

**EDIPO 2**  
**Staggered racetracks**  
**3D magnetic analysis**

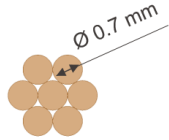
**X. Sarasola**

February 13<sup>th</sup>, 2024

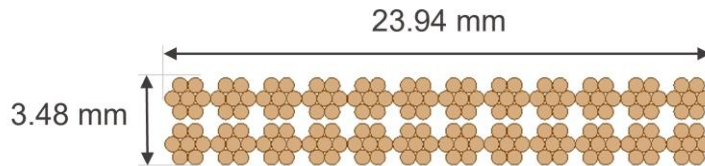
# Cable design

- Bruker strand:
  - $j_{c,nc} = 2600 \text{ A/mm}^2$  at 12 T and 4.2 K
  - Cu:nCu = 1.0
- Same cable used for all coils

- First stage:

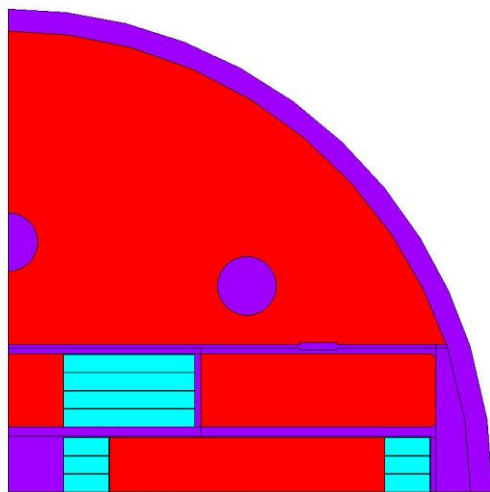


- Second stage:  $24 \times (6+1)$ , 0.7 mm

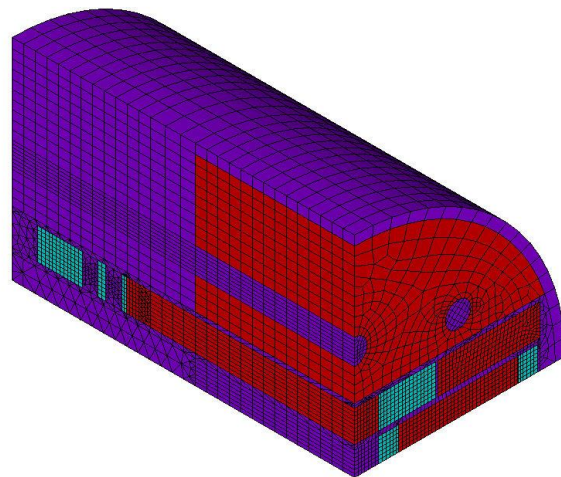


# Magnet design

- 144×144 mm<sup>2</sup> aperture
- Two sets of flat racetrack coils:
  1. Side coils: one pair of coils each made of 6 pancakes: 16 turns/pancake
  2. Vertical coils: one pair of coils each made of 4 pancakes: 46 turns/pancake
- Iron parts in red: iron yoke limited to the straight section of the side coils
- 50 mm wide spacers at the coils' ends



EDIPO, magnetic 2D model

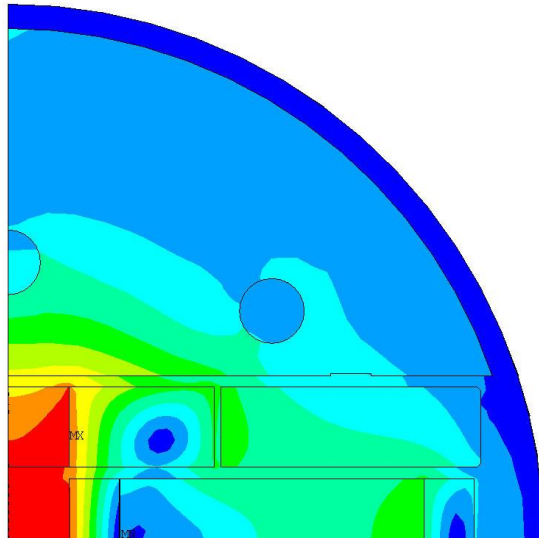


EDIPO, magnetic 3D model

# Comparison 3D vs 2D

	3D	2D
$I_{op}$ (85% $\times I_{ss}$ )	17.410 kA	17.316 kA
$B_{center\ aperture}$	15.01 T	15.03 T
$B_{coil}$	15.04 T	15.07 T
$E_{total}$	19.7 MJ	11.4 MJ/m

## Magnetic 3D model



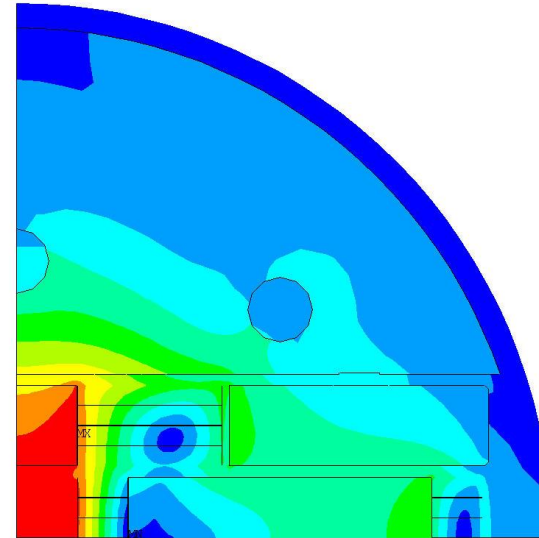
```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
BSUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.011064
SMX =16.5334
0 1.84688
1 3.6827
2 5.51852
3 7.35434
4 9.19016
5 11.026
6 12.8618
7 14.6976
8 16.5334

