EuroCirCol WP5 Review
Geneva, May 11th - 13th , 2016

Cos-theta mechanical design

Stefania Farinon
on behalf of INFN team:
G. Bellomo, B. Caiffi, P. Fabbricatore, V. Marinozzi, M. Sorbi and G. Volpini

Foreword

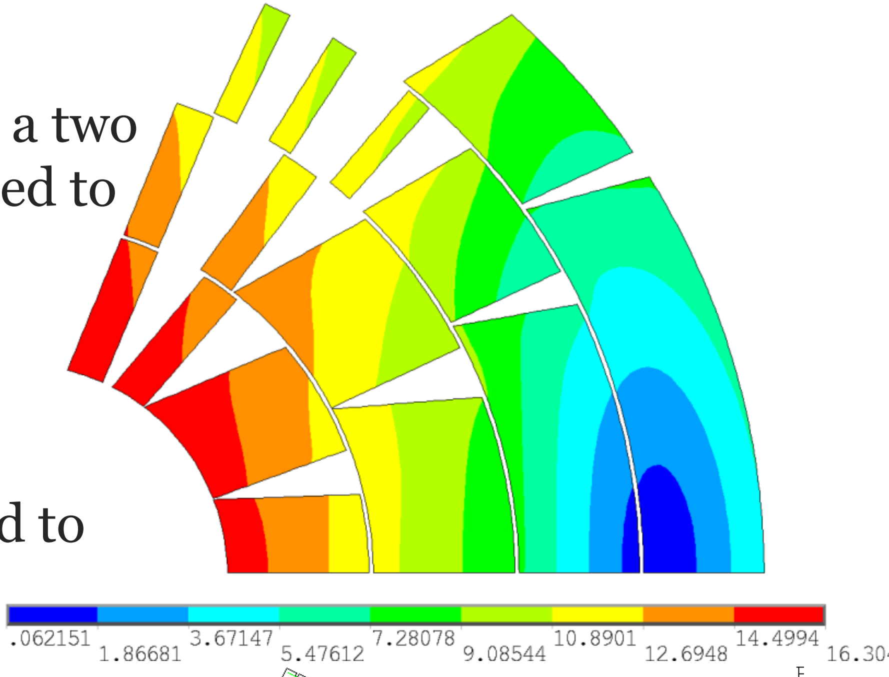
- Due to several reasons, the design of the cos-theta mechanical structure is still a **work in progress**
- In particular, several design parameters and constraints changed during the last year, and the electromagnetic design changed correspondingly (the last version of the cos-theta electromagnetic design was studied for the April 2016 FCC week)
- The main consequence is that the cos-theta electromagnetic design has been studied and optimized focusing on the electromagnetic requirements
- Because the design parameters and constraints are not frozen yet, we will perform later the last step of the electromagnetic and mechanical design optimization

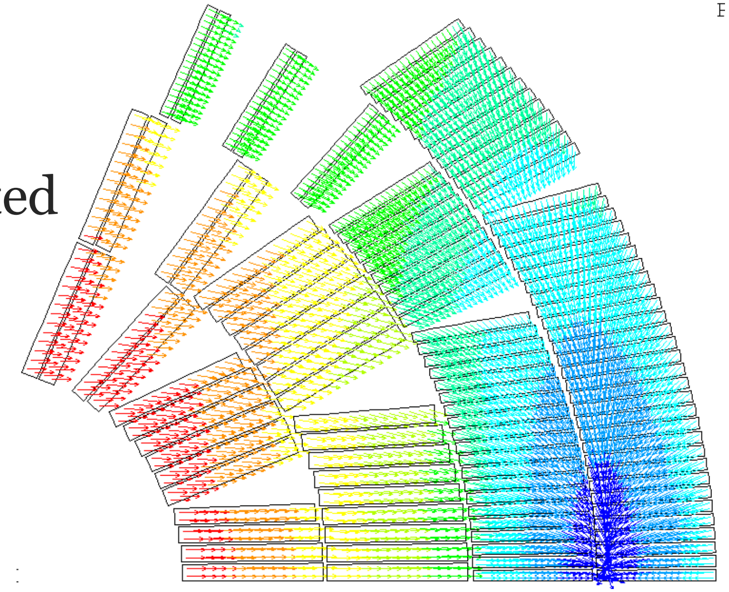
- As agreed by the collaboration, we studied the 2D mechanical structure of a single aperture producing a central field of 16 T

- We acknowledge the help of Paolo Ferracin and Shlomo Caspi

Electromagnetic design & Lorentz forces

- The present e.m. design, optimized for a two apertures configuration, has been turned to a single aperture scaling the operating current to get a central field of 16 T. The yoke diam. has been set to 800-250=550 mm
- As usual in dipoles, the e.m. forces tend to push the coil: towards the mid plane in the vertical-azimuthal direction and outwards in the radial-horizontal direction
- the radial component is directly intercepted by the mechanical structure
- the azimuthal component, if not compensated, determines an azimuthal displacement of the coil and creates a separation at the pole





Mechanical structure principle

- The winding stress limits are:
  - $\sigma_{eqv\ coil\ max} \leq 150$ MPa at 293 K and ≤ 200 MPa at 4.5 K
- Considering that the azimuthal pre-stress should be (slightly) larger than the azimuthal Lorentz forces, then:
  - the **classical collar solution**, which gives the full pre-stress during assembly, is then excluded a-priori to respect room temperature stress limit
  - a **bladder&key option** is preferred because the needed pre-stress is partly supplied by the shrinking of the Al alloy shell during cool-down

	σ_{θ} –layer (MPa)	σ_{θ} –winding (MPa)
layer 1	110	135
layer 2	140	
layer 3	200	
layer 4	90	

