16 T COSθ DIPOLE MECHANICAL ANALYSIS

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ON BEHALF OF INFN TEAM:
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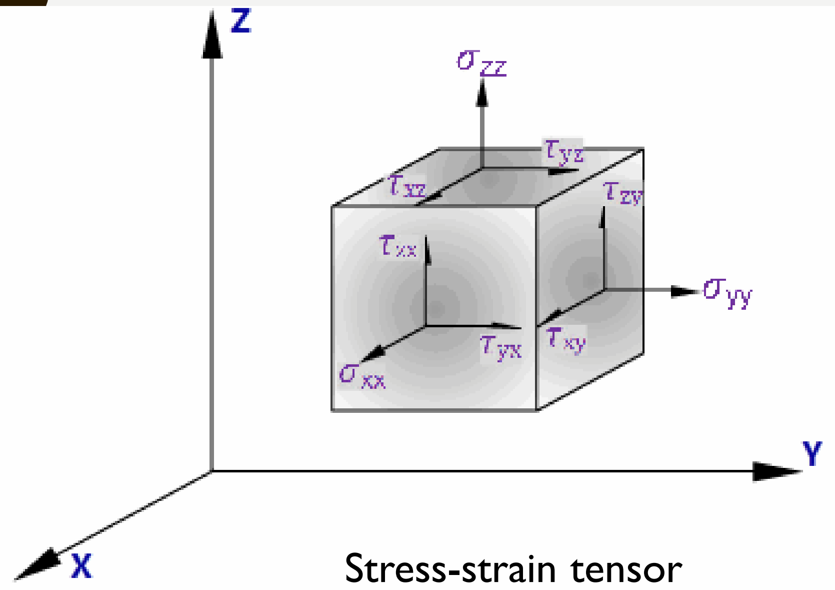
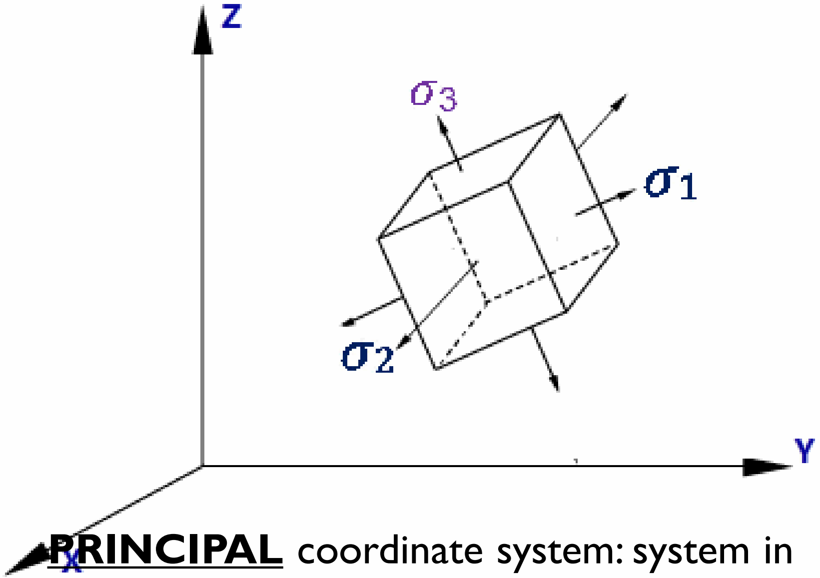
OVERVIEW

- Principal stresses and failure criteria
- 2D model: plain strain vs plain stress
- 2D mechanical optimization
- Cosθ 2D models:
- CONFIGURATION I – vertical cut
- CONFIGURATION II – horizontal cut
- CONFIGURATION III – hybrid
- CONCLUSIONS

PRINCIPAL STRESSES



Stress-strain tensor
In cartesian coordinate system



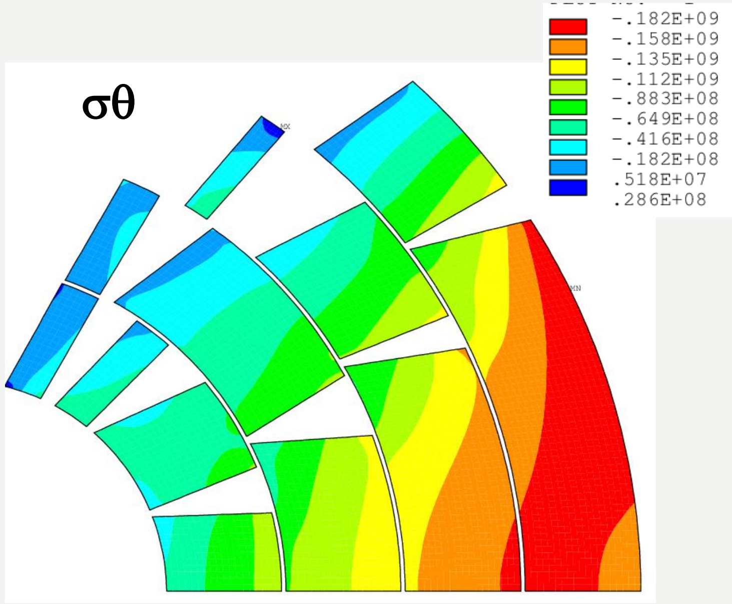
PRINCIPAL coordinate system: system in which the SS tensor is **DIAGONAL**

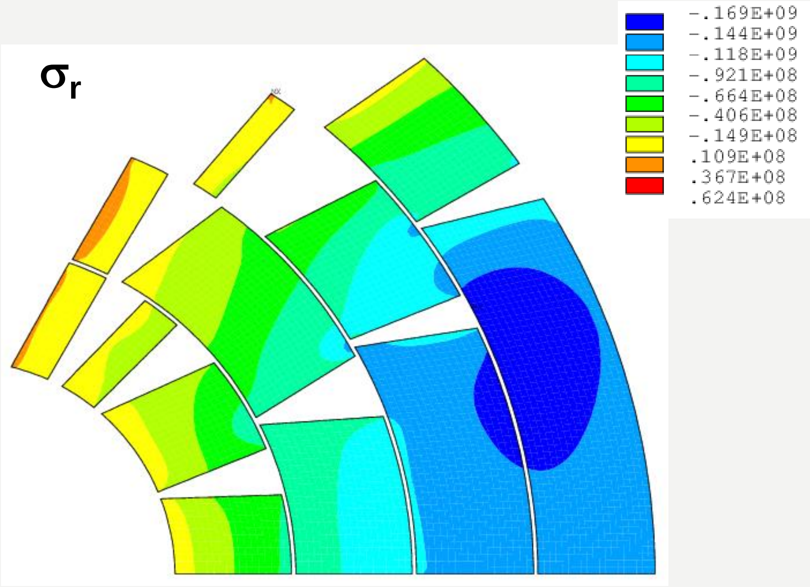
$$\sigma = \begin{Bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{Bmatrix} = \begin{Bmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{Bmatrix}$$

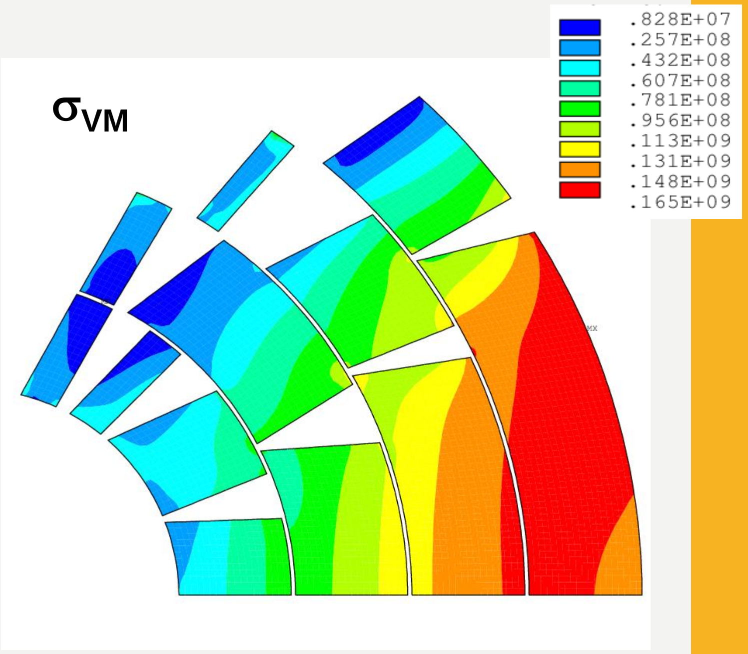
- The principal stress σ1, σ2 and σ3, defined for each single element, are those in which the stress-strain tensor is diagonal ($\sigma 3 < \sigma 2 < \sigma 1$).
- σ3 ~ σx in block coil geometry
- σ3 ~ σθ in cosθ geometry
- Von Mises stress is defined as:

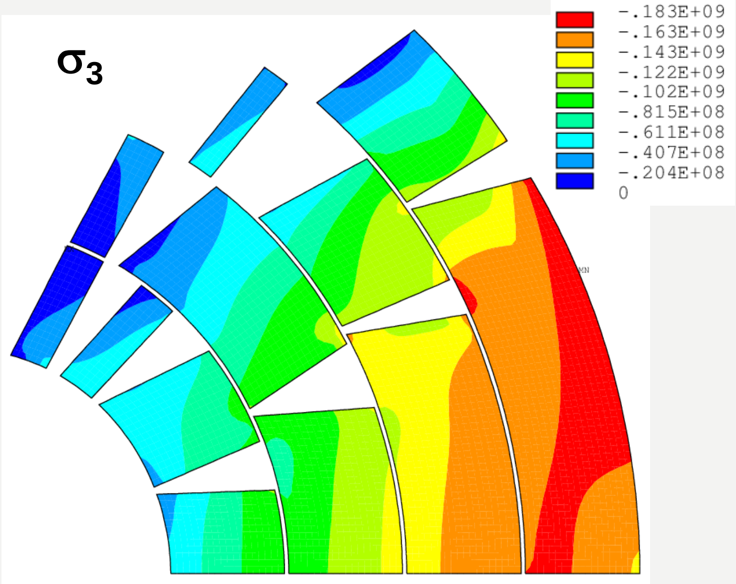
$$\sigma_v = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}}$$

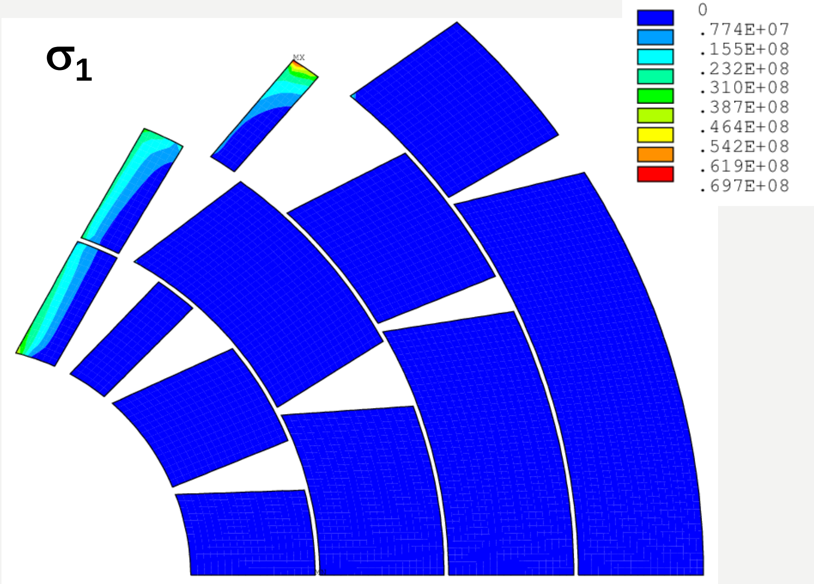
STRESSES


σθ
-.182E+09
-.158E+09
-.135E+09
-.112E+09
-.883E+08
-.649E+08
-.416E+08
-.182E+08
.518E+07
.286E+08


σr
-.169E+09
-.144E+09
-.118E+09
-.921E+08
-.664E+08
-.406E+08
-.149E+08
.109E+08
.367E+08
.624E+08

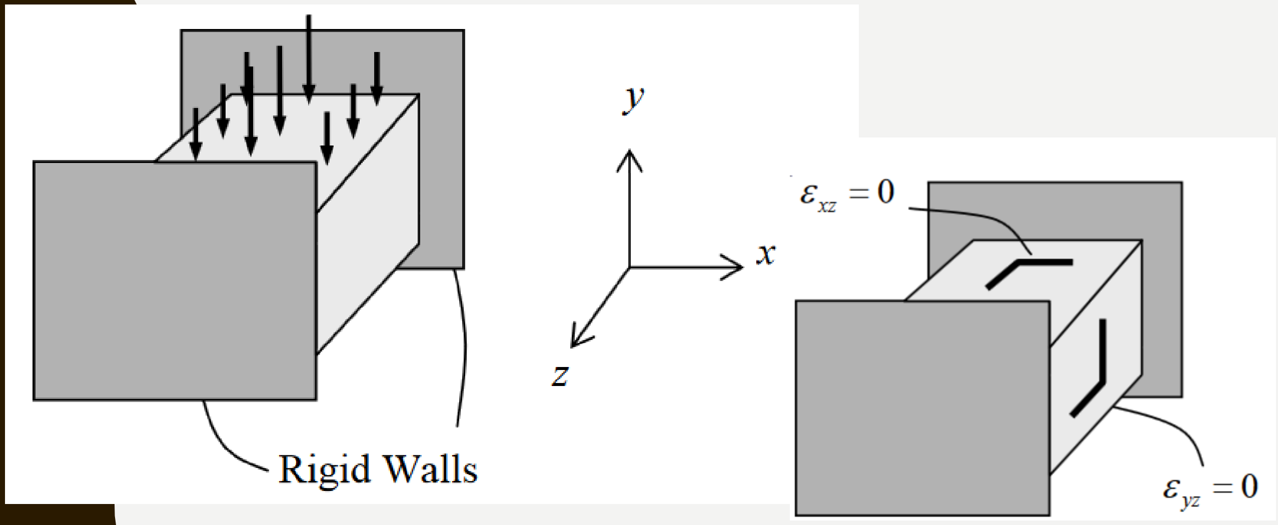

σVM
.828E+07
.257E+08
.432E+08
.607E+08
.781E+08
.956E+08
.113E+09
.131E+09
.148E+09
.165E+09


σ3
-.183E+09
-.163E+09
-.143E+09
-.122E+09
-.102E+09
-.815E+08
-.611E+08
-.407E+08
-.204E+08
0


σ1
0
.774E+07
.155E+08
.232E+08
.310E+08
.387E+08
.464E+08
.542E+08
.619E+08
.697E+08

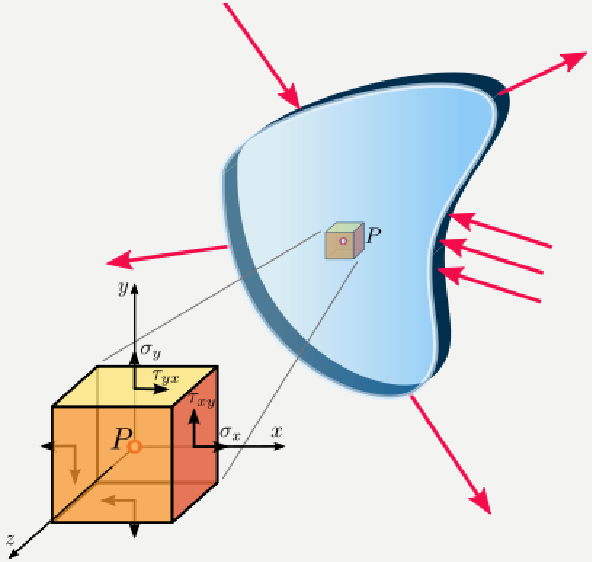
PLANE STRESS VS PLANE STRAIN

Plane strain



Plane strain is a stress state that varies only in the X and Y directions. The strain in the Z direction is always zero, as are the XZ and YZ shear strains, since the boundaries are fixed.

Plane stress



Plane stress is a stress state that varies only in the X and Y directions. The stress in the Z direction is always zero, as are the XZ and YZ shear stresses. Plane stress is generally used on flat, thin structures, where the deformation is assumed to be solely in the plane of the structure.

<u>**Plain stress**</u> approximation is less conservative but more compatible with 3D simulation results.