```

EDIPO, magnetic 3D model

## Magnetic 2D model



```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =5
TIME=1
BSUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.01
SMX =16.55
0 1.83
1 3.67
2 5.5
3 7.33
4 9.17
5 11
6 12.83
7 14.67
8 16.5

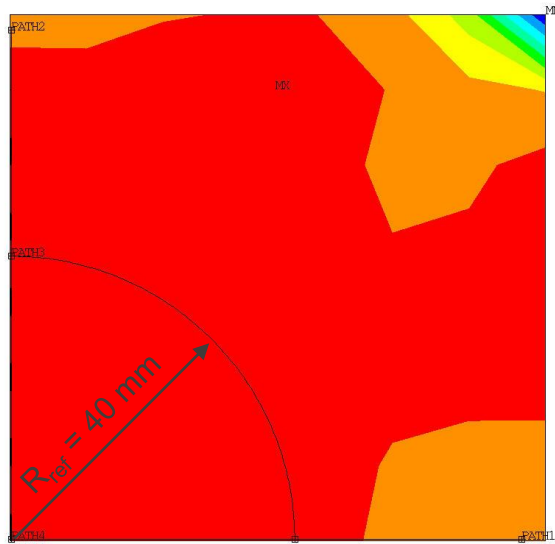
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EDIPO, magnetic 2D model

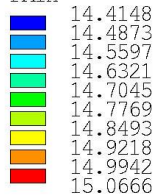
# Field in the aperture

- B field plotted along 4 paths:
  - Path 1 along x axis of the aperture
  - Path 2 along y axis of the aperture
  - Path 3 around a circumference of  $R=40$  mm
  - Path 4 along z axis

## Magnetic 3D model

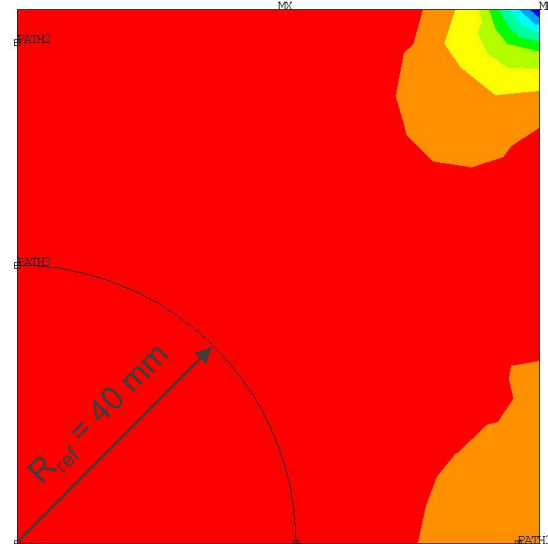


ANSYS 2021 R1  
Build 21.1  
PLOT NO. 1  
NODAL SOLUTION  
STEP=1  
SUB =1  
TIME=1  
BSUM (AVG)  
RSYS=0  
PowerGraphics  
EFACET=1  
AVRES=Mat  
SMN =14.4148  
SMX =15.0666  
PATH

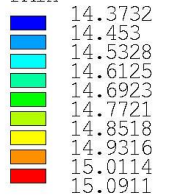


EDIPO, magnetic 3D model

## Magnetic 2D model



ANSYS 2021 R1  
Build 21.1  
PLOT NO. 1  
NODAL SOLUTION  
STEP=1  
SUB =5  
TIME=1  
BSUM (AVG)  
RSYS=0  
PowerGraphics  
EFACET=1  
AVRES=Mat  
SMN =14.3732  
SMX =15.0911  
PATH

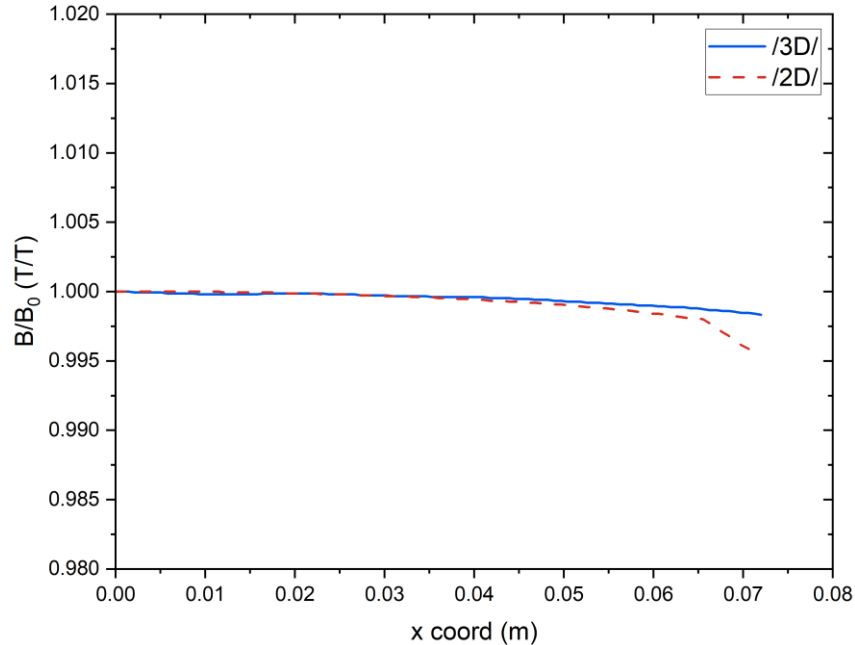


EDIPO, magnetic 2D model

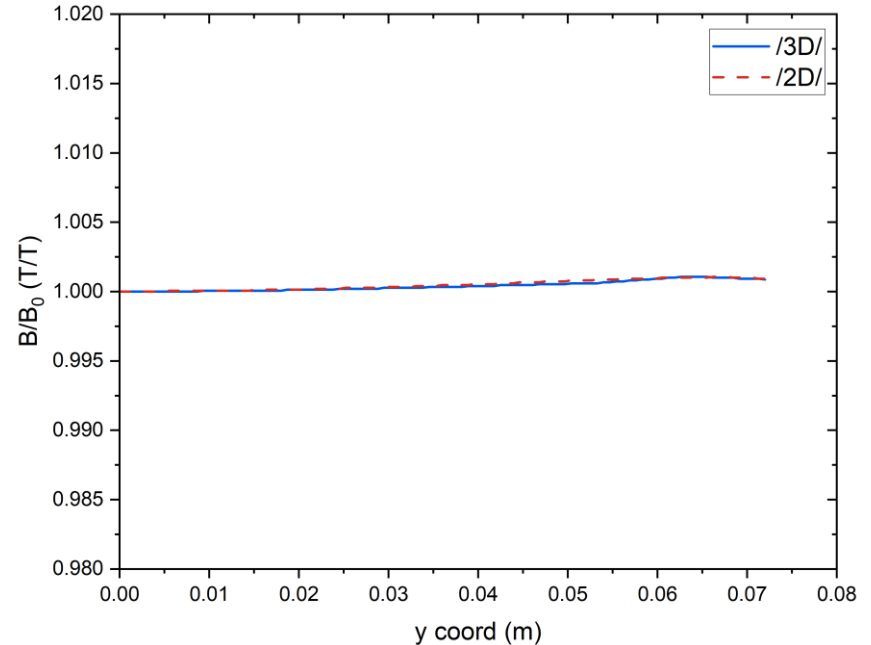
# Field along paths 1 and 2

- Good agreement between 2D and 3D

### Path 1 (x axis of the aperture)



### Path 2 (y axis of the aperture)

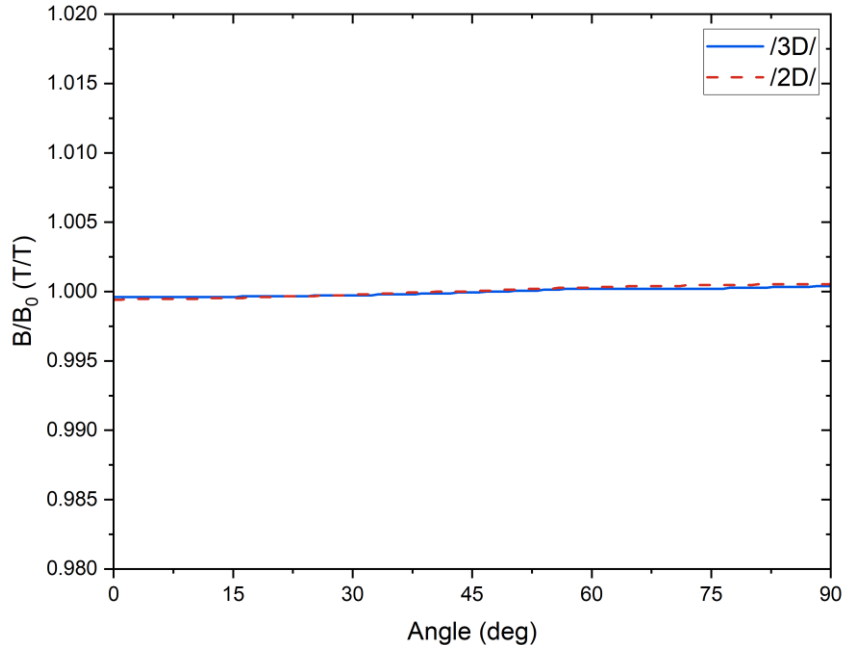


# Field along paths 3 and 4

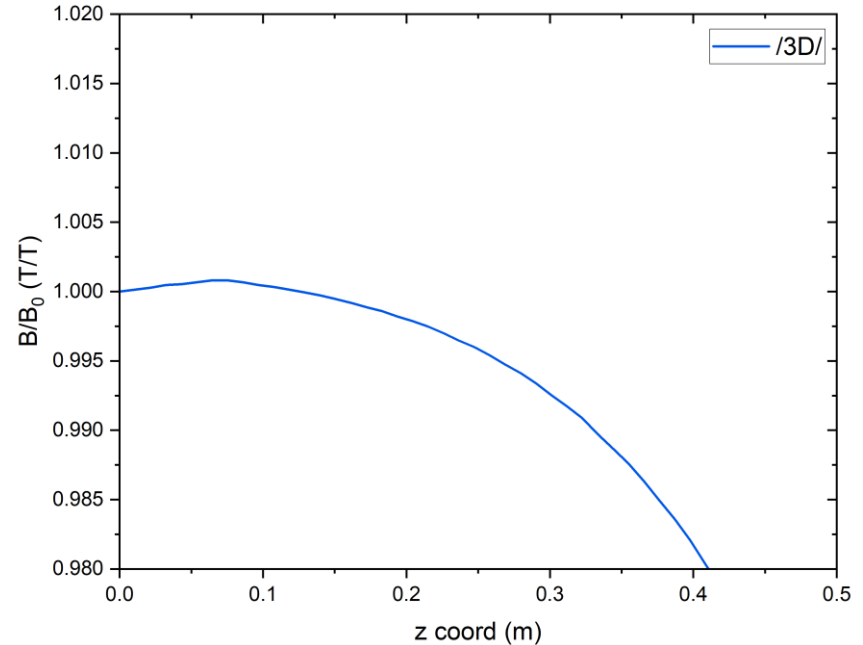
- Homogeneity along the z axis:
  - 1% drop of the field at  $z = \pm 0.331$  m
  - 2% drop of the field at  $z = \pm 0.411$  m

Large end spacers and a limited length of the iron yoke are required to bring the peak field in the coils to the straight section, but reduce the homogeneous field length

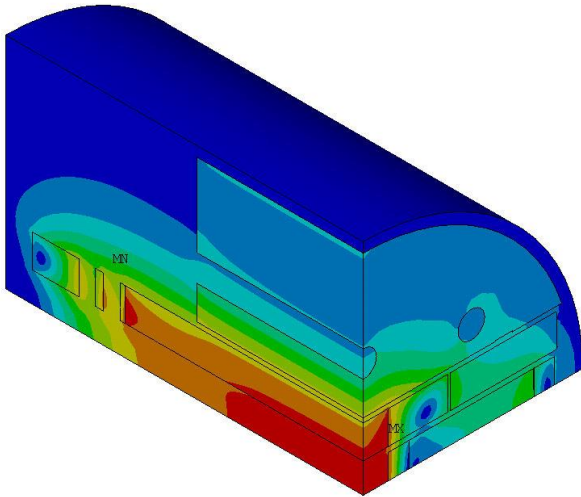
Path 3 (around circumference of  $R=40$  mm)



Path 4 (z axis of the aperture)



# B field in the coils



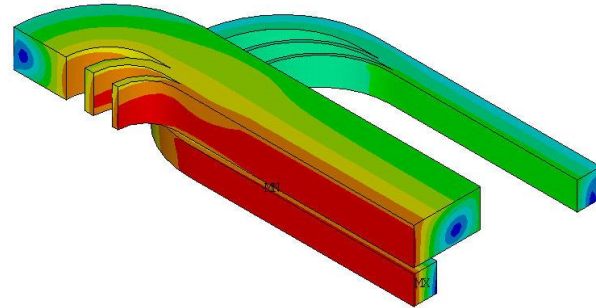
```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
BSUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.825E-03
SMX =16.5319

```

■	.825E-03
■	1.83761
■	3.6744
■	5.51118
■	7.34797
■	9.18476
■	11.0215
■	12.8583
■	14.6951
■	16.5319

EDIPO, magnetic 3D model



