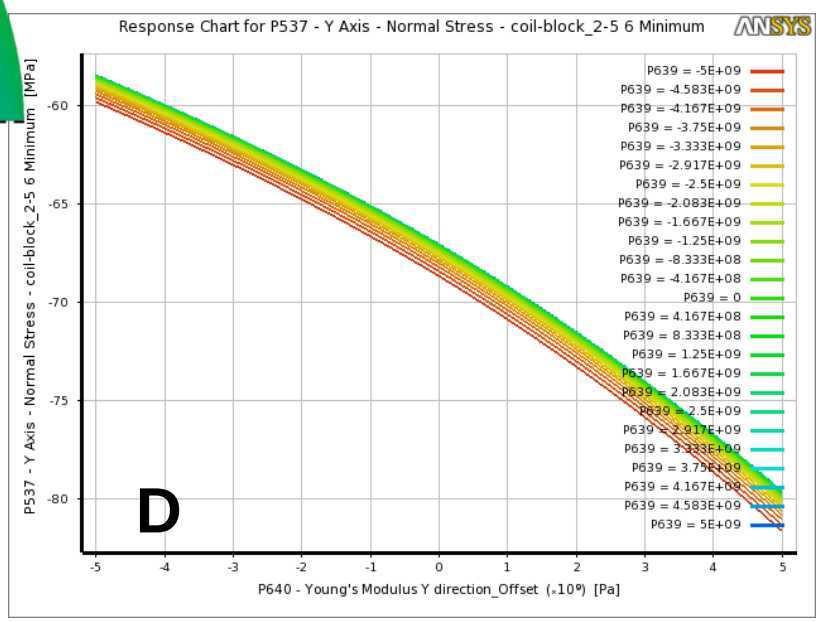

Response Chart for P660 - Y Axis - Normal Stress - coil-block_1-6 8 Minimum
ANSYS
P660 - Y Axis - Normal Stress - coil-block_1-6 8 Minimum [MPa]
P720 - coil_up+AZ_lenght Offset [mm]
P721 = 0.029098
P721 = 0.031673
P721 = 0.034248
P721 = 0.036823
P721 = 0.039398
P721 = 0.041974
P721 = 0.044549
P721 = 0.047124
P721 = 0.049699
P721 = 0.052274
P721 = 0.05485
P721 = 0.057425
P721 = 0.06
P721 = 0.062575
P721 = 0.06515
P721 = 0.067726
P721 = 0.070301
P721 = 0.072876
P721 = 0.075451
P721 = 0.078026
P721 = 0.080602
P721 = 0.083177
P721 = 0.085752
P721 = 0.088327
P721 = 0.090902
D





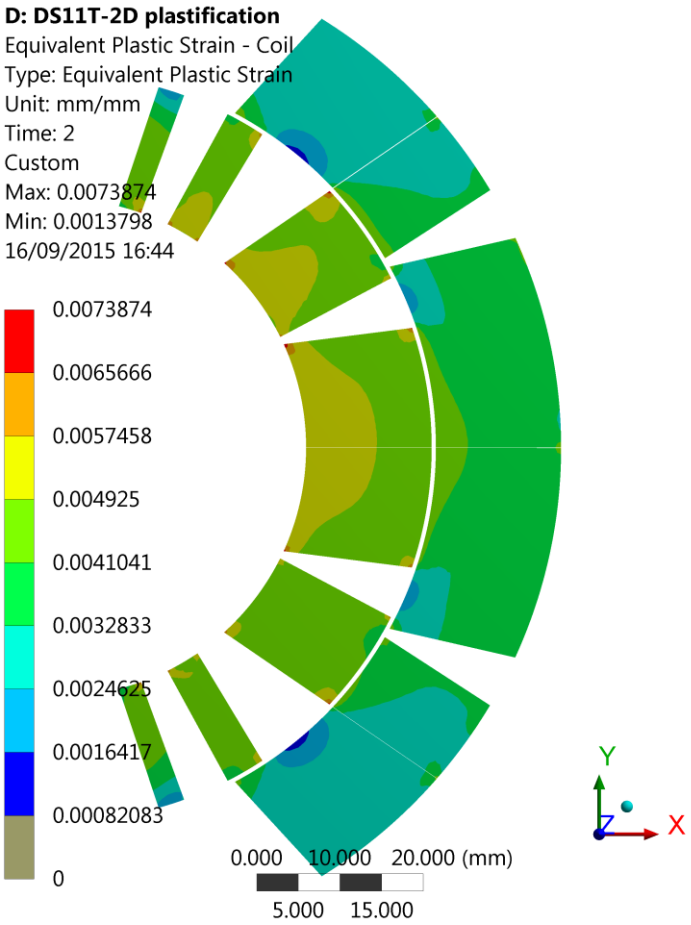


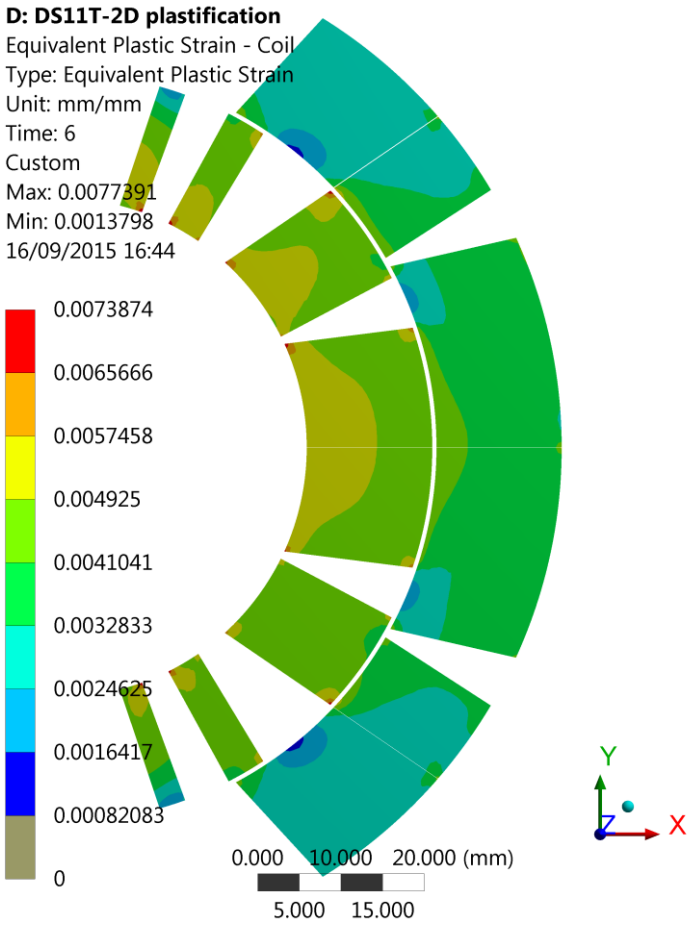




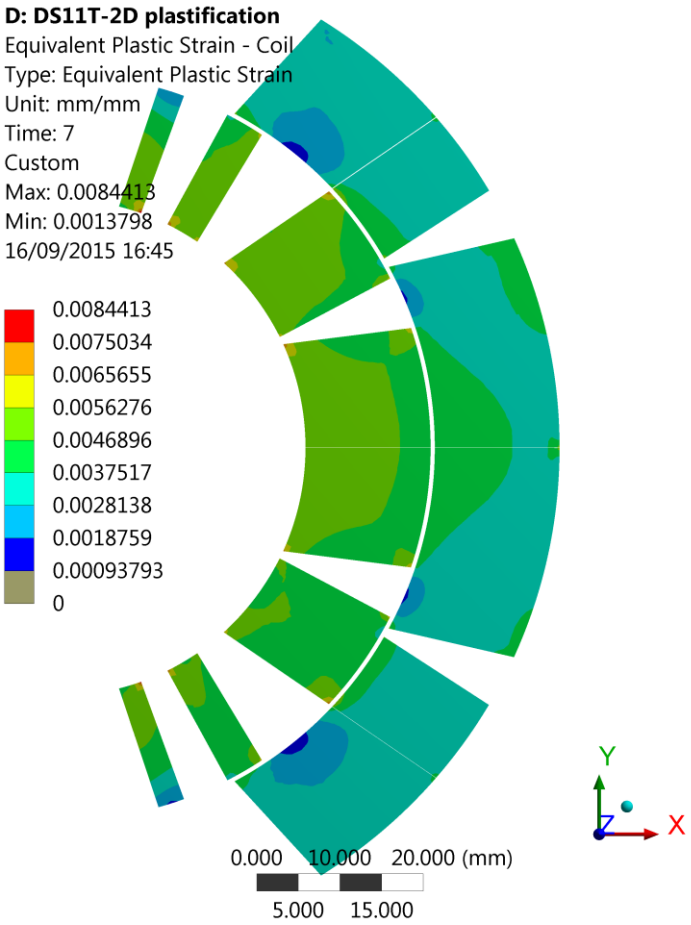
Cold mass at RT – X/Y elastic modulus coil

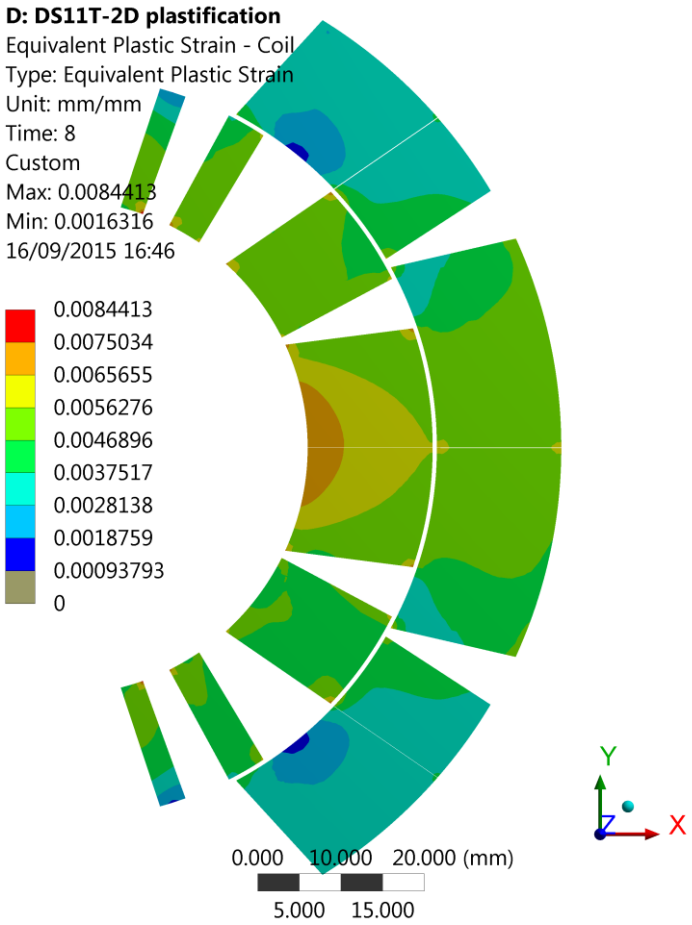
Plast. during assembly





Plast. during assembly





# Linear Correlation Matrix - friction	P712 - Frictional - pole wedge lateral TOP	P713 - Frictional - pole wedge lateral BOTTOM	P714 - Frictional - Collar TOP - Collaring Shoe	P715 - Frictional - Collar BOTTOM - Collaring Shoe	P716 - Frictional - Collar TOP - Yoke	P717 - Frictional - Collar BOTTOM - Yoke	P633 - Azimuthal Stress coil-block_4 2 Minimum	P634 - Azimuthal Stress coil-block_5 2 Minimum	P635 - Azimuthal Stress coil-block_2-5 2 Minimum	P636 - Azimuthal Stress coil-block_1-6 2 Minimum	P649 - Azimuthal Stress coil-block_4 6 Minimum	P650 - Azimuthal Stress coil-block_5 6 Minimum	P651 - Azimuthal Stress coil-block_2-5 6 Minimum	P652 - Azimuthal Stress coil-block_1-6 6 Minimum	P653 - Azimuthal Stress coil-block_4 7 Minimum	P654 - Azimuthal Stress