EDIPO 2
Staggered racetracks
3D magnetic analysis
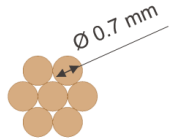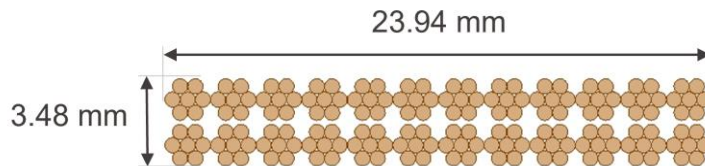
X. Sarasola

April 15th, 2024

Cable design

- Bruker strand:
  - $j_{c,nc}$ = 2600 A/mm^2 at 12 T and 4.2 K
  - Cu:nCu = 1.0

- Same cable used for all coils
 - First stage:

  Ø 0.7 mm

  - Second stage: 24×(6+1), 0.7 mm

  23.94 mm

  3.48 mm

  - Assumed insulation thickness: 0.2 mm

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EDIPO 2: MAGNETIC 3D ANALYSIS

Magnet design

- 144×144 mm^2 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 coils

- 50 mm wide spacers **(only vertical coils)**
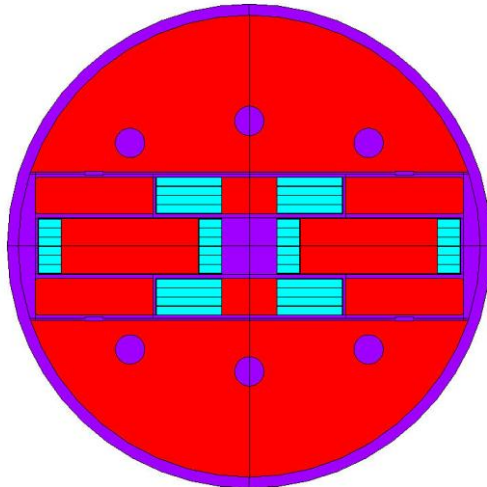
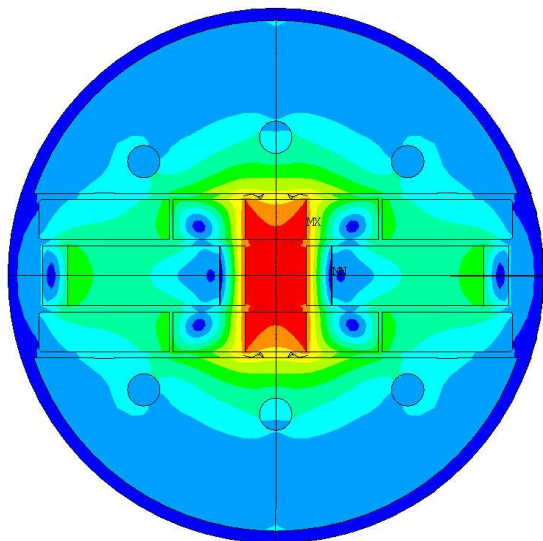EDIPO, magnetic 2D model
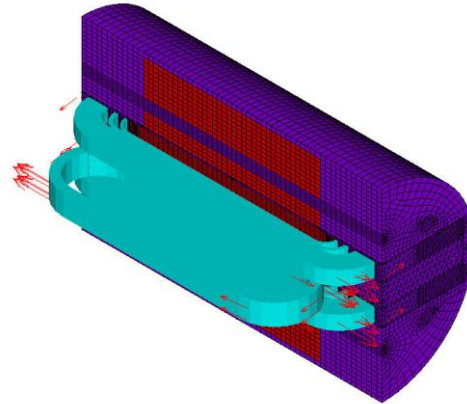
EDIPO, magnetic 3D model
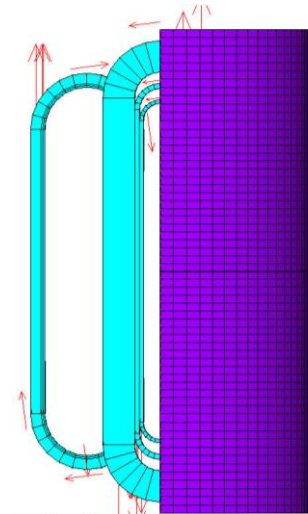
EDIPO, magnetic 3D model

