Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Starting of 3-d Optimization of the Magnetic Design of Q2pF

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June 7, 2022

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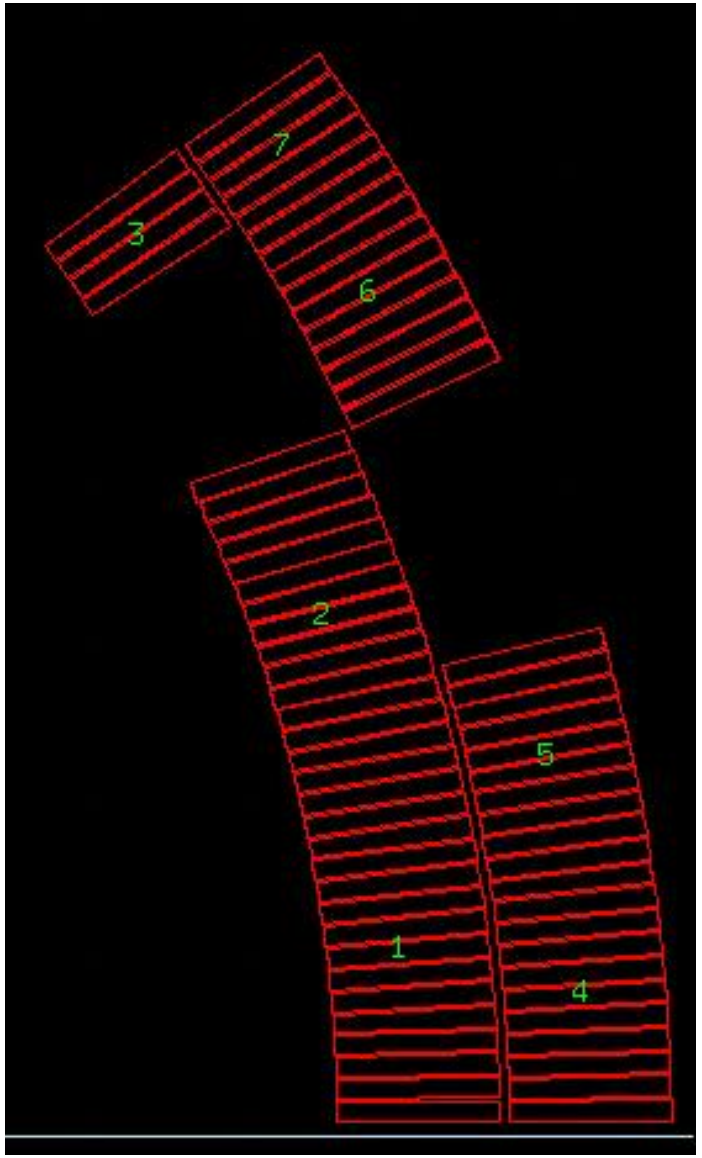
Overview

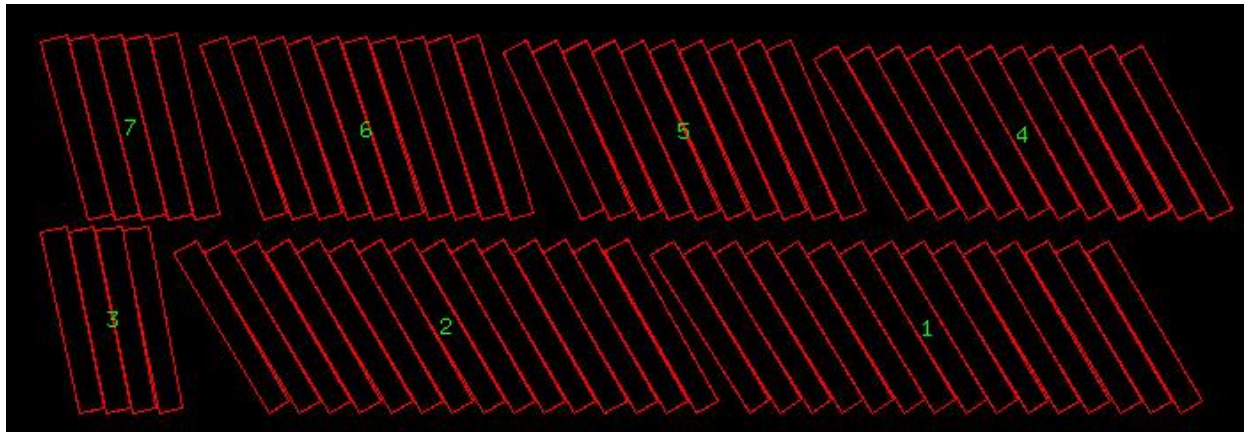
- This exercise focuses on reducing peak field in the Ends
  - Ideally peak field in the Ends should be a bit lower than in 2-d but should not be much higher than in 2-d
  - A higher peak field reduces the margin
- Ends should also have small integrated harmonics so that the straight section (body) and Ends of the magnet can be optimized independently
- End turns should also be easy to wind with minimum strain on the conductor. This and other mechanical consideration should also be taken care of.
  - It is easier if the rules for a good magnetic design and for a good mechanical design are optimized in separate runs and then the two are combined.
- This presentation summarizes the initial approach (work just started) for magnetic design of the ends. It is assumed that the mechanical layout of the turns is already optimized or will not change substantially (if do need to iterate)

Peak Field Reduction in the Ends of the Magnet



Significant enhancement in the peak field ~6.8 T (2d) to ~8 T (3d)