coil-block_5 7 Minimum	P655 - Azimuthal Stress coil-block_2-5 7 Minimum	P656 - Azimuthal Stress coil-block_1-6 7 Minimum	P657 - Azimuthal Stress coil-block_4 8 Minimum	P658 - Azimuthal Stress coil-block_5 8 Minimum	P659 - Azimuthal Stress coil-block_2-5 8 Minimum	P660 - Azimuthal Stress coil-block_1-6 8 Minimum	P670 - Azimuthal Stress coil-block_4 8 Maximum
P712 - Frictional - pole wedge lateral TOP	1.00	0.01	0.03	-0.05	0.02	-0.04	0.12	0.44	0.69	-0.05	-0.44	0.45	-0.24	-0.41	0.01	-0.26	0.18	-0.36	-0.08	0.54	-0.24	0.09	0.40
P713 - Frictional - pole wedge lateral BOTTOM	0.01	1.00	-0.01	0.01	0.00	-0.01	0.04	-0.02	-0.04	0.05	-0.39	-0.30	-0.34	0.00	-0.26	-0.13	-0.14	0.11	-0.29	-0.10	0.06	0.04	-0.27
P714 - Frictional - Collar TOP - Collaring Shoe	0.03	-0.01	1.00	-0.01	-0.03	0.01	-0.62	-0.49	-0.10	0.58	0.52	0.24	0.51	0.48	0.63	0.41	0.30	0.55	0.44	0.28	0.26	0.02	0.29
P715 - Frictional - Collar BOTTOM - Collaring Shoe	-0.05	0.01	-0.01	1.00	0.00	0.02	0.71	0.63	-0.02	0.62	-0.16	-0.73	-0.51	0.64	-0.43	-0.69	-0.56	0.55	-0.53	-0.56	-0.38	-0.31	-0.63
P716 - Frictional - Collar TOP - Yoke	0.02	0.00	-0.03	0.00	1.00	-0.01	-0.03	-0.08	0.05	0.08	0.01	0.17	0.18	-0.06	0.21	0.15	0.49	0.05	0.11	0.13	0.64	0.40	-0.06
P717 - Frictional - Collar BOTTOM - Yoke	-0.04	-0.01	0.01	0.02	-0.01	1.00	-0.04	-0.08	-0.04	-0.19	0.05	-0.08	-0.11	0.24	-0.16	-0.21	-0.20	0.16	-0.23	-0.19	-0.26	-0.20	0.19
P633 - Azimuthal Stress coil-block_4 2 Minimum	0.12	0.04	-0.62	0.71	-0.03	-0.04	1.00	0.89	0.21	0.10	-0.53	-0.63	-0.74	0.09	-0.70	-0.82	-0.57	0.00	-0.70	-0.49	-0.50	-0.19	-0.62
P634 - Azimuthal Stress coil-block_5 2 Minimum	0.44	-0.02	-0.49	0.63	-0.08	-0.08	0.89	1.00	0.53	0.16	-0.65	-0.38	-0.70	-0.07	-0.60	-0.77	-0.44	-0.13	-0.65	-0.22	-0.55	-0.13	-0.39
