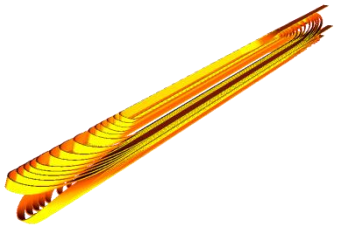
Design of alternative cos-ϑ magnet with Roebel cable



Clément Lorin and WP10.3 members

Second Workshop on Accelerator Magnets in HTS (WAMHTS-2)

13/11/2014

Framework

- **Field target**: Accelerator-type magnet
  - stand-alone mode + yoke: 5 T
  - insert mode: the more the better

- **Constraints**:
  - Magnet dimension: 40 mm aperture and 100 mm outer diameter
  - Roebel cable: stringent easyway radius (10 mm) hardway radius (2 m)

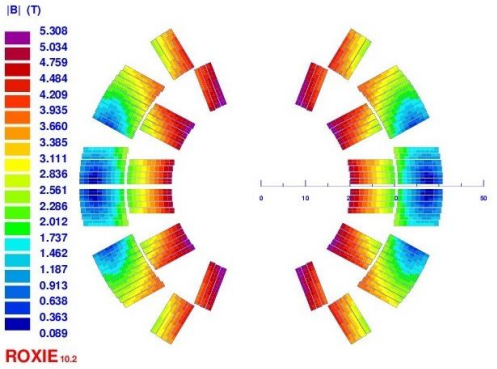
Contents

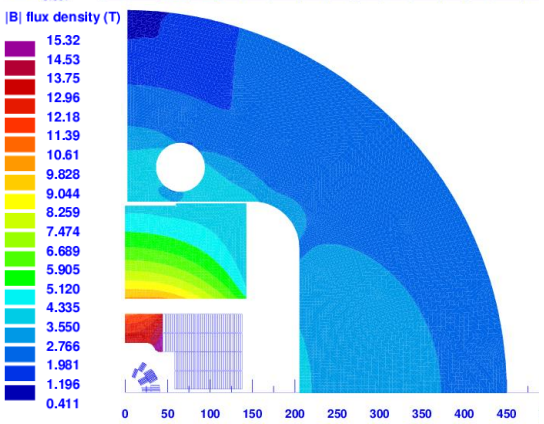
- **Double** layer design:
  - 10-mm wide Roebel cable

- **Single** layer design:
  - 12-mm wide Roebel cable

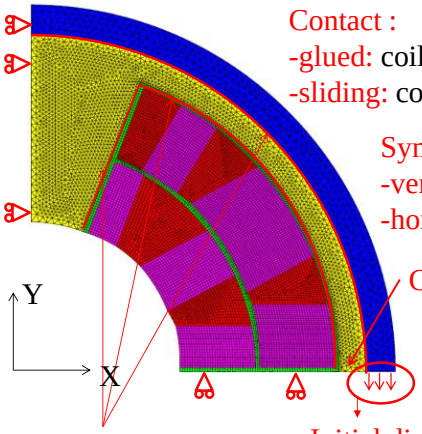
Double layer design (1/2)

- 2D **magnetism**:
  - $J_{e,cable}$ = 460 A/mm² (J_o = 386 A/mm²)
  - 5 T standalone + yoke
  - 3.75 T standalone
  - 13 T + 3.75 T in Fresca2
  - Geom. in Fresca2: b_3=6,b_5=1,b_7=1





- 2D **mechanics**:



Contact :
-glued: coil + wedges + insulation (coil block)
-sliding: collar with yoke or coil block