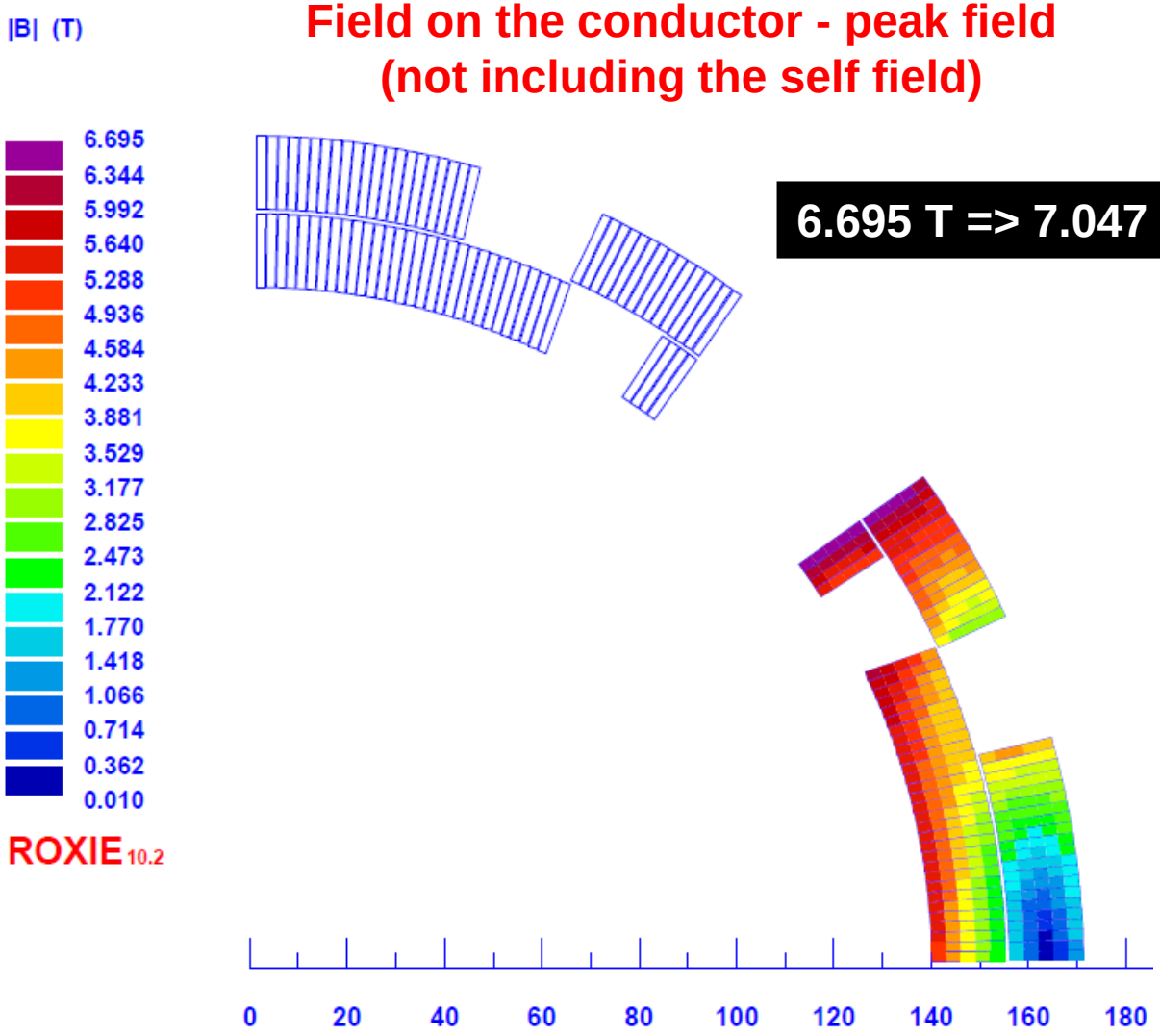
```
MARGIN CALC (USING LINEAR JC-APPROX):
BLOCK NUMBER ..........................................        3
PEAK FIELD IN CONDUCTOR   34 (T) ......................     7.9586
CURRENT IN CONDUCTOR  34 (A) ..........................  -8500.0000
SUPERCONDUCTOR CURRENT DENSITY (A/MM2) ................    -886.0233
PERCENTAGE ON THE LOAD LINE ...........................     73.8207
QUENCHFIELD (T) .......................................     10.7810
PERCENTAGE OF SHORT SAMPLE CURRENT ....................     66.0838

MARGIN CALC (USING LINEAR JC-APPROX):
BLOCK NUMBER ..........................................        7
PEAK FIELD IN CONDUCTOR   70 (T) ......................     7.7507
CURRENT IN CONDUCTOR  70 (A) ..........................  -8500.0000
SUPERCONDUCTOR CURRENT DENSITY (A/MM2) ................    -886.0233
PERCENTAGE ON THE LOAD LINE ...........................     72.2431
QUENCHFIELD (T) .......................................     10.7286
PERCENTAGE OF SHORT SAMPLE CURRENT ....................     67.3827
```

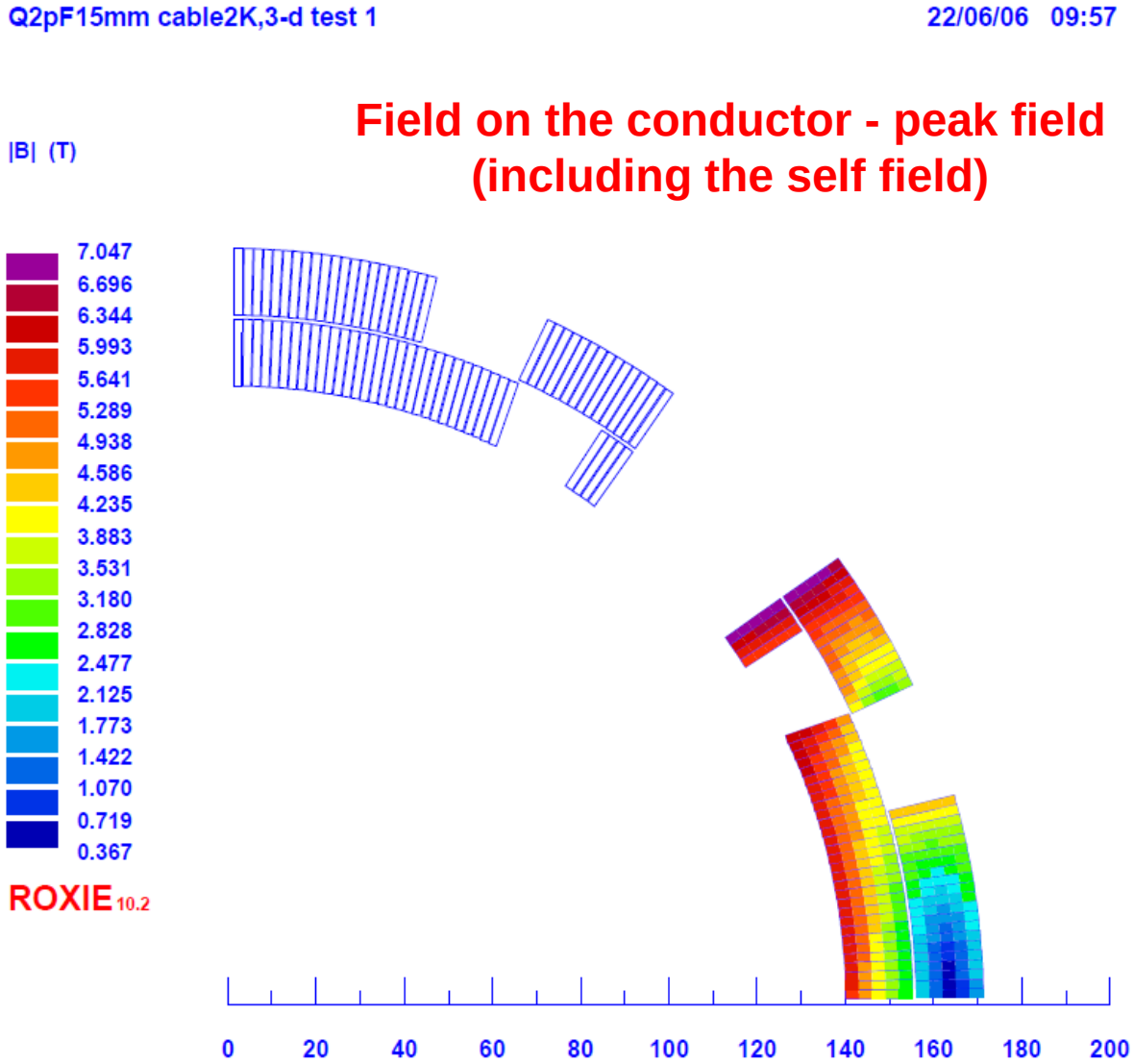


Next: Techniques that reduced this peak field by a large amount…

Peak Field in the Body of the Magnet (turns divided 1X5)

Field on the conductor - peak field (not including the self field)

