Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Revised Q2pF Return End for updated turn-to-turn spacing

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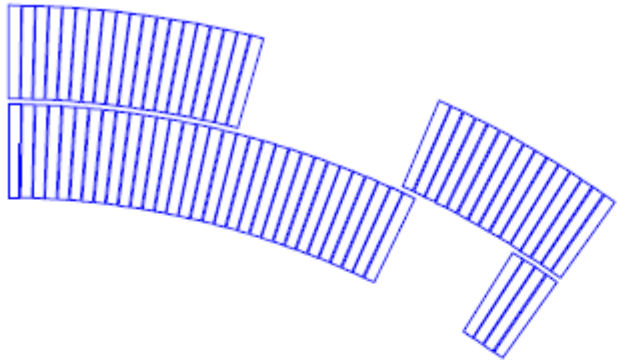
Updated Return End

- Cross-section was updated to accommodate a significant change in turn-to-turn spacing (from 0.12 mm to 0.0965 mm).
- While turn distribution in inner layer remained same (31+4=35), it changed in the outer from (21+13=34) to (19+15=34) in the outer layer. Therefore, the end design needs to be updated.
- Need to assure a good field quality (end harmonics) and low peak fields with desired layout of end turns (Min. tilt angle 70 degrees).

Final optimization after the feedback from the single turn winding trials

Revised X-section with Symmetric Wedges

(as presented last week)

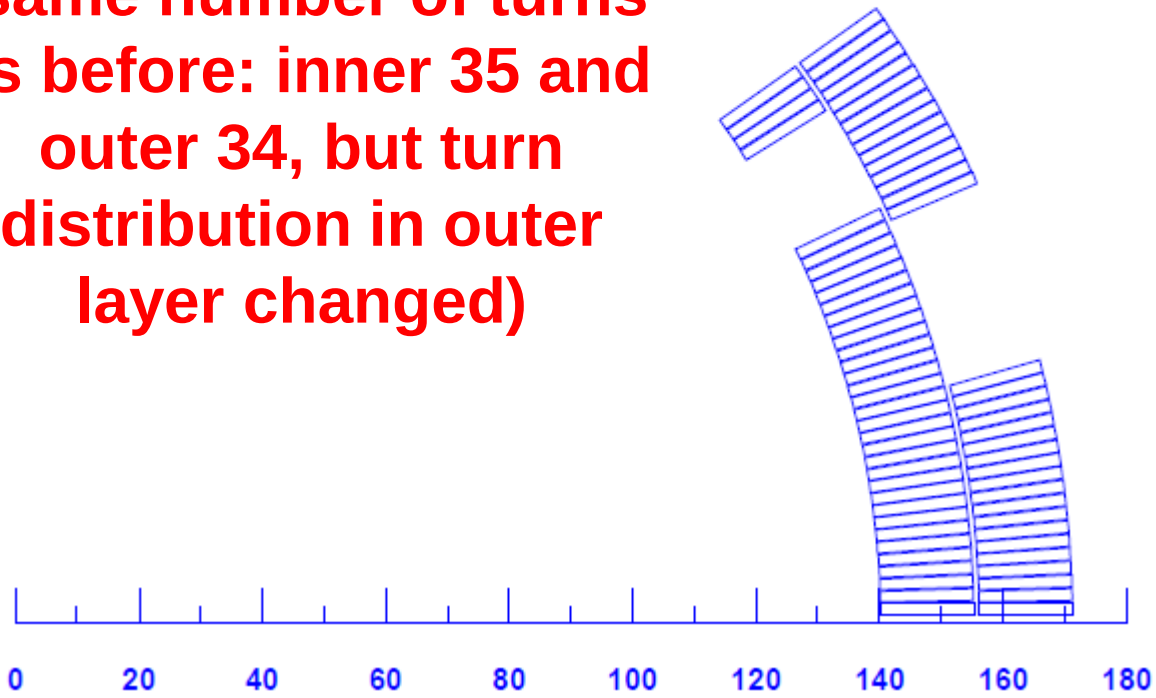


Looks good mechanically

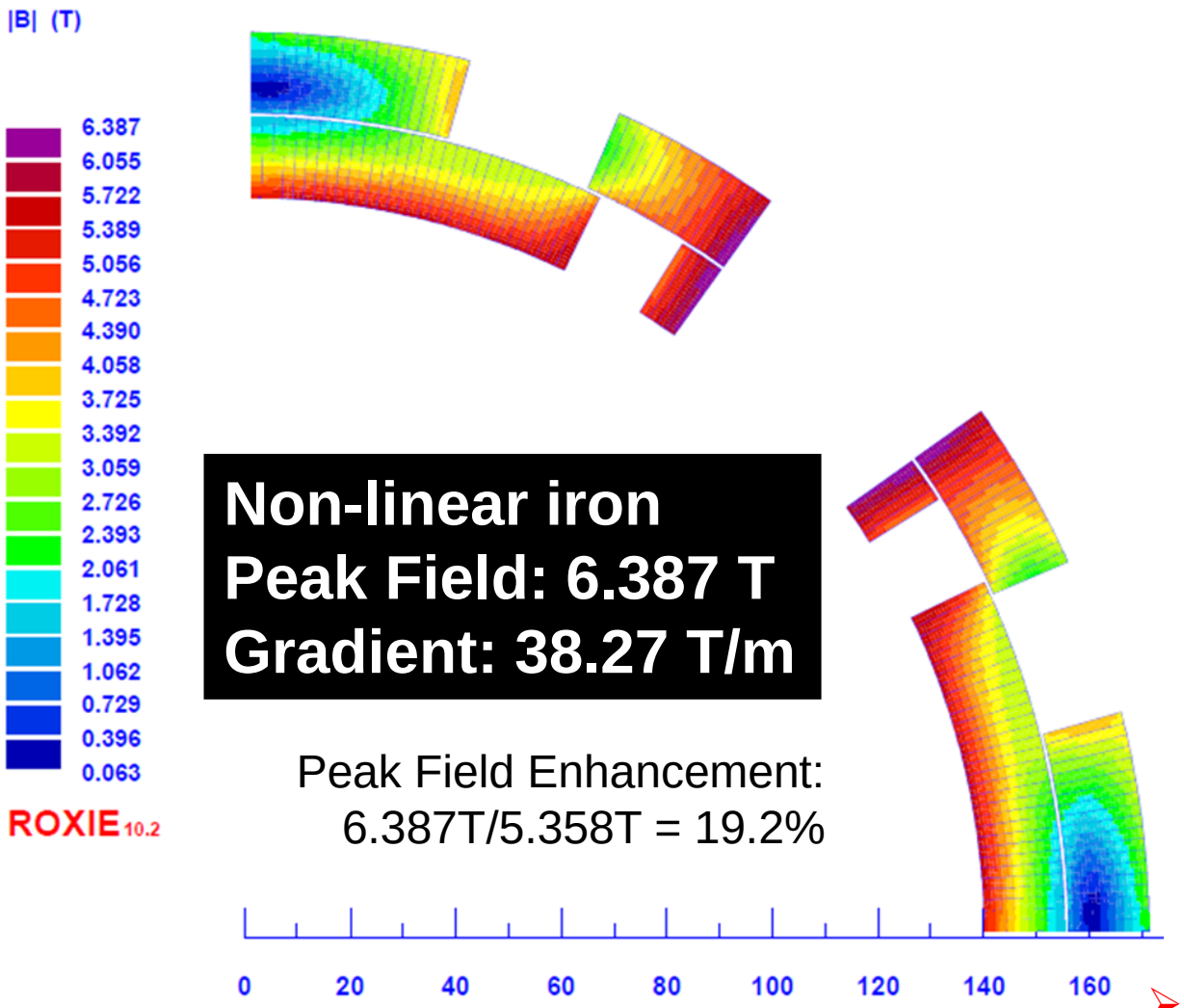
- **Uses EIC Quad Cable**
- **Field Quality Optimized**
- **Peak field Optimized**
- **Poles of Outer and Inner aligned**
- **Wedges made exactly symmetric**
- **Collaring process should provide a good pre-stress**

(note: wedge shape at poles)

(same number of turns as before: inner 35 and outer 34, but turn distribution in outer layer changed)



