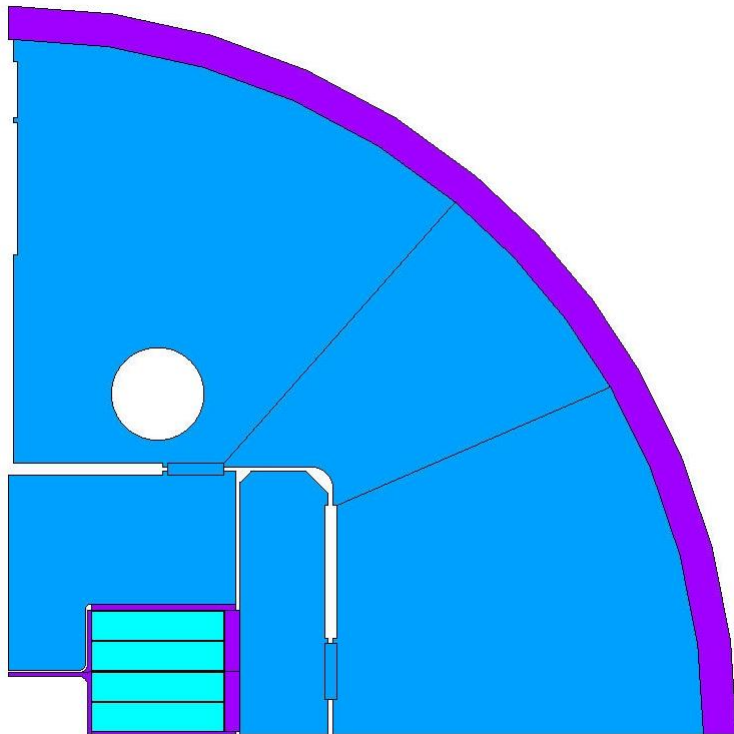


# **EDIPO: Alternative design with detachable poles**

**X. Sarasola**

**June 4<sup>th</sup>, 2020**



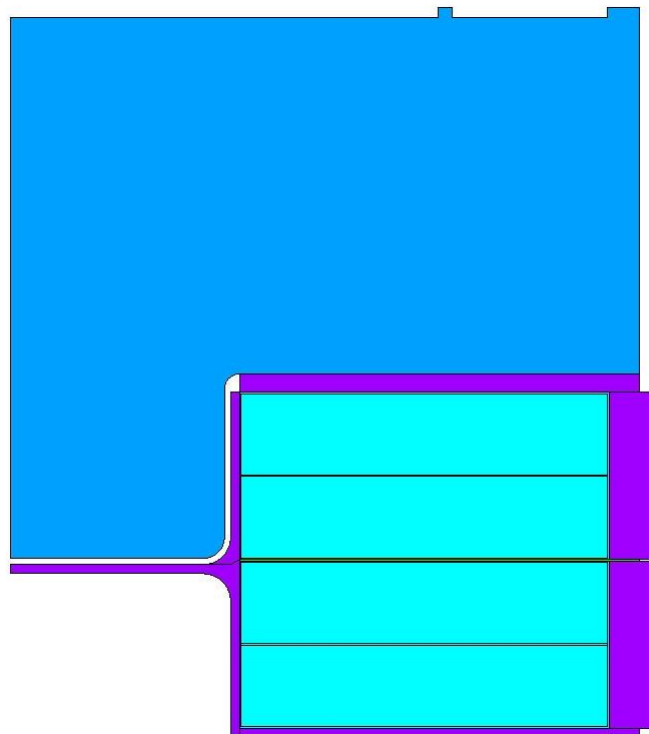
## ■ Changes in the 2D design:

- **Yoke outer radius** increases from 560 to 630 mm
- Thickness of the **steel shell** is reduced from 70 to **30 mm**
- Adjustments in the contacts and boundary conditions in order to:
  - Make the **test well stress-free** during operation
  - **Reduce the stress in the coils**
- Modifications to reduce the principal stress in the vertical pad/iron insert

# Alternative design without titanium pole

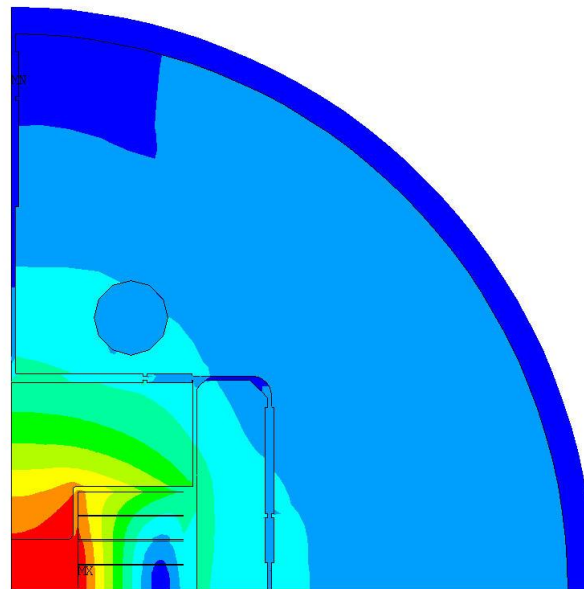
- **Changes in the 2D design:**

- **Yoke outer radius** increases from 560 to 630 mm
- Thickness of the **steel shell** is reduced from 70 to **30 mm**
- Adjustments in the contacts and boundary conditions in order to:
  - Make the **test well stress-free** during operation
  - **Reduce the stress in the coils**
- Modifications to reduce the principal stress in the vertical pad/iron insert