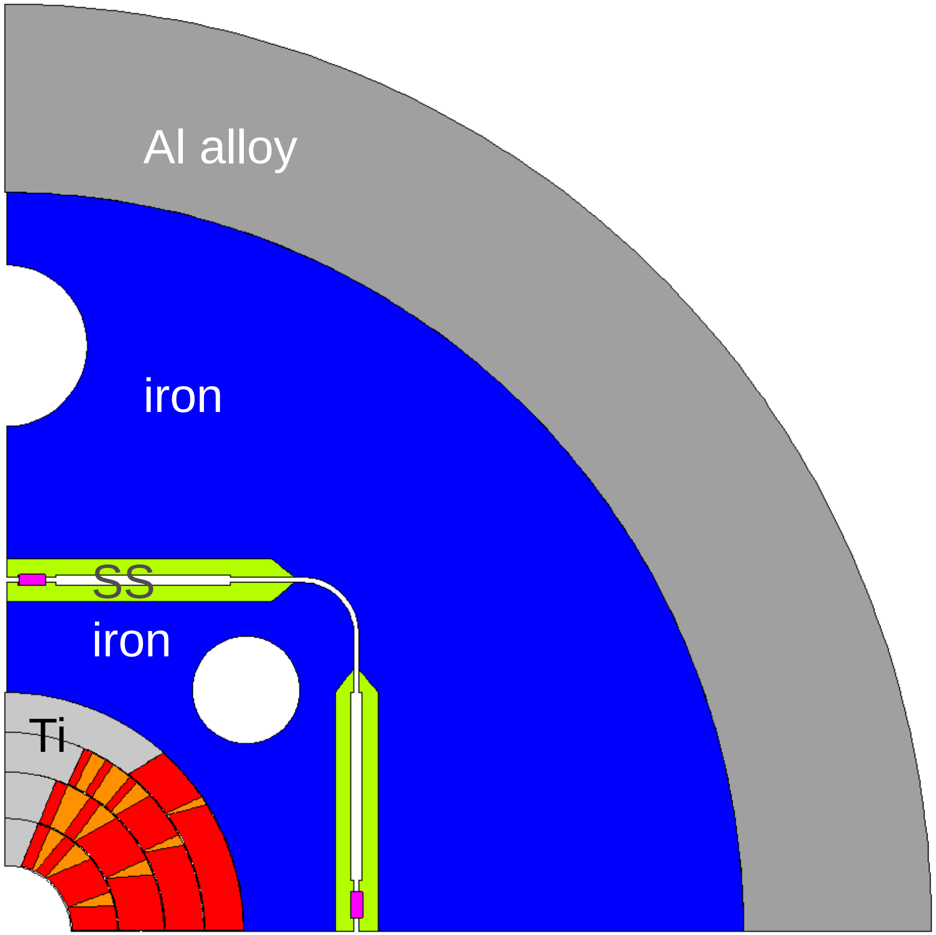
Design constraints

- The acceptance criteria are:
  - Pole-coil contact in pole-turns midpoint $p_{cont} \geq 2$ MPa
  - Max bladder pressure < 50 MPa
  - Max interference 500 μm
  - Bladder should open the interf=interf$_{nom}$ + 100 μm
  - $\sigma_{eqv\ coil\ max} \leq 150$ MPa at 293 K and ≤ 200 MPa at 4.5 K
  - All components $\sigma_{eqv} \leq R_{p\ 0.2}$
  - For iron at 4.5 K (brittle) $\sigma_1 \leq \sim 200$ MPa

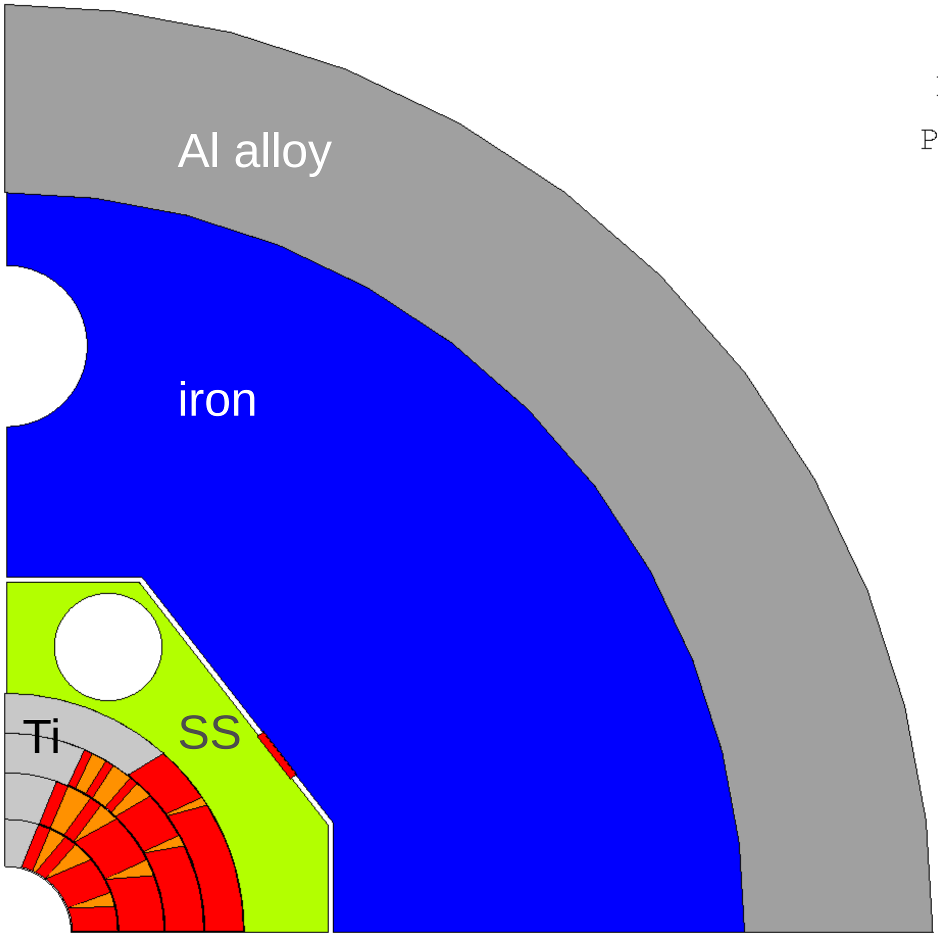
Material	Stress limit (MPa)		E (GPa)		ν	α
	293 K	4.2 K	293 K	4.2 K	293 K /4.2 K	293 K/4.2 K
Coil	150	200	EX=52 EY=44 GXY=21	EX=52 EY=44 GXY=21	0.3	X=$3.1\cdot10^{-3}$ Y=$3.4\cdot10^{-3}$
Austenitic steel 316LN	350	1050	193	210	0.28	$2.8\cdot10^{-3}$
Al 7075	480	690	70	79	0.3	$4.2\cdot10^{-3}$
Ferromagnetic iron	180	720	213	224	0.28	$2.0\cdot10^{-3}$
Pole (Ti6Al4V)	800	1650	130	130	0.3	$1.7\cdot10^{-3}$

Investigated configurations

2-key configuration



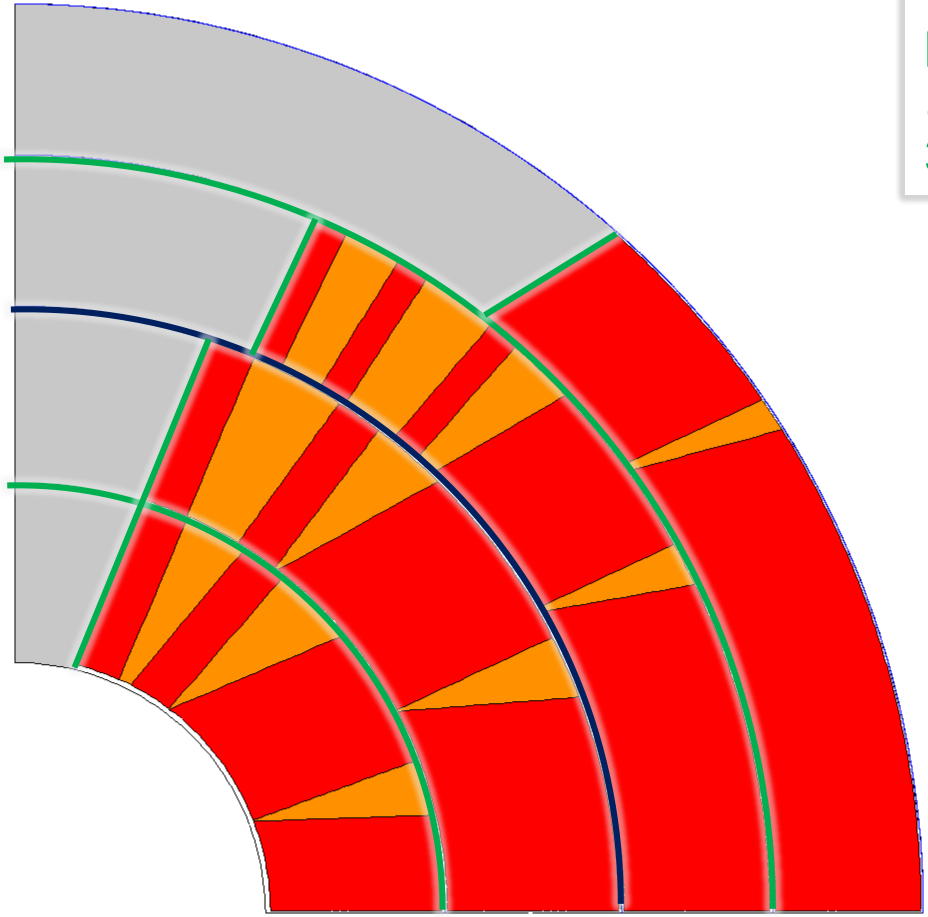
1-key configuration



Red: Winding, Orange: Copper wedges

ANSYS model

- the coil is supposed to be made by 2 pancakes, singularly impregnated
- the impregnation includes the Ti poles