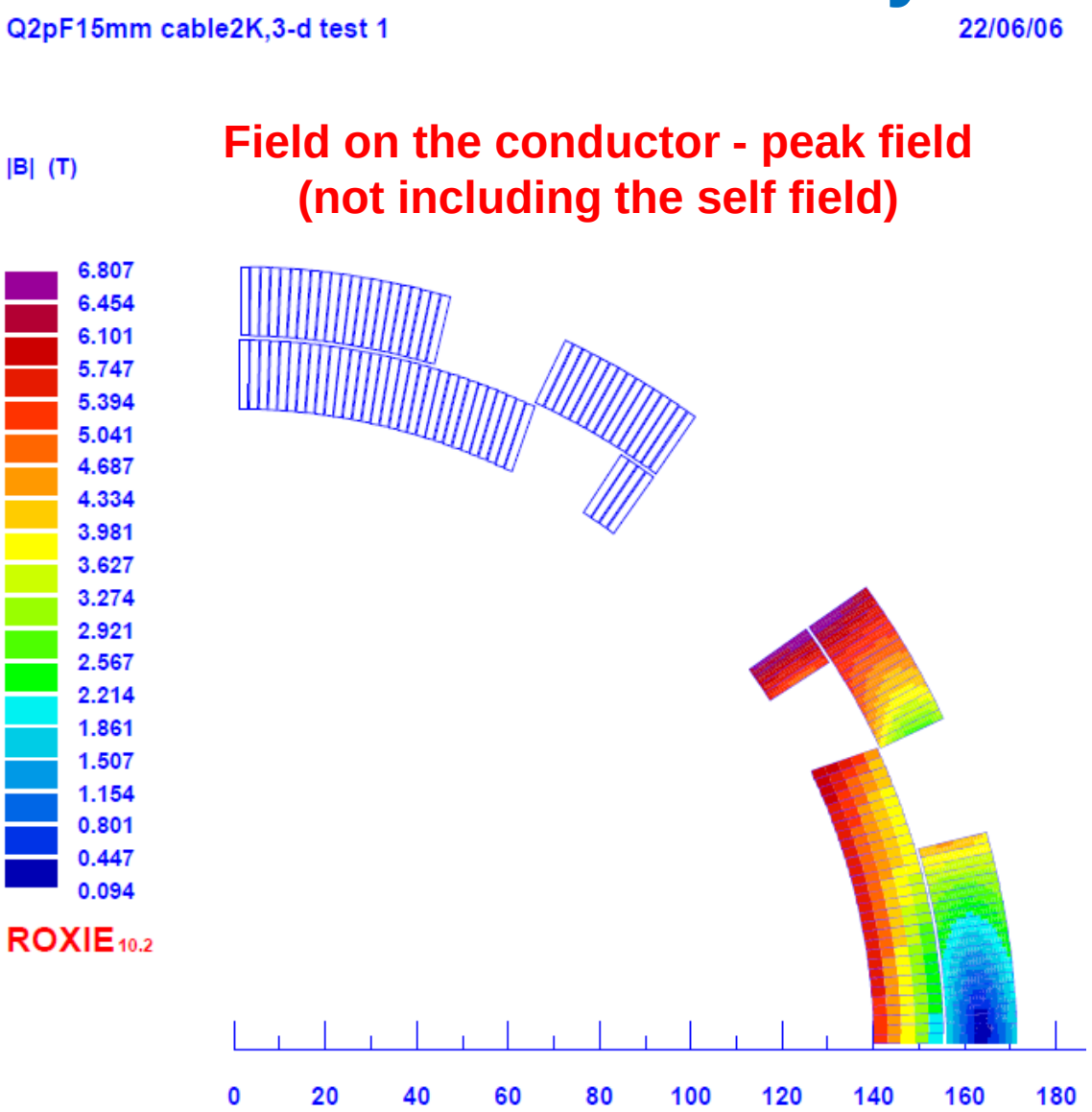


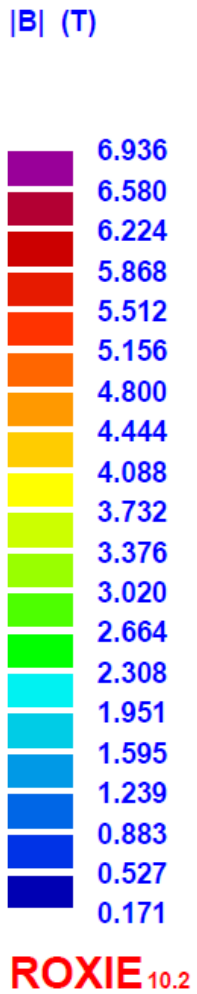


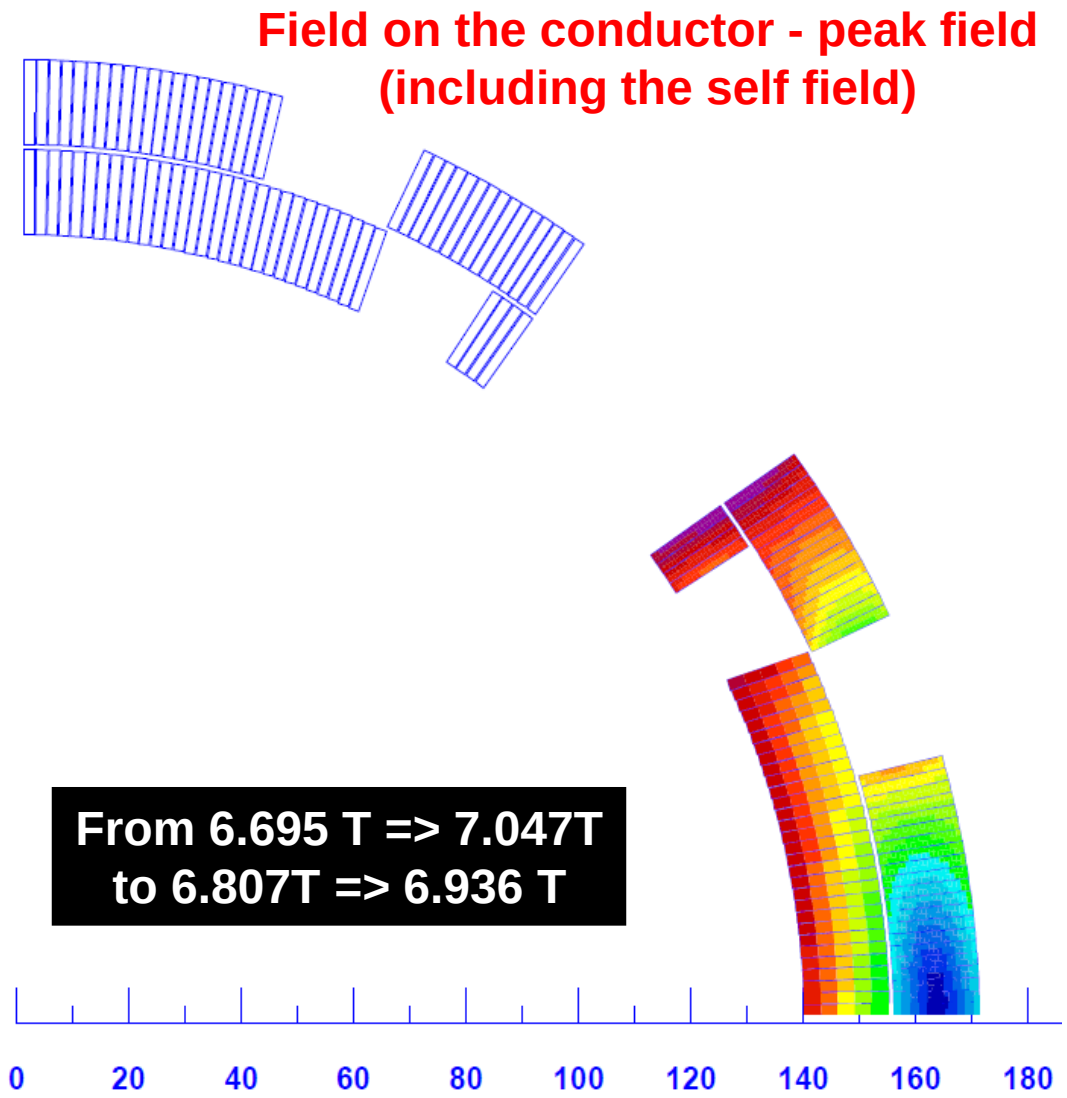
Field on the conductor - peak field (including the self field)

One should keep checking the impact of approximation

Peak Field in the Body of the Magnet (turns divided 2X20)