Comparison 3D vs 2D

	3D	2D
I_{op} (85%×I_{ss})	17.359 kA	17.316 kA
$B_{center\ aperture}$	15.02 T	15.03 T
B_{coil}	15.05 T	15.07 T
E_{total}	20.6 MJ	11.4 MJ/m

Magnetic 3D model
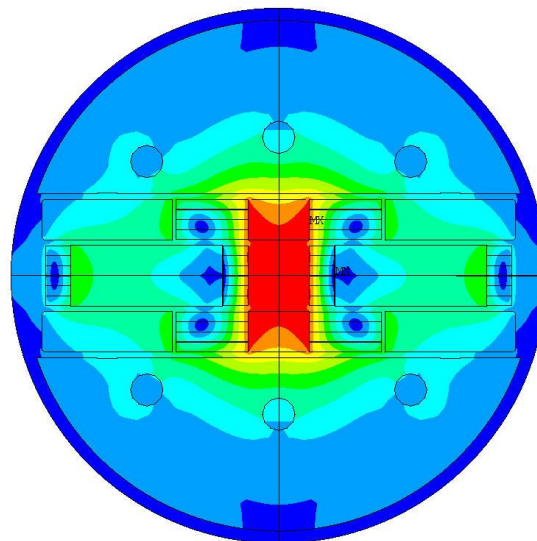
EDIPO, magnetic 3D model

Magnetic 2D model

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

Magnetic 2D model

EDIPO, magnetic 3D model

EDIPO, magnetic 2D model

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EDIPO 2: PROGRESS MAGNETIC 3D ANALYSIS

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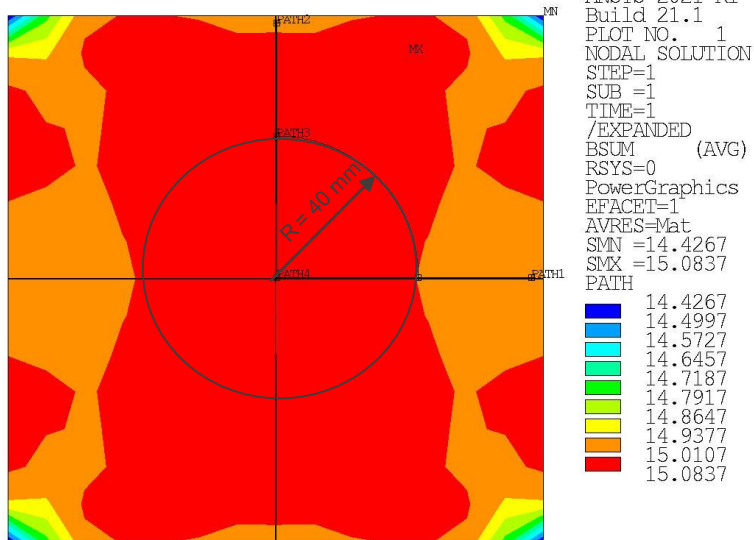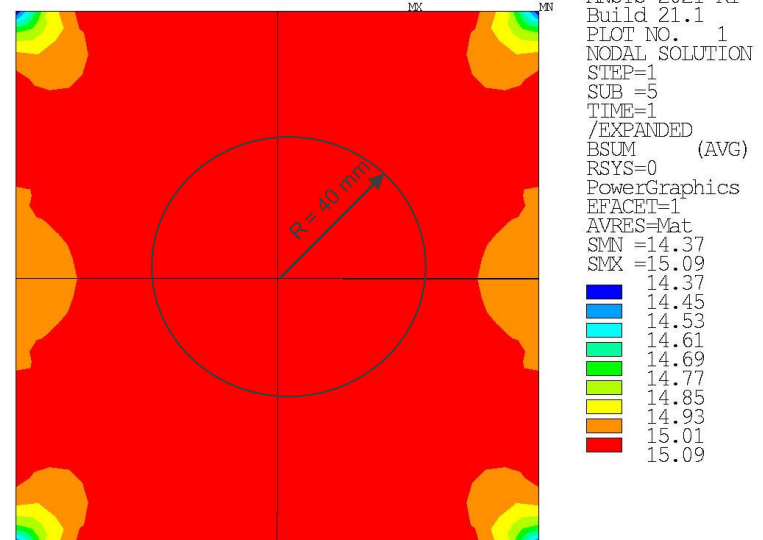
Field along paths 1 and 2