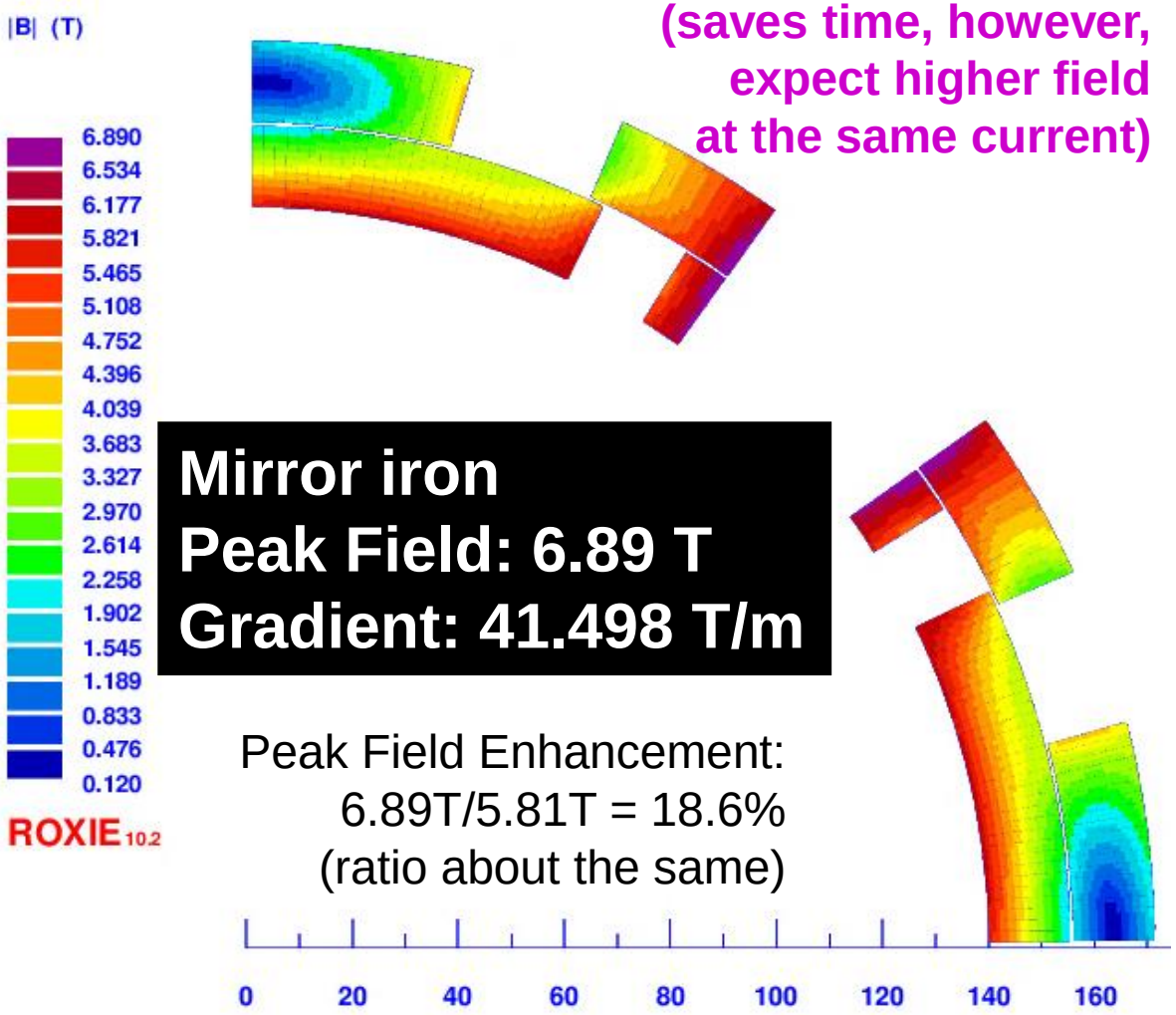
Peak Field Calculations in Q2pF Cross-section



Non-linear iron
Peak Field: 6.387 T
Gradient: 38.27 T/m

Peak Field Enhancement:
6.387T/5.358T = 19.2%

Mirror iron calculations (saves time, however, expect higher field at the same current)



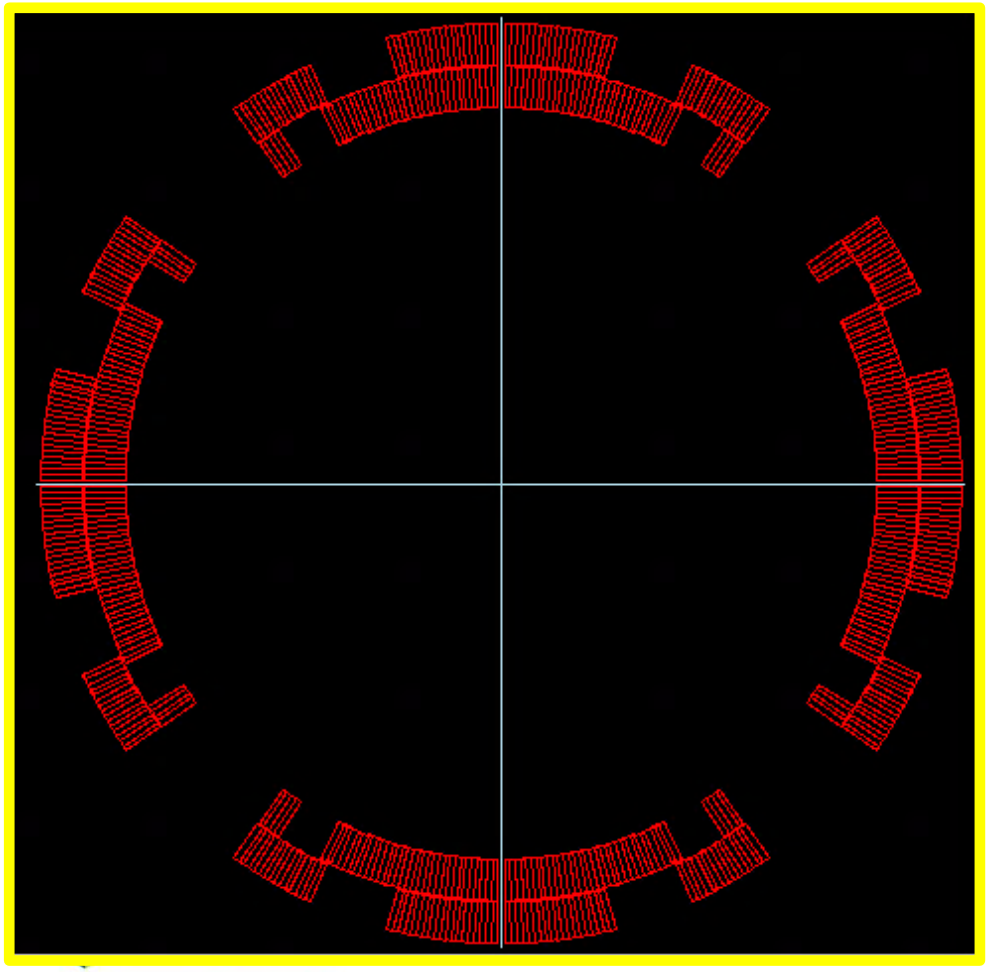
Mirror iron
Peak Field: 6.89 T
Gradient: 41.498 T/m