P635 - Azimuthal Stress coil-block_2-5 2 Minimum	0.69	-0.04	-0.10	-0.02	0.05	-0.04	0.21	0.53	1.00	0.04	-0.43	0.34	-0.09	-0.32	0.01	-0.13	0.20	-0.25	0.01	0.48	-0.20	0.27	0.27
P636 - Azimuthal Stress coil-block_1-6 2 Minimum	-0.05	0.05	0.58	0.62	0.08	-0.19	0.10	0.16	0.04	1.00	0.11	-0.34	0.04	0.61	0.13	-0.12	-0.07	0.61	-0.04	-0.16	0.04	-0.06	-0.33
P649 - Azimuthal Stress coil-block_4 6 Minimum	-0.44	-0.39	0.52	-0.16	0.01	0.05	-0.53	-0.65	-0.43	0.11	1.00	0.27	0.71	0.47	0.65	0.54	0.26	0.45	0.61	0.07	0.27	-0.05	0.30
P650 - Azimuthal Stress coil-block_5 6 Minimum	0.45	-0.30	0.24	-0.73	0.17	-0.08	-0.63	-0.38	0.34	-0.34	0.27	1.00	0.62	-0.51	0.70	0.63	0.78	-0.38	0.65	0.87	0.37	0.42	0.77
P651 - Azimuthal Stress coil-block_2-5 6 Minimum	-0.24	-0.34	0.51	-0.51	0.18	-0.11	-0.74	-0.70	-0.09	0.04	0.71	0.62	1.00	0.00	0.87	0.91	0.72	0.14	0.84	0.53	0.62	0.42	0.38
P652 - Azimuthal Stress coil-block_1-6 6 Minimum	-0.41	0.00	0.48	0.64	-0.06	0.24	0.09	-0.07	-0.32	0.61	0.47	-0.51	0.00	1.00	0.04	-0.20	-0.36	0.92	-0.06	-0.48	-0.13	-0.33	-0.28
P653 - Azimuthal Stress coil-block_4 7 Minimum	0.01	-0.26	0.63	-0.43	0.21	-0.16	-0.70	-0.60	0.01	0.13	0.65	0.70	0.87	0.04	1.00	0.78	0.79	0.21	0.79	0.69	0.60	0.47	0.45
P654 - Azimuthal Stress coil-block_5 7 Minimum	-0.26	-0.13	0.41	-0.69	0.15	-0.21	-0.82	-0.77	-0.13	-0.12	0.54	0.63	0.91	-0.20	0.78	1.00	0.74	-0.02	0.81	0.56	0.70	0.48	0.36
P655 - Azimuthal Stress coil-block_2-5 7 Minimum	0.18	-0.14	0.30	-0.56	0.49	-0.20	-0.57	-0.44	0.20	-0.07	0.26	0.78	0.72	-0.36	0.79	0.74	1.00	-0.12	0.60	0.83	0.78	0.76	0.36