- The increase in the yoke outer radius leads to a modest gain in the field or a small reduction in the required number of turns to generate 15 T:  
**now 51 turns/pancake**

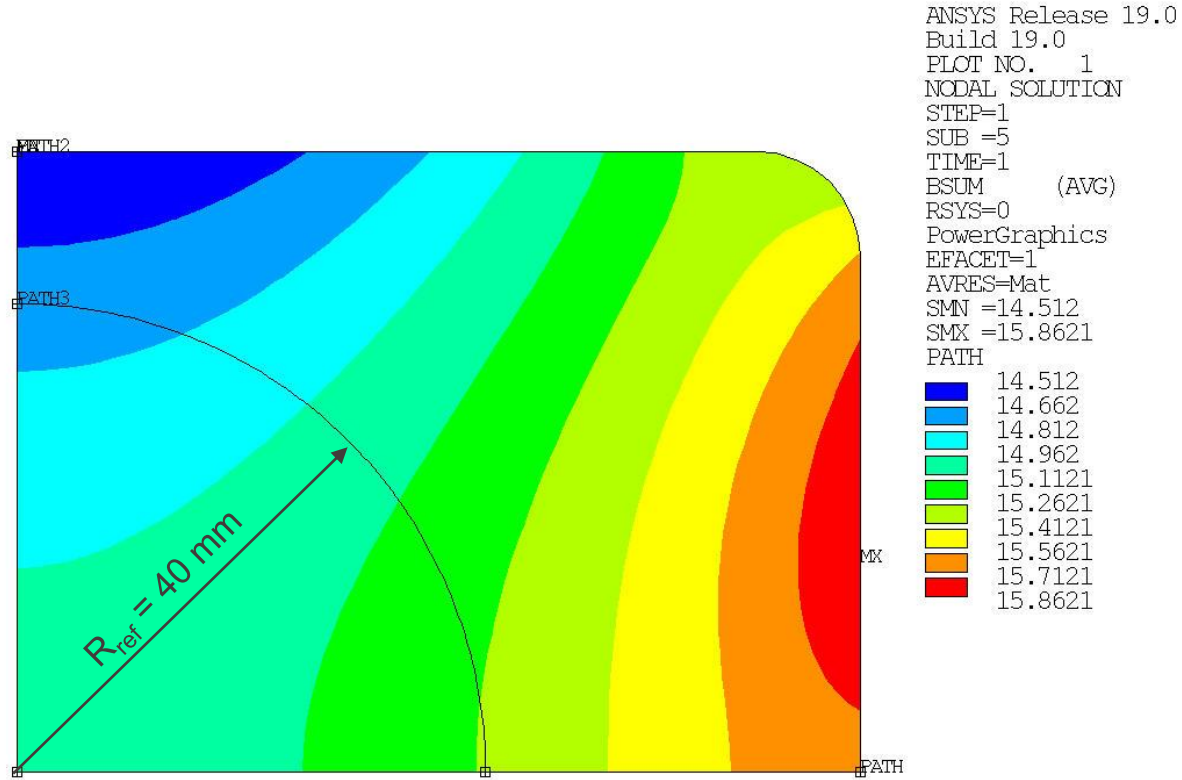
Test well thickness (mm)	3.0
# turns/pancake	51
Ins conductor area (mm <sup>2</sup> )	13002
$I_{op} = 0.85 \times I_{ss}$ (kA)	11.66
$B_{coil}$ (T)	15.98
$B_{center\ aperture}$ (T)	15.01



ANSYS Release 19.0  
 Build 19.0  
 PLOT NO. 1  
 NODAL SOLUTION  
 STEP=1  
 SUB =5  
 TIME=1  
 ESUM (AVG)  
 RSY=0  
 PowerGraphics  
 EFACET=1  
 AVRES=Mat  
 SMN =.568E-03  
 SMX =15.981  
 .568E-03  
 1.77618  
 3.55178  
 5.32739  
 7.103  
 8.87861  
 10.6542  
 12.4298  
 14.2054  
 15.981

