
Optimization in Corrector Design for Superconducting Solenoid for e-lens

Ramesh Gupta

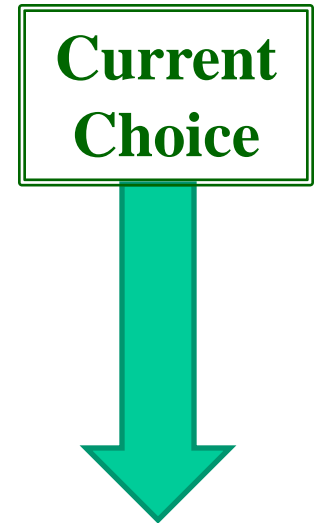
June 8, 2010

Design Considerations for e-lens correctors

- Short correctors must create a dipole field of 0.02 T and long correctors 0.006 T (both horizontal and vertical)
- Should have low operating current to minimize heat load (more important for tests when RHIC cryo-system is not on)
- Should have a minimum layers to minimize schedule and cost
- Slotted design is preferred over the direct wind for the reasons of cost, schedule, etc.
- After a brief overview, details of the design optimization will be discussed

Design Types of Conductor Dominated Correctors

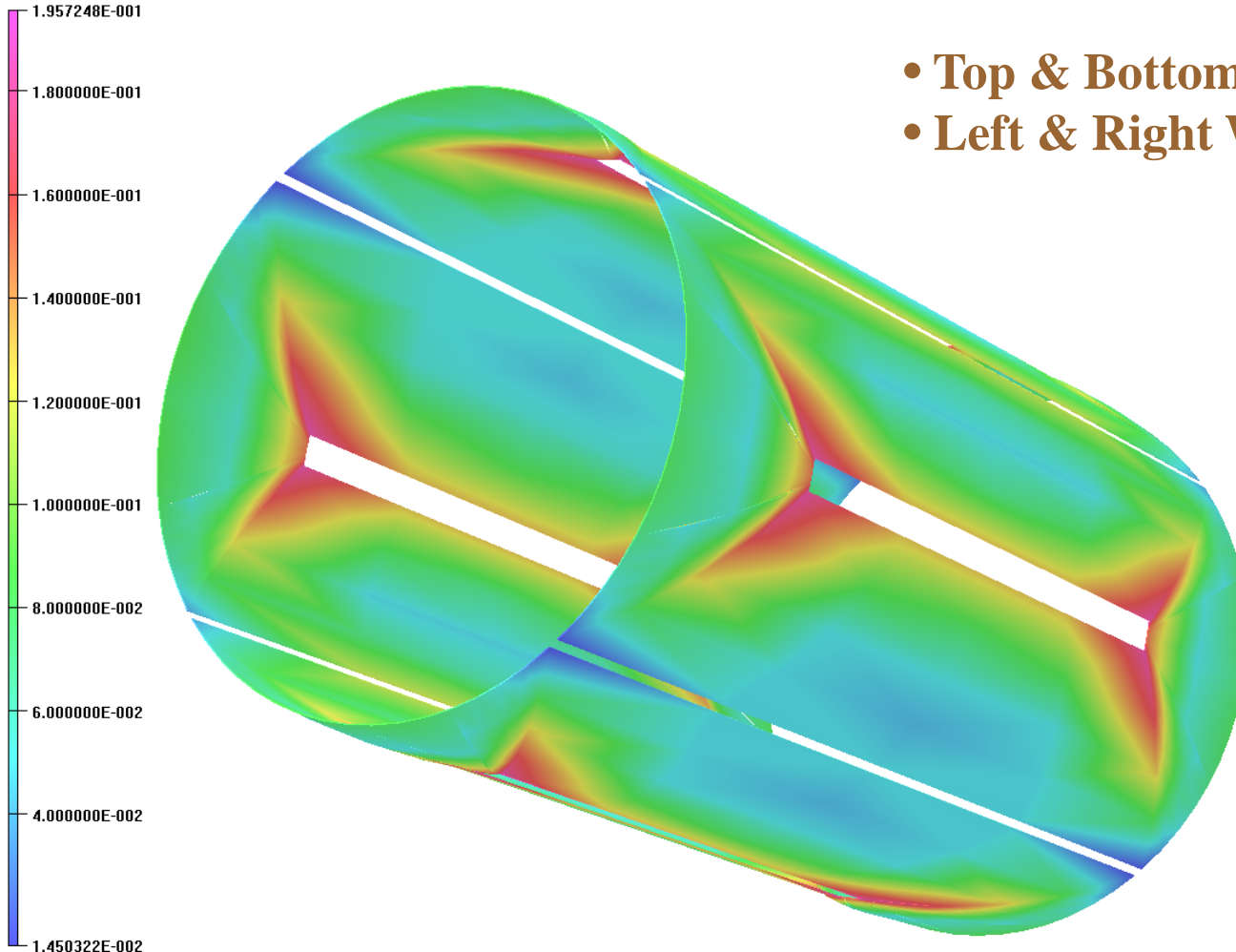
- Design with Conventional Ends
 - Used in earlier magnets (RHIC Correctors)
- Design with Serpentine Ends
 - Used in most current magnets
- Optimum Integral Design
 - Used and developed for AGS Helical magnet
- **Super-ferric Design**
 - **Morphing to even simpler and less expensive slotted design**