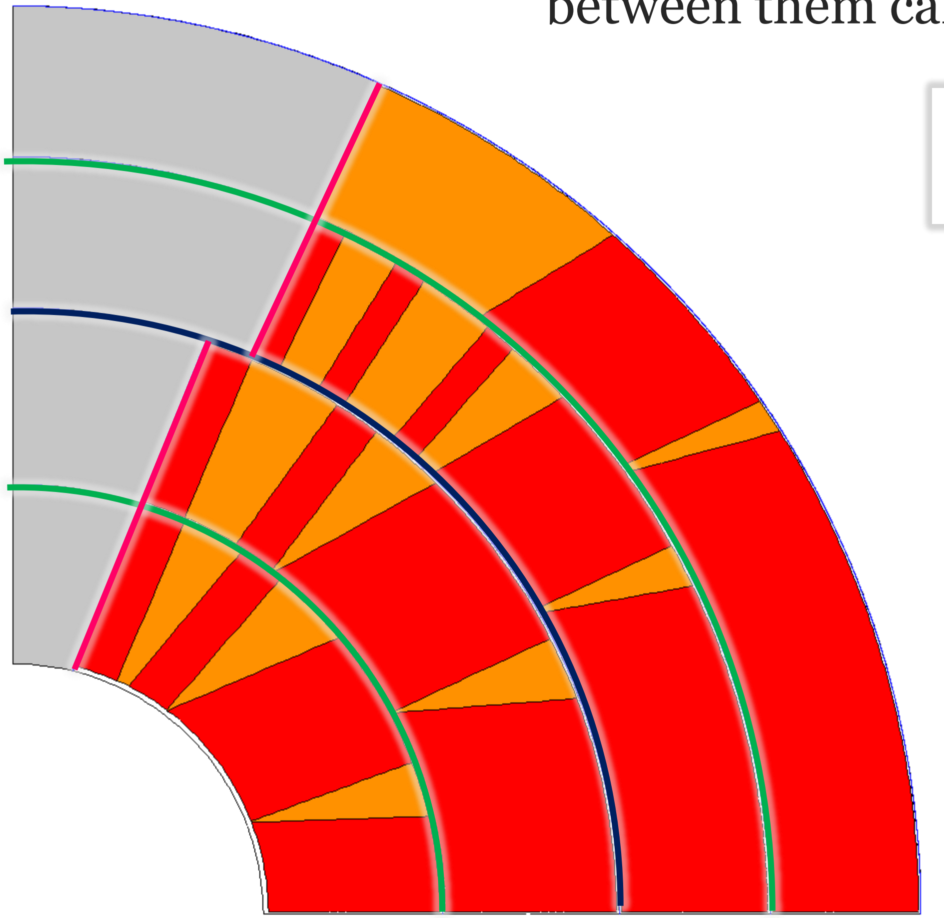
bonded contact:
pole-winding interfaces
1st-2nd layer interface
3rd-4th layer interface

bonded contact
sliding permitted (μ_r=0.2)
1st-2nd pancake interface

- all other contact surfaces are sliding with μ_r=0.2

Pole shimming

- To include pole shims, the Ti pole of each pancake has been aligned introducing a suitable wedge
- Ti poles and winding are no more bonded by impregnation, so contact between them can now be open



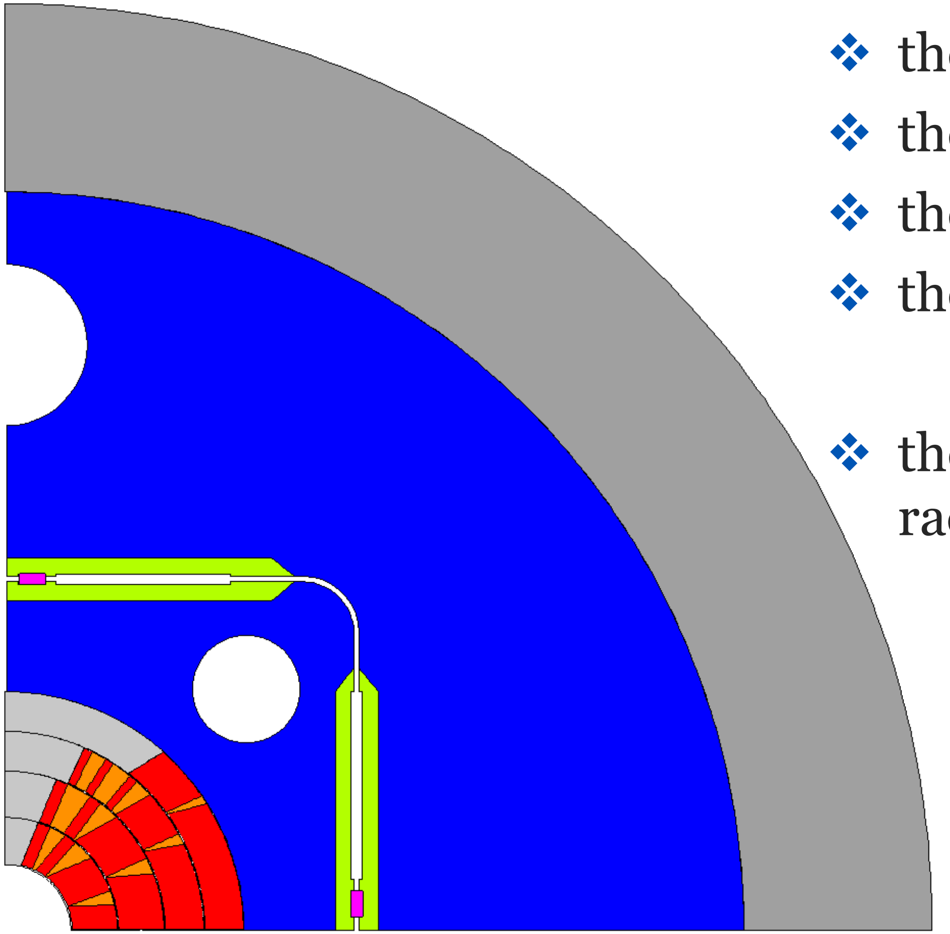
open contact
pole-winding interfaces

bonded contact
1st-2nd layer interface
3rd-4th layer interface

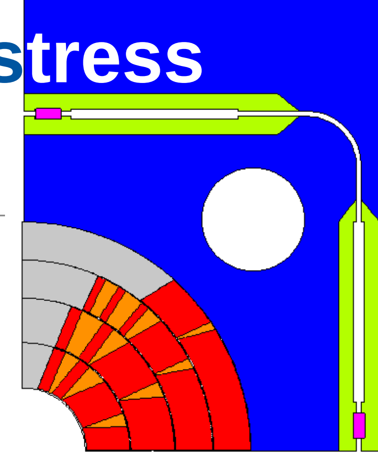
bonded contact
sliding permitted (μ_r=0.2)
1st-2nd pancake interface