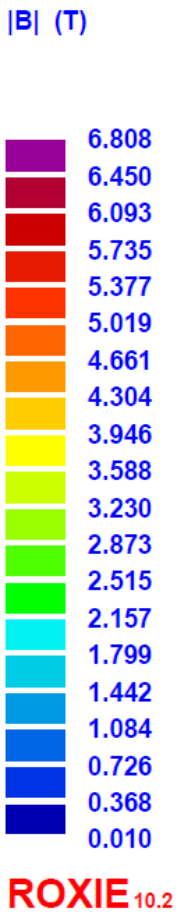




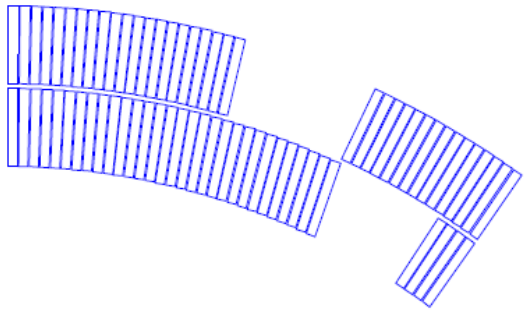


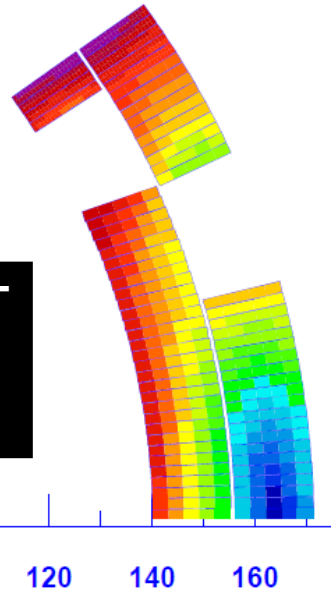
One should keep checking the impact of approximation

Peak Field in the Body of the Magnet (pole 2X20, others 1X5)

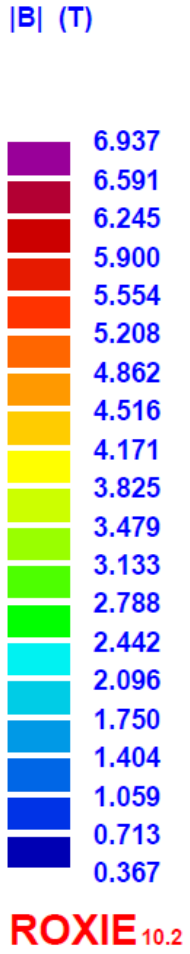


Field on the conductor - peak field (not including the self field)



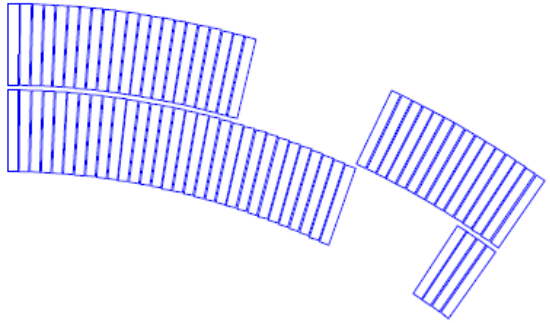


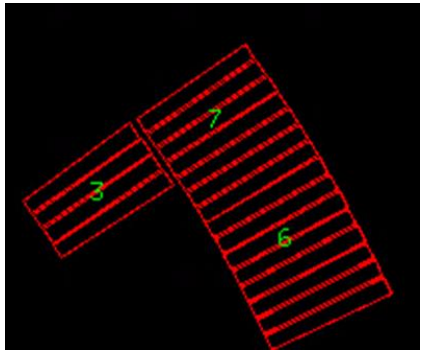
From 6.695T => 7.047T to 6.807 T => 6.936 T to 6.808 T=> 6.937 T



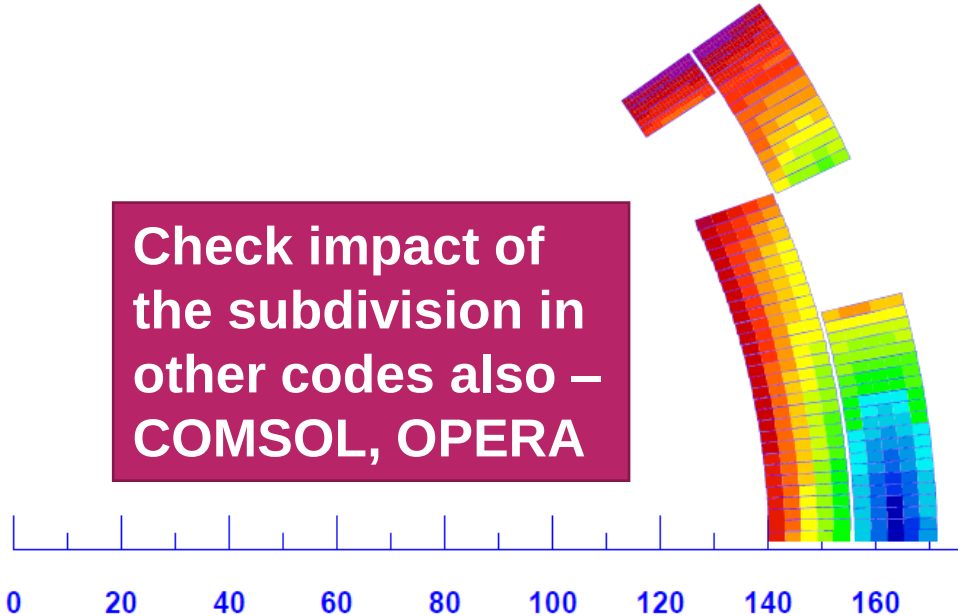
Field on the conductor - peak field (including the self field)

(#3 & #7)





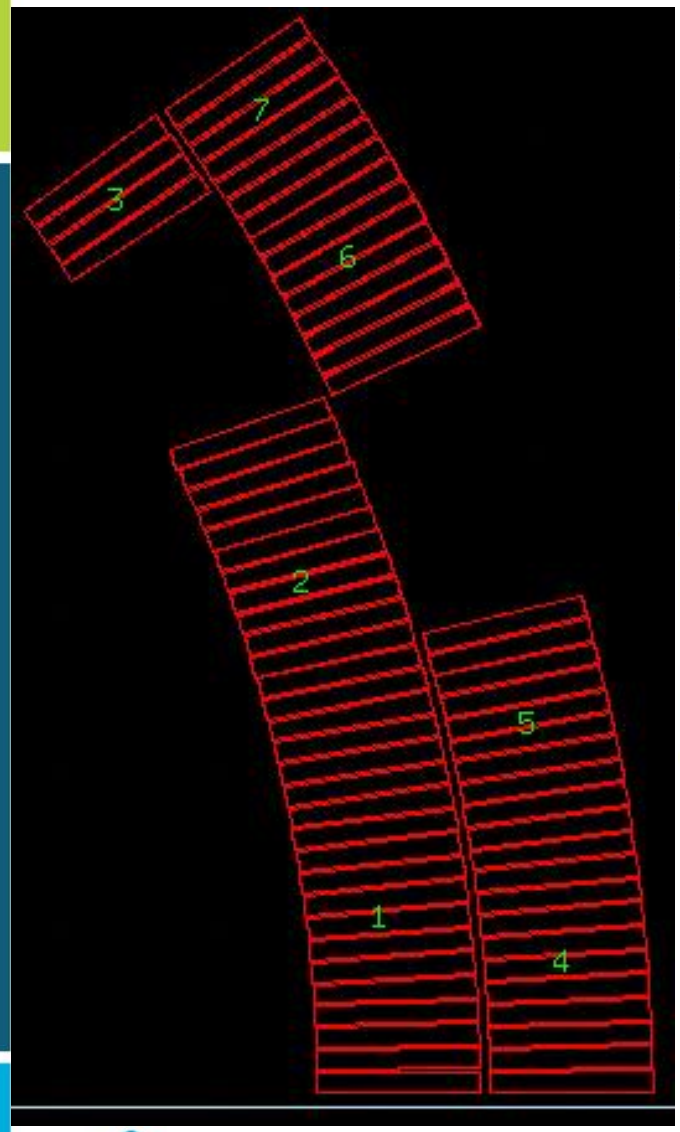
Check impact of the subdivision in other codes also – COMSOL, OPERA