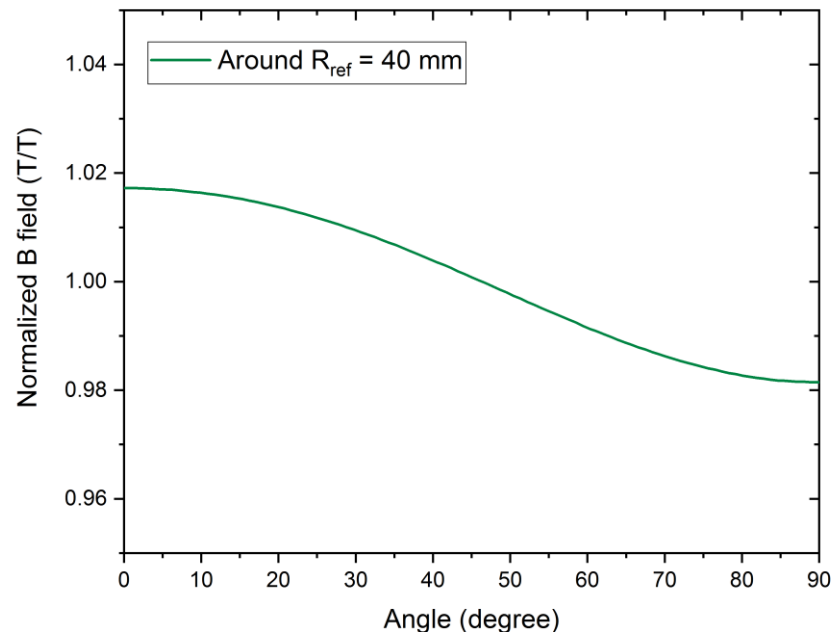
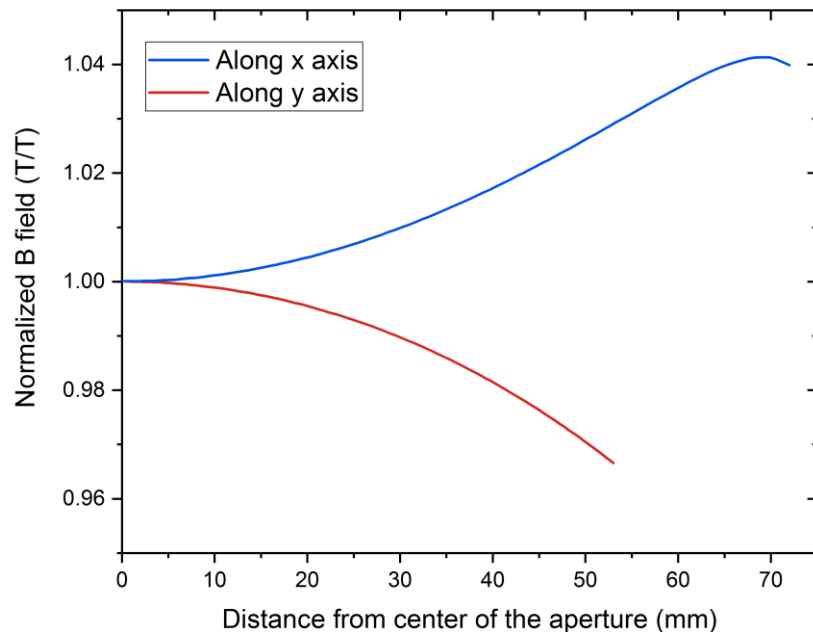
EDIPO, magnetic model

# Magnetic model – field quality



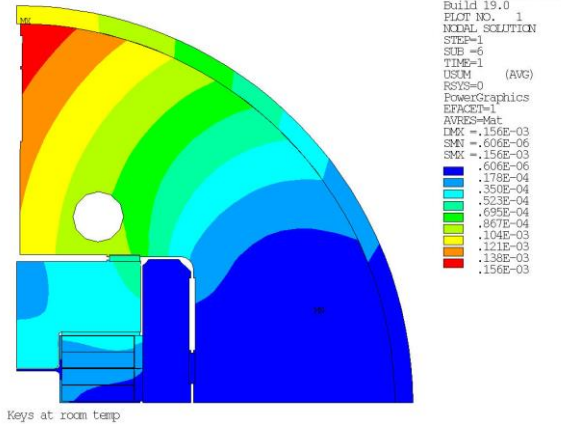
# Magnetic model – field quality

- Along x and y axis:  $\pm 4\%$
- Around a circumference of  $R_{\text{ref}} = 40$  mm:  $\pm 2\%$

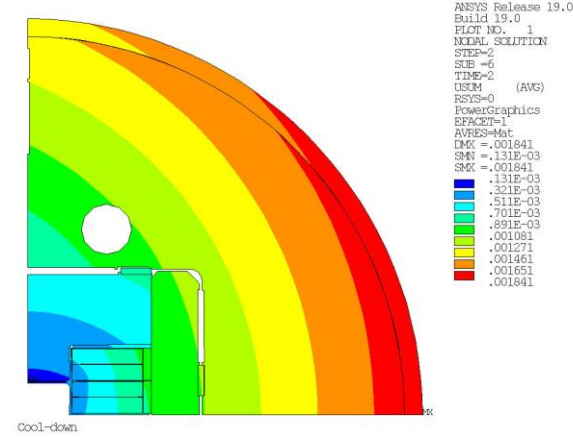


- During powering of the magnet, the iron parts experience forces in the directions highlighted by the arrows in the bottom right plot.