```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
BSUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.004936
SMX =15.0403

```

■	.004936
■	1.67553
■	3.34613
■	5.01672
■	6.68732
■	8.35791
■	10.0285
■	11.6991
■	13.3697
■	15.0403

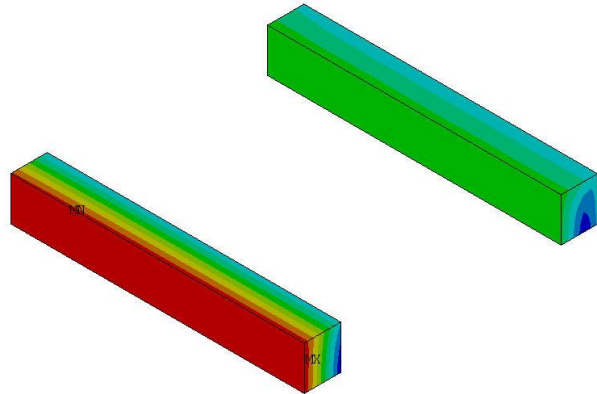
EDIPO, magnetic 3D model



# B field in coil 1: straight section vs ends

- 50 mm wide spacers in the coil ends
- The difference in peak field is 0.54 T

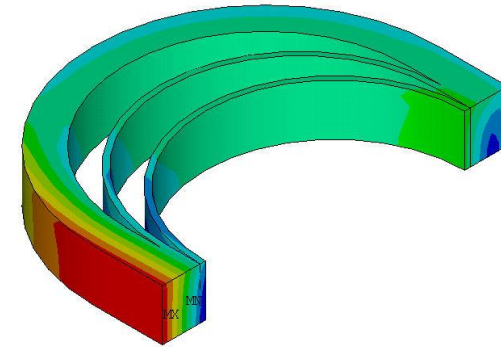
Straight section ( $B_{\max} = 15.04 \text{ T}$ )



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
BSUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.004936
SMX =15.0403
.004936
1.67553
3.34613
5.01672
6.68732
8.35791
10.0285
11.6991
13.3697
15.0403
```

EDIPO, magnetic 3D model

Coil ends ( $B_{\max} = 14.50 \text{ T}$ )