- Good agreement between 2D and 3D

Path 1 (x axis of the aperture)
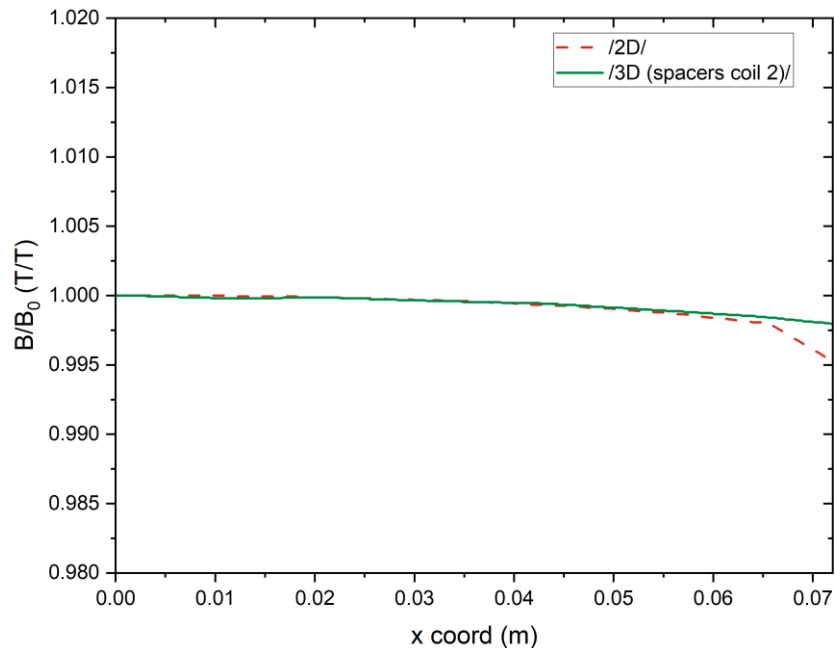
Path 2 (y axis of the aperture)
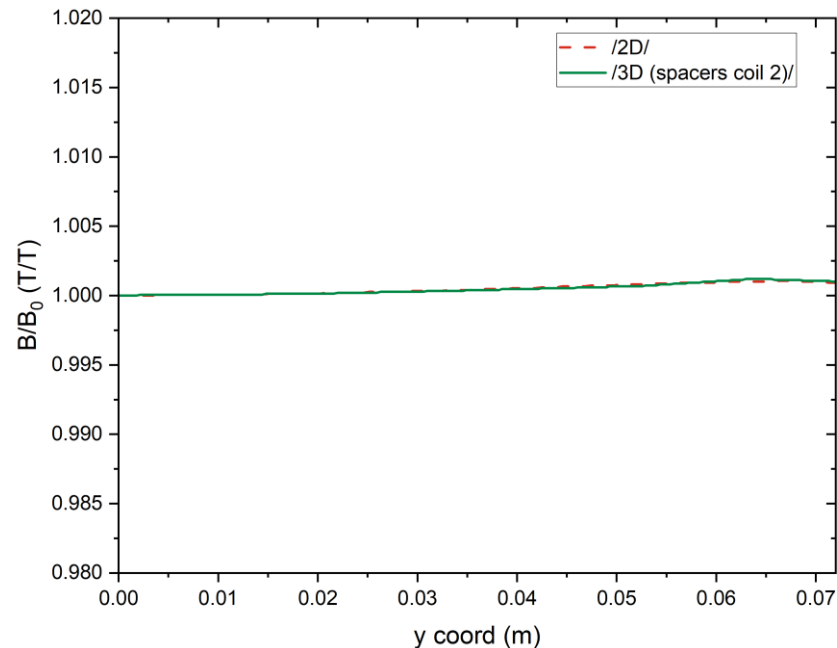
Field along paths 3 and 4

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- Homogeneity along the z axis:
  - 1% drop of the field at z = ±0.450 m
  - 2% drop of the field at z = ±0.526 m