Symmetry :
-vertical: collar + yoke
-horizontal: coil only

Collar extremity free displacement

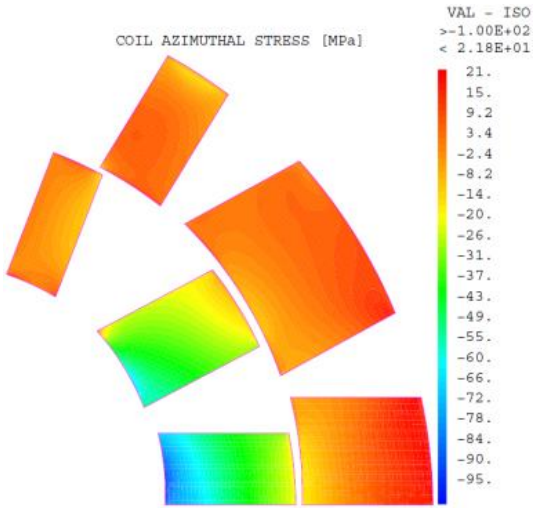
Sliding contacts

Initial displacement to simulate the prestress due to the press + welding

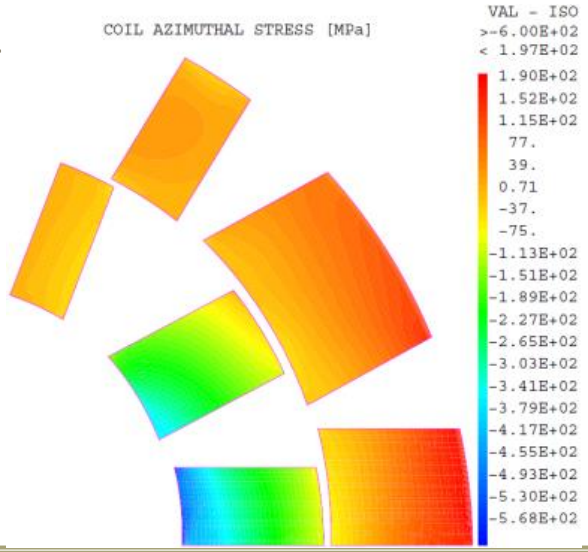
- Prestress + cool-down + Lorentz forces
- 8.6 mm left for mechanical structure

Double layer design (2/2)

- Azimuthal stress (no prestress)
  - Stand-alone: 5 T



  - Insert: 16.78 T



Field [T]	ET thickness [mm]	Peak stress [MPa]
5.00	8.0	100
16.78	8.0	600
5.00	20.0	30
16.78	20.0	250

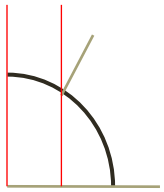
Show stopper: Mechanical structure for double layer cosine-theta too weak.

What can be done with a single layer design?

Single layer design (1/5)

- End coil design + Roebel cable
  - Easyway bending radius (10 mm)

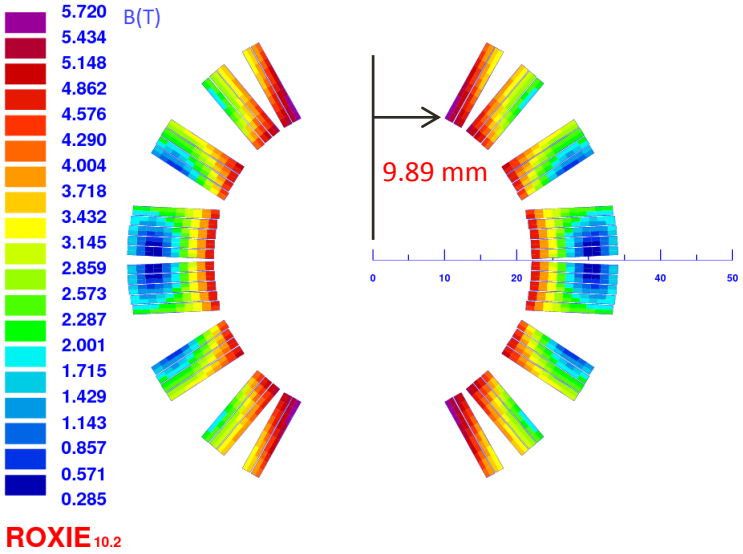
    -> R = 22 mm and field degradation in stand-alone



Rossi-Todesco
PhysRevSTAB.10.112401

Block angles
[0° –60°]
[0° –48°, 60° –72°]
[0° –43.2°, 53.2° –67.3°]
[0° –33.3°, 37.1° –53.1°, 63.4° –71.8°]

R·sin(angle) = 6.84 mm
R = 20 mm ; angle = 70°



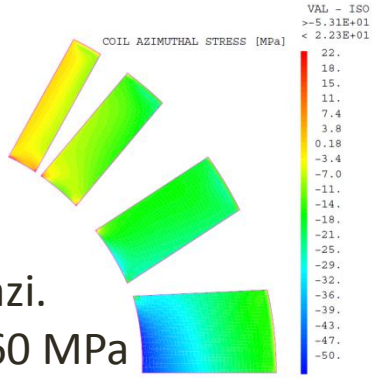
Standalone, 5 T if:
I = 11635 A (15x5.5x0.15 & 80 % margin)
$J_{e,cable}$ = 811 A/mm²
J_o = 684 A/mm²
$Jc_{e,tape}$ = 1200 A/mm² (6 T@4.2 K)