Optimum Integral Design

Both horizontal and vertical dipole correctors are accommodated in a single layer

Surface contours: BMOD



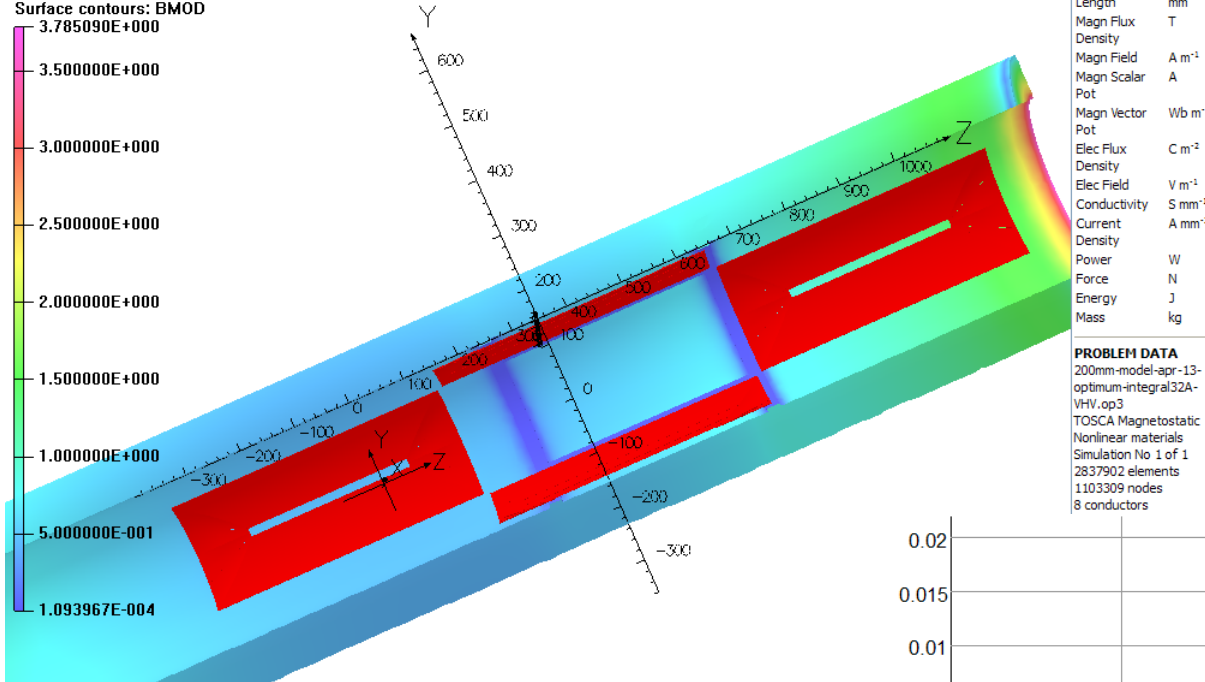
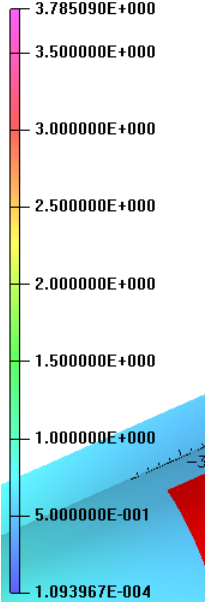
- Top & Bottom Windings for Vertical
- Left & Right Windings for Horizontal