One should keep checking the impact of approximation; this choice may be a good compromise

Peak Field Computations with different number of divisions

Same ends in both cases



All 1X5

- **Block #3: 7.96 T**
- **Block #7: 7.75 T**

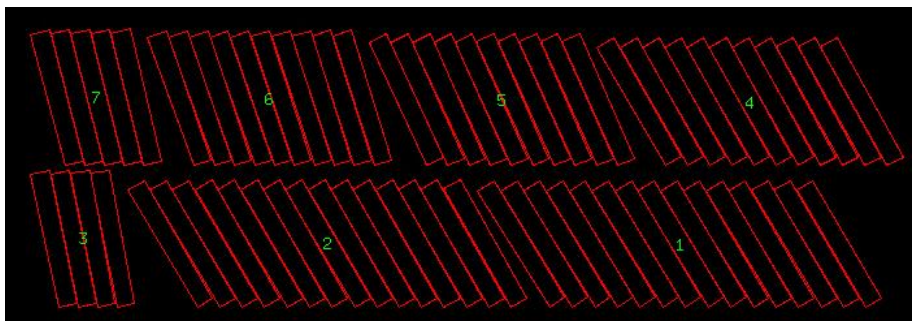
Pole 2X20
Others 1X5

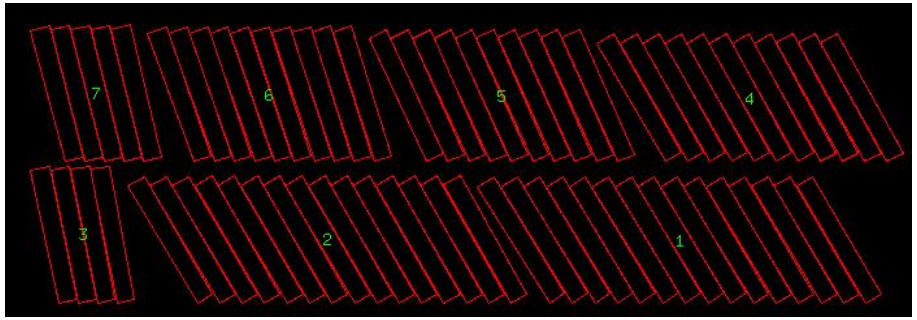
- **Block #3: 8.05 T**
- **Block #7: 7.87 T**

3D REFERENCE MAIN FIELD (T)	2.6314	2.6314	
REFERENCE MAGNET STRENGTH (T/(m^(n-1))	31.7036	31.7037	
MAGNETIC LENGTH (mm)	1505.2139	1505.2139	
MARGIN CALC (USING LINEAR JC-APPROX):			
BLOCK NUMBER	3	3	
PEAK FIELD IN CONDUCTOR 34 (T)	7.9586	8.0586	
CURRENT IN CONDUCTOR 34 (A)	-8500.0000	-8500.0000	
SUPERCONDUCTOR CURRENT DENSITY (A/MM2)	-886.0233	-886.0233	
PERCENTAGE ON THE LOAD LINE	73.8207		
QUENCHFIELD (T)	10.7810		
PERCENTAGE OF SHORT SAMPLE CURRENT	66.0838		
MARGIN CALC (USING LINEAR JC-APPROX):			
BLOCK NUMBER	7	7	
PEAK FIELD IN CONDUCTOR 70 (T)	7.7507	7.8721	
CURRENT IN CONDUCTOR 70 (A)	-8500.0000	-8500.0000	
SUPERCONDUCTOR CURRENT DENSITY (A/MM2)	-886.0233	-886.0233	
PERCENTAGE ON THE LOAD LINE	72.2431		
QUENCHFIELD (T)	10.7286		
PERCENTAGE OF SHORT SAMPLE CURRENT	67.3827		

Takeaway:

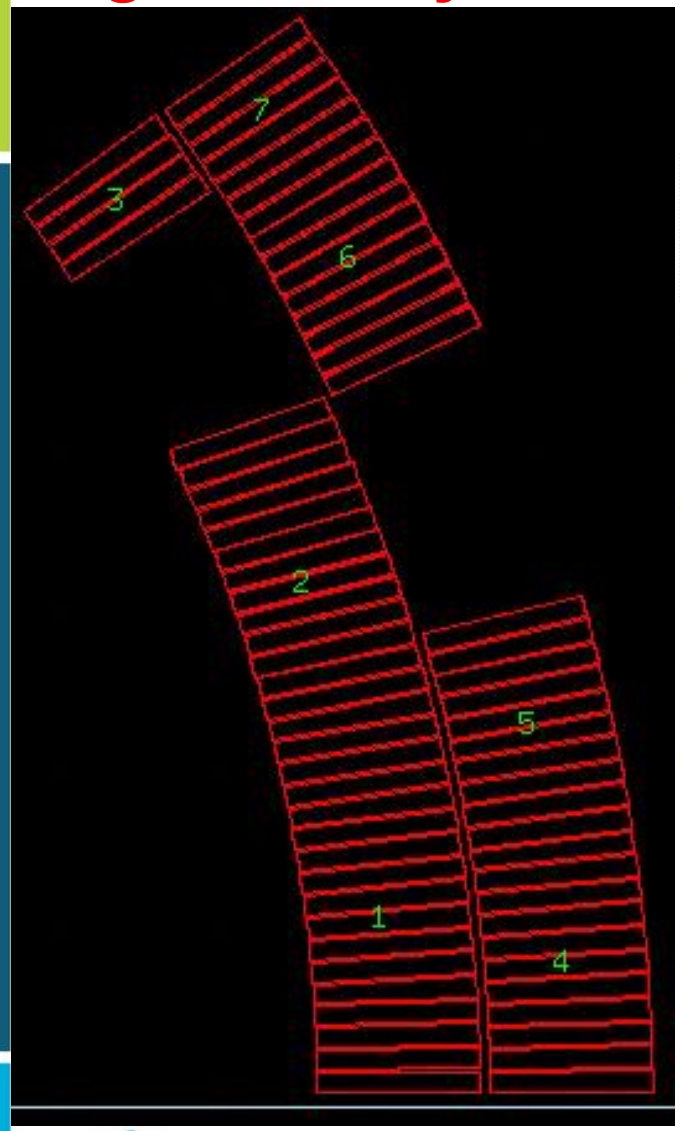
1X5 may be ok for relative optimization but subdivide in more for the final case





Peak Field Reduction-Lower Peak Fields (both inner & outer)