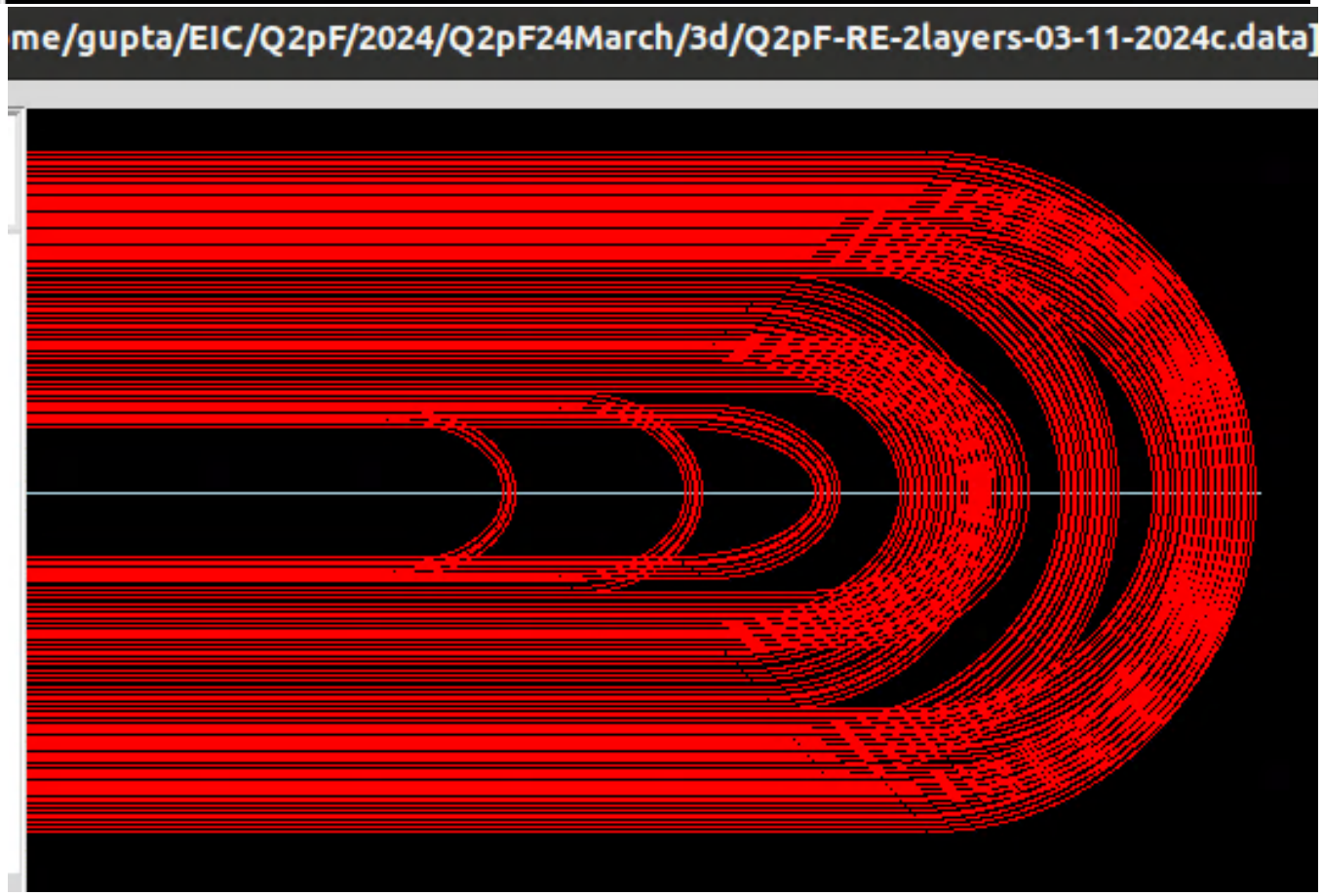
Peak Field Enhancement:
6.89T/5.81T = 18.6%
(ratio about the same)

- Mirror iron calculations takes significantly less time
Important in 3-d calculations; used during the optimization

Return End for updated turn-to-turn spacing (min tilt angle 70º)

- **End turns of the outer layer and the inner layers aligned**





Additional Peak Field Enhancement in the Ends

End configuration iterated for smaller peak fields in the ends. Final optimization after the winding trials.

ROXIE calculations with mirror iron

- **Peak field in 2-d: 6.89 T**
- **Peak field in 3-d: 7.09 T**

Only about ~2.9% higher peak field than that in the x-section

(what are the calculation errors?)

Turn #34 is the pole turn in the outer layer

```
RESULTS OF THE 3D PEAK FIELD CALCULATION
PEAK FIELD IN CONDUCTOR   10 (T) ..................      3.0567
PEAK FIELD IN CONDUCTOR   10 (T) ..................      3.0567
RESULTS OF THE 3D PEAK FIELD CALCULATION
PEAK FIELD IN CONDUCTOR   19 (T) ..................      4.4683
PEAK FIELD IN CONDUCTOR   19 (T) ..................      4.4683
RESULTS OF THE 3D PEAK FIELD CALCULATION
PEAK FIELD IN CONDUCTOR   29 (T) ..................      6.7153
PEAK FIELD IN CONDUCTOR   29 (T) ..................      6.7153
RESULTS OF THE 3D PEAK FIELD CALCULATION
PEAK FIELD IN CONDUCTOR   32 (T) ..................      6.7893
PEAK FIELD IN CONDUCTOR   32 (T) ..................      6.7893
RESULTS OF THE 3D PEAK FIELD CALCULATION
PEAK FIELD IN CONDUCTOR   34 (T) ..................      7.0905
PEAK FIELD IN CONDUCTOR   34 (T) ..................      7.0905
RESULTS OF THE 3D PEAK FIELD CALCULATION
PEAK FIELD IN CONDUCTOR   45 (T) ..................      5.8845
PEAK FIELD IN CONDUCTOR   45 (T) ..................      5.8845
RESULTS OF THE 3D PEAK FIELD CALCULATION
PEAK FIELD IN CONDUCTOR   65 (T) ..................      6.8664
PEAK FIELD IN CONDUCTOR   65 (T) ..................      6.8664
RESULTS OF THE 3D PEAK FIELD CALCULATION
PEAK FIELD IN CONDUCTOR   69 (T) ..................      6.8508
PEAK FIELD IN CONDUCTOR   69 (T) ..................      6.8508
```

Integrated harmonics (3-d) in the Return End

End configuration iterated for lower integrated harmonics in the ends.

A reasonable end design:

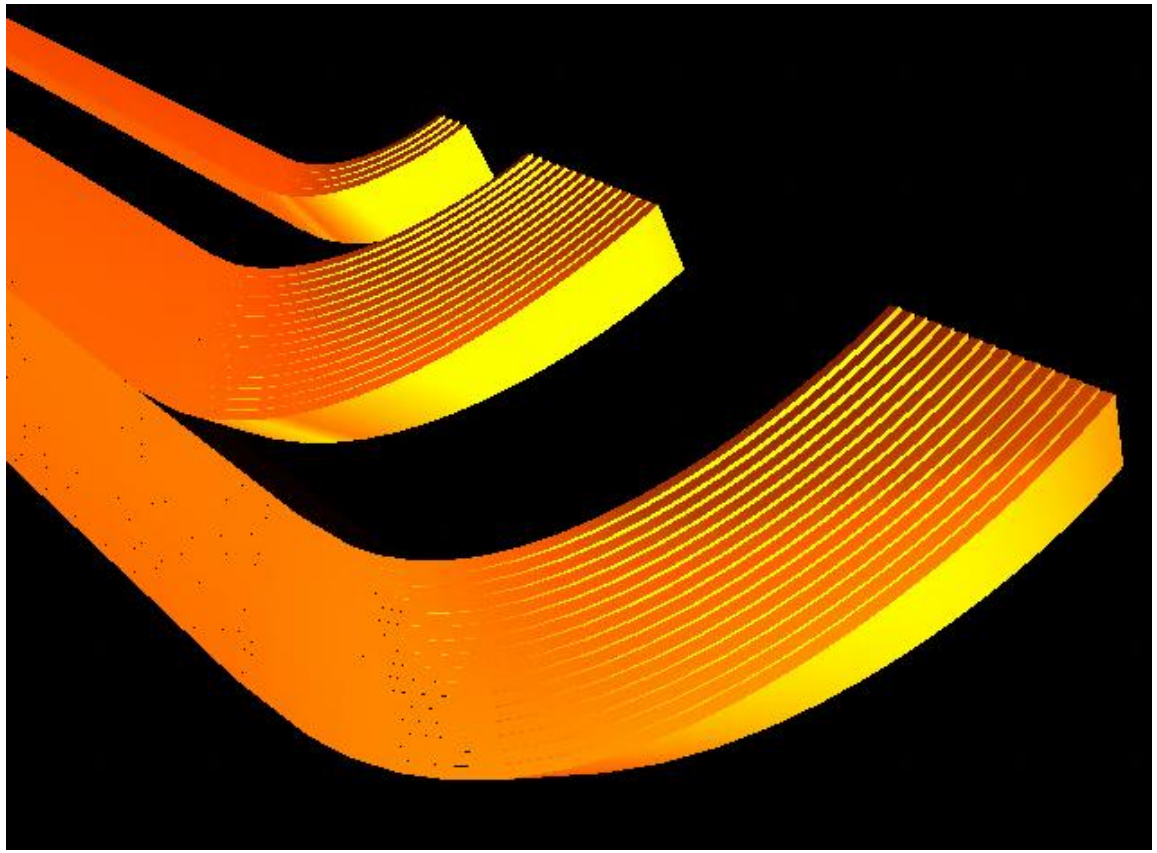
- **All integrated field harmonics are well within 1 units (mirror iron).**
- **Final optimization to be performed after the winding trials and with non-linear iron.**