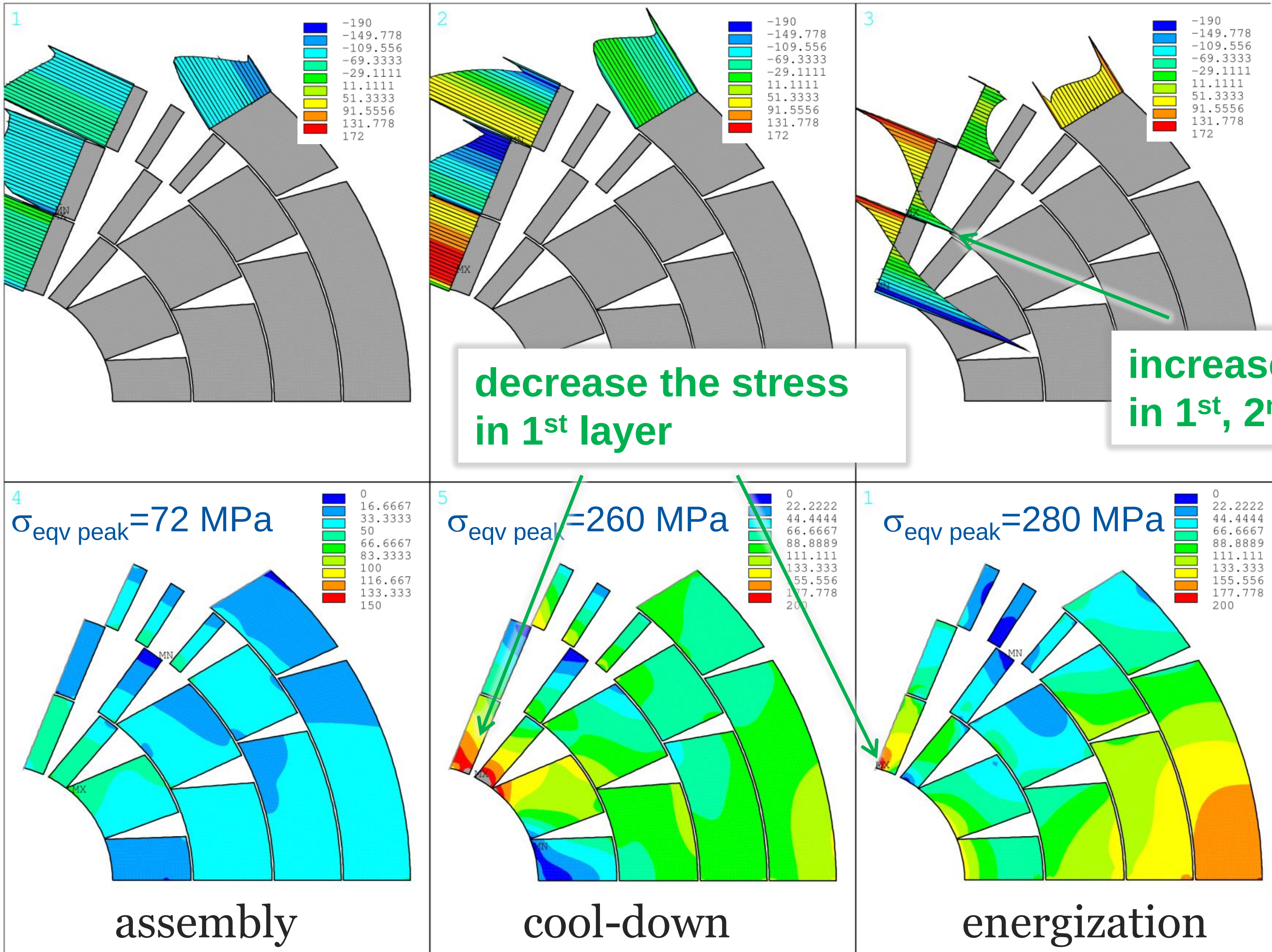
2-key option

- this configuration has been optimized considering the following parameters:
  - the dimension of the pad
  - the position and the length of the key
  - the Al alloy shell thickness
  - the shape of the Ti poles
  - the eventual insertion of shimming
  - the key interference is set to 0.4 mm radially and 0.1 mm vertically