2D MECHANICAL OPTIMIZATION

Cables undergo degradation if:

- stress on conductors >150 MPa @room temperature;
- stress on conductors > 200 MPa @cold;
- stress on conductors > 150 MPa @cold after energization in the high field region → attention must be given in particular to first layers.

- Tensile stress on the iron yoke at 4 K < 200 Mpa.

- Contact pressure Ti pole-conductors > 2 MPa after energization at 16T.

Critical Current Measurements of High-J_c Nb_3Sn Rutherford Cables under Transverse Compression

B. Bordini, P. Alknes, A. Ballarino, L. Bottura, L. Oberli

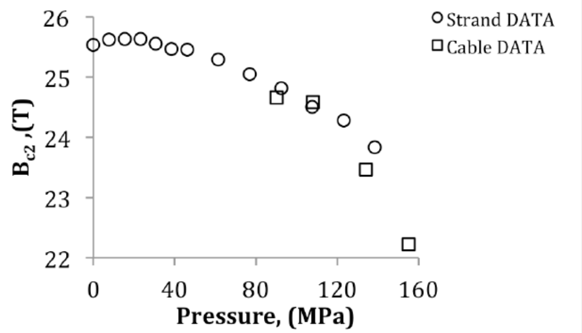
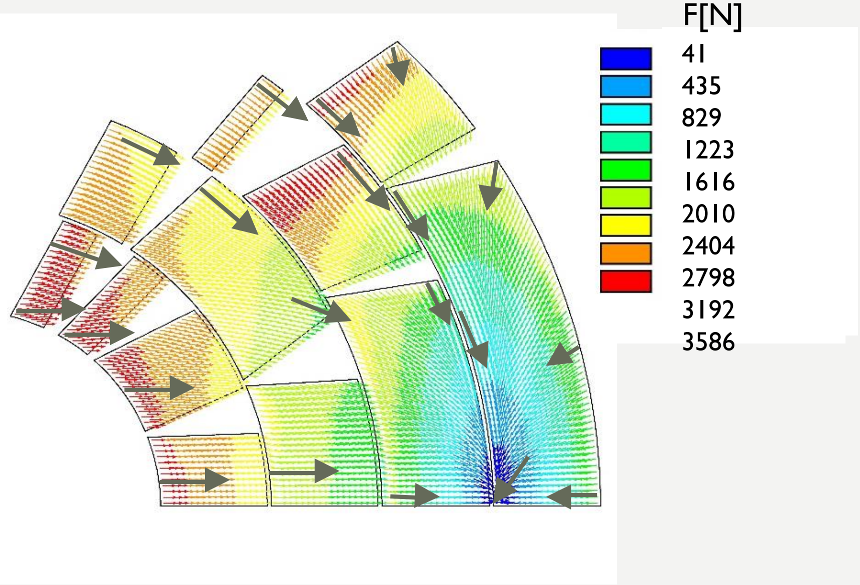


Fig. 6. Upper critical field at 4.2 K estimated from the critical current measurements under transversal pressure.

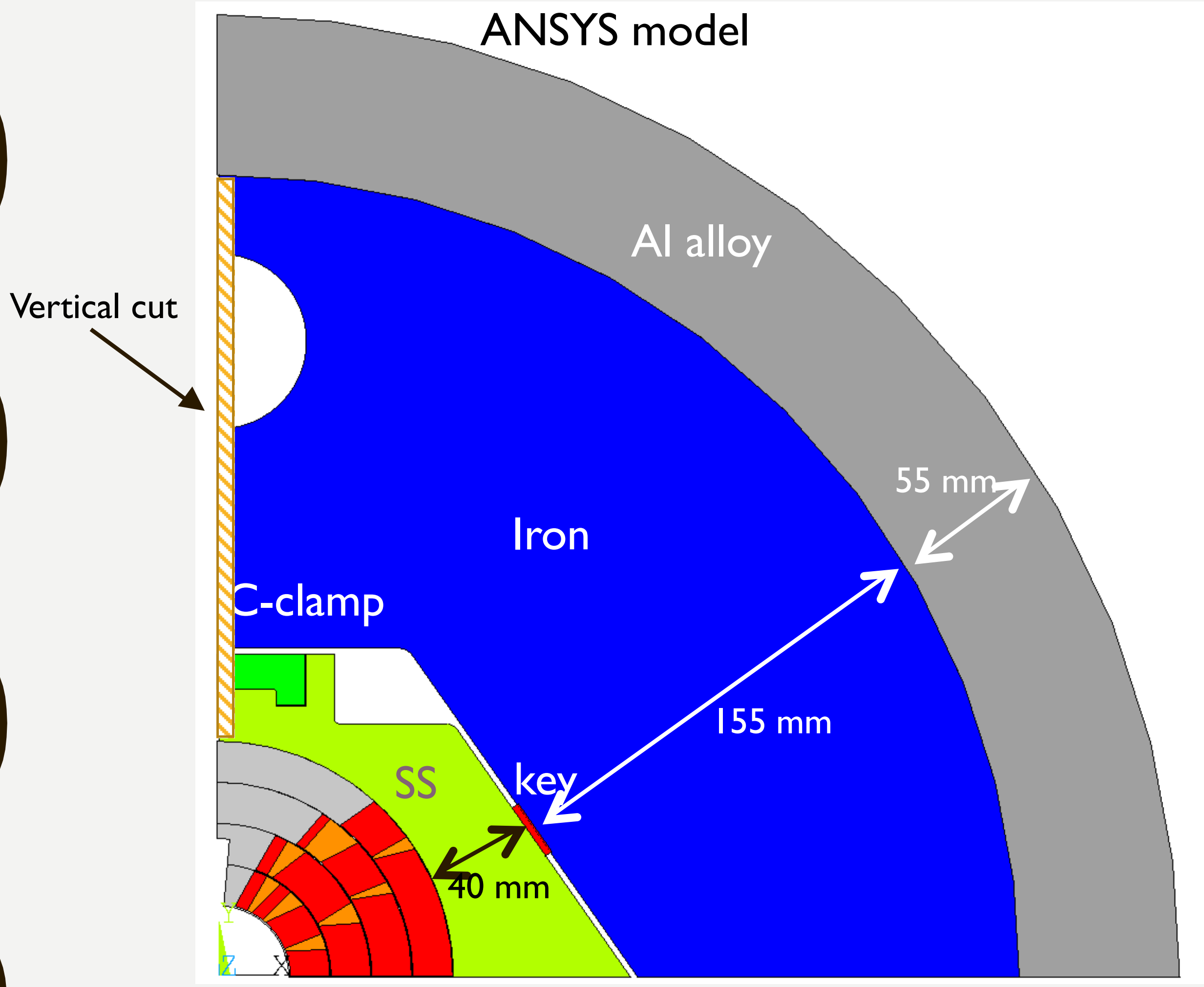


MATERIAL PARAMETERS

	E modulus [GPa] (T=4K)	E modulus [GPa] (T=300K)	α (K^{-1})	ν_{xy}
Conductor	E_x=33 E_y=27.5	E_x=30 E_y=25	α_x=3.08E-3/296 α_y=3.36E-3/296	0.3
Steel	210	191	2.8e-3/296	0.28
Iron	224	204	2.0e-3/296	0.28
Aluminum	79	72	4.2e-3/296	0.3
Copper	110	100	3.4e-3/296	0.3
Resin	27.5	25	2.5e-3/296	0.2
Titanium	126.5	115	1.7e-3/296	0.3