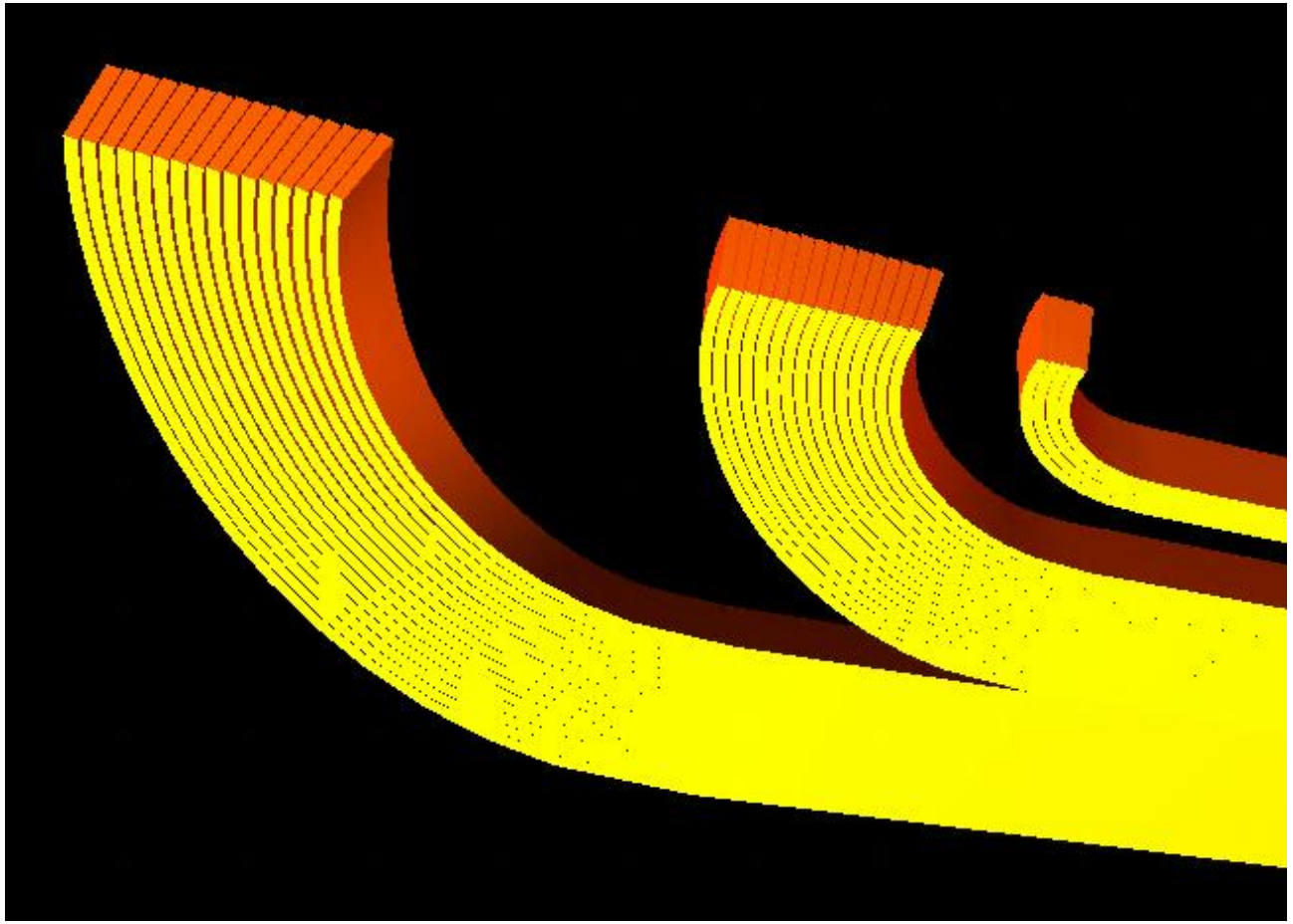
```
HARMONIC ANALYSIS NUMBER ..............................          1
MAIN HARMONIC .........................................          2
REFERENCE RADIUS (mm) .................................       83.0000
X-POSITION OF THE HARMONIC COIL (mm) ..................        0.0000
Y-POSITION OF THE HARMONIC COIL (mm) ..................        0.0000
NUMBER OF ANALYSES ALONG Z ............................        200
LENGTH OF VIRTUAL COIL (mm) ...........................     5000.0000
REFERENCE POSITION NUMBER .............................        100
MEASUREMENT TYPE ..........................  ALL FIELD CONTRIBUTIONS
ERROR OF HARMONIC ANALYSIS OF Br ......................   0.7379E-04
SUM (Br(p) - SUM (An cos(np) + Bn sin(np))

3D REFERENCE MAIN FIELD (T) ...........................      -3.4447
REFERENCE MAGNET STRENGTH (T/(m^(n-1)) ................     -41.5020
MAGNETIC LENGTH (mm) ..................................    3449.5399

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:     -0.34649
b 7:     -0.00000  b 8:     -0.00000  b 9:     -0.00000
b10:     -0.02086  b11:      0.00000  b12:      0.00000
b13:     -0.00000  b14:     -0.27946  b15:     -0.00000
b16:     -0.00000  b17:      0.00000  b18:     -0.00529
```

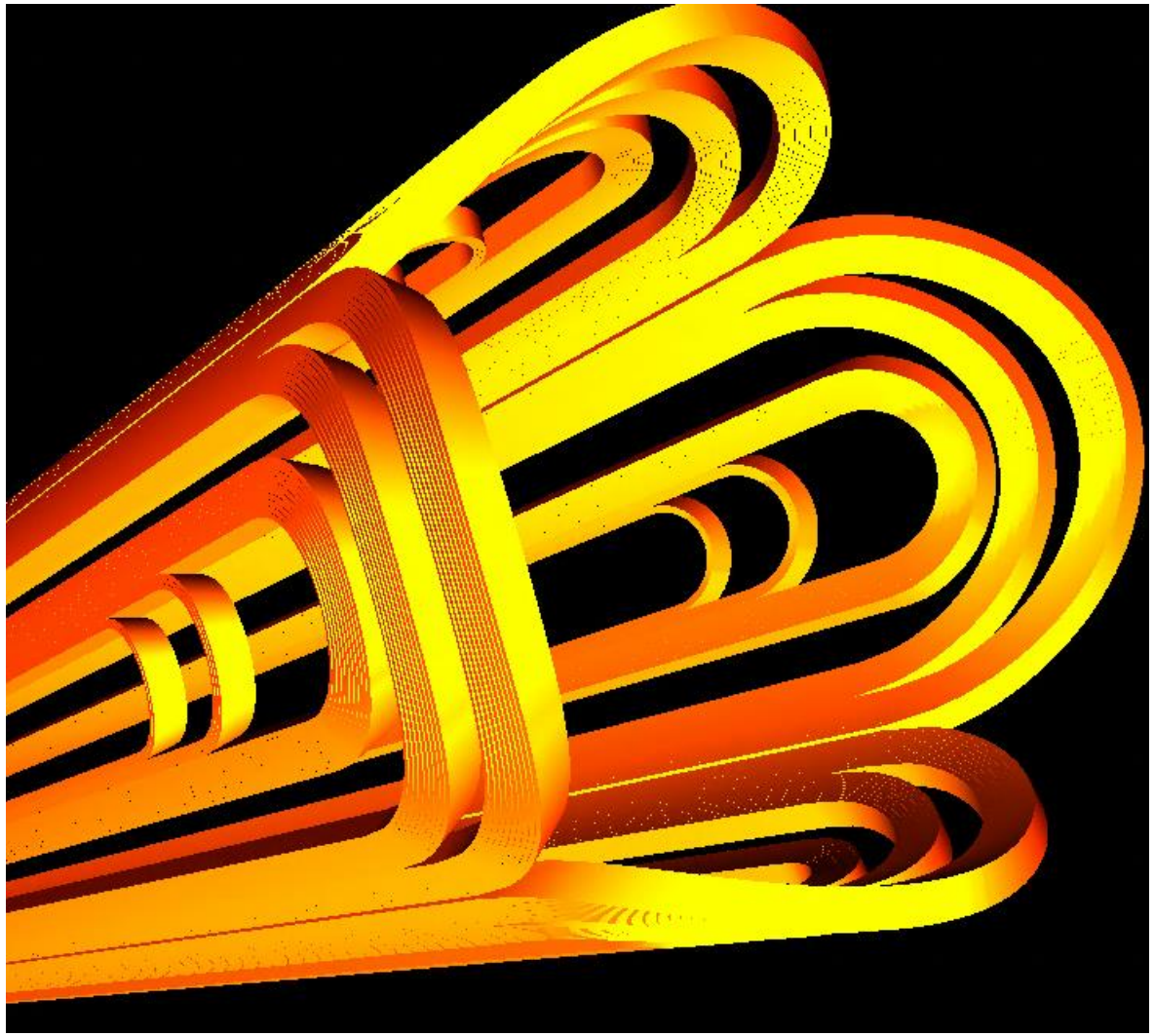
Renderings of the Inner Layer of the Return End