Significantly better



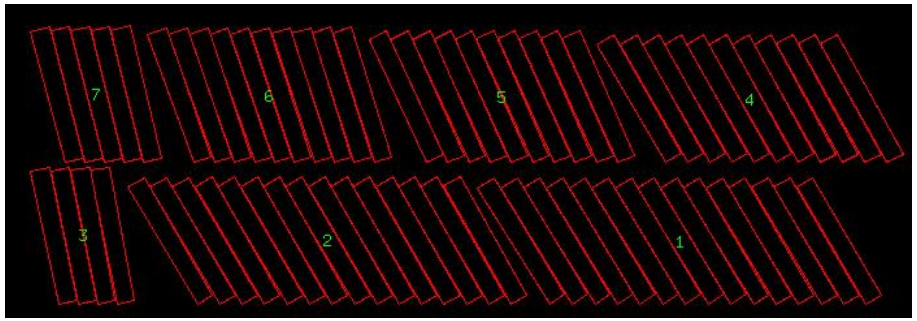
OLD

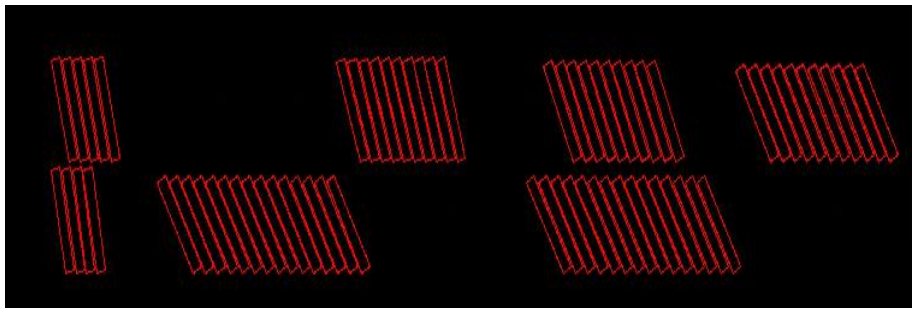
- Block #3: 7.96 T
- Block #7: 7.75 T

NEW

- Block #3: 7.16 T
- Block #7: 7.18 T

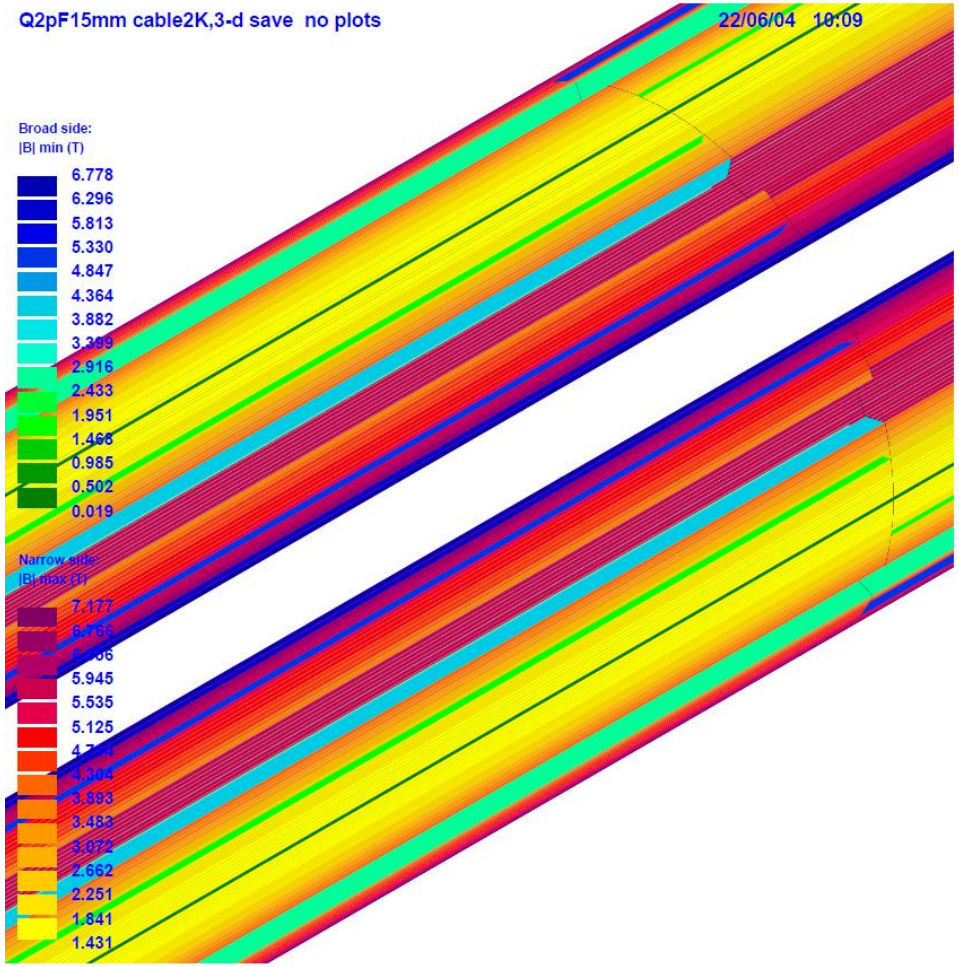
3D REFERENCE MAIN FIELD (T)	2.6314	...	2.7383
REFERENCE MAGNET STRENGTH (T/(m^(n-1)) ..	31.7036	...	32.9913
MAGNETIC LENGTH (mm)	1505.2139	...	1505.6175
MARGIN CALC (USING LINEAR JC-APPROX):			
BLOCK NUMBER	3	.....	3
PEAK FIELD IN CONDUCTOR 34 (T)	7.9586	.....	7.1622
CURRENT IN CONDUCTOR 34 (A)	-8500.0000	.....	-8500.0000
SUPERCONDUCTOR CURRENT DENSITY (A/MM2)	-886.0233	.....	-886.0233
PERCENTAGE ON THE LOAD LINE	73.8207		
QUENCHFIELD (T)	10.7810		
PERCENTAGE OF SHORT SAMPLE CURRENT	66.0838		
MARGIN CALC (USING LINEAR JC-APPROX):			
BLOCK NUMBER	7	.....	7
PEAK FIELD IN CONDUCTOR 70 (T)	7.7507	.....	7.1772
CURRENT IN CONDUCTOR 70 (A)	-8500.0000	.....	-8500.0000
SUPERCONDUCTOR CURRENT DENSITY (A/MM2)	-886.0233	.....	-886.0233
PERCENTAGE ON THE LOAD LINE	72.2431		
QUENCHFIELD (T)	10.7286		
PERCENTAGE OF SHORT SAMPLE CURRENT	67.3827		