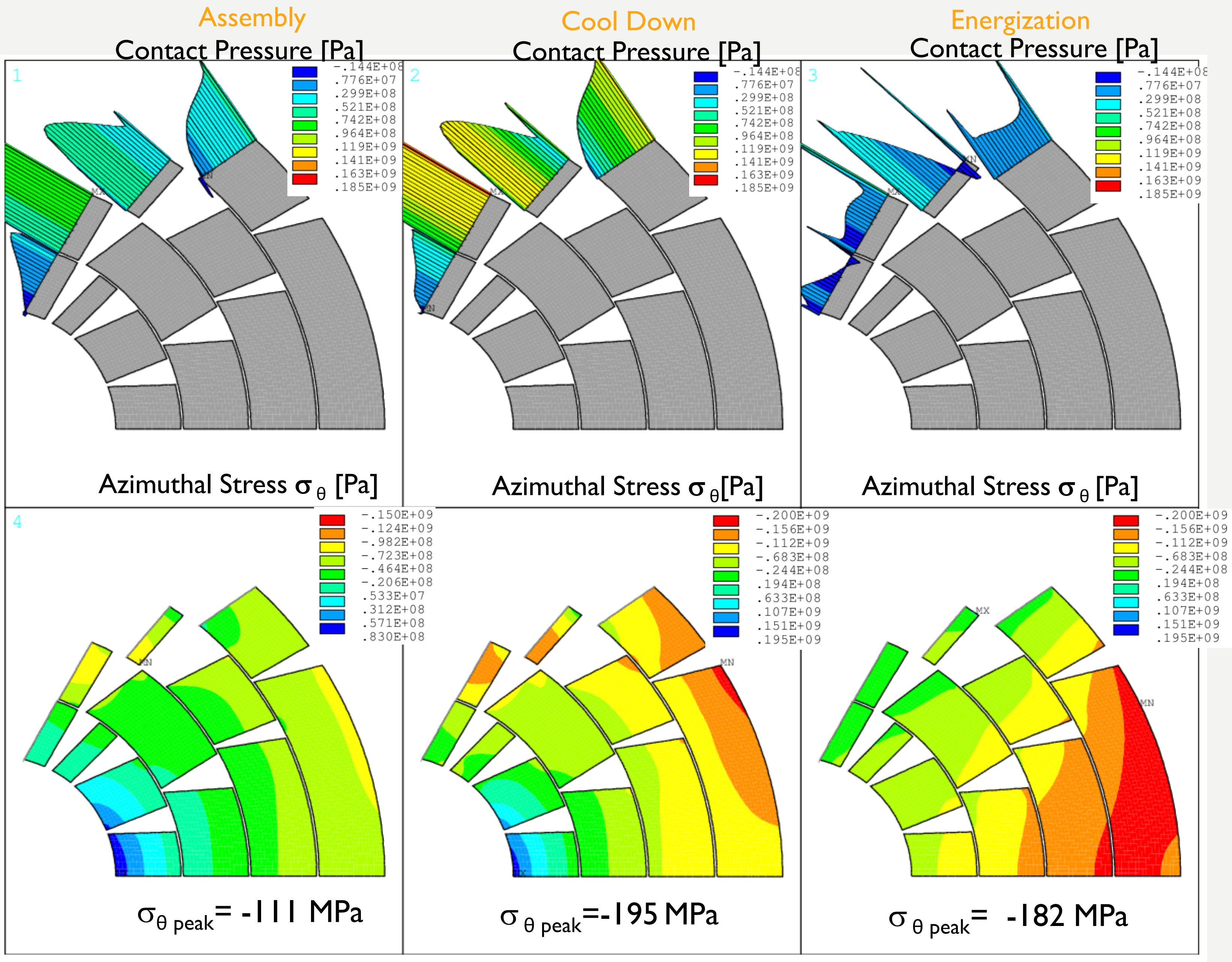
+10%

CONFIGURATION 1

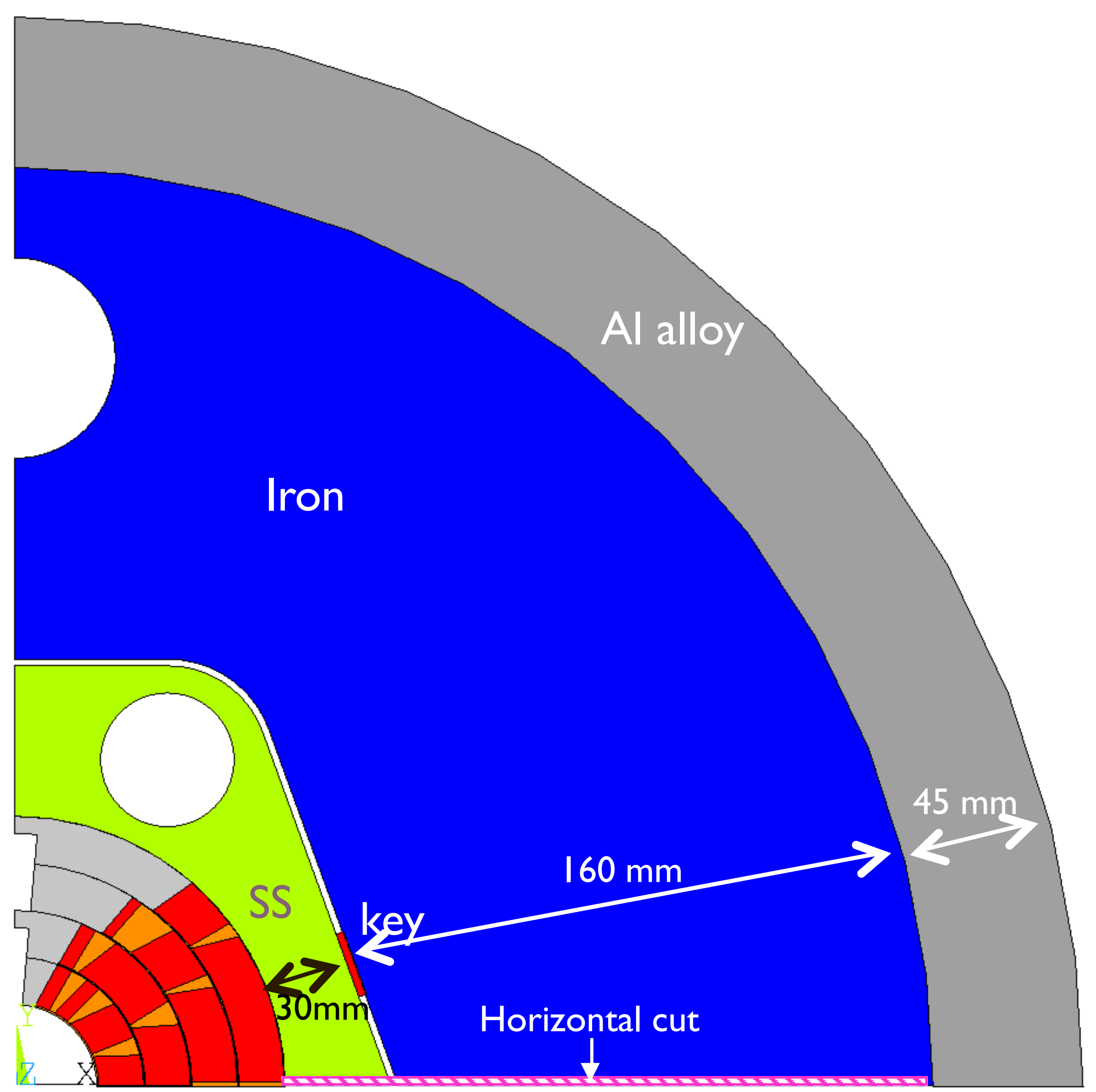


- Bladder & key configuration
  Key length= 20 mm, interference= 0.6 mm
- Vertical cut both in the steel collar and in the iron yoke
- C-clamp mandatory to achieve enough contact pressure at the pole, interference= 0.15 mm