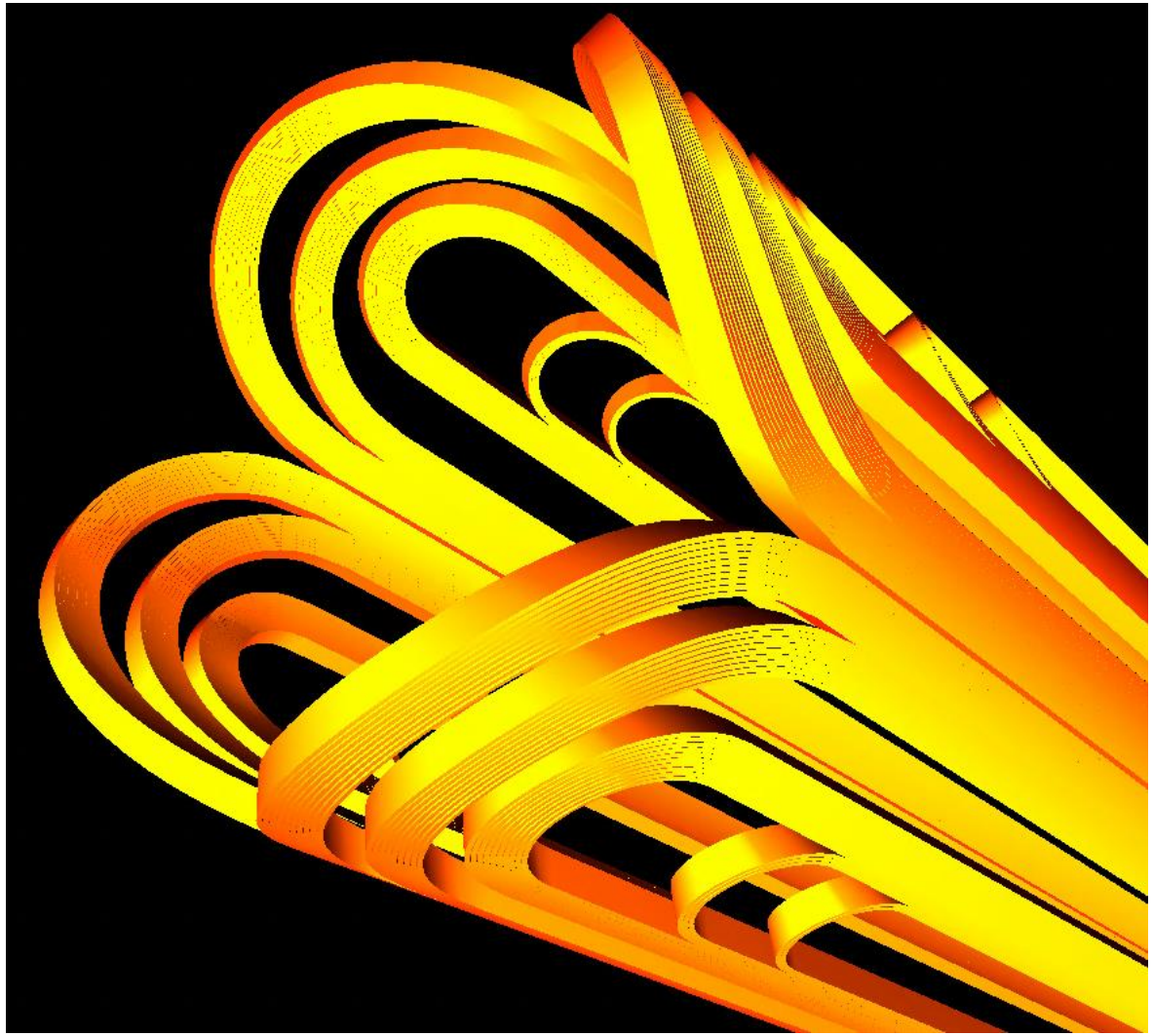




Looks reasonably ok; to be examined more carefully

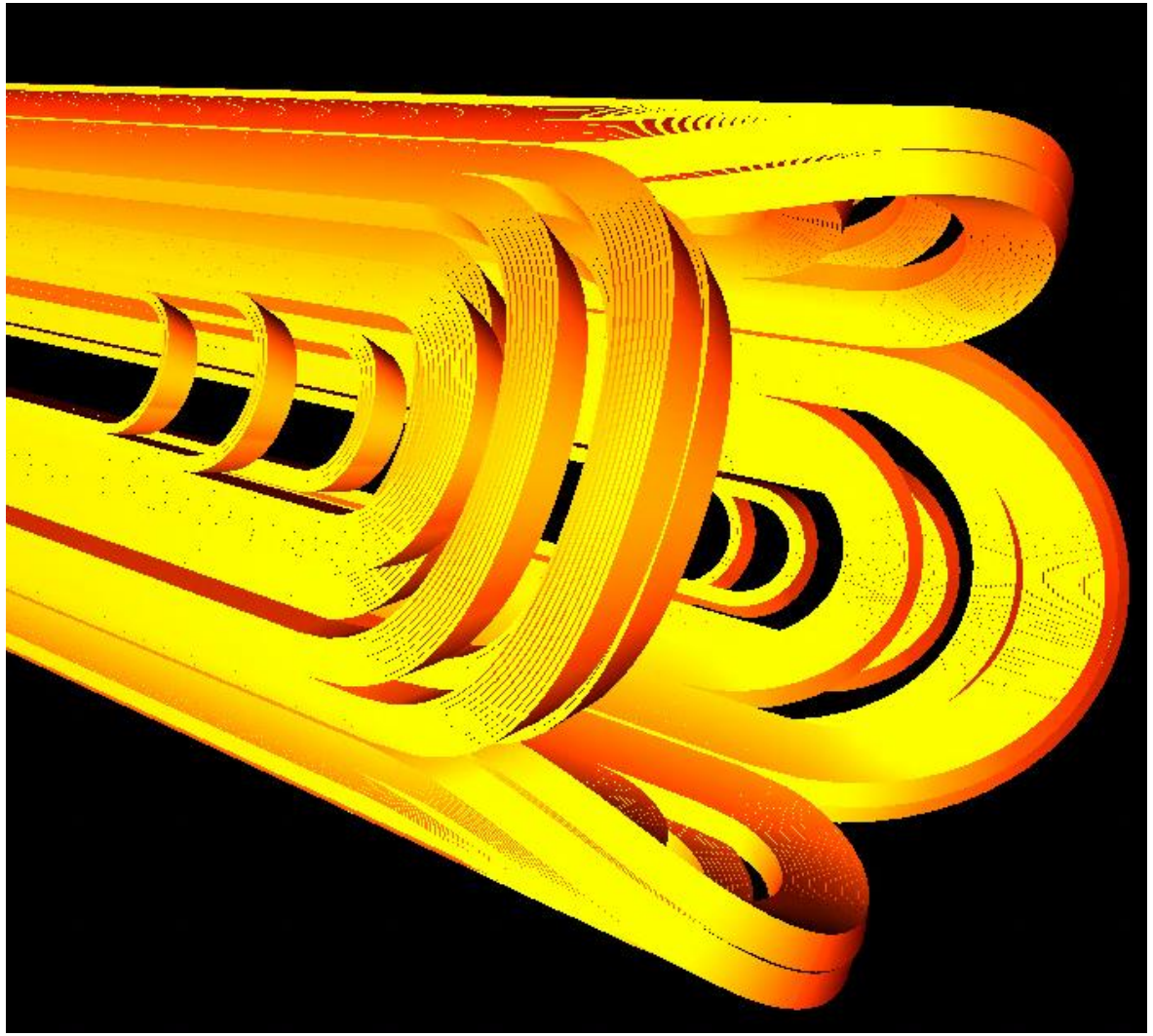
Renderings of the Outer Layer of the Return End