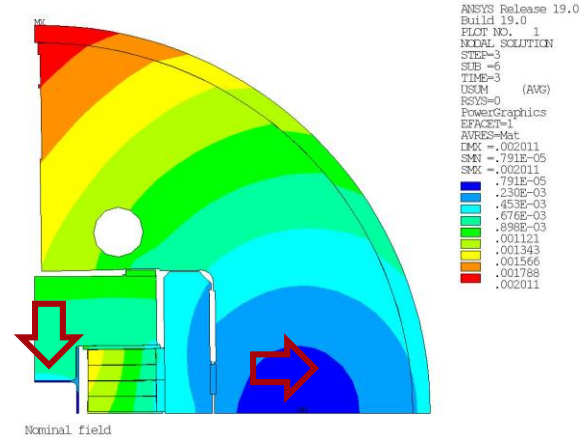
## 1. Room temp



## 2. Cool-down

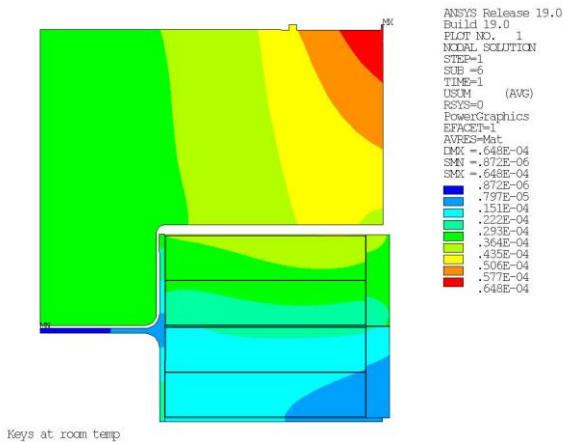


## 3. Nominal field

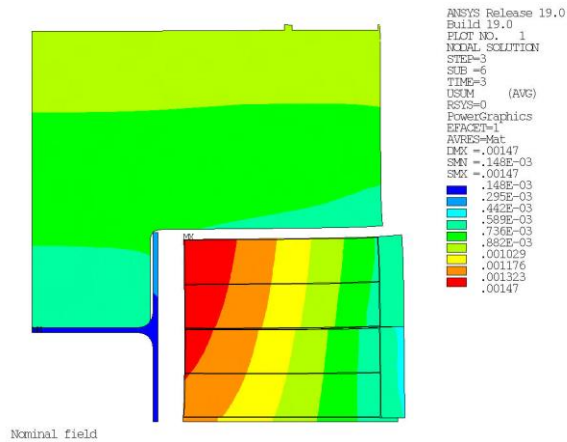


# Mechanical model - Deformation (zoom)

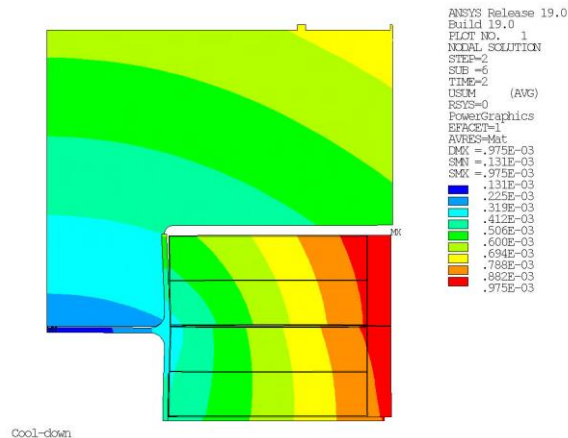
## 1. Room temp



## 3. Nominal field



## 2. Cool-down

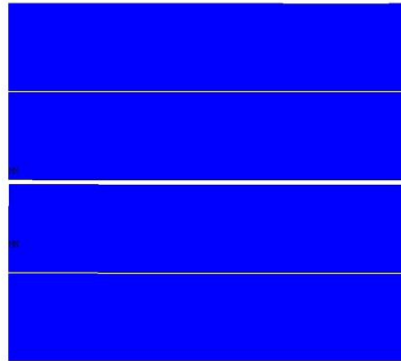




# Stress in the coils (von Mises)

- Coils are essentially stress-free at room temperature (small lateral interference) and after cool down (shell is made of steel)
- After powering the **von Mises stress** remains **below 121 MPa**

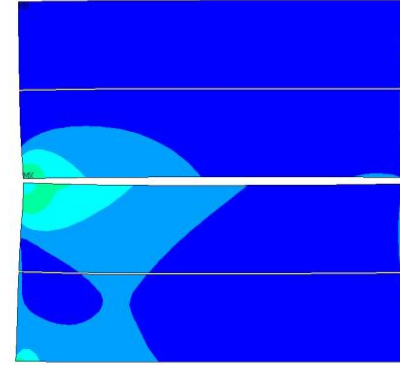
## 1. Room temp



Keys

ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=1  
SUB =6  
TIME=1  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =0  
SMN =.531E+07  
SMX =.101E+08  
0  
.133E+08  
.267E+08  
.400E+08  
.533E+08  
.667E+08  
.800E+08  
.933E+08  
.107E+09  
.120E+09

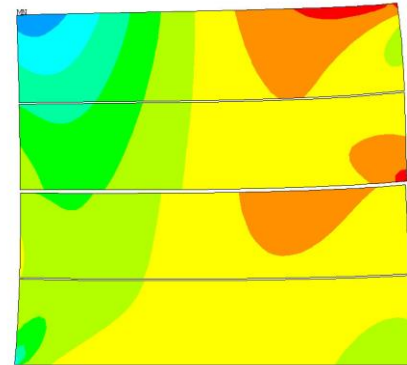
## 2. Cool-down



Cool-down

ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=2  
SUB =6  
TIME=2  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =0  
SMN =22925.7  
SMX =.498E+08  
0  
.133E+08  
.267E+08  
.400E+08  
.533E+08  
.667E+08  
.800E+08  
.933E+08  
.107E+09  
.120E+09