CONTACT PRESSURE AND PRINCIPAL STRESS

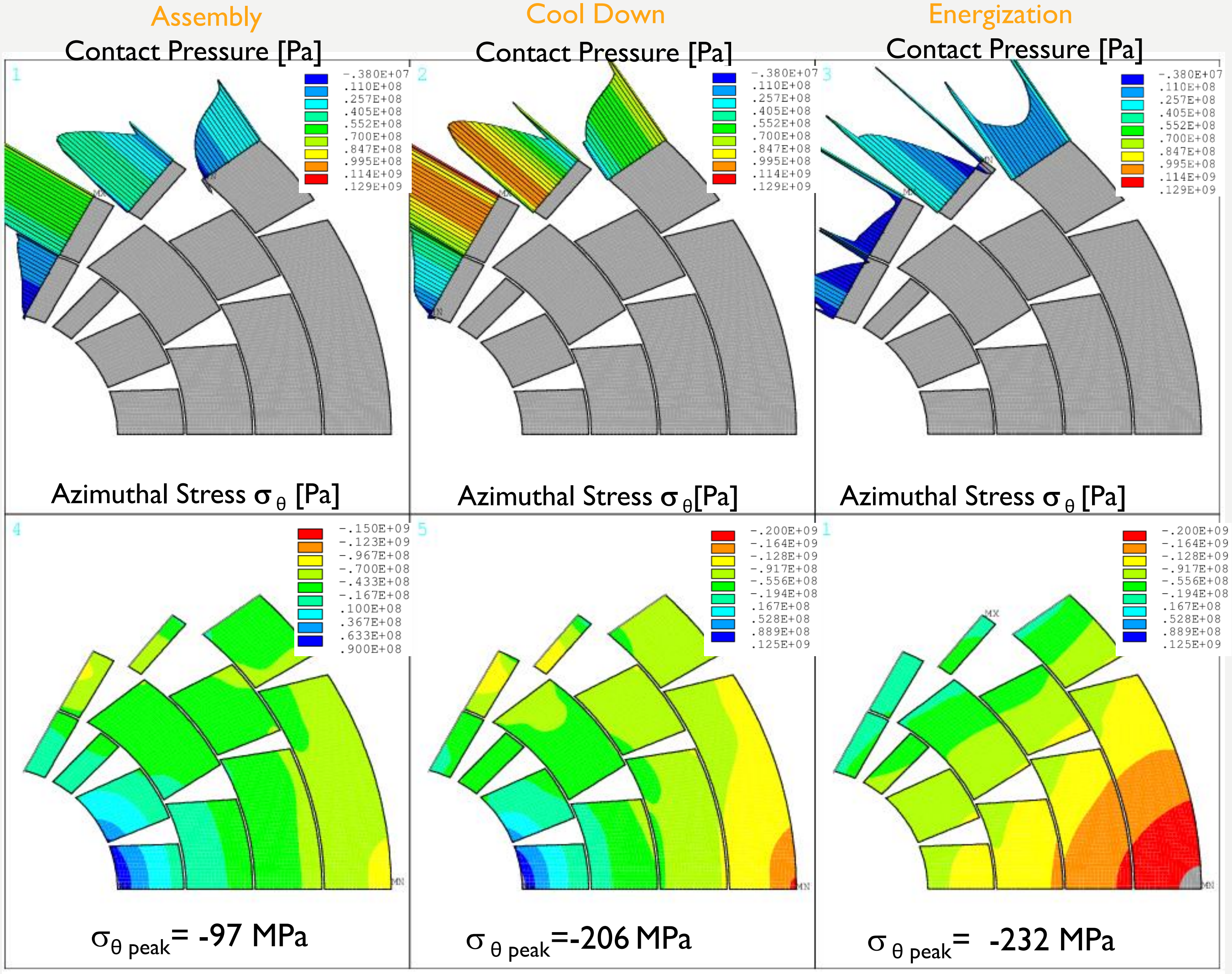


CONFIGURATION 2

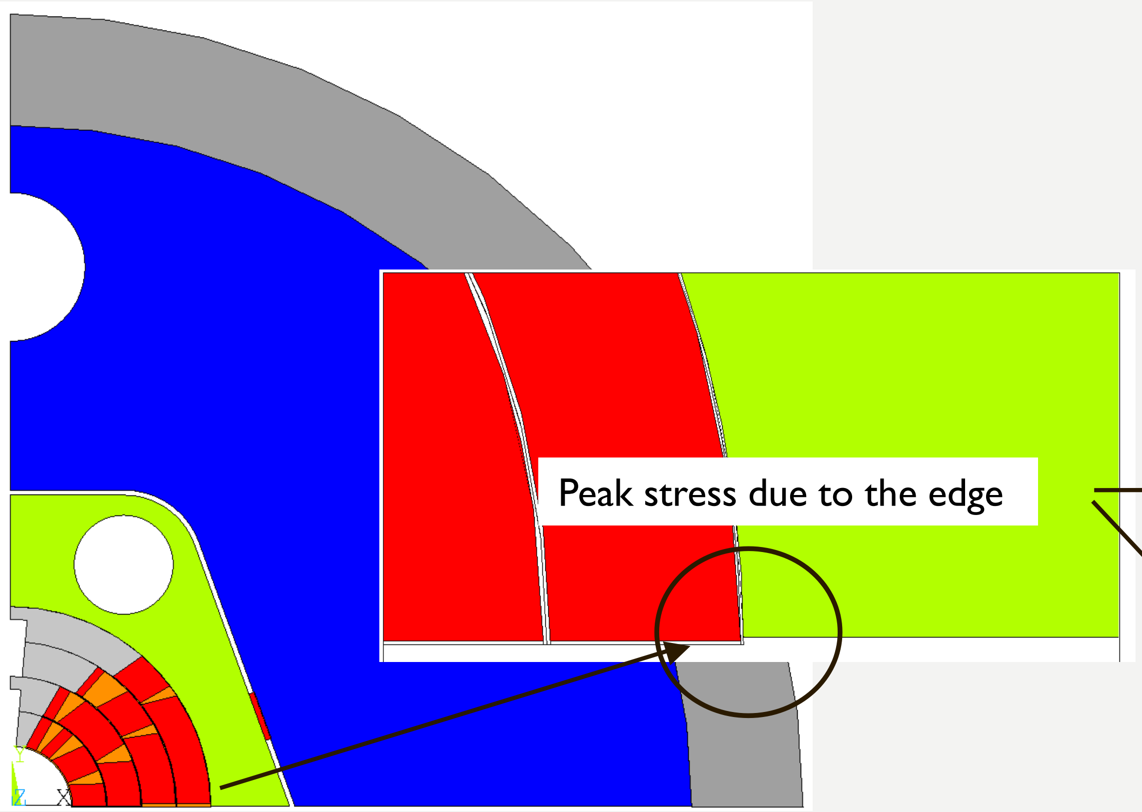


- Bladder & key configuration
  Key length= 20 mm, interference= 0.4 mm
- Horizontal cut both in the steel collar and in the iron yoke