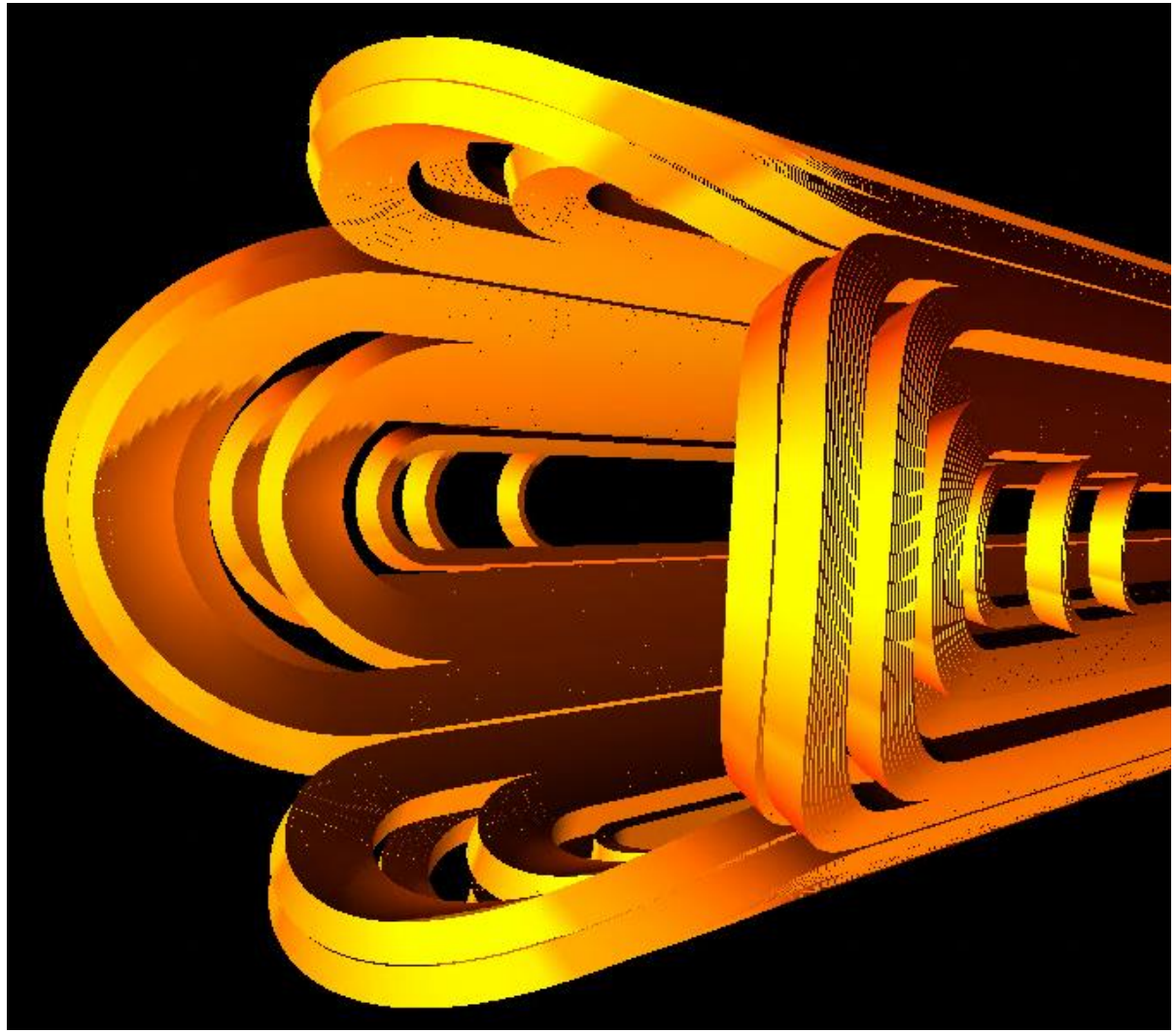




Looks reasonably ok; to be examined more carefully

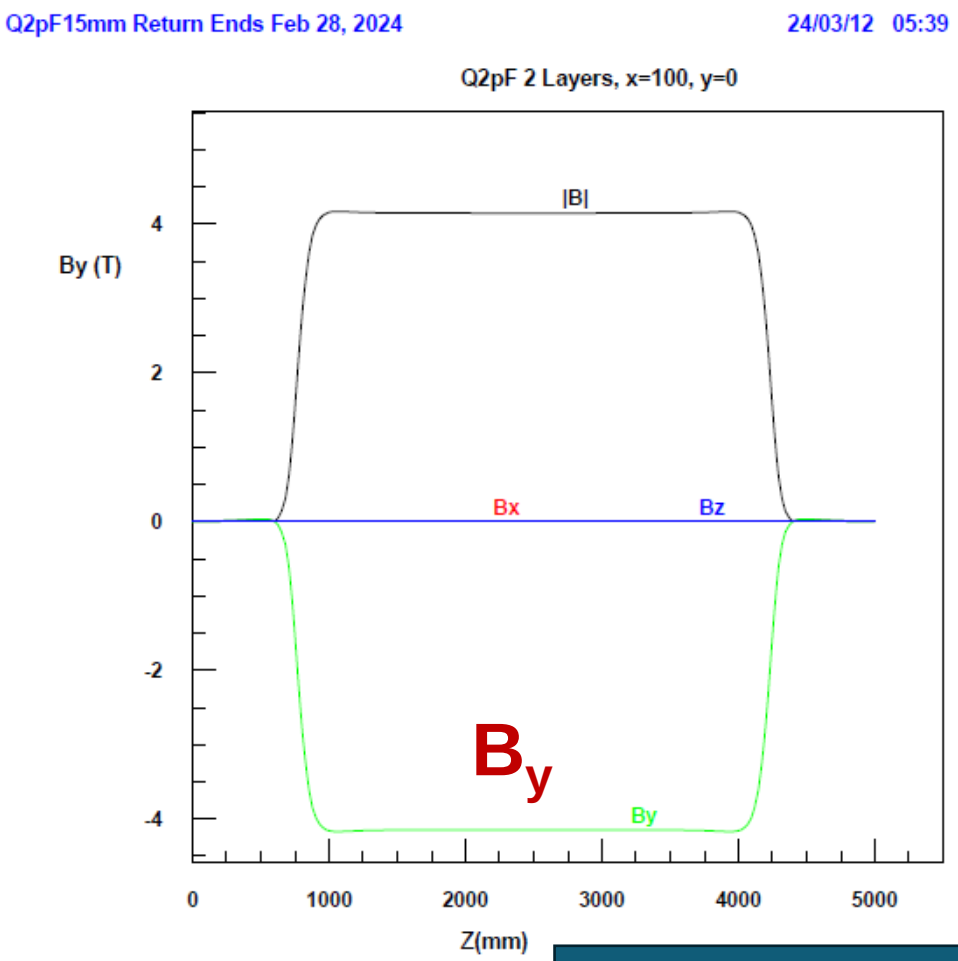
Renderings of Both Layers of the Return End