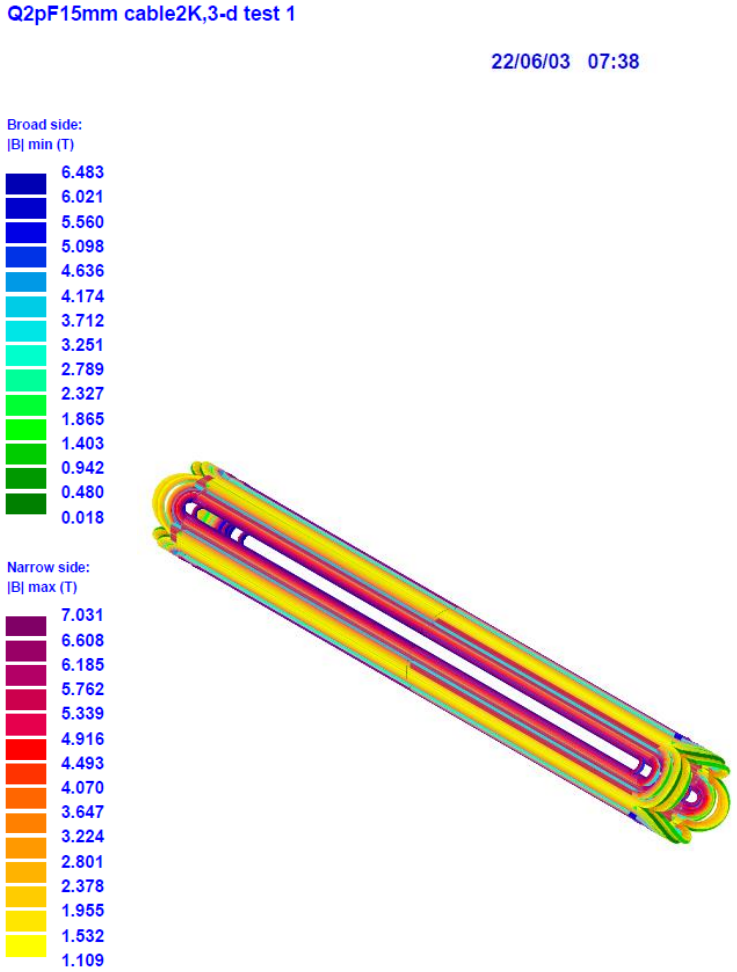


a1

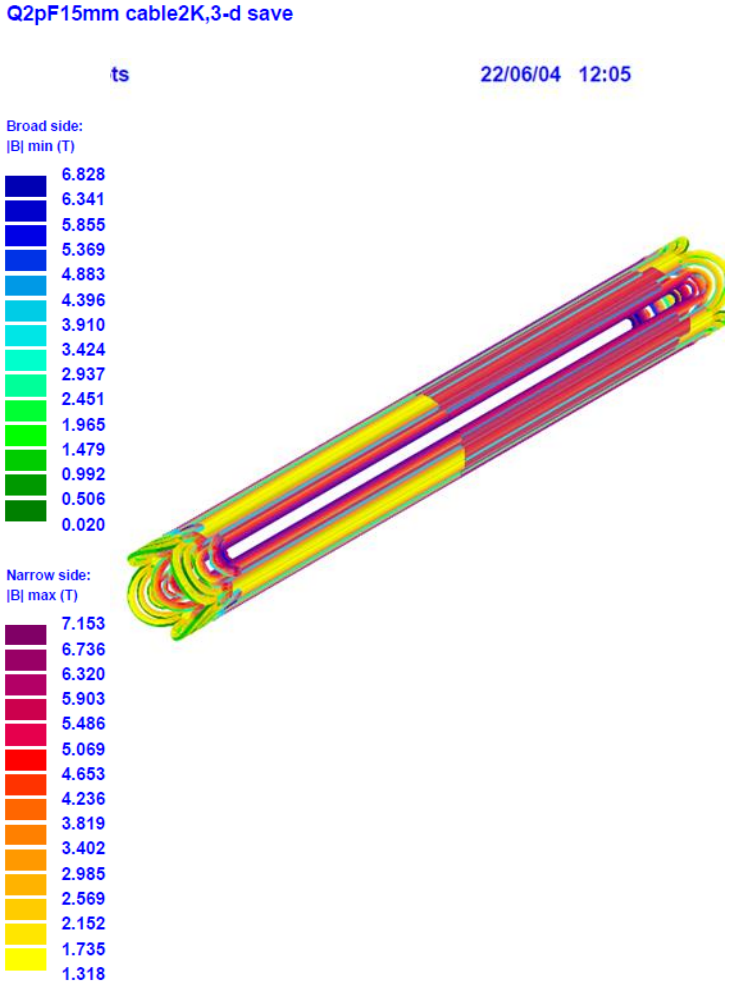
Peak Field Reduction – Three cases - Slide 1 (similar peak fields but different end geometries)



a1



a2



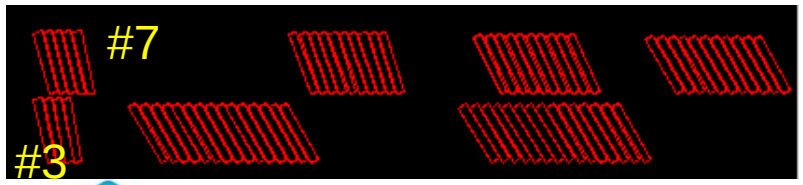
b2save

Peak Field Reduction – Three cases – Slide 2

(impact of pole blocks of inner and outer ending at different places on peak field)

- **Block #3: 7.16 T**
- **Block #7: 7.18 T**

```
3D REFERENCE MAIN FIELD (T) ..... 2.7383
REFERENCE MAGNET STRENGTH (T/(m^(n-1)) .. 32.9913
MAGNETIC LENGTH (mm) ..... 1505.6175

BLOCK NUMBER ..... 3
PEAK FIELD IN CONDUCTOR 34 (T) .... 7.1622
CURRENT IN CONDUCTOR 34 (A) ..... -8500.0000
SUPERCONDUCTOR CURRENT DENSITY (A/MM2 ..... -886.0233

BLOCK NUMBER ..... 7
PEAK FIELD IN CONDUCTOR 34 (T) .... 7.1772
CURRENT IN CONDUCTOR 34 (A) ..... -8500.0000
SUPERCONDUCTOR CURRENT DENSITY (A/MM2 ..... -886.0233
```



a1

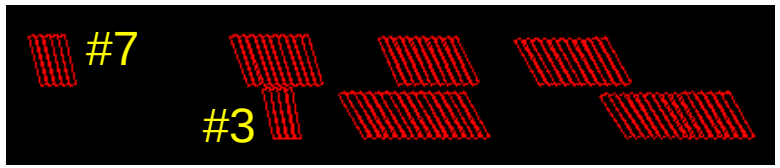
- **Block #3: 7.15 T**
- **Block #7: 6.70 T**

```
.. 2.8144
.. 33.9084
.. 1505.8820

. 3
. 7.1537
. -8500.0000

. 7
. 6.7028
. -8500.0000
```

a2

- **Block #3: 6.74 T**
- **Block #7: 7.03 T**

```
.. 2.8237
.. 34.0199
.. 1505.9138

.. 3
.. 6.7449
.. -8500.0000

.. 7
.. 7.0314
.. -8500.0000
```



b2save

Techniques for Reducing in Peak Field in the Ends

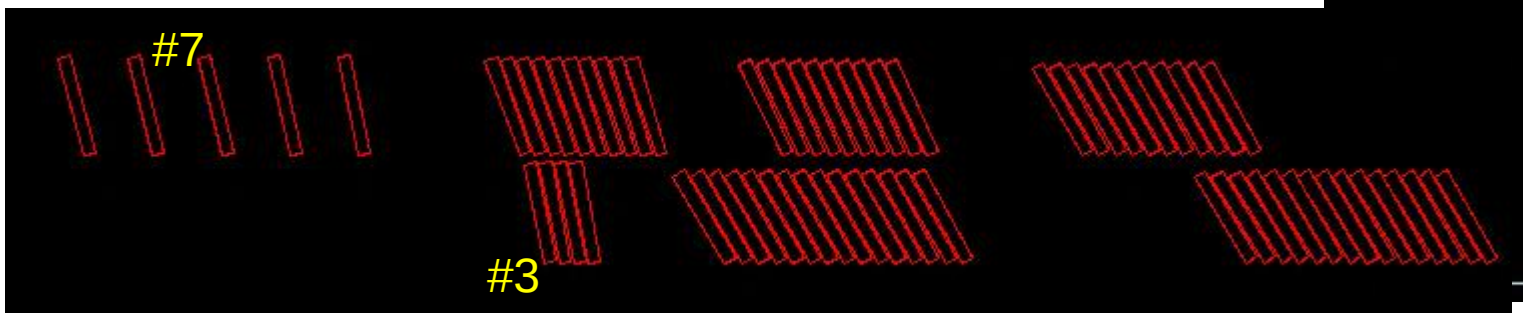
(spread the turns in the end block with high peak fields)