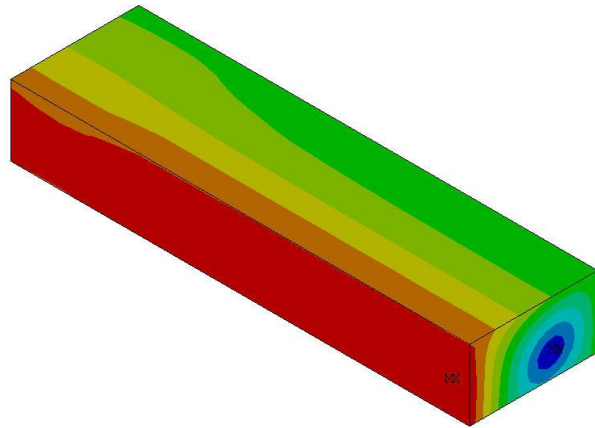
```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
BSUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.018852
SMX =14.4965
.018852
1.62748
3.2361
4.84472
6.45334
8.06197
9.67059
11.2792
12.8878
14.4965
```

EDIPO, magnetic 3D model

# B field in coil 2: straight section vs ends

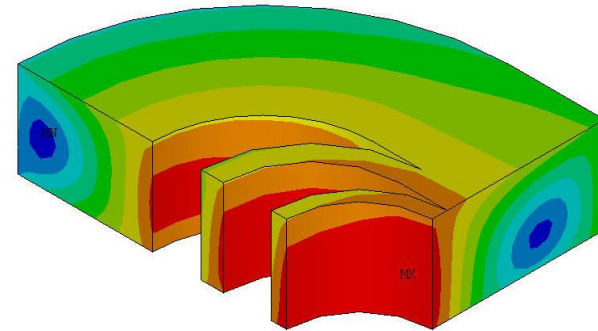
- 50 mm wide spacers in the coil ends
- The difference in peak field is 0.25 T

Straight section ( $B_{\max} = 14.43 \text{ T}$ )



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
BSUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.557279
SMX =14.4307
.557279
2.09876
3.64025
5.18174
6.72322
8.26471
9.8062
11.3477
12.8892
14.4307
```

Coil ends ( $B_{\max} = 14.18 \text{ T}$ )



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
BSUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.241288
SMX =14.18
.241288
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4.88752
6.43626
7.98501
9.53375
11.0825
12.6312
14.18
```

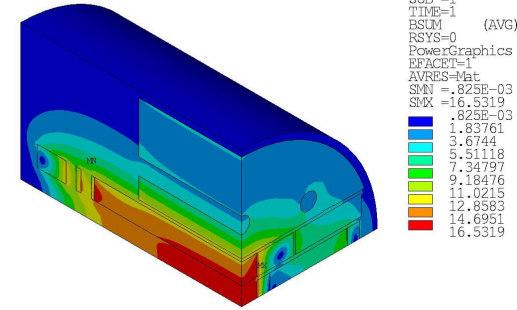
EDIPO, magnetic 3D model

EDIPO, magnetic 3D model

	$I_{op} = 0.85 \times I_{ss}$	$I_{op} = I_{max}$	
Cable layout	24x(6+1), 0.7 mm diam		
Number of turns	Side coils: 2x6x16 Vertical coils: 2x4x46		
Total number of turns, $n_{total}$	560		
Total area of insulated conductor	52886		mm <sup>2</sup>
Operating current, $I_{op}$	17.41 (85% $\times I_{ss}$ )	18.00 (87.9% $\times I_{ss}$ )	kA
B field in the center of the aperture, $B_0$	15.01	15.46	T
Peak B field in the coils, $B_{peak}$	15.04	15.51	T
Total ampere-turns, $I_{total}$	9.75	10.08	MA <sub>t</sub>
Total magnet stored energy, $E_{total}$	19.7	21.0	MJ
Magnet self-inductance, L	129.8		mH
Engineering current density, $j_{eng}$	184.3	190.6	A/mm <sup>2</sup>
Copper current density, $j_{Cu}$	538.6	556.8	A/mm <sup>2</sup>

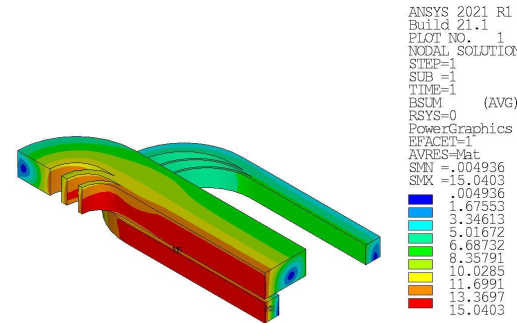
$$I_{op} = 0.85 \times I_{ss}$$

B field in the magnet



EDIPO, magnetic 3D model

B field in the winding pack

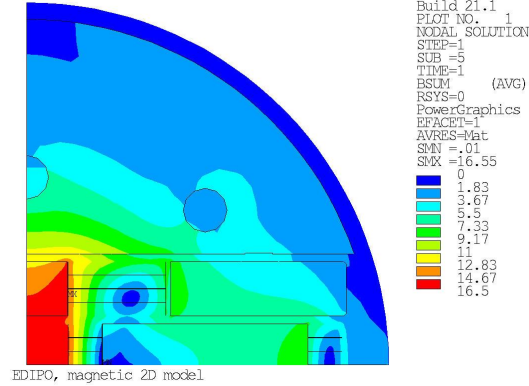


EDIPO, magnetic 3D model

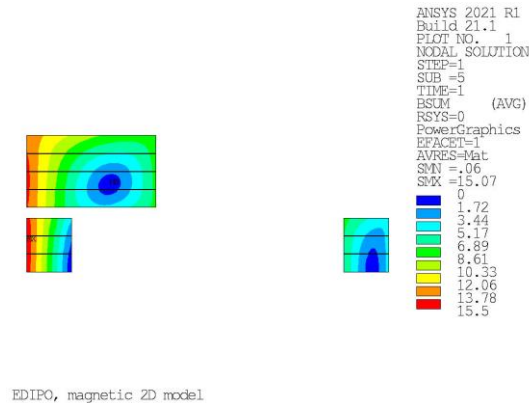
	$I_{op} = 0.85 \times I_{ss}$	$I_{op} = I_{max}$	
Cable layout	24x(6+1), 0.7 mm diam		
Number of turns	Side coils: 2x6x16 Vertical coils: 2x4x46		
Total number of turns, $n_{total}$	560		
Total area of insulated conductor	52886		mm <sup>2</sup>
Operating current, $I_{op}$	17.316 (85% $\times I_{ss}$ )	18.00 (88.4% $\times I_{ss}$ )	kA
B field in the center of the aperture, $B_0$	15.03	15.56	T
Peak B field in the coils, $B_{peak}$	15.07	15.61	T
Total ampere-turns, $I_{total}$	9.70	10.08	MA
Total magnet stored energy, $E_{total}$	11.44	12.33	MJ/m
Magnet self-inductance, L	76.1		mH/m
Engineering current density, $j_{eng}$	183.4	190.6	A/mm <sup>2</sup>
Copper current density, $j_{Cu}$	535.7	556.8	A/mm <sup>2</sup>