## 3. Nominal field



Nominal field

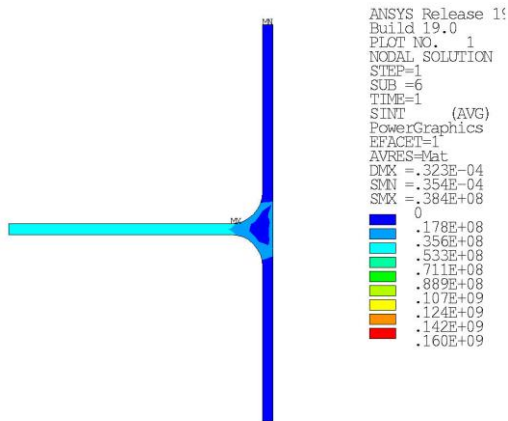
ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=3  
SUB =6  
TIME=3  
SEQV (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =0  
SMN =.164E+08  
SMX =.121E+09  
0  
.133E+08  
.267E+08  
.400E+08  
.533E+08  
.667E+08  
.800E+08  
.933E+08  
.107E+09  
.120E+09

# Stress in the test well

- The test well is stress-free during operation

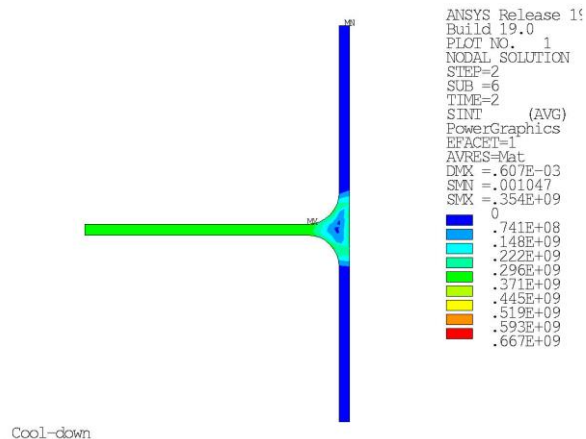
Load step	Membrane (MPa)	Memb+bend (MPa)
Room temp	36	37
Cool-down	337	339
Nom. field	1	3.3

## 1. Room temp



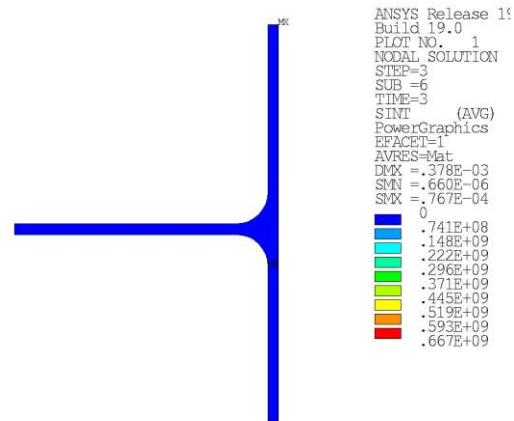
Keys

## 2. Cool-down



Cool-down

## 3. Nominal field

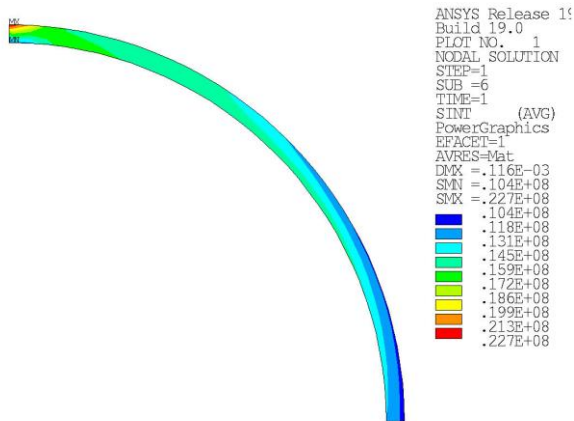


Nominal field

# Stress in the steel shell

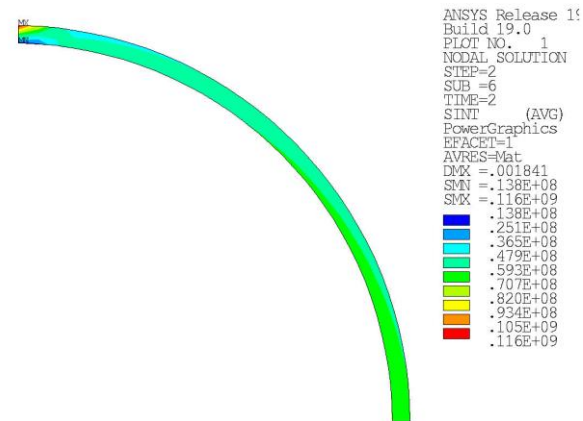
- The stress in the shell is always below allowable, despite of the reduction in thickness.