2-key option contact pressure and VM stress

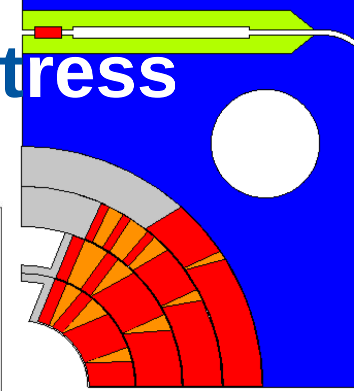


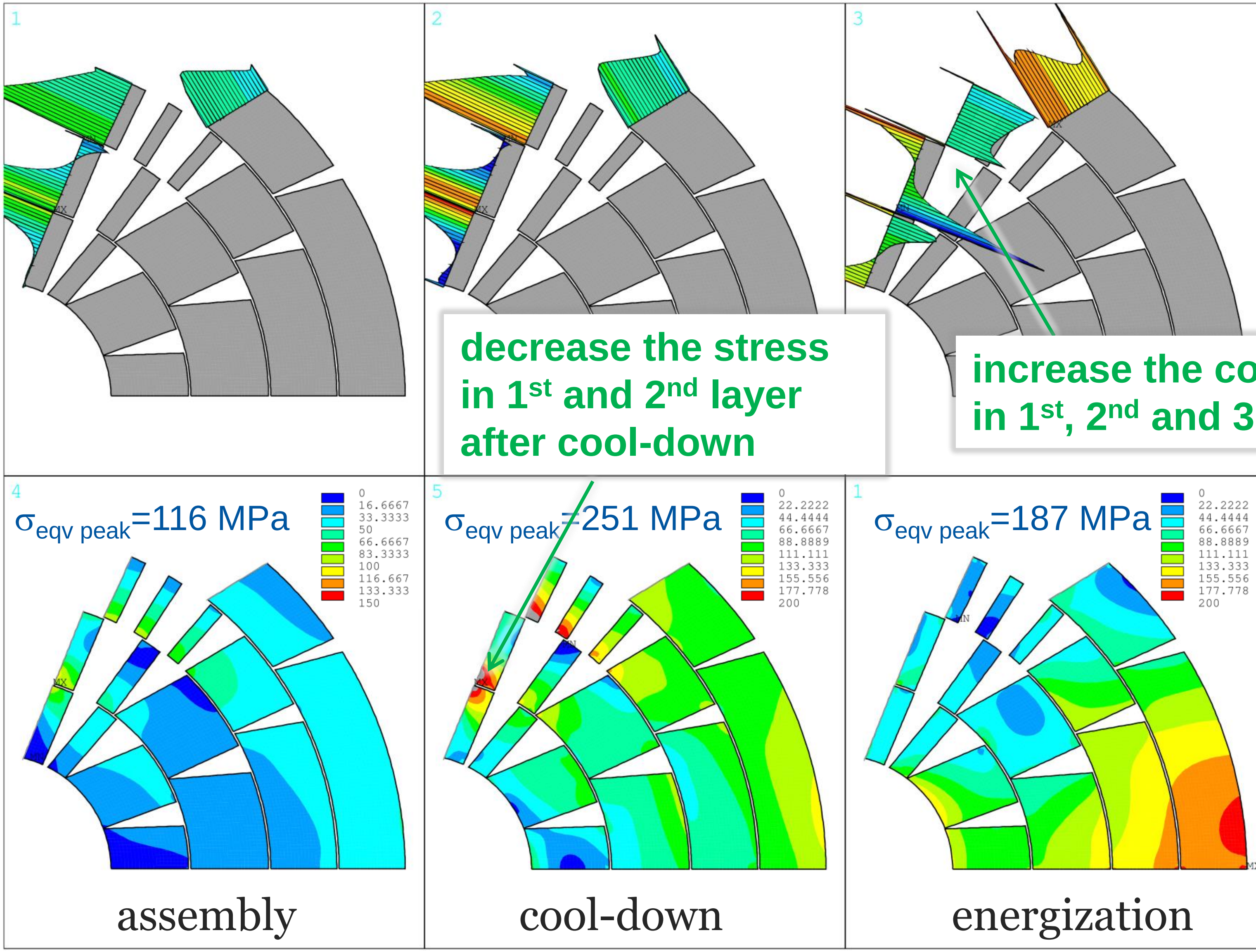


decrease the stress in 1st layer

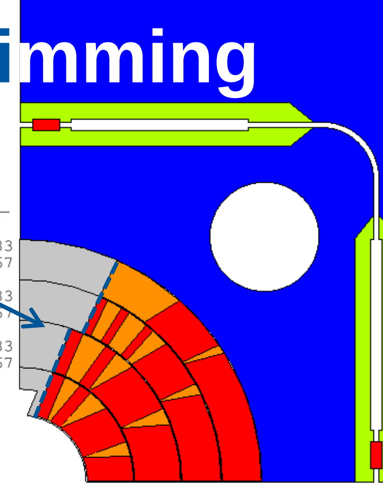
increase the cont. press in 1st, 2nd and 3rd layer

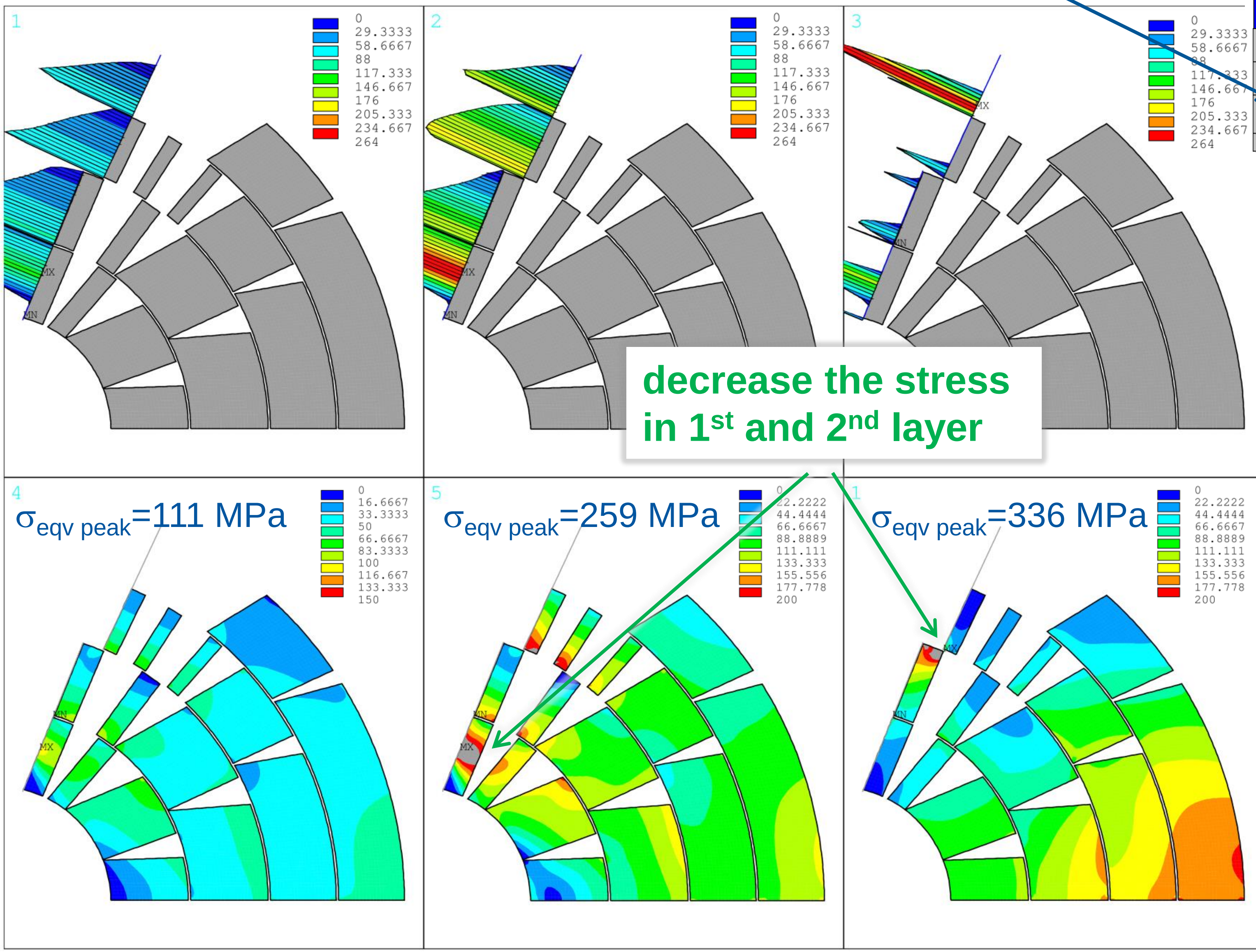
2-key option contact pressure and VM stress Ti pole undercuts