Significantly cuts down on the construction time and the cost – the main motivation

Optimum Integral Design for e-lens Correctors in Series

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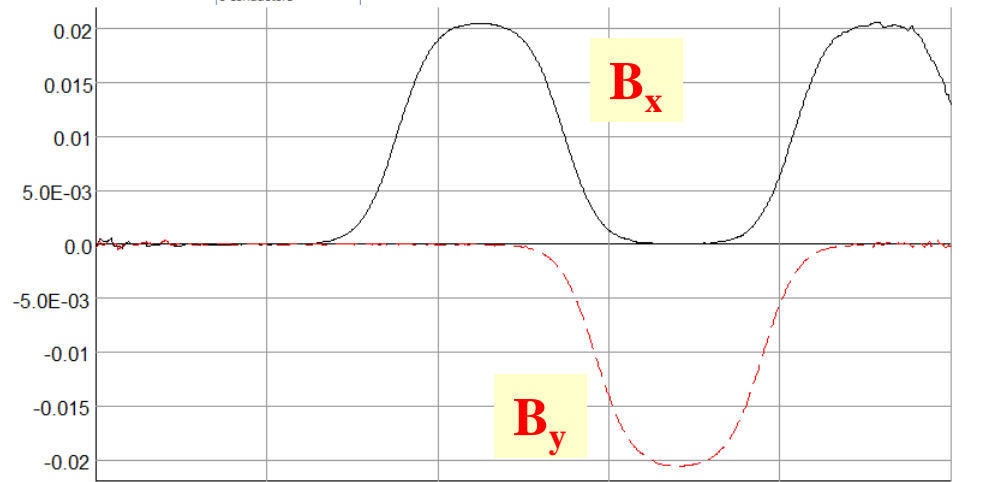
Surface contours: BMOD



UNITS	
Length	mm
Magn Flux	T
Density	
Magn Field	A m ⁻¹
Magn Scalar	A
Pot	
Magn Vector	Wb m ⁻¹
Pot	
Elec Flux	C m ⁻²
Density	
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current	A mm ⁻²
Density	
Power	W
Force	N
Energy	J
Mass	kg

PROBLEM DATA
200mm-model-apr-13-
optimum-integral32A-
VHV.op3
TOSCA Magnetostatic
Nonlinear materials
Simulation No 1 of 1
2837902 elements
1103309 nodes
8 conductors

Powered alternately at full horizontal or full vertical field



Works well.

Little cross-talk, etc. for transverse field in other direction.