EDIPO 2: PROGRESS MAGNETIC 3D ANALYSIS

Path 3 (around circumference of R=40 mm)

Path 4 (z axis of the aperture)

B field in the coils

EDIPO, magnetic 3D model

EDIPO, magnetic 3D model

B field in coil 1: straight section vs ends

Straight sect (B$_{max}$ = 15.05 T)

Coil ends (B$_{max}$ = 14.28 T)


```
ANSYS 2021 R1
Build 21.1
PLOT NO.   1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
BSUM      (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.005986
SMX =15.0492
      .005986
      1.67745
      3.34892
      5.02038
      6.69185
      8.36331
      10.0348
      11.7062
      13.3777
      15.0492
```
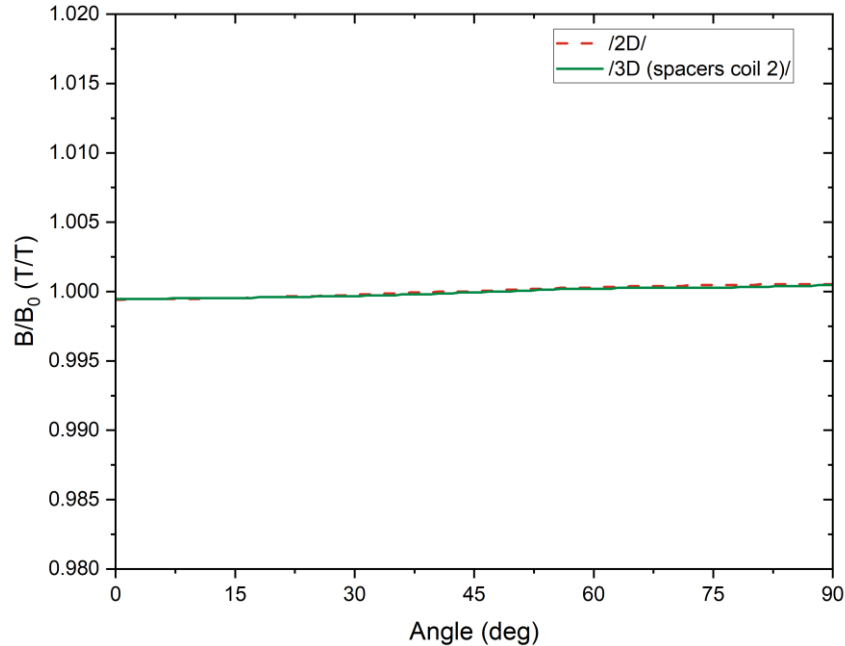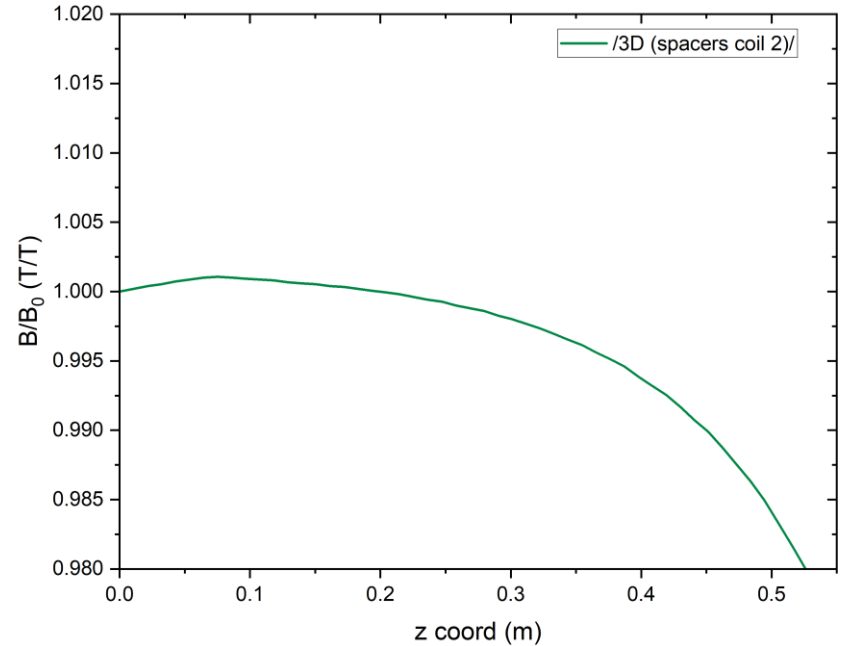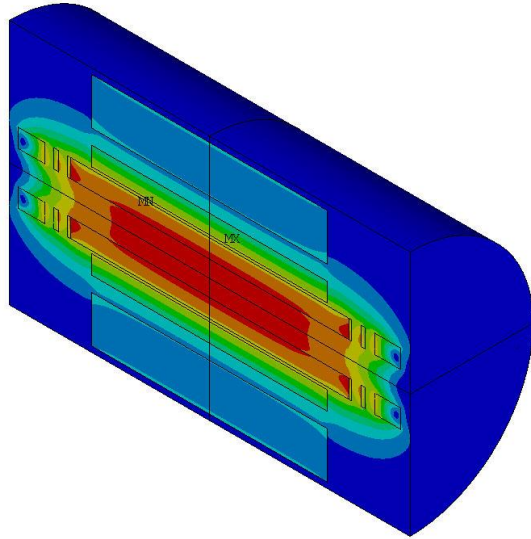
EDIPO, magnetic 3D model

```
ANSYS 2021 R1
Build 21.1
PLOT NO.   1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
BSUM      (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.005986
SMX =15.0492
      .005986
      1.67745
      3.34892
      5.02038
      6.69185
      8.36331
      10.0348
      11.7062
      13.3777
      15.0492
```
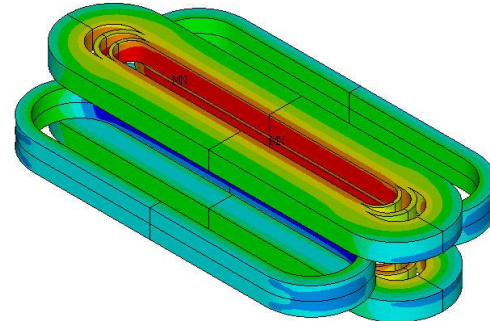
EDIPO, magnetic 3D model

```
ANSYS 2021 R1
Build 21.1
PLOT NO.   1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
BSUM      (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.021614
SMX =14.285
      .021614
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      3.19126
      4.77608
      6.3609
      7.94573
      9.53055
      11.1154
      12.7002
      14.285
```