$$I_{op} = 0.85 \times I_{ss}$$

B field in the magnet

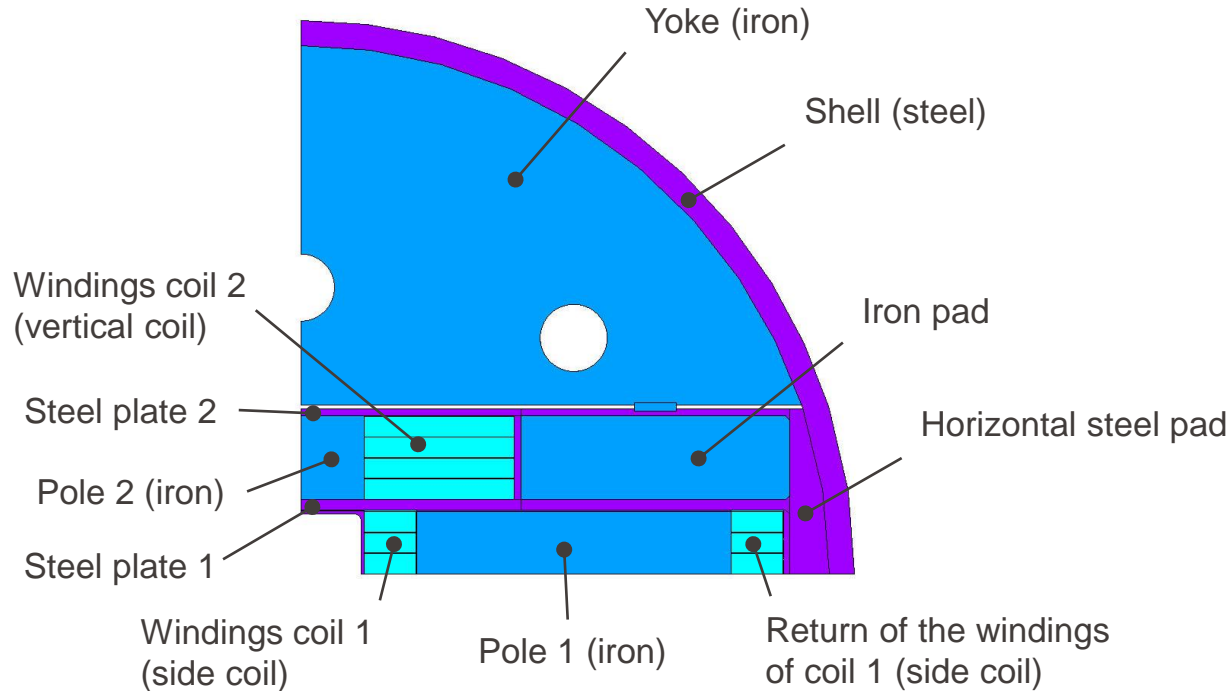


B field in the winding pack



# Mechanical 2D analysis

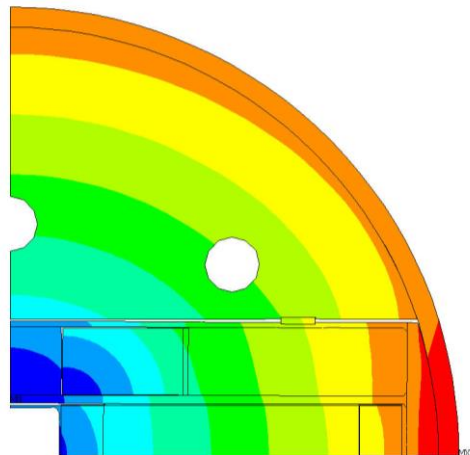
- Three loading steps:
  - Room temperature
  - Cool-down
  - Powering



# Displacement (magnet)

- Both sets of coils are pulled radially outward:
  - Side coils detach from the test well
  - Vertical coils detach from their poles
- Pole 2 is pulled toward the midplane

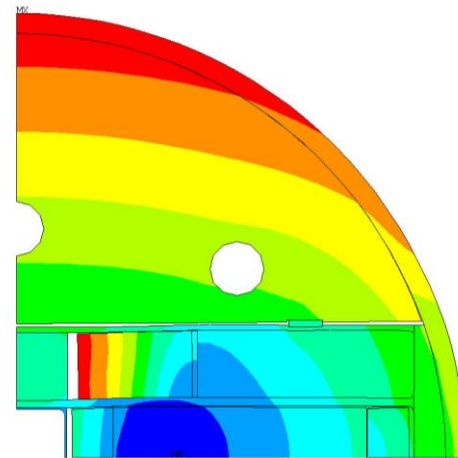
Cool-down



Cool-down

```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =8
TIME=2
USUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX = .001636
SMN = .515E-04
SMX = .001636
.515E-04
.228E-03
.404E-03
.580E-03
.756E-03
.932E-03
.001108
.001284
.00146
.001636
```

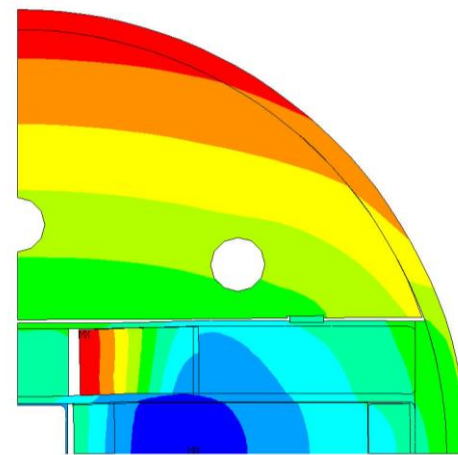
$I_{op} = 0.85 \times I_{ss}$



'I<sub>op</sub> = 0.85\*I<sub>ss</sub>'

```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
USUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX = .00168
SMN = .178E-06
SMX = .00168
.178E-06
.187E-03
.373E-03
.560E-03
.747E-03
.933E-03
.00112
.001307
.001493
.00168
```

$I_{op} = 18.0 \text{ kA}$



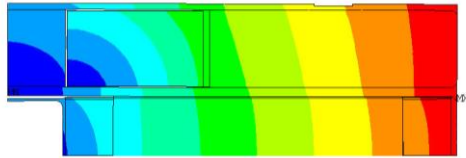
I<sub>op</sub> = 18.0 kA

```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
USUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX = .001705
SMN = .377E-05
SMX = .001705
.377E-05
.193E-03
.382E-03
.571E-03
.760E-03
.949E-03
.001138
.001327
.001516
.001705
```

# Displacement (coil pack)

- Both sets of coils are pulled radially outward:
  - Side coils detach from the test well
  - Vertical coils detach from their poles
- Pole 2 is pulled toward the midplane

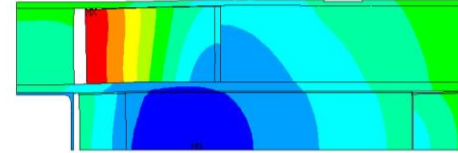
Cool-down



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =8
TIME=2
USUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX = .001425
SMN = .515E-04
SMK = .001425
.515E-04
.204E-03
.357E-03
.509E-03
.662E-03
.814E-03
.967E-03
.00112
.001272
.001425
```

Cool-down

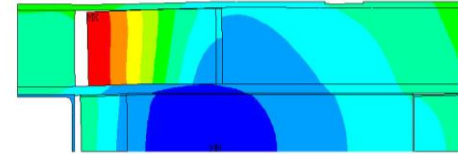
$I_{op} = 0.85 \times I_{ss}$



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
USUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX = .001608
SMN = .178E-06
SMK = .001608
.178E-06
.179E-03
.357E-03
.536E-03
.715E-03
.893E-03
.001072
.001251
.001429
.001608
```