2-key option with ~0.1 mm thick pole shimming

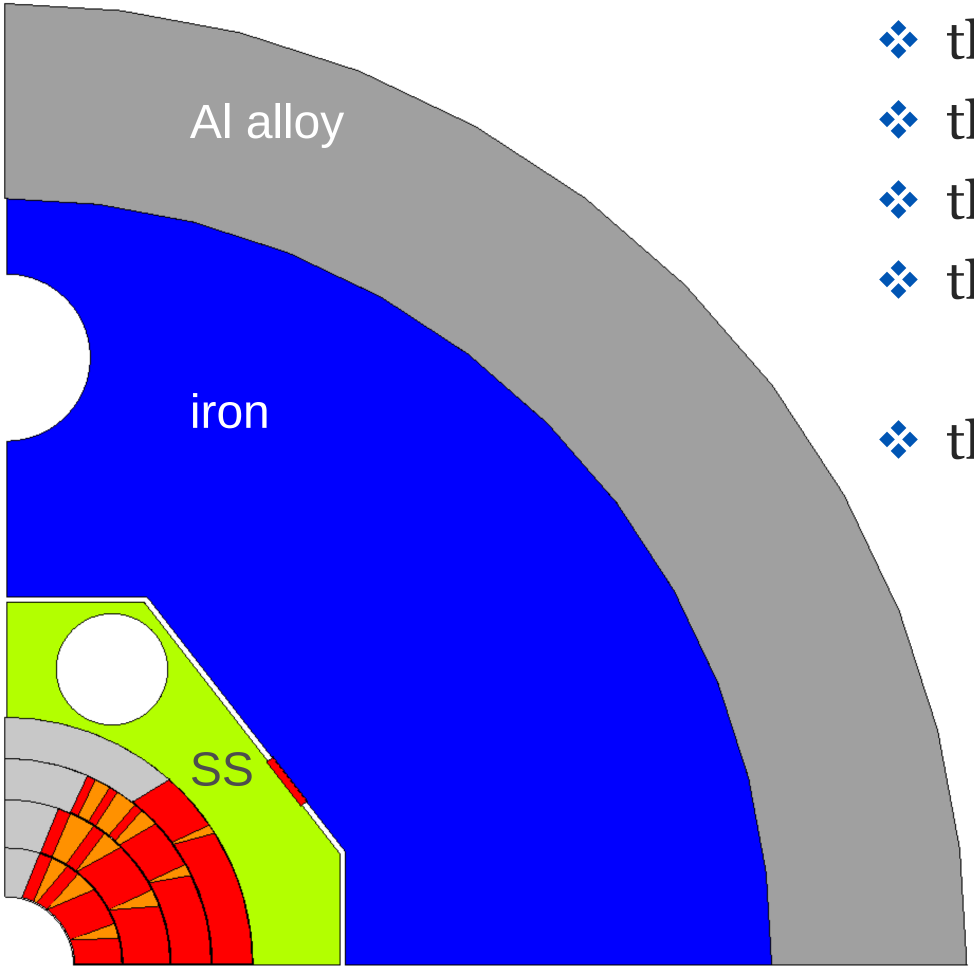




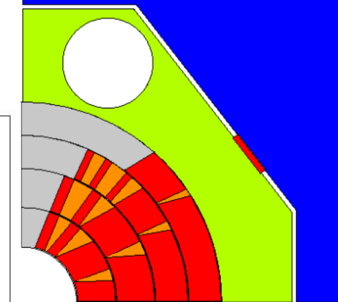
1-key option

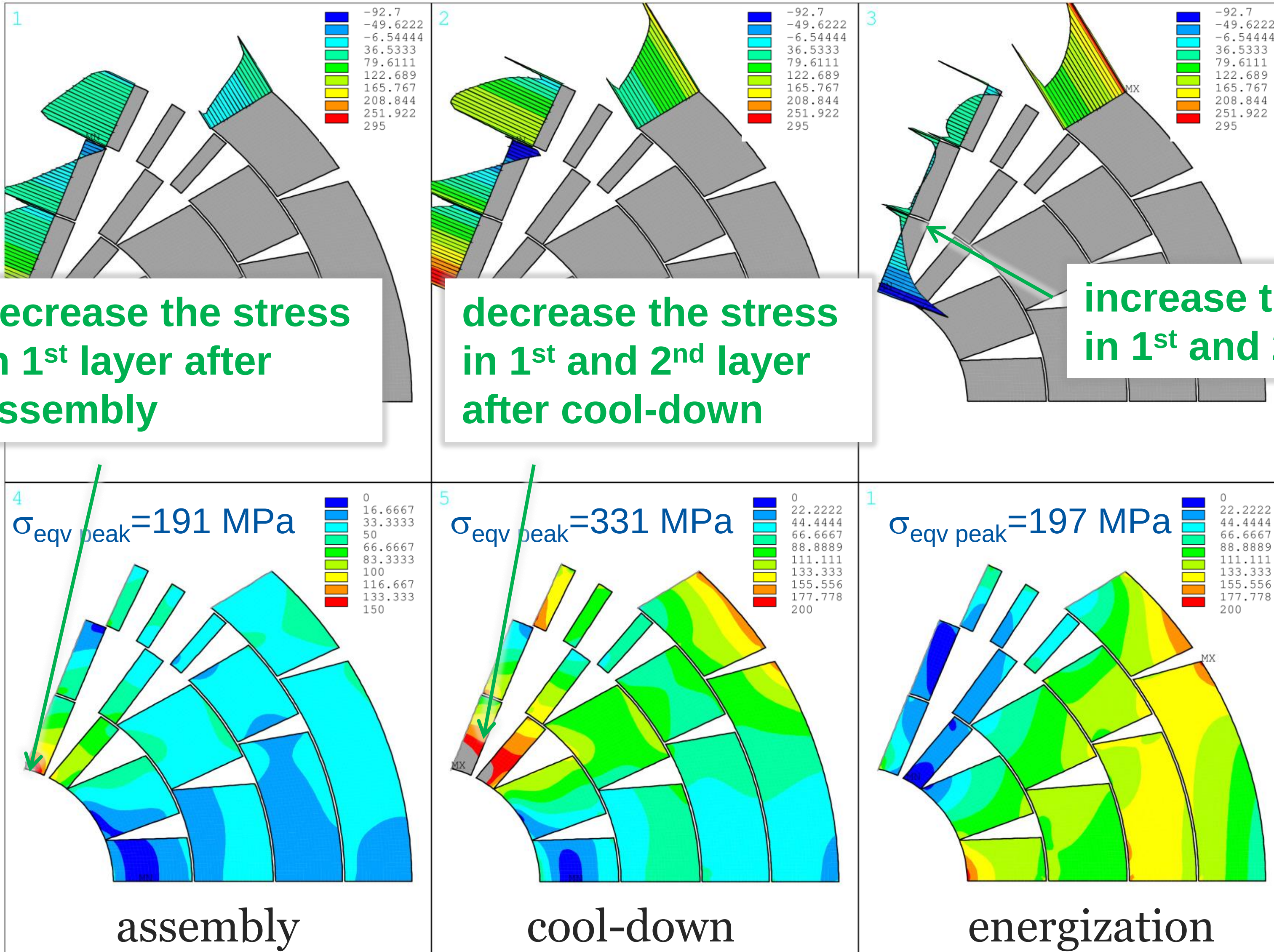
- this configuration has been optimized considering the following parameters:
  - the position of the octagon corners
  - the position and the length of the key
  - the Al alloy shell thickness
  - the shaping of the Ti poles
  - the eventual insertion of shimming