EDIPO, magnetic 3D model

B field in coil 2: straight section vs ends

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EDIPO 2: PROGRESS MAGNETIC 3D ANALYSIS

- 50 mm wide spacers in the coil ends (minimum to move the peak field away from the coil ends)


```
ANSYS 2021 R1
Build 21.1
PLOT NO.    1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
BSUM       (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.144547
SMX =14.4438
        .144547
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        11.2662
        12.855
        14.4438
```
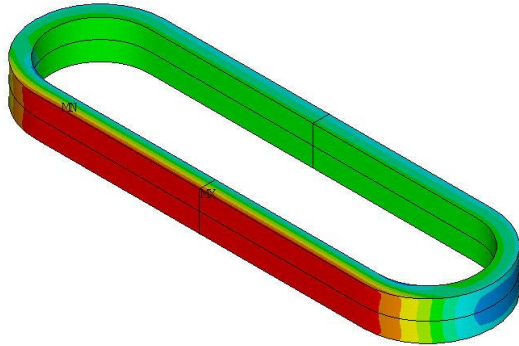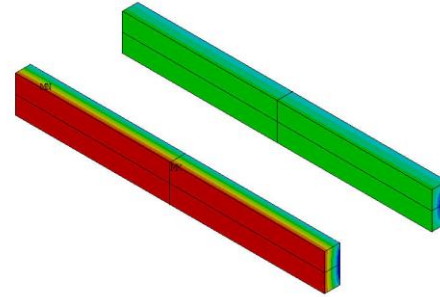
EDIPO, magnetic 3D model