'I<sub>op</sub> = 0.85\*I<sub>ss</sub>'

$I_{op} = 18.0 \text{ kA}$



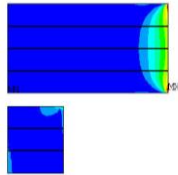
```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
USUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX = .001705
SMN = .377E-05
SMK = .001705
.377E-05
.193E-03
.382E-03
.571E-03
.760E-03
.949E-03
.001138
.001327
.001516
.001705
```

I<sub>op</sub> = 18.0 kA

# Von Mises stress in the coils

- Very modest stress after cool-down
- $\sigma_{eq} \leq 130$  MPa at  $I_{op} = 0.85 \times I_{ss}$
- $\sigma_{eq} \leq 139$  MPa at 18.0 kA
- More modest stress in the high field region

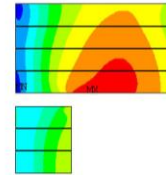
Cool-down



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =8
TIME=2
SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001412
SMN =39.0919
SMX =.232E+08
.39.0919
.258E+07
.517E+07
.775E+07
.103E+08
.129E+08
.155E+08
.181E+08
.207E+08
.232E+08
```

Cool-down

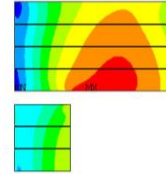
$I_{op} = 18.0$  kA



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001702
SMN =884497
SMX =.139E+09
.884497
.163E+08
.317E+08
.471E+08
.625E+08
.779E+08
.933E+08
.109E+09
.124E+09
.139E+09
```

$I_{op} = 18.0$  kA

$I_{op} = 0.85 \times I_{ss}$



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001605
SMN =599329
SMX =.130E+09
.599329
.150E+08
.295E+08
.439E+08
.583E+08
.727E+08
.872E+08
.102E+09
.116E+09
.130E+09
```

' $I_{op} = 0.85 \times I_{ss}$ '

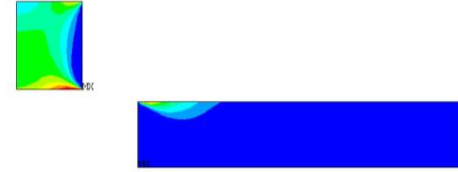


# Max principal stress in the poles

- Within allowable limits at  $I_{op}=0.85 \times I_{ss}$ 
  - $\sigma_1 \leq 259$  MPa
- Slightly above limits at  $I = 18.0$  kA
  - $\sigma_1 \leq 289$  MPa

```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
S1 (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.759E-03
SMX =.259E+09
0
.288E+08
.576E+08
.864E+08
.115E+09
.144E+09
.173E+09
.202E+09
.230E+09
.259E+09
```

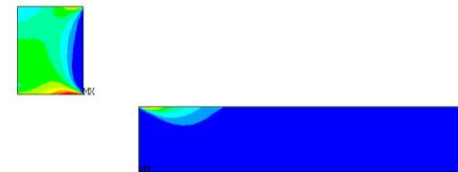
$I_{op} = 0.85 \times I_{ss}$



'Iop = 0.85\*Iss'

```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
S1 (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.783E-03
SMX =.289E+09
0
.321E+08
.642E+08
.964E+08
.128E+09
.161E+09
.193E+09
.225E+09
.257E+09
.289E+09
```

$I_{op} = 18.0$  kA



Iop = 18.0 kA

Cool-down



Cool-down

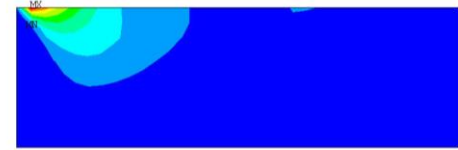
```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =8
TIME=2
S1 (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001218
SMX =.882E+08
0
.980E+07
.196E+08
.294E+08
.392E+08
.490E+08
.588E+08
.686E+08
.784E+08
.882E+08
```

# Max principal stress in the iron pad

- Always within allowable limits:
  - $\sigma_1 \leq 134 \text{ MPa}$  at  $I_{op} = 0.85 \times I_{ss}$
  - $\sigma_1 \leq 148 \text{ MPa}$  at 18 kA

```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
S1 (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.884E-03
SMX =.134E+09
0
.149E+08
.298E+08
.446E+08
.595E+08
.744E+08
.893E+08
.104E+09
.119E+09
.134E+09
```

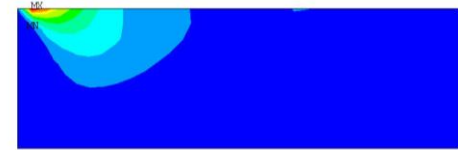
$I_{op} = 0.85 \times I_{ss}$



'Iop = 0.85\*Iss'

```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
S1 (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.844E-03
SMX =.148E+09
0
.165E+08
.329E+08
.494E+08
.658E+08
.823E+08
.987E+08
.115E+09
.132E+09
.148E+09
```

$I_{op} = 18.0 \text{ kA}$



Iop = 18.0 kA

Cool-down



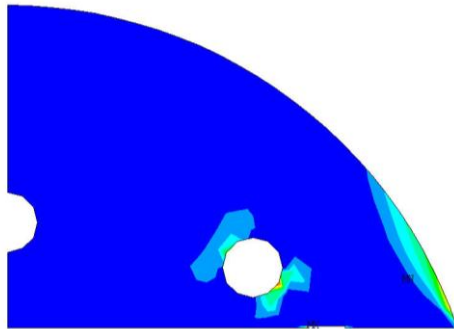
```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =8
TIME=2
S1 (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001409
SMX =.549E+08
0
.610E+07
.122E+08
.183E+08
.244E+08
.305E+08
.366E+08
.427E+08
.488E+08
.549E+08
```

Cool-down

# Max principal stress in the iron yoke

- Always within allowable limits:
  - $\sigma_1 \leq 130$  MPa at  $I_{op} = 0.85 \times I_{ss}$
  - $\sigma_1 \leq 134$  MPa at 18 kA

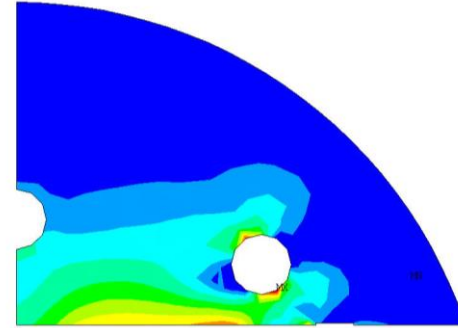
Cool-down



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =8
TIME=2
S1 (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001364
SMX =.418E+08
0
.464E+07
.929E+07
.139E+08
.186E+08
.232E+08
.279E+08
.325E+08
.372E+08
.418E+08
```