CONTACT PRESSURE AND PRINCIPAL STRESS

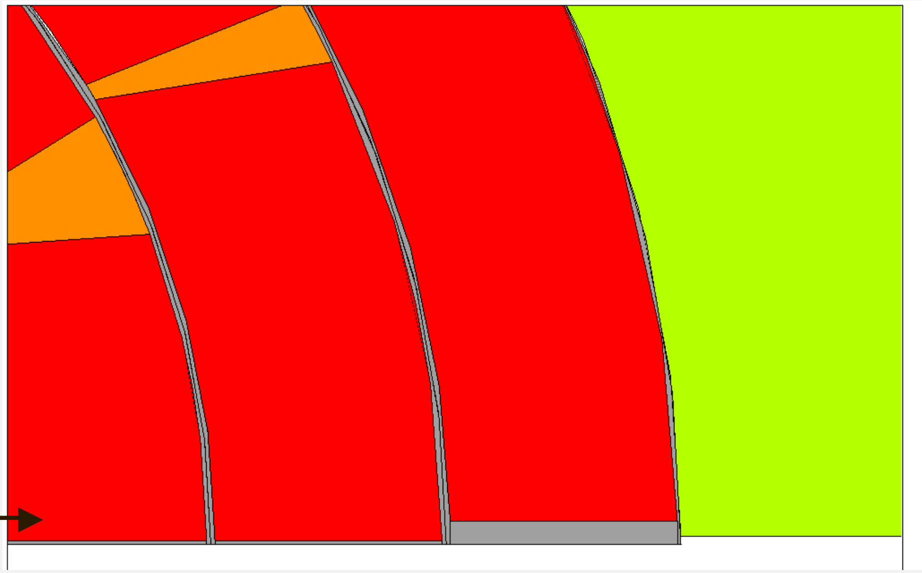


CONFIGURATION 2



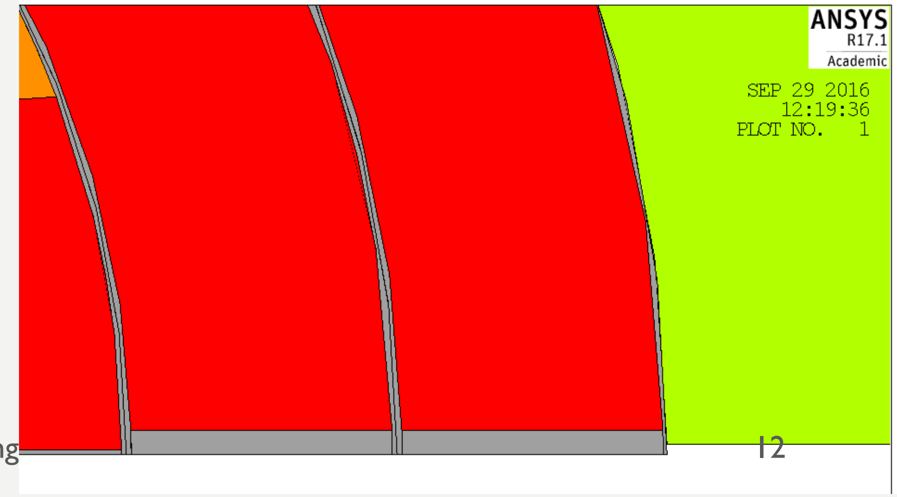
IVth layer shifted upward by 1 mm

A

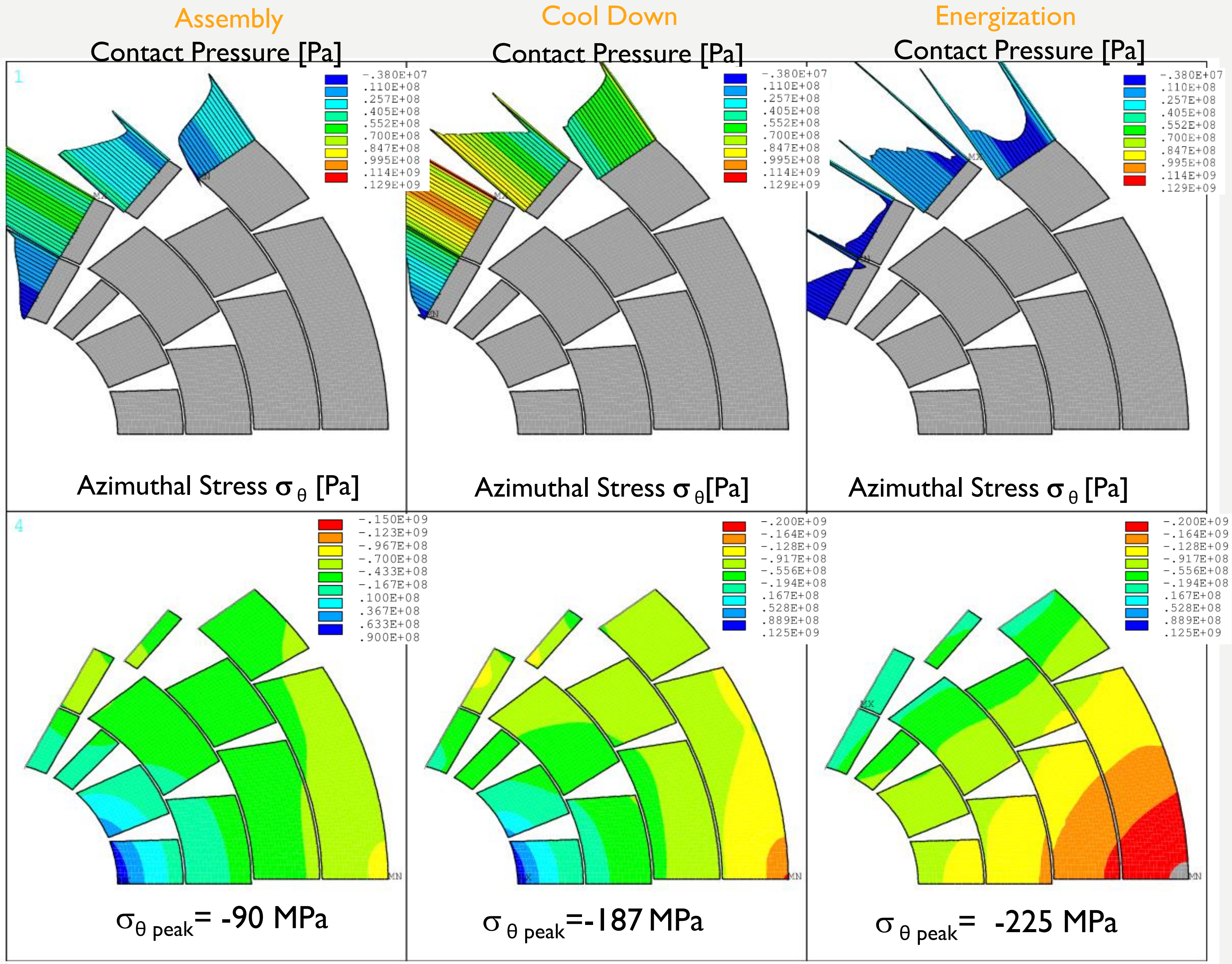


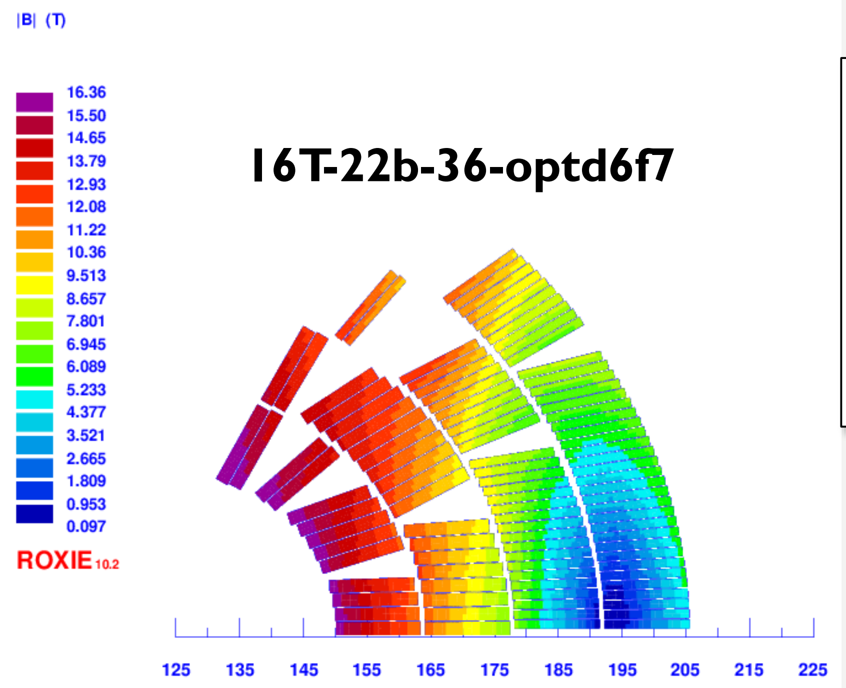
IIIrd and IVth layers shifted upward by 1 mm

B



CONTACT PRESSURE AND PRINCIPAL STRESS





Turn number:
Layer 1: 13
Layer 2: 20
Layer 3: 30
Layer 4: 38
Tot: 202/ap.