Straight sect (B$_{max}$ = 14.44 T)


```
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Build 21.1
PLOT NO.    1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
BSUM       (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.614354
SMX =14.4438
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```

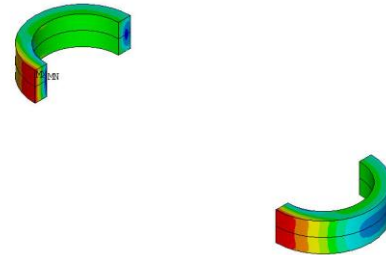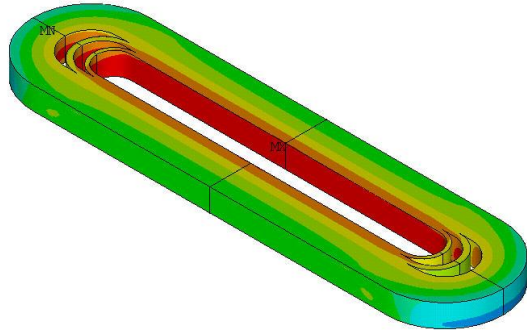EDIPO, magnetic 3D model

Coil ends (B$_{max}$ = 14.4 T)


```
ANSYS 2021 R1
Build 21.1
PLOT NO.    1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
BSUM       (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.144547
SMX =14.4
        .144547
        1.72849
        3.31243
        4.89637
        6.48031
        8.06425
        9.64819
        11.2321
        12.8161
        14.4
```

EDIPO, magnetic 3D model

B field in coil 2 (no end spacers)

- If no end spacers are used in coil 2, the peak field in the ends will limit the magnet performance

Straight sect (B$_{max}$ = 15.16 T)

EDIPO, magnetic 3D model

Coil ends (B$_{max}$ = 16.28 T)

EDIPO, magnetic 3D model

EDIPO, magnetic 3D model

X. Sarasola

EDIPO 2: PROGRESS MAGNETIC 3D ANALYSIS
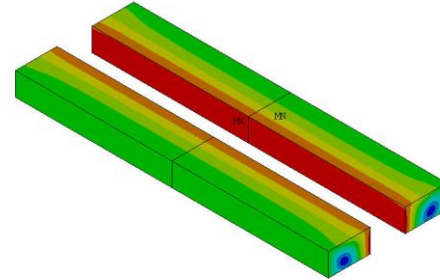
ANSYS 2021 R1
Build 21.1
PLOT NO.   1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
BSUM   (AVG)
RSYS=0
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EFACET=1
AVRES=Mat
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.597499
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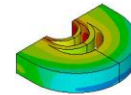3.8347
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7.07189
8.69049
10.3091
11.9277
13.5463
15.1649

ANSYS 2021 R1
Build 21.1
PLOT NO.   1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
BSUM   (AVG)
RSYS=0
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EFACET=1
AVRES=Mat
SMN =.297441
SMX =16.2841
.297441
2.07373
3.85003
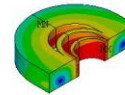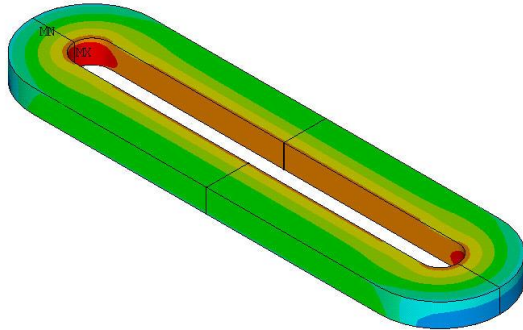5.62632
7.40262
9.17891
10.9552
12.7315
14.5078
16.2841

ANSYS 2021 R1
Build 21.1
PLOT NO.   1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
BSUM   (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.297441
SMX =16.2841
.297441
2.07373
3.85003
5.62632
7.40262
9.17891
10.9552
12.7315
14.5078
16.2841

Magnetostatic 3D analysis

	$I_{op} = 0.85 \times I_{ss}$	$I_{op} = I_{max}$	
Cable layout	24×(6+1), 0.7 mm diam		
Number of turns	Side coils: 2×6×16 Vertical coils: 2×4×46		
Total number of turns, n_{total}	560		
Total area of insulated conductor	52886		mm^2
Operating current, I_{op}	17.359 (85%×I_{ss})	18.00 (88.1%×I_{ss})	kA