P656 - Azimuthal Stress coil-block_1-6 7 Minimum	-0.36	0.11	0.55	0.55	0.05	0.16	0.00	-0.13	-0.25	0.61	0.45	-0.38	0.14	0.92	0.21	-0.02	-0.12	1.00	0.03	-0.26	0.12	-0.03	-0.35
P657 - Azimuthal Stress coil-block_4 8 Minimum	-0.08	-0.29	0.44	-0.53	0.11	-0.23	-0.70	-0.65	0.01	-0.04	0.61	0.65	0.84	-0.06	0.79	0.81	0.60	0.03	1.00	0.55	0.47	0.26	0.54
P658 - Azimuthal Stress coil-block_5 8 Minimum	0.54	-0.10	0.28	-0.56	0.13	-0.19	-0.49	-0.22	0.48	-0.16	0.07	0.87	0.53	-0.48	0.69	0.56	0.83	-0.26	0.55	1.00	0.41	0.63	0.53
P659 - Azimuthal Stress coil-block_2-5 8 Minimum	-0.24	0.06	0.26	-0.38	0.64	-0.26	-0.50	-0.55	-0.20	0.04	0.27	0.37	0.62	-0.13	0.60	0.70	0.78	0.12	0.47	0.41	1.00	0.67	-0.06
P660 - Azimuthal Stress coil-block_1-6 8 Minimum	0.09	0.04	0.02	-0.31	0.40	-0.20	-0.19	-0.13	0.27	-0.06	-0.05	0.42	0.42	-0.33	0.47	0.48	0.76	-0.03	0.26	0.63	0.67	1.00	-0.08
P670 - Azimuthal Stress coil-block_4 8 Maximum	0.40	-0.27	0.29	-0.63	-0.06	0.19	-0.62	-0.39	0.27	-0.33	0.30	0.77	0.38	-0.28	0.45	0.36	0.36	-0.35	0.54	0.53	-0.06	-0.08	1.00

Linear Correlation Matrix - offset

	P718 - pole wedge lateral TOP Offset	P719 - pole wedge lateral BOTTOM Offset	P720 - coil_up+AZ_lenght Offset	P721 - coil_down+AZ_lenght Offset	P722 - midplane_shim Offset	P723 - Pole Shim Collar Nose Offset	P724 - Long Collar-Yoke TOP Offset	P725 - Long Collar-Yoke BOTTOM Offset	P633 - Azimuthal Stress coil-block_4 2 Minimum	P634 - Azimuthal Stress coil-block_5 2 Minimum	P635 - Azimuthal Stress coil-block_2-5 2 Minimum	P636 - Azimuthal Stress coil-block_1-6 2 Minimum	P649 - Azimuthal Stress coil-block_4 6 Minimum	P650 - Azimuthal Stress coil-block_5 6 Minimum	P651 - Azimuthal Stress coil-block_2-5 6 Minimum	P652 - Azimuthal Stress coil-block_1-6 6 Minimum	P653 - Azimuthal Stress coil-block_4 7 Minimum	P654 - Azimuthal Stress coil-block_5 7 Minimum	P655 - Azimuthal Stress coil-block_2-5 7 Minimum	P656 - Azimuthal Stress coil-block_1-6 7 Minimum	P657 - Azimuthal Stress coil-block_4 8 Minimum	P658 - Azimuthal Stress coil-block_5 8 Minimum	P659 - Azimuthal Stress coil-block_2-5 8 Minimum	P660 - Azimuthal Stress coil-block_1-6 8 Minimum	P670 - Azimuthal Stress coil-block_4 8 Maximum
P718 - pole wedge lateral TOP Offset	1.00	0.01	0.03	-0.04	0.03	-0.04	-0.08	-0.07	-0.66	-0.44	-0.50	-0.42	-0.38	-0.35	-0.30	-0.26	-0.38	-0.25	-0.42	-0.28	-0.38	-0.19	-0.35	-0.26	-0.39
P719 - pole wedge lateral BOTTOM Offset	0.01	1.00	-0.01	0.00	0.00	-0.03	-0.01	0.04	-0.22	-0.35	-0.10	-0.31	-0.21	-0.40	-0.29	-0.26	-0.22	-0.53	-0.22	-0.27	-0.22	-0.58	-0.11	-0.14	-0.19
P720 - coil_up+AZ_lenght Offset	0.03	-0.01	1.00	0.01	-0.02	-0.02	0.00	-0.03	-0.51	-0.50	-0.67	-0.44	-0.33	-0.45	-0.34	-0.18	-0.35	-0.28	-0.56	-0.17	-0.36	-0.16	-0.46	-0.28	-0.33
P721 - coil_down+AZ_lenght Offset	-0.04	0.00	0.01	1.00	-0.01	0.03	0.03	-0.02	-0.28	-0.40	-0.22	-0.43	-0.18	-0.37	-0.23	-0.25	-0.20	-0.46	-0.23	-0.25	-0.19	-0.45	-0.15	-0.27	-0.18
P722 - midplane_shim Offset	0.03	0.00	-0.02	-0.01	1.00	-0.01	-0.04	0.04	-0.40	-0.43	-0.39	-0.54	-0.13	-0.34	-0.23	-0.57	-0.17	-0.35	-0.34	-0.56	-0.15	-0.43	-0.31	-0.54	-0.14
P723 - Pole Shim Collar Nose Offset	-0.04	-0.03	-0.02	0.03	-0.01	1.00	0.00	0.03	-0.07	-0.21	-0.27	-0.15	-0.10	-0.19	-0.21	-0.13	-0.15	-0.18	-0.25	-0.15	-0.25	-0.16	-0.15	-0.08	-0.22
P724 - Long Collar-Yoke TOP Offset	-0.08	-0.01	0.00	0.03	-0.04	0.00	1.00	-0.03	0.09	0.07	0.06	0.07	-0.54	-0.22	-0.50	-0.27	-0.46	-0.17	0.05	-0.26	-0.54	0.08	0.64	0.36	-0.55