Cool-down

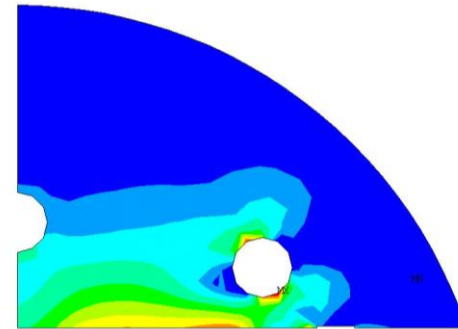
$I_{op} = 0.85 \times I_{ss}$



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
S1 (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.00159
SMX =.130E+09
0
.144E+08
.288E+08
.432E+08
.576E+08
.720E+08
.864E+08
.101E+09
.115E+09
.130E+09
```

'Iop = 0.85\*Iss'

$I_{op} = 18.0$  kA



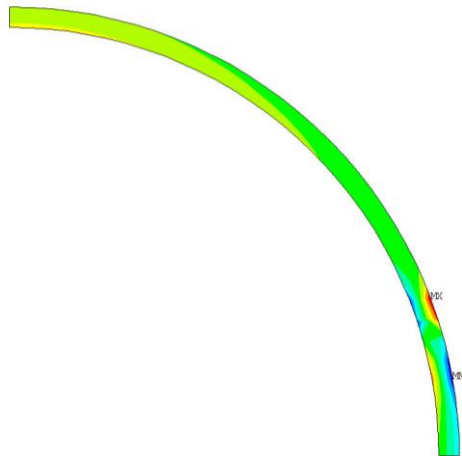
```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
S1 (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.00159
SMX =.134E+09
0
.149E+08
.298E+08
.446E+08
.595E+08
.744E+08
.893E+08
.104E+09
.119E+09
.134E+09
```

Iop = 18.0 kA

# Stress intensity in the shell

- Always within allowable limits

Cool-down

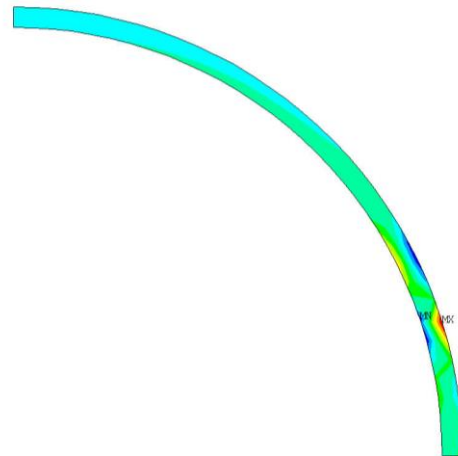


```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =8
TIME=2
SINT (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001636
SMN =.571E+08
SMX =.195E+09
.571E+08
.724E+08
.877E+08
.103E+09
.118E+09
.134E+09
.149E+09
.164E+09
.179E+09
.195E+09
    
```

Cool-down

$I_{op} = 18.0 \text{ kA}$

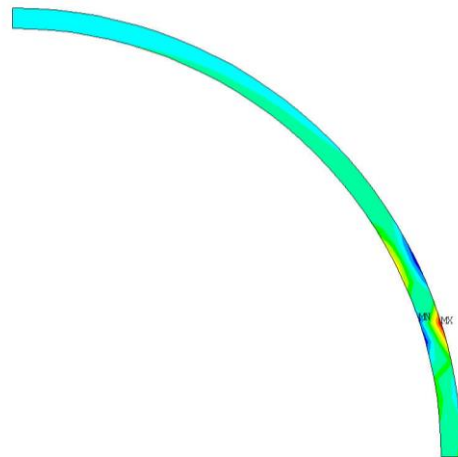


```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
SINT (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001689
SMN =.623E+08
SMX =.316E+09
.623E+08
.905E+08
.119E+09
.147E+09
.175E+09
.203E+09
.231E+09
.259E+09
.288E+09
.316E+09
    
```

$I_{op} = 18.0 \text{ kA}$

$I_{op} = 0.85 \times I_{ss}$



```

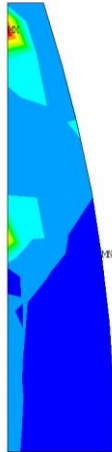
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
SINT (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.00168
SMN =.673E+08
SMX =.298E+09
.673E+08
.929E+08
.119E+09
.144E+09
.170E+09
.196E+09
.221E+09
.247E+09
.272E+09
.298E+09
    
```

' $I_{op} = 0.85 \times I_{ss}$ '

# Von Mises stress in the H-pad

- Always within allowable limits

Cool-down

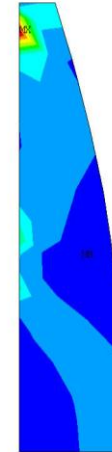


```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =8
TIME=2
SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001545
SMN =.781E+07
SMX =.258E+09
.781E+07
.356E+08
.633E+08
.911E+08
.119E+09
.147E+09
.174E+09
.202E+09
.230E+09
.258E+09
    
```

Cool-down

$I_{op} = 18.0 \text{ kA}$

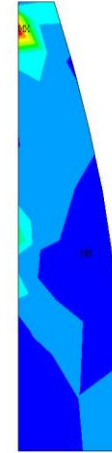


```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.915E-03
SMN =.134E+08
SMX =.332E+09
.134E+08
.488E+08
.843E+08
.120E+09
.155E+09
.191E+09
.226E+09
.262E+09
.297E+09
.332E+09
    
```

$I_{op} = 18.0 \text{ kA}$

$I_{op} = 0.85 \times I_{ss}$



$I_{op} = 0.85 \times I_{ss}$

```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.954E-03
SMN =.138E+08
SMX =.328E+09
.138E+08
.487E+08
.836E+08
.118E+09
.153E+09
.188E+09
.223E+09
.258E+09
.293E+09
.328E+09
    
```

# Stress intensity in the steel plates

- The high stress in the steel plate 1 call for the use of a high strength austenitic steel

Cool-down



```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =8
TIME=2
SINT (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.001419
SMN =47550.6
SMX =.470E+09
.47550,6
.523E+08
.104E+09
.157E+09
.209E+09
.261E+09
.313E+09
.366E+09
.418E+09
.470E+09
    
```

Cool-down

$I_{op} = 0.85 \times I_{ss}$



```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
SINT (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.899E-03
SMN =820380
SMX =.103E+10
820380
.115E+09
.229E+09
.342E+09
.456E+09
.570E+09
.684E+09
.798E+09
.912E+09
.103E+10
    
```

'Iop = 0.85\*Iss'

$I_{op} = 18.0 \text{ kA}$



```

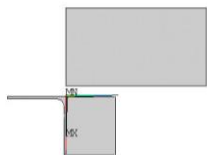
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
SINT (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.860E-03
SMN =336583
SMX =.115E+10
336583
.128E+09
.256E+09
.383E+09
.511E+09
.639E+09
.766E+09
.894E+09
.102E+10
.115E+10
    
```

$I_{op} = 18.0 \text{ kA}$

# Gap between test well and side coils

- Between the test well and side coils:
  - gap  $\leq 0.9$  mm at  $I_{op} = 0.85 \times I_{ss}$
  - gap  $\leq 0.9$  mm at 18 kA

Cool-down

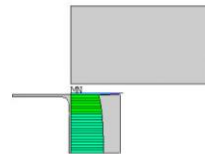