B field in the center of the aperture, B_0	15.02	15.51	T
Peak B field in the coils, B_{peak}	15.03	15.56	T
Total ampere-turns, I_{total}	9.72	10.08	MAt
Total magnet stored energy, E_{total}	20.6	21.0	MJ
Magnet self-inductance, L	136.6		mH
Engineering current density, j_{eng}	183.8	190.6	A/mm^2
Copper current density, j_{Cu}	520.9	540.1	A/mm^2

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

B field in the magnet
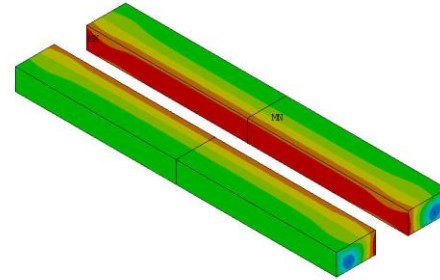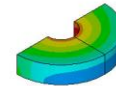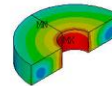

ANSYS 2021 R1
Build 21.1
PLOT NO.   1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
BSUM   (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.354E-03
SMX =16.5438
.354E-03
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5.51484
7.353
9.19116
11.0293
12.8675
14.7056
16.5438

EDIPO, magnetic 3D model
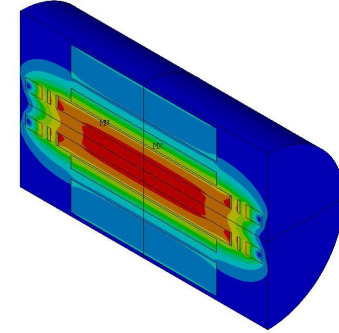
B field in the winding pack

ANSYS 2021 R1
Build 21.1
PLOT NO.   1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
/EXPANDED
BSUM   (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.005986
SMX =15.0492
.005986
1.67745
3.34892
5.02038
6.69185
8.36331
10.0348
11.7062
13.3777
15.0492

EDIPO, magnetic 3D model

Magnetostatic 2D analysis

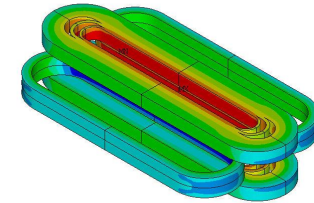|	$I_{op} = 0.85 \times I_{ss}$	$I_{op} = I_{max}$	
Cable layout	24×(6+1), 0.7 mm diam		
Number of turns	Side coils: 2×6×16 Vertical coils: 2×4×46		
Total number of turns, n_{total}	560		
Total area of insulated conductor	52886		mm^2
Operating current, I_{op}	17.316 (85%×I_{ss})	18.00 (88.4%×I_{ss})	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	MAt
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^2
Copper current density, j_{Cu}	519.6	540.1	A/mm^2

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

B field in the magnet
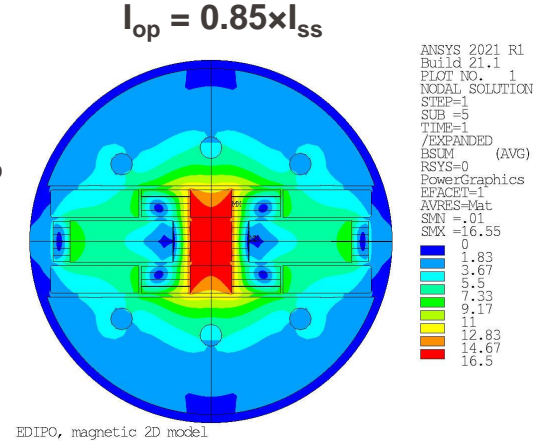


```
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NODAL SOLUTION
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SUB =5
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/EXPANDED
BSUM      (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.01
SMX =16.55
      0
      1.83
      3.67
      5.5
      7.33
      9.17
      11
      12.83
      14.67
      16.5
```

EDIPO, magnetic 2D model

B field in the winding pack


```
ANSYS 2021 R1
Build 21.1
PLOT NO.   1
NODAL SOLUTION
STEP=1
SUB =5
TIME=1
/EXPANDED
BSUM      (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =.06
SMX =15.07
      0
      1.72
      3.44
      5.17
      6.89
      8.61
      10.33
      12.06
      13.78
      15.5
```

EDIPO, magnetic 2D model