Wedge minimum thikness: **0.86 mm**

In LHC: 0.70 mm
In D11: 0.98 mm

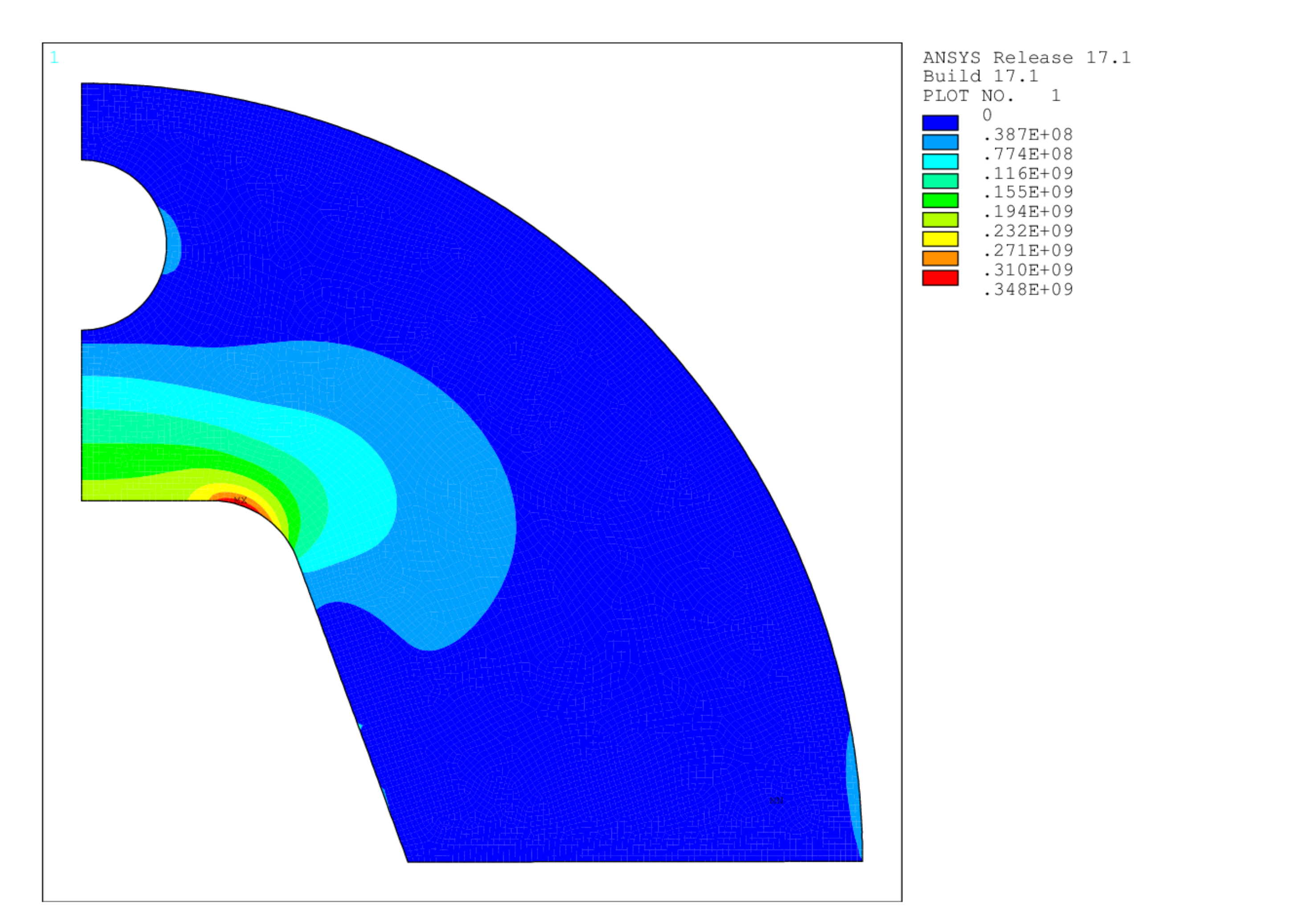
Field harmonics < 1 unit

	Cable 1 (inner)	Cable 2 (outer)
Strand number	22	36
Strand diameter	1.1 mm	0.712 mm
Bare width	13.2 mm	13.5mm
Bare inner thickness	1.892 mm	1.225 mm
Bare outer thickness	2.072 mm	1.343 mm
Insulation	0.15 mm	0.15 mm
Keystone angle	0.5°	0.5°
Cu/NCu	0.85	2.15
Operating current	**11180 A**	**11180A**
Copper current density	1165 A/mm²	1143 A/mm²
Operating point on LL (1.9 K)	**86%**	**86%**

→

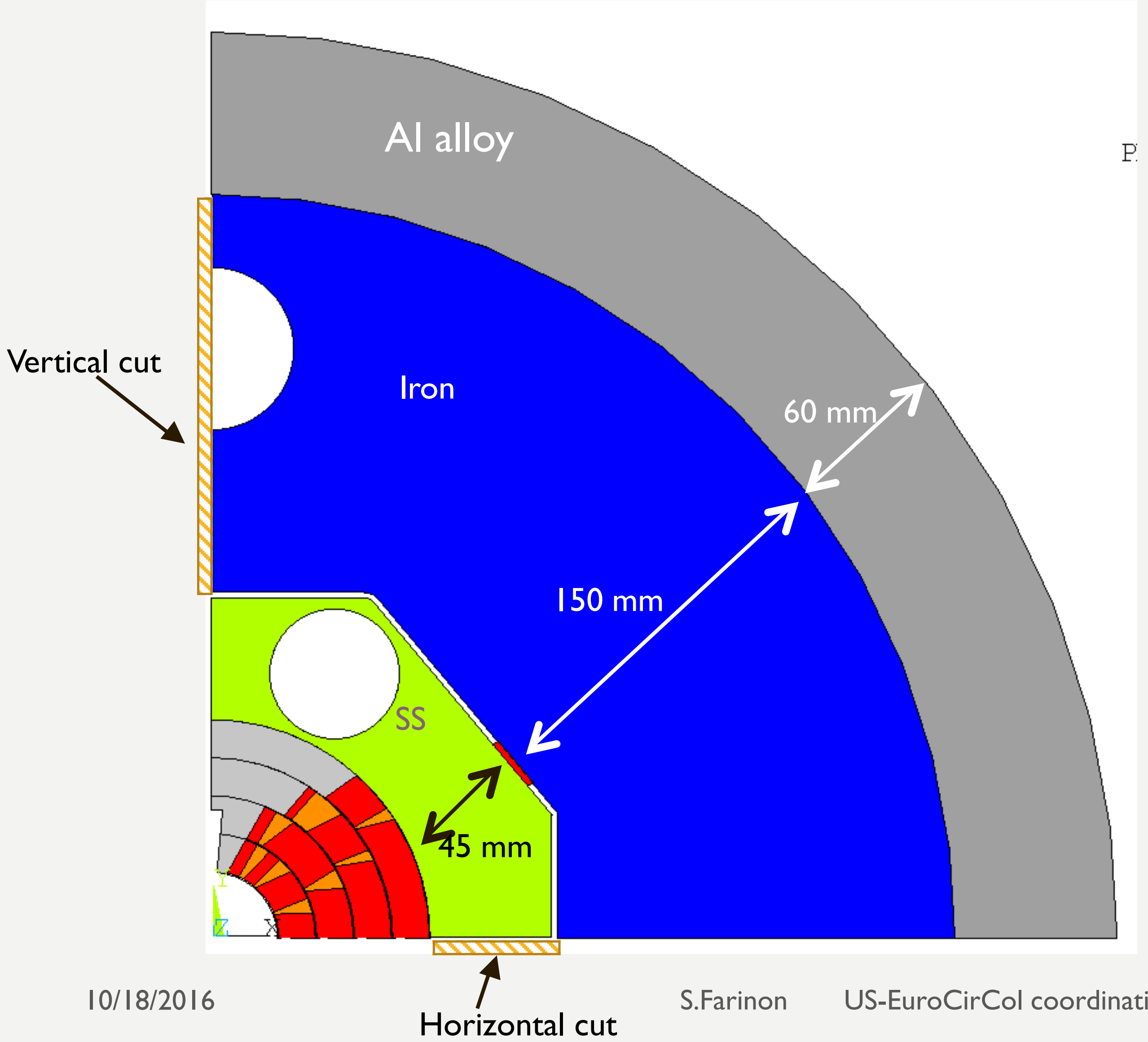
Cable 1 (inner)	Cable 2 (outer)
22	36
1.1 mm	0.712 mm
13.2 mm	13.5mm
1.892 mm	1.225 mm
2.072 mm	1.343 mm
0.15 mm	0.15 mm
0.5°	0.5°
0.85	2.1
11200 A	**11200 A**
1167 A/mm²	1154 A/mm²
86%	**86%**