P725 - Long Collar-Yoke BOTTOM Offset	-0.07	0.04	-0.03	-0.02	0.04	0.03	-0.03	1.00	0.02	0.00	0.02	0.00	-0.44	-0.31	-0.28	-0.43	-0.49	-0.21	-0.25	-0.41	-0.31	0.11	-0.28	0.30	-0.39
P633 - Azimuthal Stress coil-block_4 2 Minimum	-0.66	-0.22	-0.51	-0.28	-0.40	-0.07	0.09	0.02	1.00	0.94	0.94	0.93	0.57	0.82	0.61	0.63	0.61	0.73	0.85	0.65	0.62	0.66	0.70	0.65	0.58
P634 - Azimuthal Stress coil-block_5 2 Minimum	-0.44	-0.35	-0.50	-0.40	-0.43	-0.21	0.07	0.00	0.94	1.00	0.92	0.98	0.56	0.88	0.65	0.68	0.61	0.85	0.87	0.70	0.62	0.80	0.68	0.68	0.58
P635 - Azimuthal Stress coil-block_2-5 2 Minimum	-0.50	-0.10	-0.67	-0.22	-0.39	-0.27	0.06	0.02	0.94	0.92	1.00	0.90	0.55	0.80	0.62	0.59	0.60	0.67	0.88	0.61	0.63	0.59	0.71	0.64	0.59
P636 - Azimuthal Stress coil-block_1-6 2 Minimum	-0.42	-0.31	-0.44	-0.43	-0.54	-0.15	0.07	0.00	0.93	0.98	0.90	1.00	0.53	0.87	0.63	0.72	0.58	0.84	0.84	0.73	0.59	0.81	0.66	0.72	0.55
P649 - Azimuthal Stress coil-block_4 6 Minimum	-0.38	-0.21	-0.33	-0.18	-0.13	-0.10	-0.54	-0.44	0.57	0.56	0.55	0.53	1.00	0.83	0.88	0.81	0.99	0.65	0.64	0.81	0.95	0.26	0.17	-0.06	0.98
P650 - Azimuthal Stress coil-block_5 6 Minimum	-0.35	-0.40	-0.45	-0.37	-0.34	-0.19	-0.22	-0.31	0.82	0.88	0.80	0.87	0.83	1.00	0.85	0.84	0.86	0.92	0.85	0.84	0.85	0.69	0.51	0.39	0.84
P651 - Azimuthal Stress coil-block_2-5 6 Minimum	-0.30	-0.29	-0.34	-0.23	-0.23	-0.21	-0.50	-0.28	0.61	0.65	0.62	0.63	0.88	0.85	1.00	0.75	0.87	0.77	0.77	0.75	0.91	0.44	0.23	0.15	0.89
P652 - Azimuthal Stress coil-block_1-6 6 Minimum	-0.26	-0.26	-0.18	-0.25	-0.57	-0.13	-0.27	-0.43	0.63	0.68	0.59	0.72	0.81	0.84	0.75	1.00	0.84	0.71	0.65	1.00	0.77	0.44	0.35	0.17	0.79