  - the key interference is set to 0.4 mm



1-key option contact pressure and VM stress



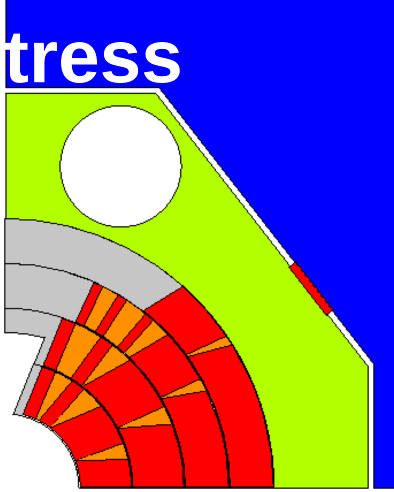


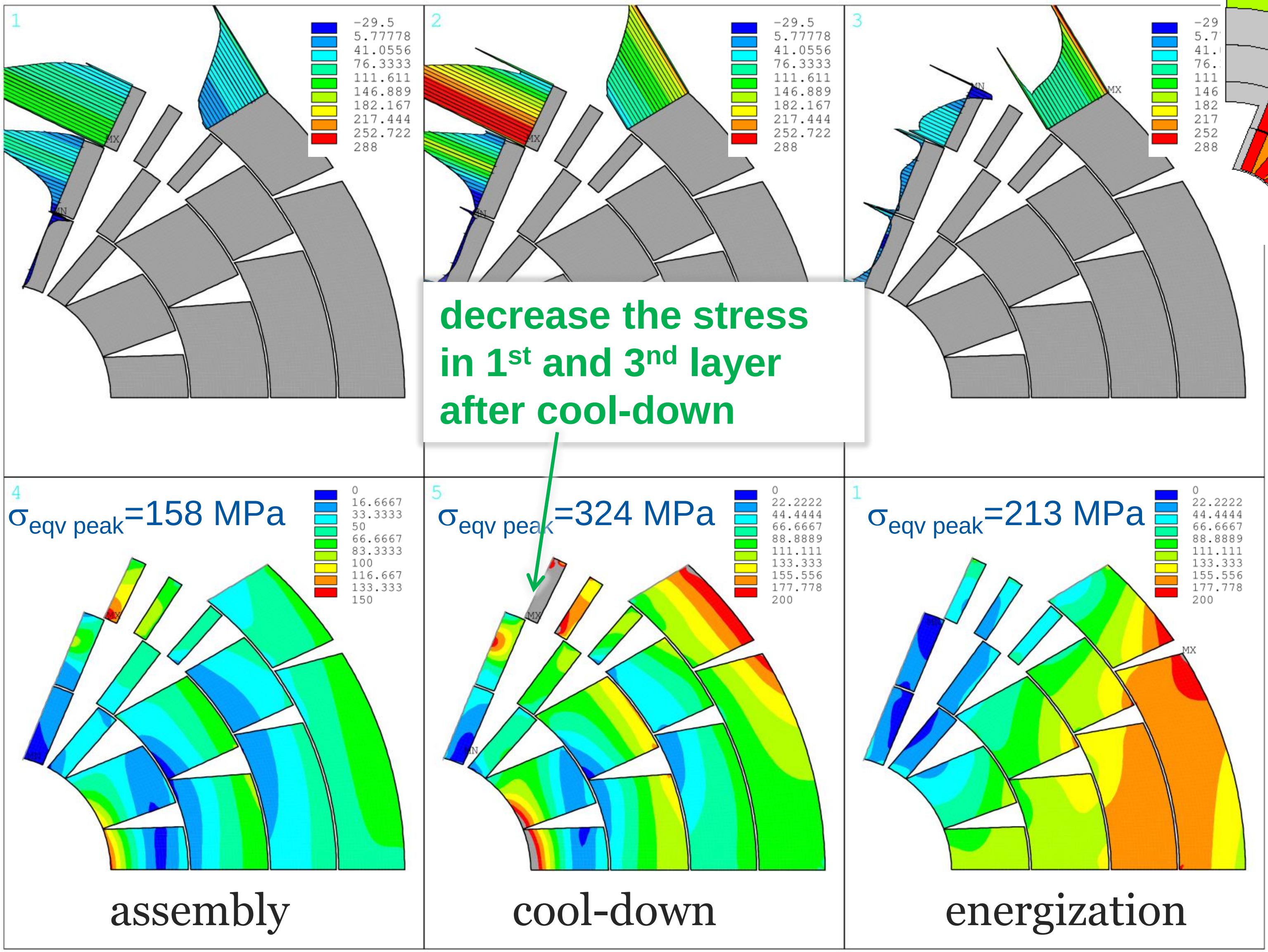
decrease the stress in 1st layer after assembly

decrease the stress in 1st and 2nd layer after cool-down

increase the cont. press. in 1st and 2nd layer

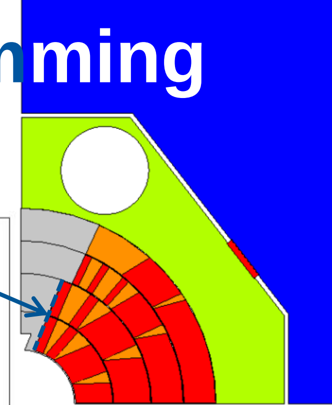
1-key option contact pressure and VM stress Ti pole undercuts