## 1. Room temp

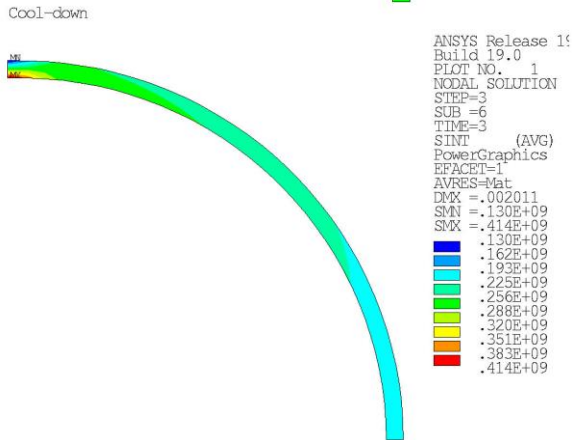


Keys

## 2. Cool-down



## 3. Nominal field

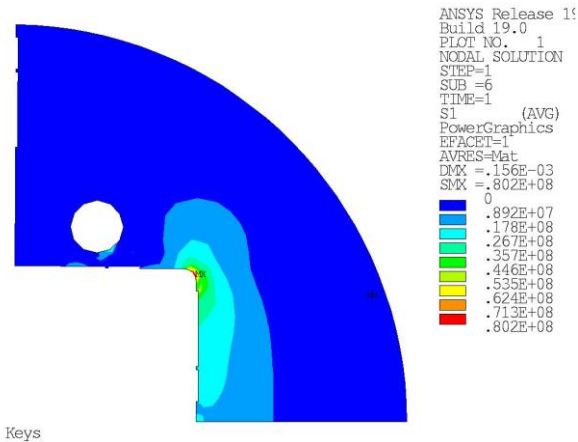


Nominal field

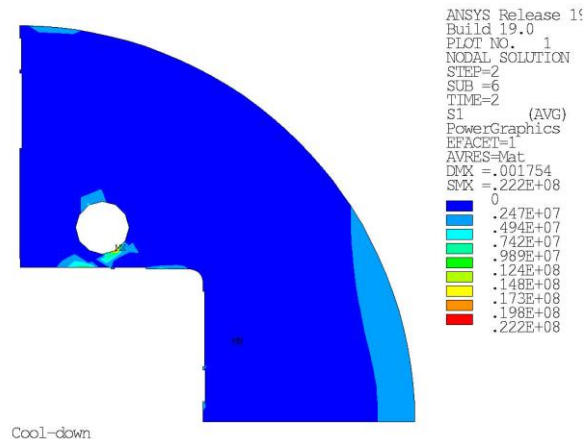
# Stress in the iron yoke

- Iron yoke satisfies stress criteria

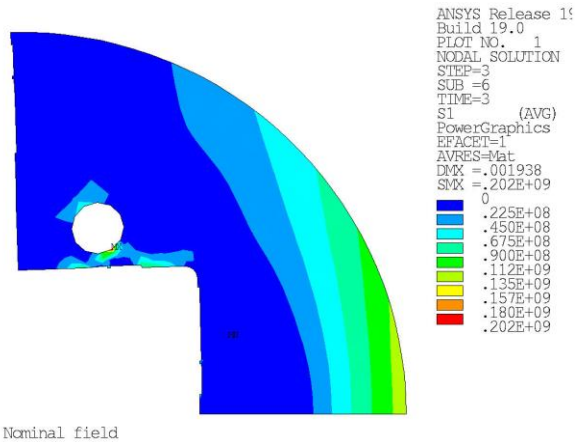
1. Room temp



2. Cool-down



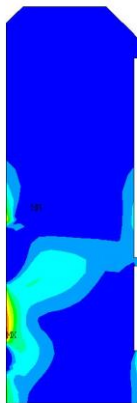
3. Nominal field



# Stress in the horizontal pad

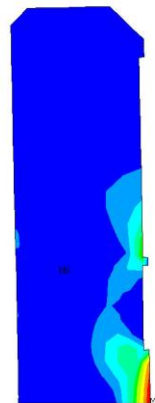
- H pad satisfies stress criteria

## 1. Room temp



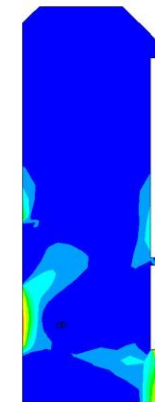
ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=1  
SUB =6  
TIME=1  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.106E-04  
SMX =.371E+07  
0  
411938  
823876  
.124E+07  
.165E+07  
.206E+07  
.247E+07  
.288E+07  
.330E+07  
.371E+07

## 3. Nominal field



ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=3  
SUB =6  
TIME=3  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.608E-03  
SMX =.183E+09  
0  
.203E+08  
.406E+08  
.609E+08  
.812E+08  
.101E+09  
.122E+09  
.142E+09  
.162E+09  
.183E+09

## 2. Cool-down



ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=2  
SUB =6  
TIME=2  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.001153  
SMX =.144E+08  
0  
.160E+07  
.319E+07  
.479E+07  
.638E+07  
.798E+07  
.958E+07  
.112E+08  
.128E+08  
.144E+08

Nominal field

Cool-down

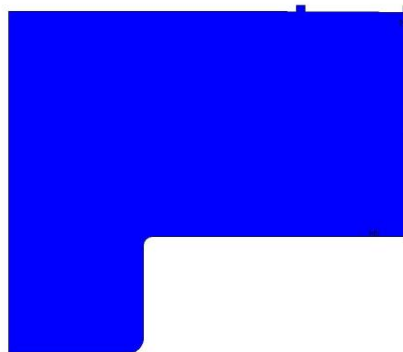
Keys

# Stress in the vertical pad + iron insert

- Parameters varied to reduce the max principal stress:

- Location of the vertical key
- Interference of the vertical key
- Tapering of the surface in contact with the coils

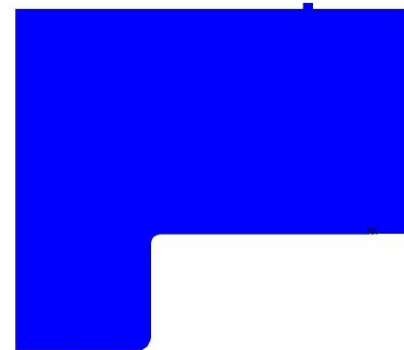
## 1. Room temp



ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=1  
SUB =6  
TIME=1  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =0  
SMX =.172E+08  
0  
.200E+08  
.400E+08  
.600E+08  
.800E+08  
.100E+09  
.120E+09  
.140E+09  
.160E+09  
.180E+09

Keys

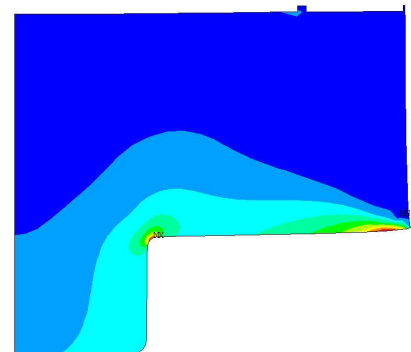
## 2. Cool-down



ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=2  
SUB =6  
TIME=2  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =0  
SMX =.169E+08  
0  
.422E+08  
.844E+08  
.127E+09  
.169E+09  
.211E+09  
.253E+09  
.296E+09  
.338E+09  
.380E+09

Cool-down

## 3. Nominal field



ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=3  
SUB =6  
TIME=3  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =0  
SMX =.395E+09  
0  
.422E+08  
.844E+08  
.127E+09  
.169E+09  
.211E+09  
.253E+09  
.296E+09  
.338E+09  
.380E+09

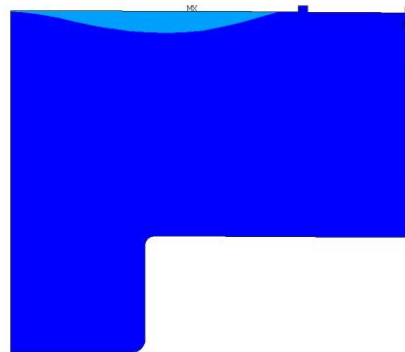
Nominal field

# Stress in the vertical pad + iron insert

- Parameters varied to reduce the max principal stress:

- Location of the vertical key
- Interference of the vertical key
- Tapering of the surface in contact with the coils**

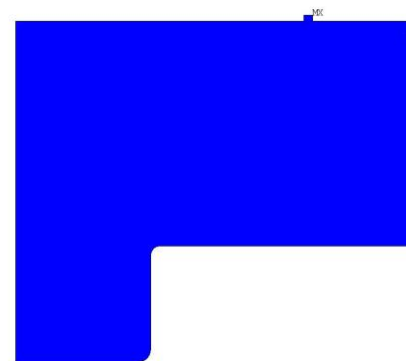
## 1. Room temp



Keys

ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=1  
SUB =6  
TIME=1  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =0  
SMX =.275E+08  
0  
.200E+08  
.400E+08  
.600E+08  
.800E+08  
.100E+09  
.120E+09  
.140E+09  
.160E+09  
.180E+09

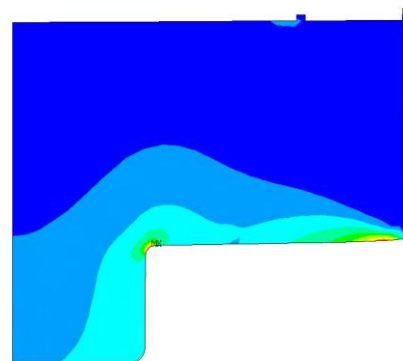
## 2. Cool-down



Cool-down

ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=2  
SUB =6  
TIME=2  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =0  
SMX =.654E+07  
0  
.422E+08  
.844E+08  
.127E+09  
.169E+09  
.211E+09  
.253E+09  
.296E+09  
.338E+09  
.380E+09