P653 - Azimuthal Stress coil-block_4 7 Minimum	-0.38	-0.22	-0.35	-0.20	-0.17	-0.15	-0.46	-0.49	0.61	0.61	0.60	0.58	0.99	0.86	0.87	0.84	1.00	0.69	0.69	0.84	0.95	0.30	0.26	-0.01	0.98
P654 - Azimuthal Stress coil-block_5 7 Minimum	-0.25	-0.53	-0.28	-0.46	-0.35	-0.18	-0.17	-0.21	0.73	0.85	0.67	0.84	0.65	0.92	0.77	0.71	0.69	1.00	0.76	0.71	0.70	0.84	0.46	0.52	0.66
P655 - Azimuthal Stress coil-block_2-5 7 Minimum	-0.42	-0.22	-0.56	-0.23	-0.34	-0.25	0.05	-0.25	0.85	0.87	0.88	0.84	0.64	0.85	0.77	0.65	0.69	0.76	1.00	0.65	0.69	0.58	0.76	0.54	0.65
P656 - Azimuthal Stress coil-block_1-6 7 Minimum	-0.28	-0.27	-0.17	-0.25	-0.56	-0.15	-0.26	-0.41	0.65	0.70	0.61	0.73	0.81	0.84	0.75	1.00	0.84	0.71	0.65	1.00	0.78	0.46	0.35	0.17	0.80
P657 - Azimuthal Stress coil-block_4 8 Minimum	-0.38	-0.22	-0.36	-0.19	-0.15	-0.25	-0.54	-0.31	0.62	0.62	0.63	0.59	0.95	0.85	0.91	0.77	0.95	0.70	0.69	0.78	1.00	0.33	0.19	0.03	0.96
P658 - Azimuthal Stress coil-block_5 8 Minimum	-0.19	-0.58	-0.16	-0.45	-0.43	-0.16	0.08	0.11	0.66	0.80	0.59	0.81	0.26	0.69	0.44	0.44	0.30	0.84	0.58	0.46	0.33	1.00	0.44	0.75	0.29
P659 - Azimuthal Stress coil-block_2-5 8 Minimum	-0.35	-0.11	-0.46	-0.15	-0.31	-0.15	0.64	-0.28	0.70	0.68	0.71	0.66	0.17	0.51	0.23	0.35	0.26	0.46	0.76	0.35	0.19	0.44	1.00	0.62	0.17
P660 - Azimuthal Stress coil-block_1-6 8 Minimum	-0.26	-0.14	-0.28	-0.27	-0.54	-0.08	0.36	0.30	0.65	0.68	0.64	0.72	-0.06	0.39	0.15	0.17	-0.01	0.52	0.54	0.17	0.03	0.75	0.62	1.00	-0.02
P670 - Azimuthal Stress coil-block_4 8 Maximum	-0.39	-0.19	-0.33	-0.18	-0.14	-0.22	-0.55	-0.39	0.58	0.58	0.59	0.55	0.98	0.84	0.89	0.79	0.98	0.66	0.65	0.80	0.96	0.29	0.17	-0.02	1.00