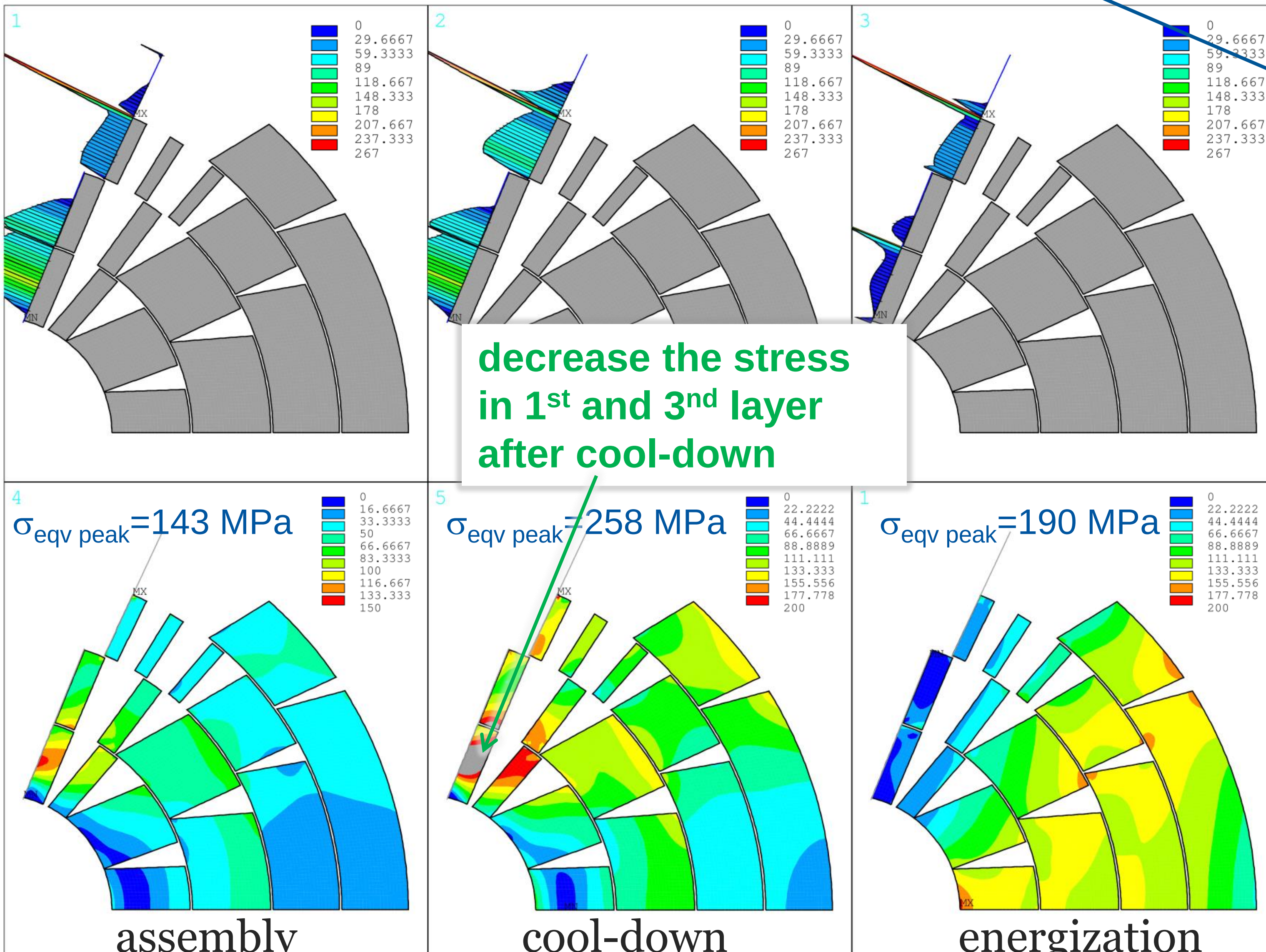




decrease the stress in 1st and 3rd layer after cool-down

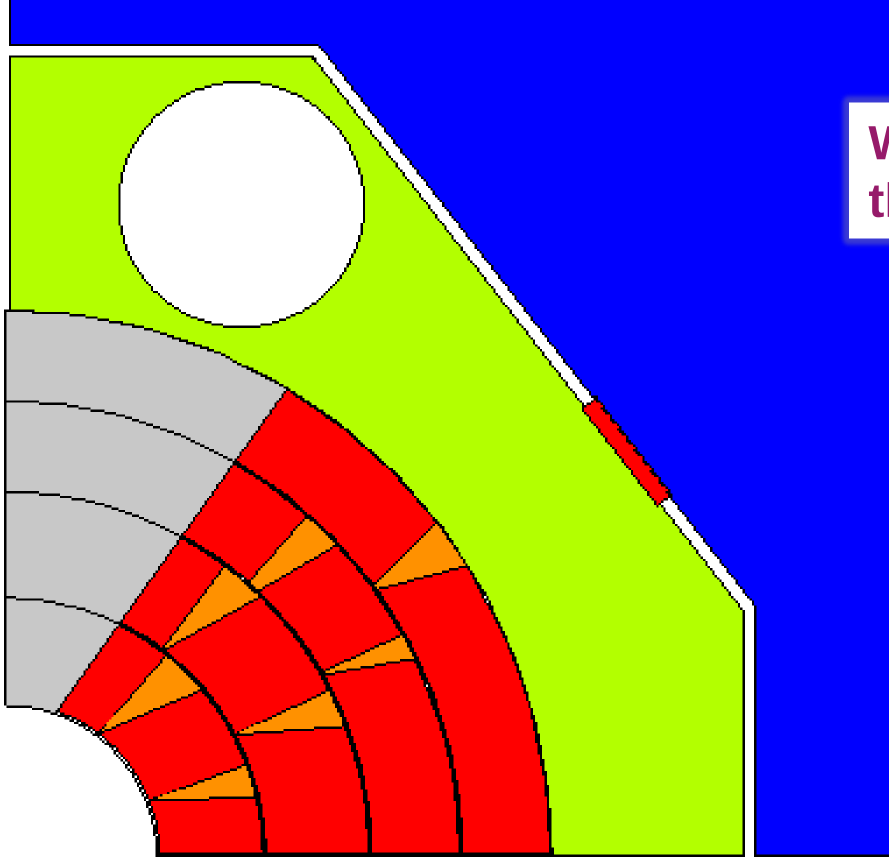
1-key option with 50 μm thick pole shimming





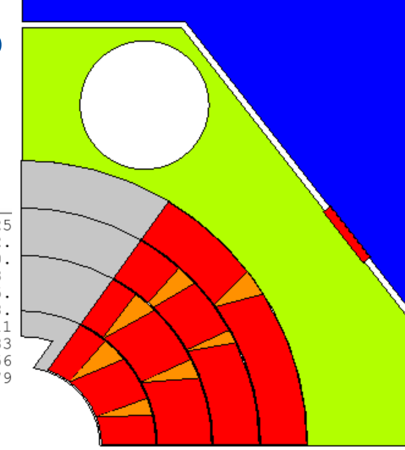
Is there margin for improvement?

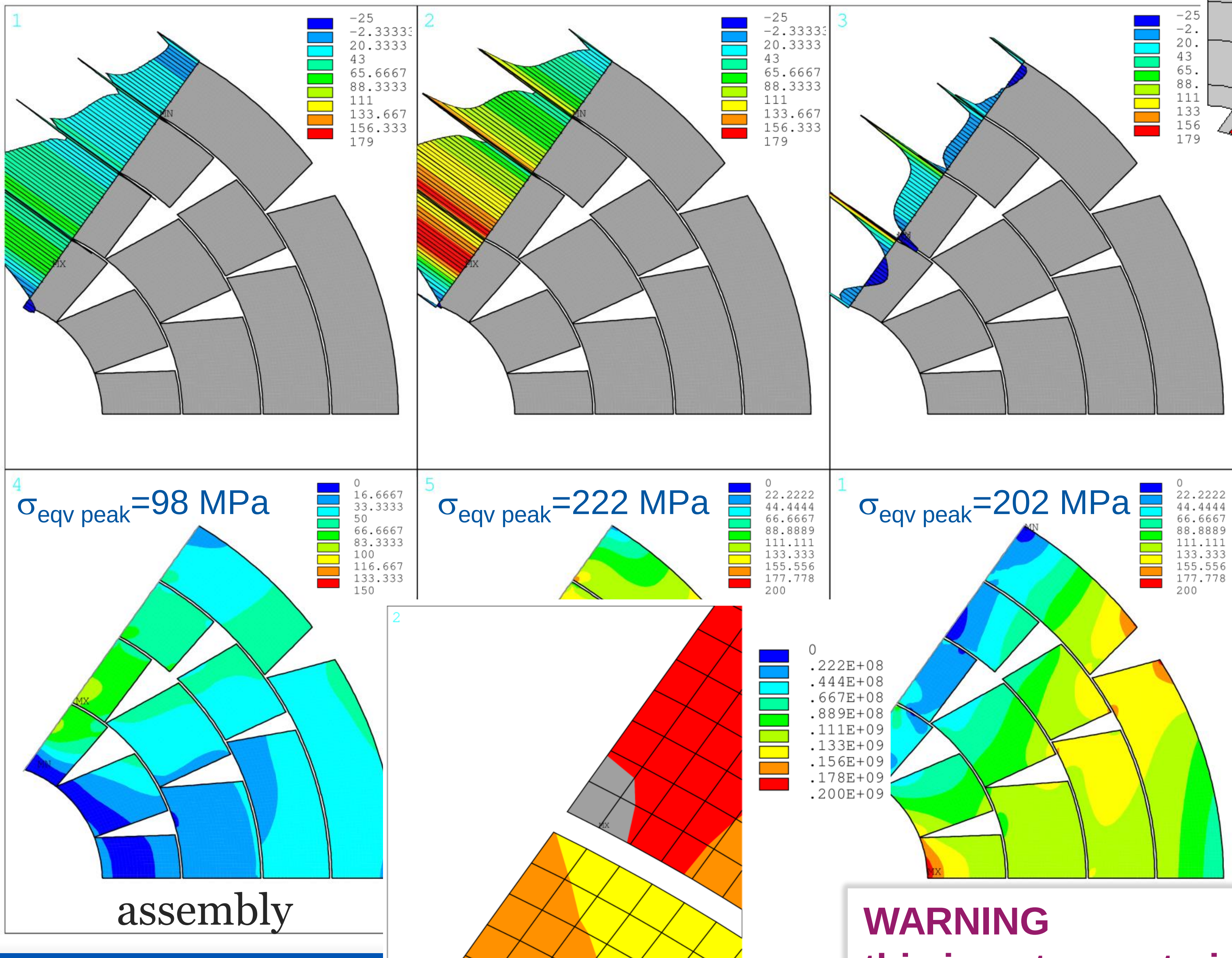
- We made a numerical exercise looking for an ideal solution from a mechanical point of you
- We tried modifying several different parameters, finding that a better solution looks like the following:



WARNING
this is not an optmized e.m. design

Is there margin for improvement?





WARNING
this is not an optmized e.m. design

Final considerations

- The best mechanical structure succeeds in giving appropriate pre-stress to the selected electromagnetic design but overcoming the imposed stress limit (200 MPa @ 4.5 K) in the winding at cool-down
- Better solutions in terms of winding layout do exist, but we still need to clarify if they are feasible from an electromagnetic point of view (they imply to decrease the margin ➔ decrease the number of turns)
- In general, being near the feasibility limit for this kind of structure, we have found that very small geometrical variations can cause big variations of both stress peak in winding and contact pressure. Warning: the solution is hard to be found and unstable.

Thank you for your attention