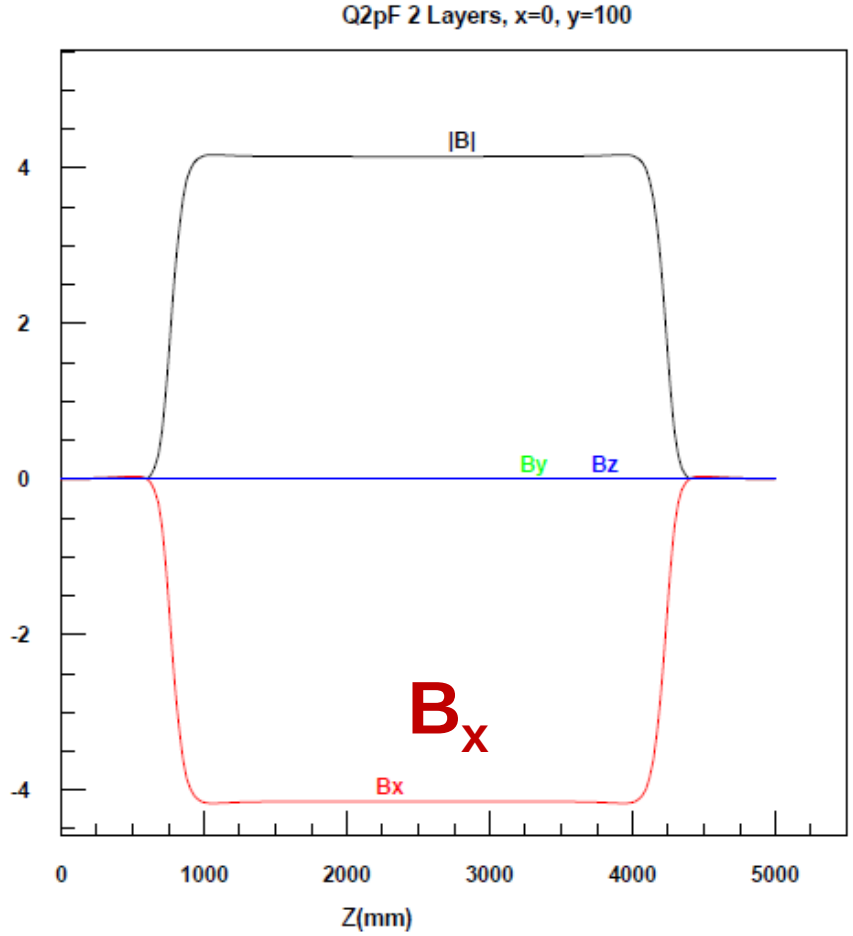




Looks reasonably ok; to be examined more carefully

Field along the z-axis at a radius of 100 mm on the horizonal axis and vertical axis

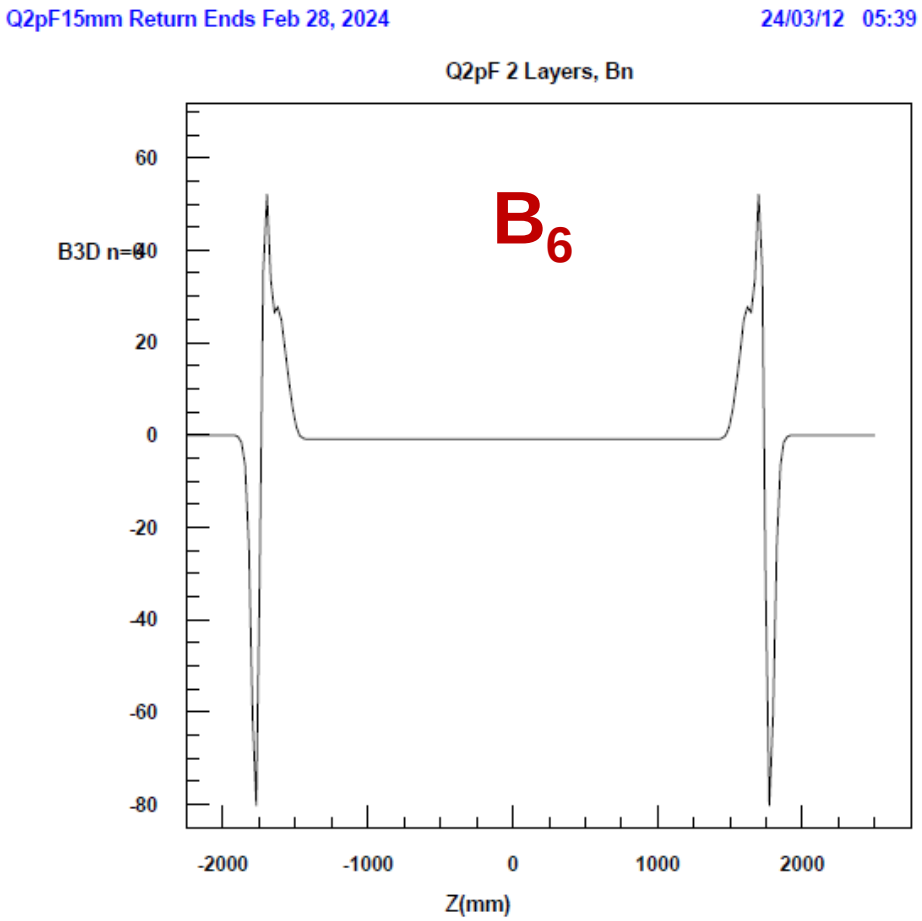


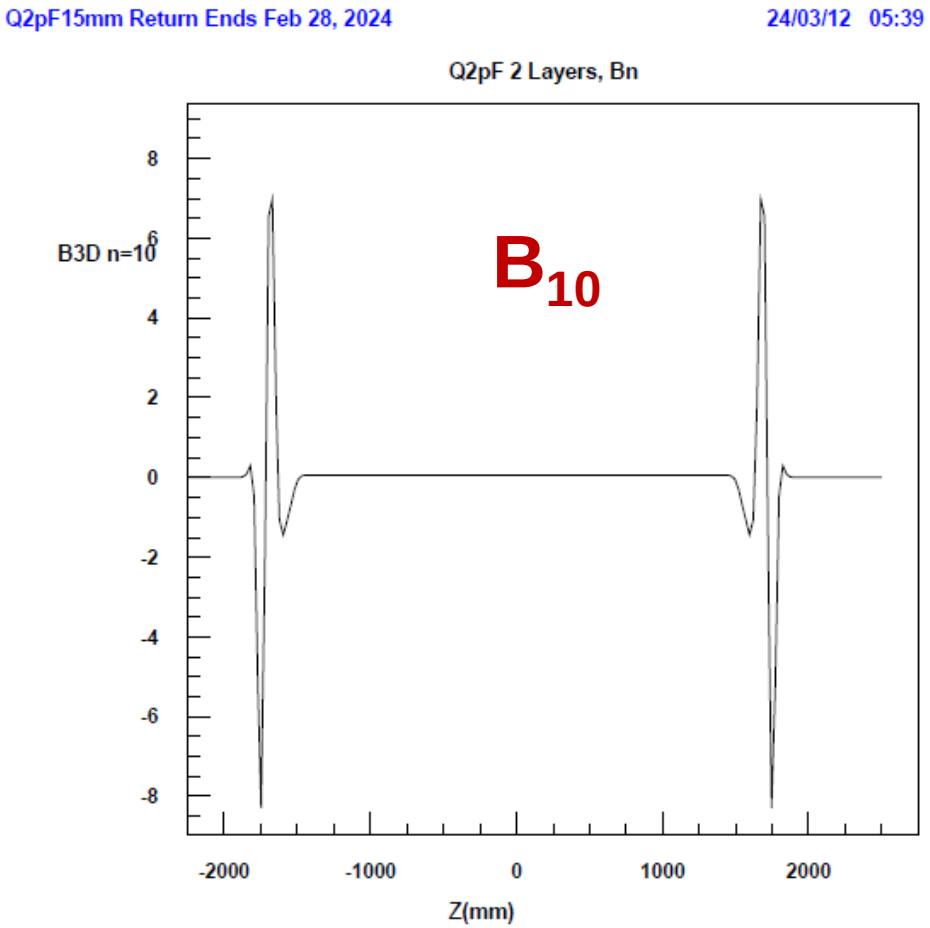


(symmetric return end)

Next set of runs with the separate lead end

Field harmonics B_6 and B_{10} along the z-axis





(symmetric return end)

Summary

- Initial return end design completed for the updated turn-to-turn spacing
- The present solution has a reasonable peak field enhancement in the ends and reasonable integral harmonics
- Next : Update the Lead End
- Final finer optimization to be performed after the winding trials in case parameters have to be adjusted

Extra Slides

Comparison with the Previous Design

Previous Design

5	ALLPOLYIL	0.15	0.12	POLYIMID MB INNER

Block Data 2D

No	Type	NCab	R	ϕ	α	Current	Cable name	N1	N2	I
1	Cos	31	140	0.54	0	-8500	EICLHCQ2K	2	20	0
2	Cos	4	140	31.179	25.196	-8500	EICLHCQ2K	2	20	0
3	Cos	21	156	0.54	0	-8500	EICLHCQ2K	2	20	0
4	Cos	13	156	17	30	-8500	EICLHCQ2K	2	20	0