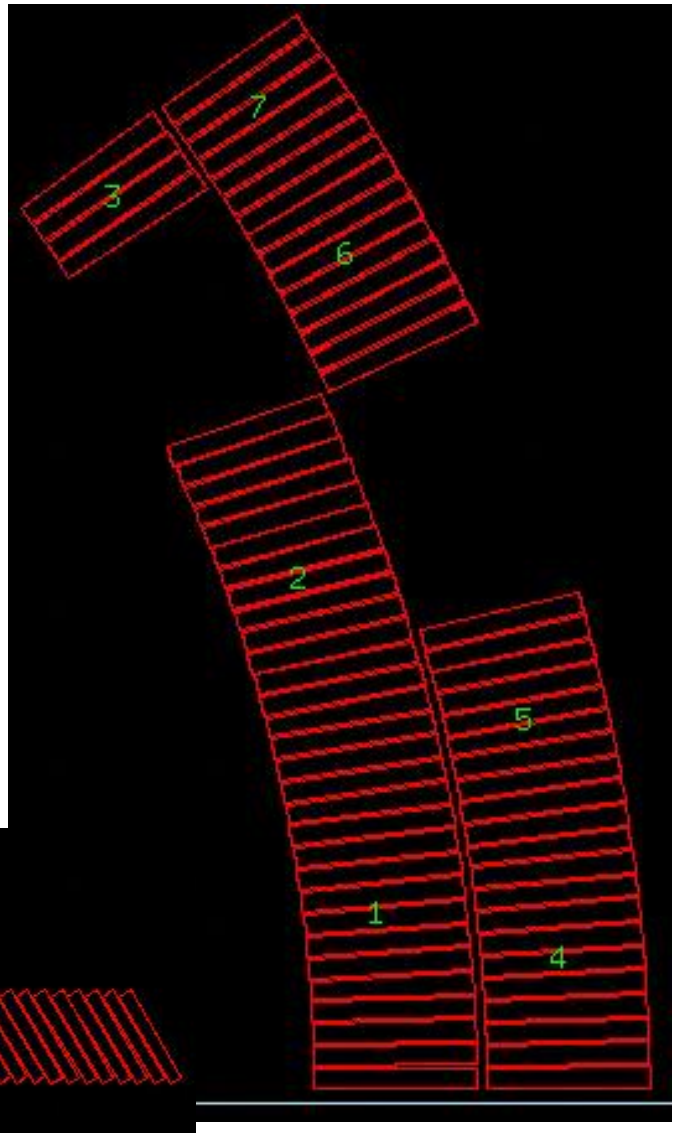
- **Block #3: 6.82 T**
- **Block #7: 6.92 T**

Significant reduction in the peak field in the ends

First case: 7.96 T
Last case: 7.03 T
This case: 6.92 T

```
3D REFERENCE MAIN FIELD (T) ..........................      2.8254
REFERENCE MAGNET STRENGTH (T/(m^(n-1)) ..............     34.0408
MAGNETIC LENGTH (mm) .................................   1505.9196

MARGIN CALC (USING JC-FIT):
BLOCK NUMBER .........................................         3
PEAK FIELD IN CONDUCTOR   34 (T) .....................      6.8167
CURRENT IN CONDUCTOR  34 (A) .........................  -8500.0000
SUPERCONDUCTOR CURRENT DENSITY (A/MM2) ..............   -886.0233
PERCENTAGE ON THE LOAD LINE ..........................     65.0746
QUENCHFIELD (T) ......................................     10.4753
TEMPERATURE MARGIN TO QUENCH (K) .....................      3.2089
PERCENTAGE OF SHORT SAMPLE CURRENT ...................     26.1400

MARGIN CALC (USING LINEAR JC-APPROX):
BLOCK NUMBER .........................................         7
PEAK FIELD IN CONDUCTOR   70 (T) .....................      6.9172
CURRENT IN CONDUCTOR  70 (A) .........................  -8500.0000
SUPERCONDUCTOR CURRENT DENSITY (A/MM2) ..............   -886.0233
PERCENTAGE ON THE LOAD LINE ..........................     65.9191
QUENCHFIELD (T) ......................................     10.4934
PERCENTAGE OF SHORT SAMPLE CURRENT ...................     71.7238
```





Initial Optimization of Peak Field and End Harmonics
(with inner and outer layers ending at about the same place)

Objectives

No	String	S1	S2	Oper	N/a	Weight
1	B	6	1	MINABS	0	1
2	B	10	1	MINABS	0	1
3	PEAK3D	3	0	MIN	0	1
4	PEAK3D	7	0	MIN	0	1

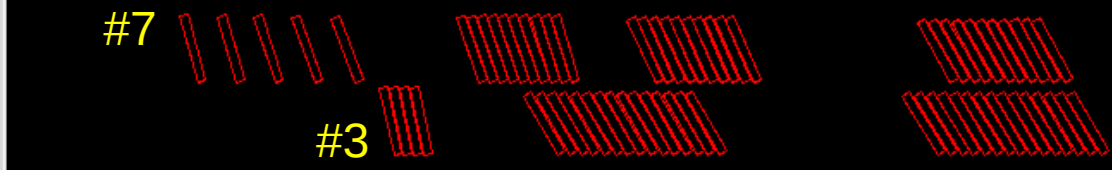
Jun 6 09:04

/home/gupta/EIC/Q2pF+/2022/3D2022May/Q2pF3D-peak-opt03.data]

Design Variables

Optimization algorithm : 1 Extrem ?

No	Xl	Xu	Xs	String	Act	N/a
1	1100	1200	1162.71	Z0	2	3
2	1100	1200	1118.53	Z0	2	7
3	5	10	6.2169	WI	2	7
4	5	10	5.6257	WO	2	7
5	20	50	45.9788	DZZR	2	1
6	10	30	22.7173	DZZR	2	2
7	10	60	40.2589	DZZR	2	4
8	10	30	14.6026	DZZR	2	5
9	10	30	25.6626	DZZR	2	6



/Q2pF3D-peak-opt03.data

➢ **Block #3: 6.82 T; Block #7: 6.92 T**

```
MARGIN CALC (USING JC-FIT):
BLOCK NUMBER ..........................................        3
PEAK FIELD IN CONDUCTOR   34 (T) ......................     6.6522
CURRENT IN CONDUCTOR  34 (A) ..........................  -8500.0000
SUPERCONDUCTOR CURRENT DENSITY (A/MM2) ................     -886.0233
PERCENTAGE ON THE LOAD LINE ...........................       63.8421
QUENCHFIELD (T) .......................................       10.4197
TEMPERATURE MARGIN TO QUENCH (K) ......................        3.2942
PERCENTAGE OF SHORT SAMPLE CURRENT ....................       25.2997

 MARGIN CALC (USING LINEAR JC-APPROX):
 BLOCK NUMBER .........................................        7
 PEAK FIELD IN CONDUCTOR   70 (T) .....................     6.9507
 CURRENT IN CONDUCTOR  70 (A) .........................  -8500.0000
 SUPERCONDUCTOR CURRENT DENSITY (A/MM2) ...............     -886.0233
 PERCENTAGE ON THE LOAD LINE ..........................       66.1734
 QUENCHFIELD (T) ......................................       10.5038
 PERCENTAGE OF SHORT SAMPLE CURRENT ...................       71.5716

3D REFERENCE MAIN FIELD (T) ..........................        2.8559
REFERENCE MAGNET STRENGTH (T/(m^(n-1)) ...............       34.4083
MAGNETIC LENGTH (mm) .................................     1506.0212

NORMAL 3D INTEGRAL RELATIVE MULTIPOLES (1.D-4):
b 1:       0.00000  b 2:   10000.00000  b 3:      -0.00000
b 4:       0.00000  b 5:       0.00000  b 6:      -0.09342
b 7:       0.00000  b 8:       0.00000  b 9:       0.00000
b10:      -0.12319  b11:       0.00000  b12:       0.00000
b13:      -0.00000  b14:      -0.51991  b15:      -0.00000
b16:      -0.00000  b17:       0.00000  b18:       0.00995
```

Optimization to continue