```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =8
TIME=2
CONTIGAP (AVG)
DMX =.001416
SMN =-.001273
SMX =-.001132
    -.001132
    -.990E-03
    -.849E-03
    -.707E-03
    -.566E-03
    -.424E-03
    -.283E-03
    -.141E-03
    0
    
```

Cool-down

$I_{op} = 0.85 \times I_{ss}$



```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
CONTIGAP (AVG)
DMX =.001608
SMN =-.00129
SMX =-.125E-03
    -.00129
    -.001161
    -.001031
    -.902E-03
    -.772E-03
    -.643E-03
    -.514E-03
    -.384E-03
    -.255E-03
    -.125E-03
    
```

'Iop = 0.85\*Iss'

$I_{op} = 18.0$  kA



```

ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
CONTIGAP (AVG)
DMX =.001705
SMN =-.001303
SMX =-.131E-03
    -.001303
    -.001173
    -.001042
    -.912E-03
    -.782E-03
    -.652E-03
    -.522E-03
    -.392E-03
    -.261E-03
    -.131E-03
    
```

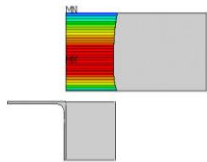
Iop = 18.0 kA

# Gap between pole 2 and vertical coils

- Between pole 2 and vertical coils:

- gap  $\leq 1.6$  mm at  $I_{op} = 0.85 \times I_{ss}$
- gap  $\leq 1.7$  mm at 18 kA

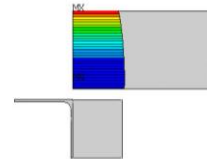
Cool-down



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =8
TIME=2
CONTIGAP (AVG)
DMX =.001416
SMN =-.184E-03
SMX =-.169E-03
.184E-03
.183E-03
.181E-03
.179E-03
.177E-03
.176E-03
.174E-03
.172E-03
.170E-03
.169E-03
```

Cool-down

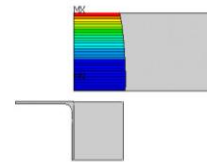
$I_{op} = 0.85 \times I_{ss}$



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
CONTIGAP (AVG)
DMX =.001608
SMN =-.001626
SMX =-.001432
.001626
.001605
.001583
.001561
.00154
.001518
.001497
.001475
.001453
.001432
```

'I<sub>op</sub> = 0.85\*I<sub>ss</sub>'

$I_{op} = 18.0$  kA



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
CONTIGAP (AVG)
DMX =.001705
SMN =-.001731
SMX =-.001529
.001731
.001709
.001686
.001664
.001641
.001619
.001596
.001574
.001551
.001529
```

I<sub>op</sub> = 18.0 kA



# Gap between steel plate 1 and test well

- The steel plate 1 bends, but never touches the test well
- The gap is always higher than 1.4 mm

Cool-down



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=2
SUB =8
TIME=2
CONTIGAP (AVG)
DMX =.001408
SMN =-.001952
SMX =-.001911
-.001952
-.001948
-.001943
-.001939
-.001934
-.001929
-.001925
-.00192
-.001916
-.001911
```

Cool-down

$$I_{op} = 0.85 \times I_{ss}$$



```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
CONTIGAP (AVG)
DMX =.816E-03
SMN =-.001502
SMX =-.001428
-.001502
-.001494
-.001486
-.001477
-.001469
-.001461
-.001453
-.001445
-.001436
-.001428
```

'Iop = 0.85\*Iss'

$$I_{op} = 18.0 \text{ kA}$$



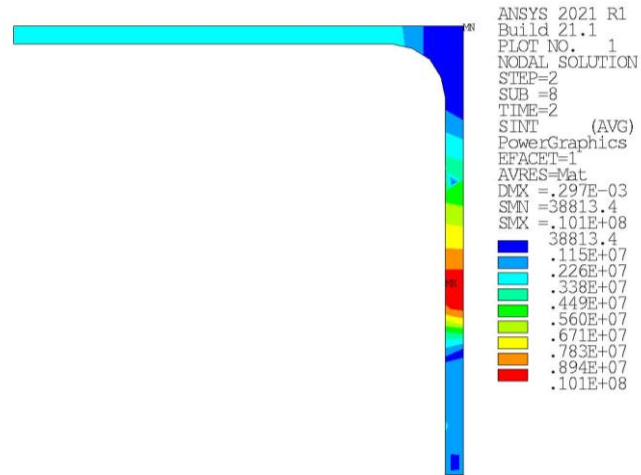
```
ANSYS 2021 R1
Build 21.1
PLOT NO. 1
NODAL SOLUTION
STEP=3
SUB =6
TIME=3
CONTIGAP (AVG)
DMX =.769E-03
SMN =-.001483
SMX =-.001402
-.001483
-.001474
-.001465
-.001456
-.001447
-.001438
-.001429
-.00142
-.001411
-.001402
```

Iop = 18.0 kA

# Stress intensity in the test well

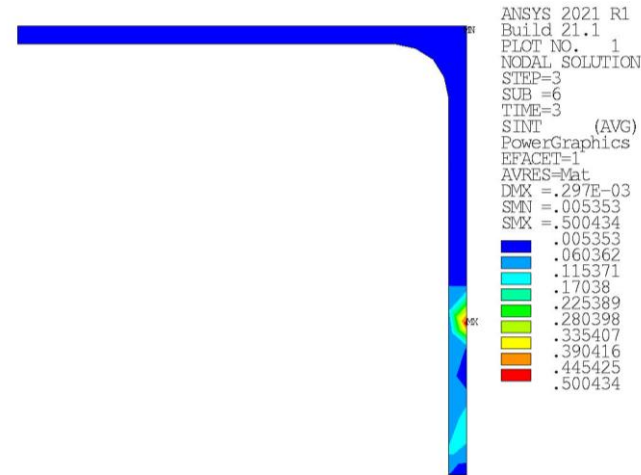
- The test well always remains stress-free

Cool-down



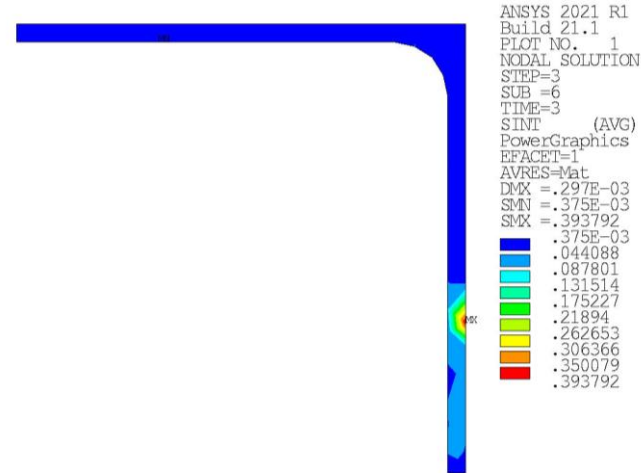
Cool-down

$I_{op} = 18.0 \text{ kA}$



$I_{op} = 18.0 \text{ kA}$

$I_{op} = 0.85 \times I_{ss}$



$I_{op} = 0.85 \times I_{ss}$