Insert, 2 T if:
I = 6210 A (15x5.5x0.15 & 80 % margin)
$J_{e,cable}$ = 431 A/mm²
J_o = 363 A/mm²
$Jc_{e,tape}$ = 630 A/mm² (18 T@4.2 K)

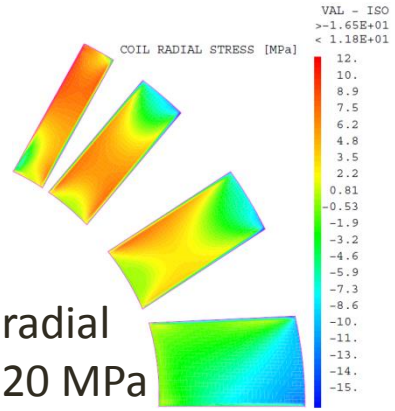
Geom. in Fresca2: $b_3 = 9$; $b_5 = 1$; $b_7 = 5$

Single layer design (2/5)

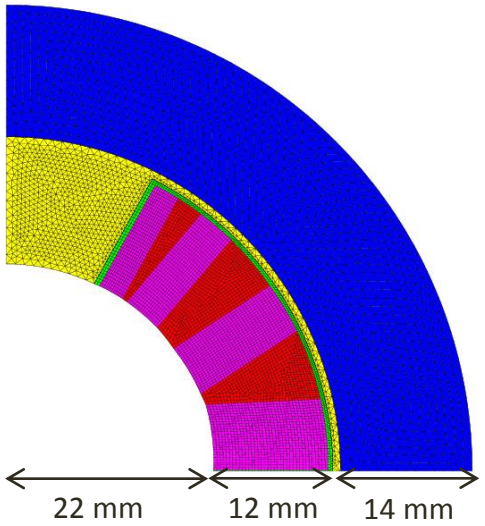
- 2D **mechanics**: (peak values)
  - Stand-alone: 5 T



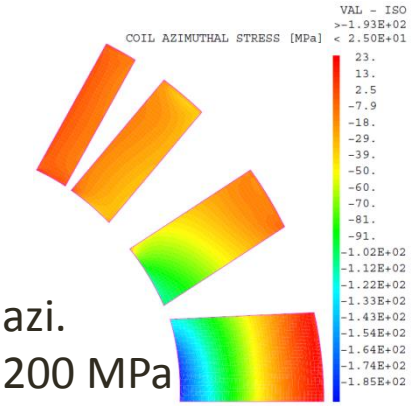
azi.
60 MPa



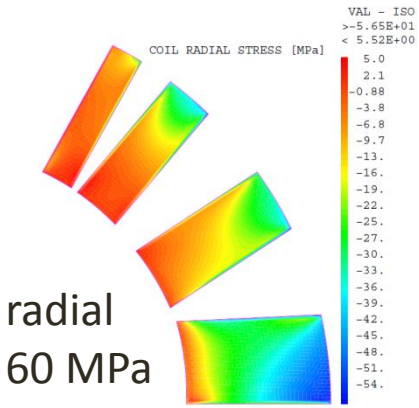
radial
20 MPa



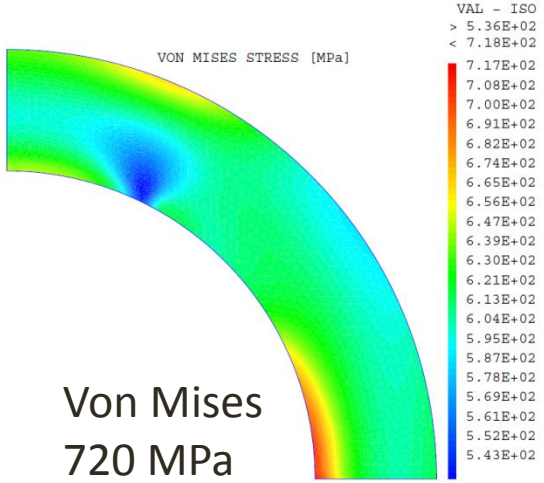
  - Fresca2 (@1.9 K) + insert = 15 T + 2 T