## 3. Nominal field



Nominal field

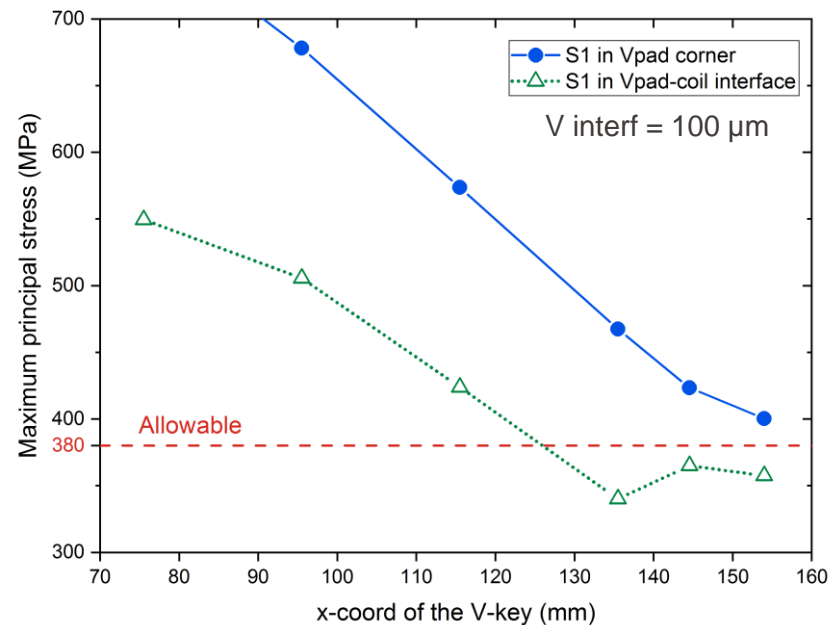
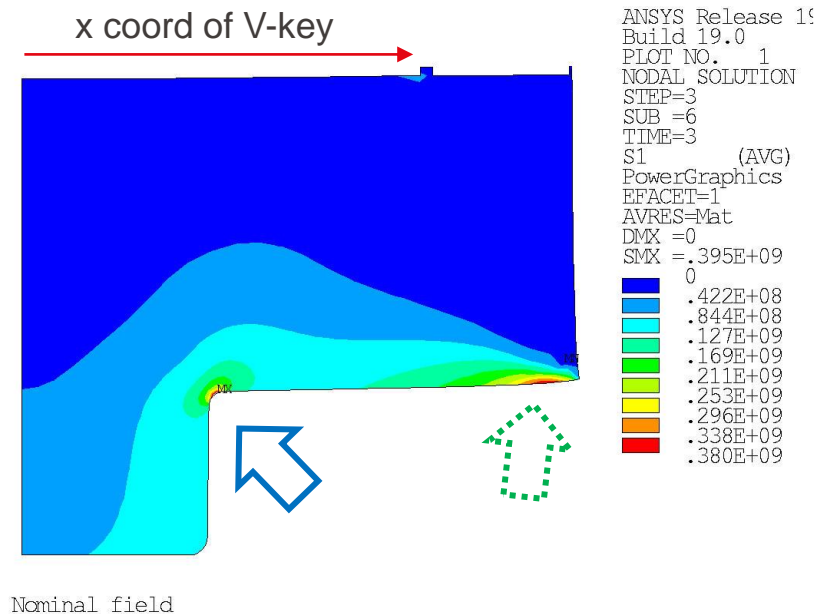
ANSYS Release 15  
Build 19.0  
PLOT NO. 1  
NODAL SOLUTION  
STEP=3  
SUB =6  
TIME=3  
S1 (AVG)  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =0  
SMN =.222E+07  
SMX =.347E+09  
0  
.422E+08  
.844E+08  
.127E+09  
.169E+09  
.211E+09  
.253E+09  
.296E+09  
.338E+09  
.380E+09

- The use of **detachable poles** and the **elimination of the Ti pole** result in a **more efficient coil design**
- **The field quality** in the aperture **is not excellent, but acceptable**:
  - Along x and y axis:  $\pm 4\%$
  - Around  $R_{\text{ref}} = 40 \text{ mm}$ :  $\pm 2\%$
- **Stress in the coils is always below 121 MPa**
- The **test well** is **stress-free** during operation
  - **A gap** of  $< 1.5 \text{ mm}$  **opens** between coils and test well (this can be reduced by increasing the lateral pre-compression)
- The stress in the steel shell is acceptable (despite of a  $> 50\%$  reduction in thickness)
- Issues of peak of maximum principal stress in the vertical pad can be managed

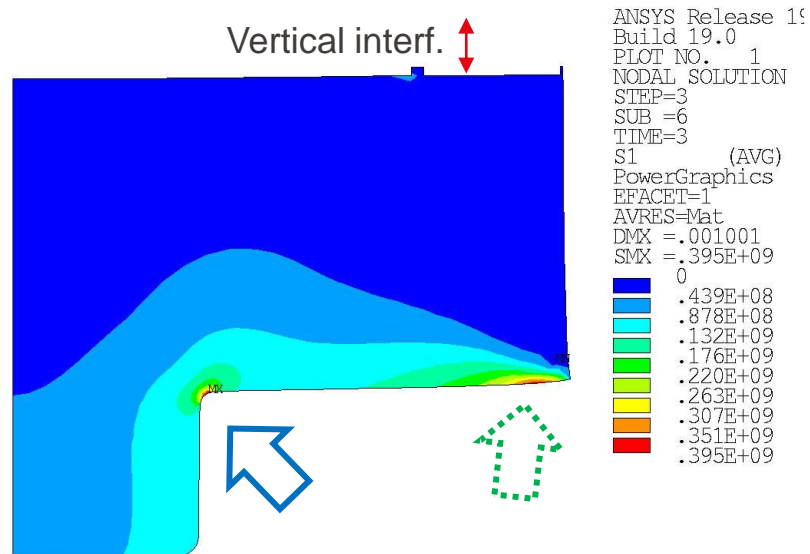


**Additional slides**

# Stress in the vertical pad + iron insert



# Stress in the vertical pad + iron insert



Nominal field