TENSILE STRESS IN THE IRON



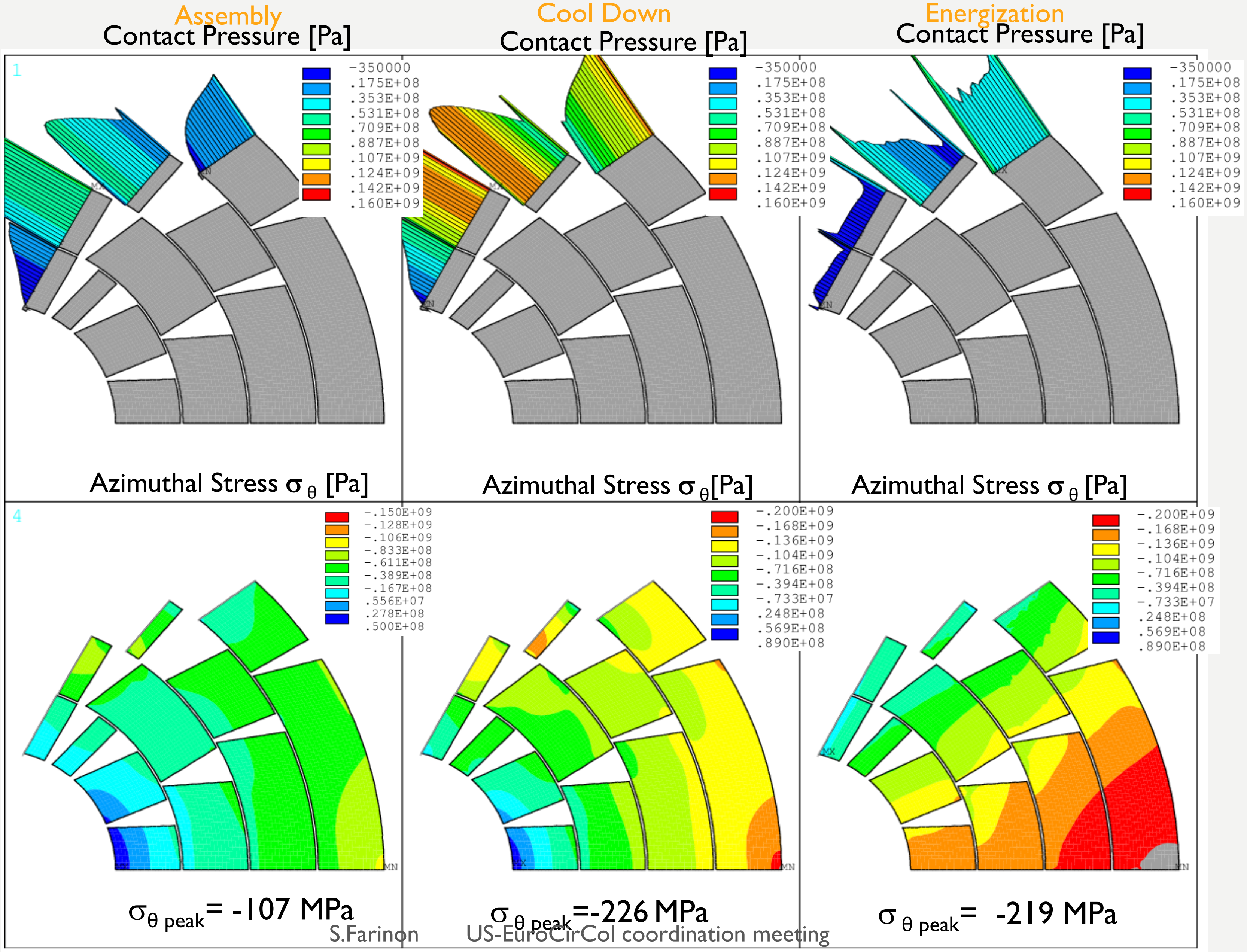
Tensile stress peak in the iron ($\sigma_{I\ peak}$) ~ 350 MPa

CONFIGURATION 3

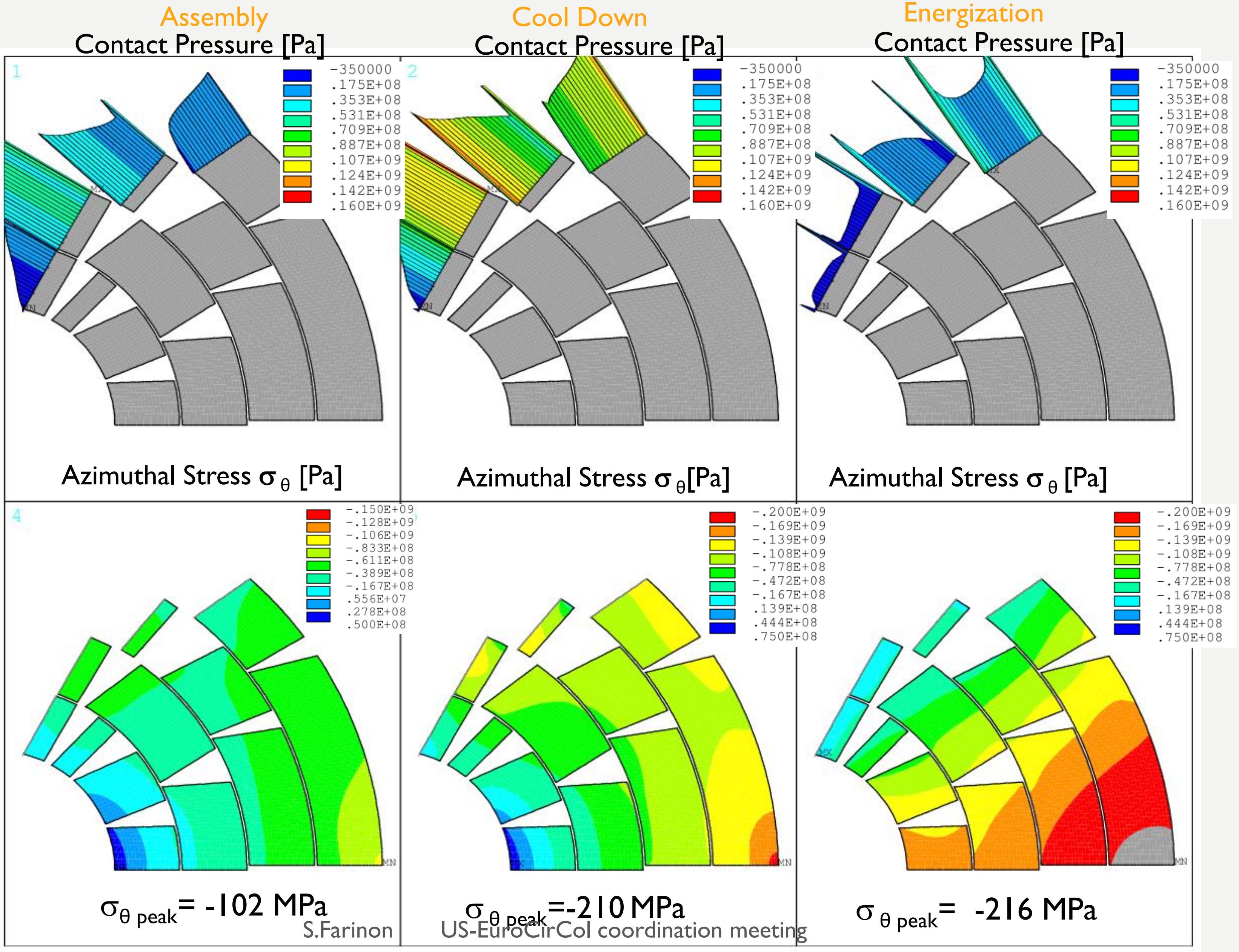


- <u>Bladder & key configuration</u>
  Key length= 20 mm, interference= 0.5 mm
- <u>Horizontal cut in the steel collar</u>
  →greater contact pressure at the pole
- <u>Vertical cut in the iron yoke</u>
  →smaller tensile stress on the iron

CONTACT PRESSURE AND PRINCIPAL STRESS



CONTACT PRESSURE AND PRINCIPAL STRESS



CONCLUSIONS

- The mechanics of the 16T costheta dipole has been investigated, giving particular importance to the fulfillment of the following requirements: stress on conductors <150 MPa @room temperature, stress on conductors < 200 MPa @cold and contact pressure Ti pole-conductors > 2 MPa after energization.
- Different configurations were considered, among those the more promising were presented:
- CONFIGURATION I- vertical cut in the steel collar and the in the iron yoke

  Bladder&Key + C-clamp mandatory to achieve contact pressure at the pole

  Almost fulfill stress limits on the conductor

  Good contact pressure at the pole for all the layers
- CONFIGURATION II – horizontal cut in the steel collar and in the iron yoke

  Almost fulfill stress limits on the conductor

  Good contact pressure at the pole for all the layers

  Very high values for tensile stress on the iron (350 MPa)
- CONFIGURATION III- hybrid solutions, horizontal cut in the steel collar and vertical cut in the iron yoke

  Almost fulfill stress limits on the conductor

  Good contact pressure at the pole for all the layers