azi.
200 MPa



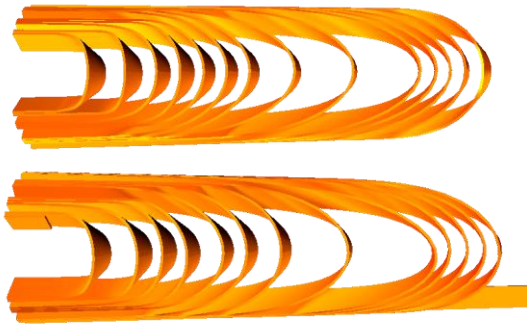
radial
60 MPa



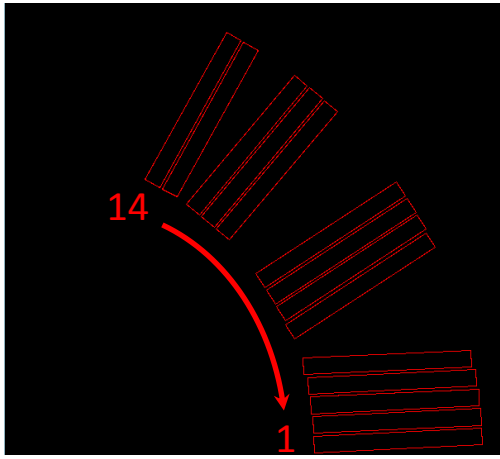
Von Mises
720 MPa

Single layer design (3/5)

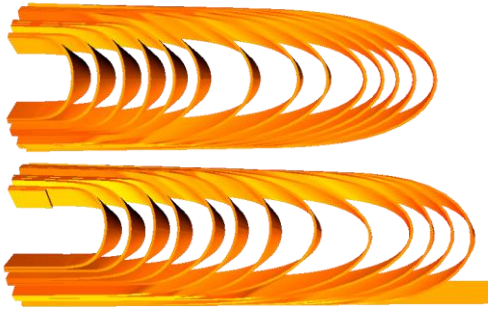
- Coil end design:
  - First try:



cable	ew (mm)	hw (m)	L (mm)
14	8.73	2.71	20
13	9.43	3.75	29
12	9.44	2.30	57
11	10.61	6.32	36
10	9.80	3.03	44
9	10.11	4.21	74
8	9.91	7.92	70
7	9.55	4.10	106
6	10.03	2.57	111
5	10.24	2.06	176
4	10.81	2.88	176
3	12.10	3.82	176
2	13.98	5.37	160
1	16.72	11.04	130



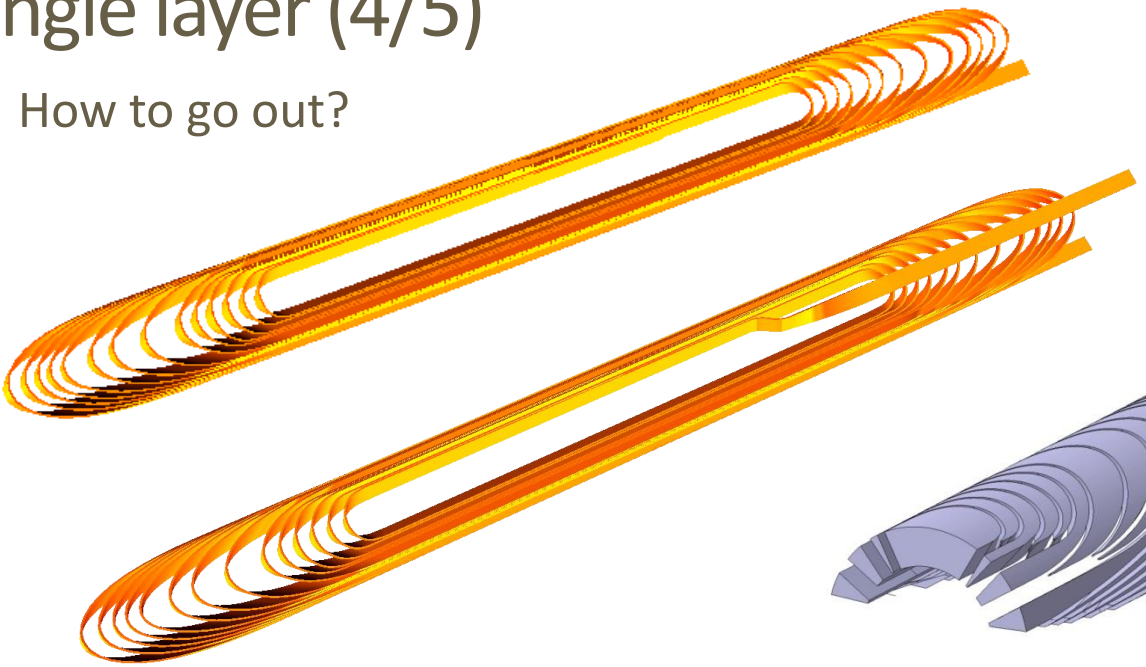
  - Upper cable less square + shorter lower cable:



cable	ew (mm)	hw (m)	L (mm)
14	7.60	2.05	22
13	8.33	3.46	28
12	9.81	2.03	33
11	10.61	6.32	36
10	9.80	3.03	44
9	10.11	4.21	74
8	9.91	7.92	70
7	9.55	4.10	106
6	10.03	2.57	111
5	9.29	2.48	144
4	10.05	3.26	145
3	11.03	4.87	145
2	11.48	3.00	142
1	12.24	7.80	138

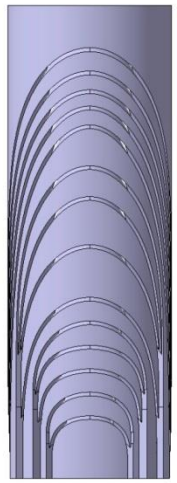
Single layer (4/5)

- How to go out?

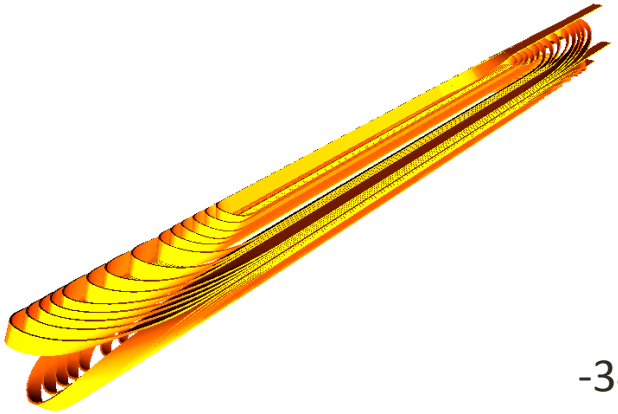


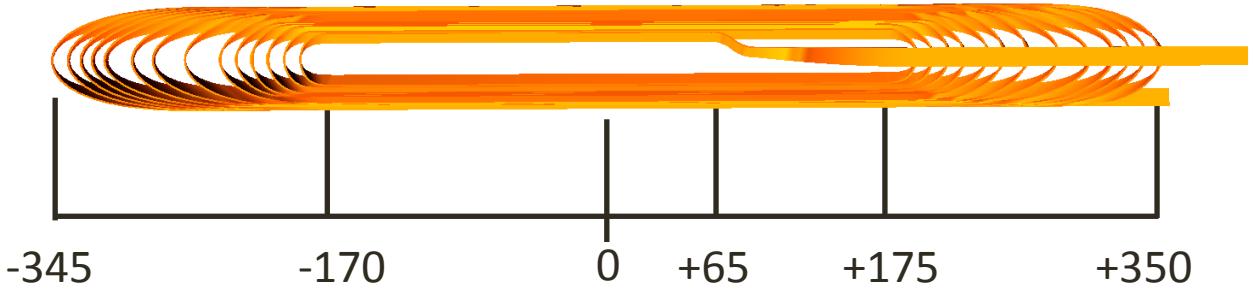
Easyway: 20 mm radius

Twist: 60° over 100 mm



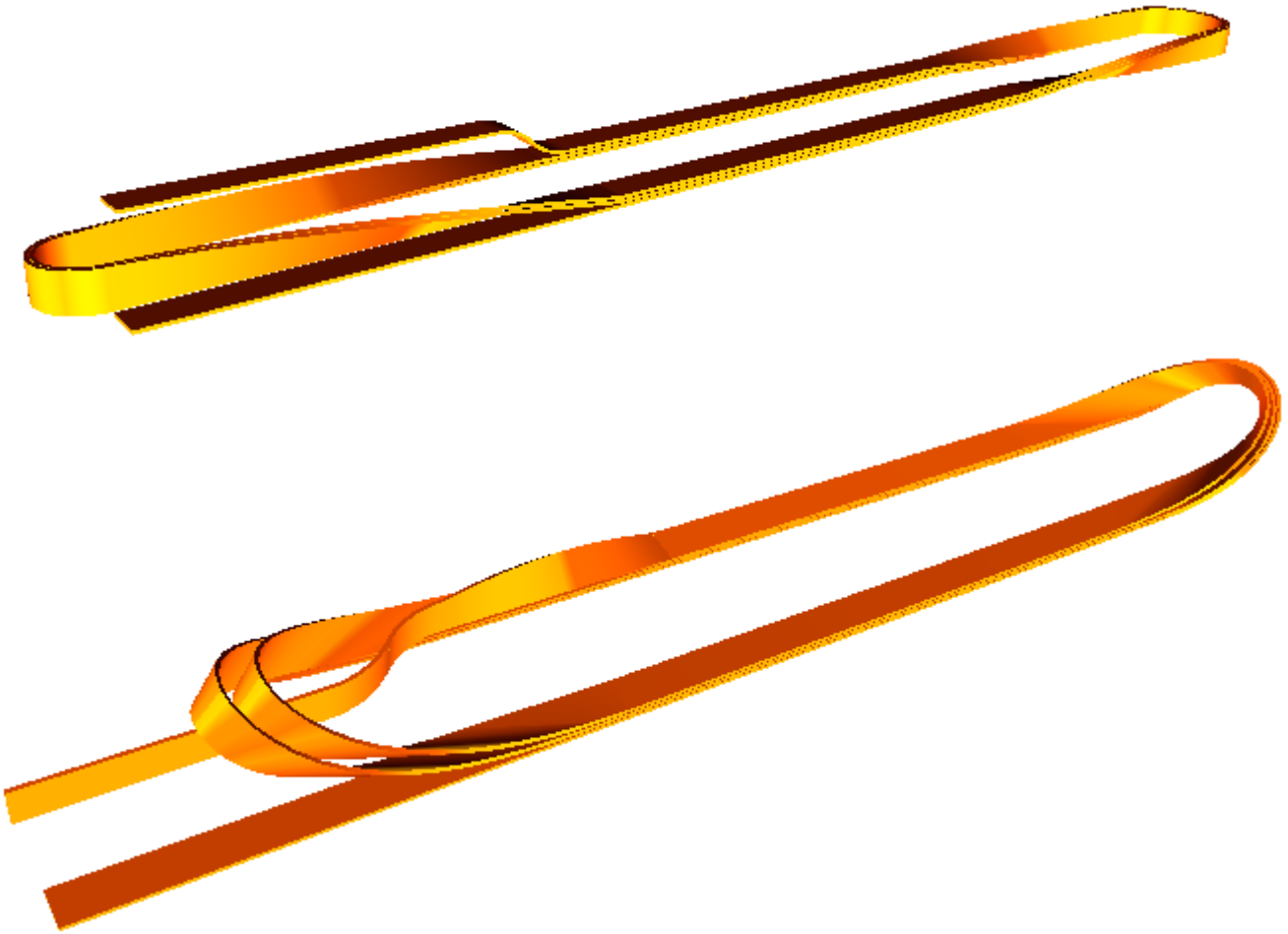
- Full design: SS ≈ 230 mm; heads ≈ 2x180 mm, cable length ≈ 2 x 17 m





Single layer design (5/5)

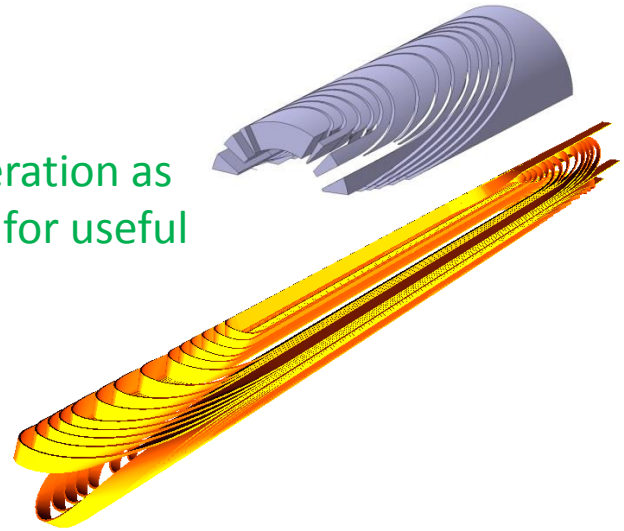
- Subscales:



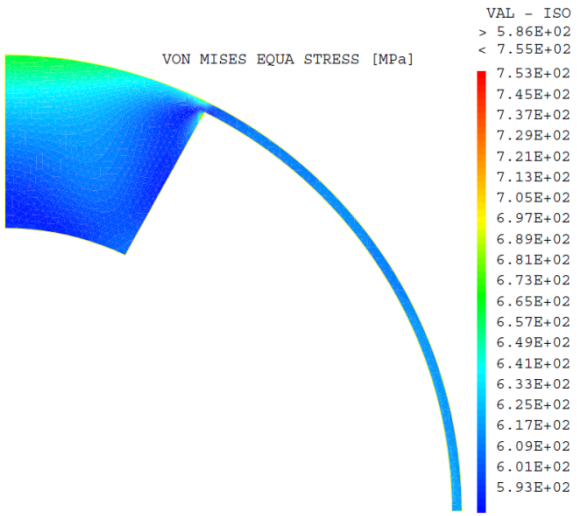
Conclusion

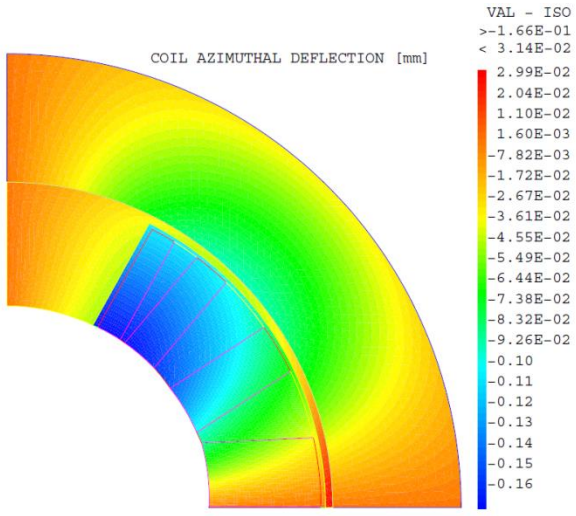
- Double layer design does not fit into Fresca2
- Single layer if cosϑ configuration must be investigated (200 MPa, still challenging)
- Between 4 - 5 T in stand-alone and 2 T as insert
- One dedicated spacer for each turn

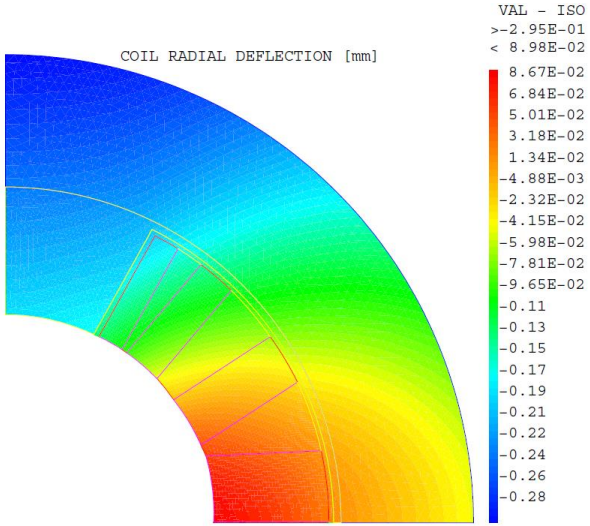
Thank you to William Gamache from CEA for end spacer generation as well as Susana Izquierdo-Bermudez and Bernhard Auchmann for useful discussion about Roxie and coil end design.



Extra data 1/2







SI Frettage;
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SINON;
MCOIL = MATE OCOIL YOUN 42000. NU 0.3 ALPH 3.9E-3;
FINSI;
MWEDGE = MATE OWEDGE YOUN 110000. NU 0.3 ALPH 3.6E-3;
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MIMAS = MATE OIMAS YOUN 4000. NU 0.3 ALPH 6.0E-3;
MCOLL = MATE OCOLL YOUN 210000. NU 0.3 ALPH 2.9E-3;
MFRETTE = MATE OFRETTE YOUN 210000. NU 0.3 ALPH 2.9E-3;

Extra data 2/2

- ew = 6.6 mm; hw = 2.65 m

It is certainly very hard to make good dipole ends with basically no hard-way bend AND little easy-way bend, and 2 meters seems to me to be a very ambitious goal. Personally I think it's almost impossible, unless you implement one dedicated spacer for each turn […]
But I think it's the boundary conditions imposed by mathematics you're fighting with more than ROXIE