Previous value of insulation

No	X1	Xu	Xs	String	Act	Block
1	3	9	6.44	PHIRS	2	2
2	6	12	10.34	PHIRS	2	4
3	0	0	0	ALPHRS	2	2
4	0	0	0	ALPHRS	2	4

New Design

2	EICQ2INS	0.15	0.0965	EICQ2PF insulation

Block Data 2D

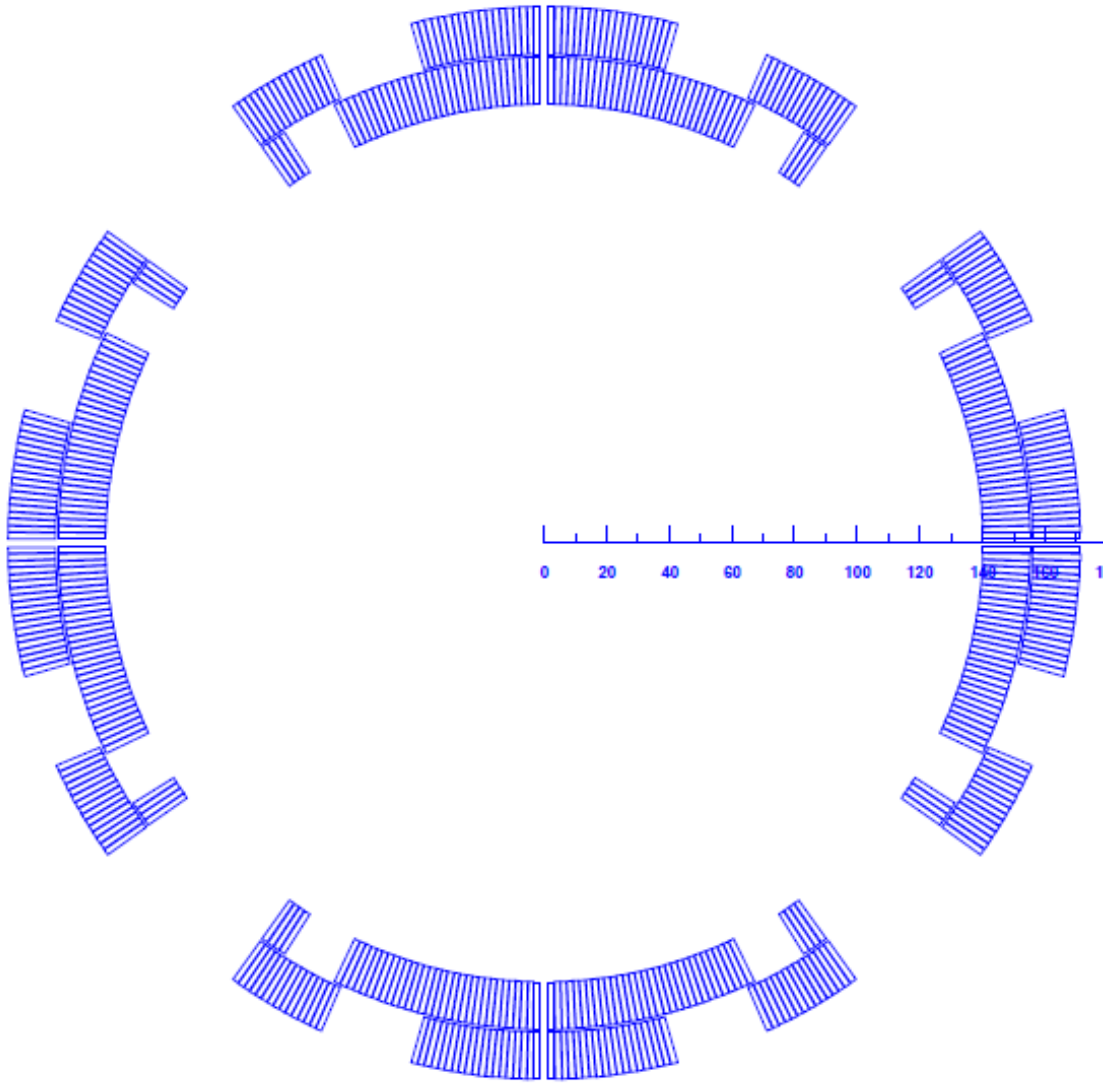
No	Type	NCab	X	Y	α	Current	Cable name	N1	N2	I
1	Cos	31	140	0.5	0	1000	EICQ2PF	2	20	0
2	Cos	4	140	32.2986	32.0511	1000	EICQ2PF	2	20	0
3	Cos	19	156	0.46	0	1000	EICQ2PF	2	20	0
4	Cos	15	156	24.6366	23.0593	1000	EICQ2PF	2	20	0

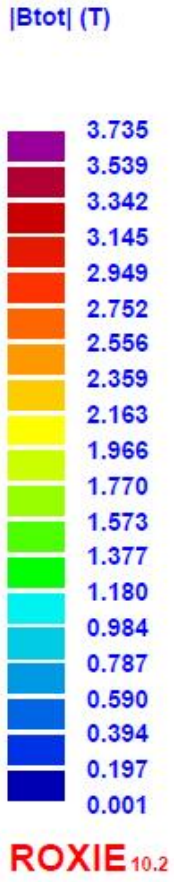
New value of insulation

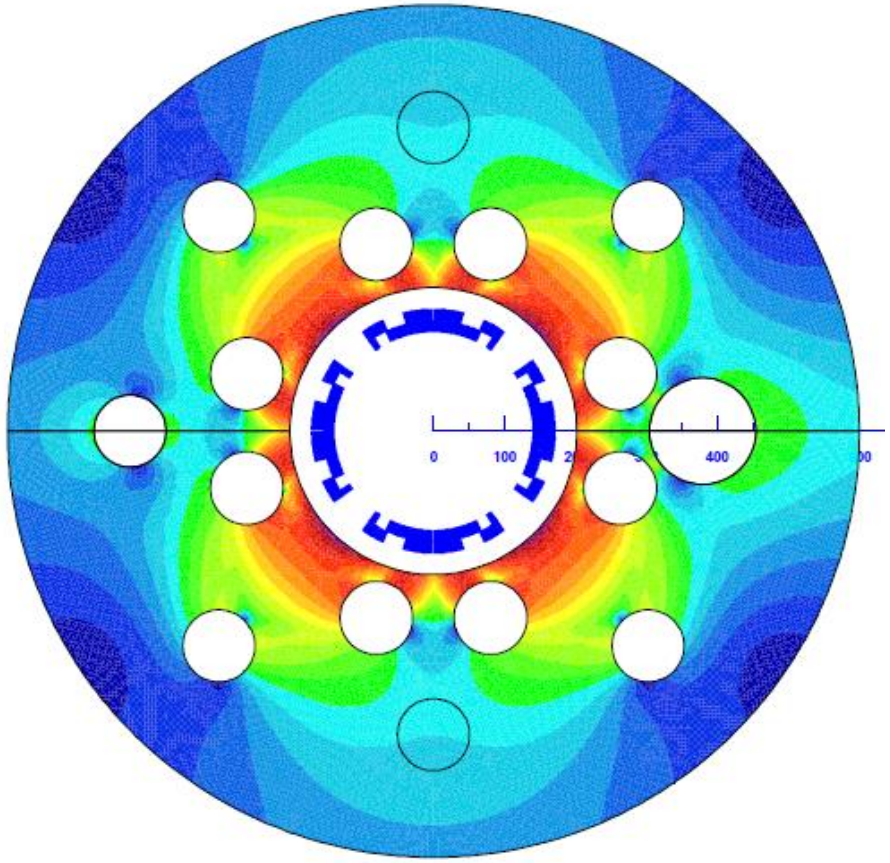
Optimization algorithm : 1 Extrem

No	X1	Xu	Xs	String	Act	N/a
1	0.5	1.3	0.5	PHI	2	1
2	0.45	1.3	0.46	PHI	2	3
3	2	9	6.6685	PHIRS	2	2
4	2	12	10.3535	PHIRS	2	4
5	0	0	0	ALPHRS	2	2
6	0	0	0	ALPHRS	2	4

Cross-section (ROXIE)







- **Symmetric wedges**