Super-ferric Design

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Surface contours: BMOD

3.875063E+000

3.500000E+000

3.000000E+000

2.500000E+000

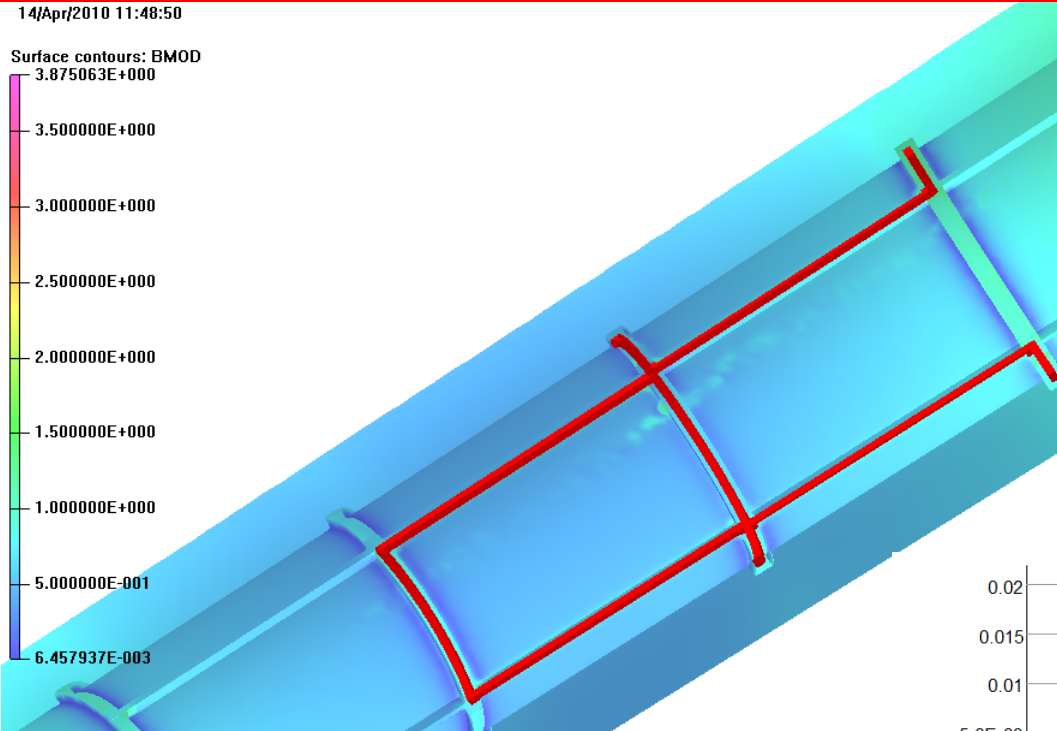
2.000000E+000

1.500000E+000

1.000000E+000

5.000000E-001

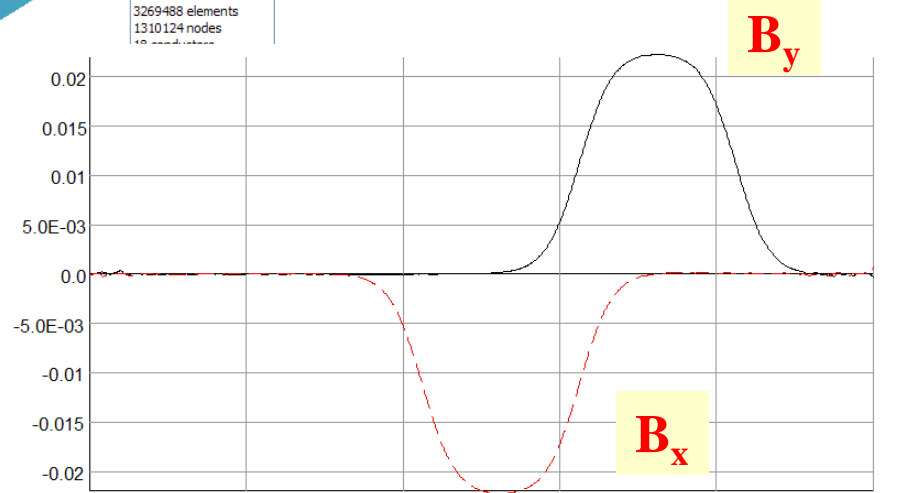
6.457937E-003



UNITS	
Length	mm
Magn Flux	T
Density	
Magn Field	A m ⁻¹
Magn Scalar	A
Pot	
Magn Vector	Wb m ⁻¹
Pot	
Elec Flux	C m ⁻²
Density	
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current	A mm ⁻²
Density	
Power	W
Force	N
Energy	J
Mass	kg

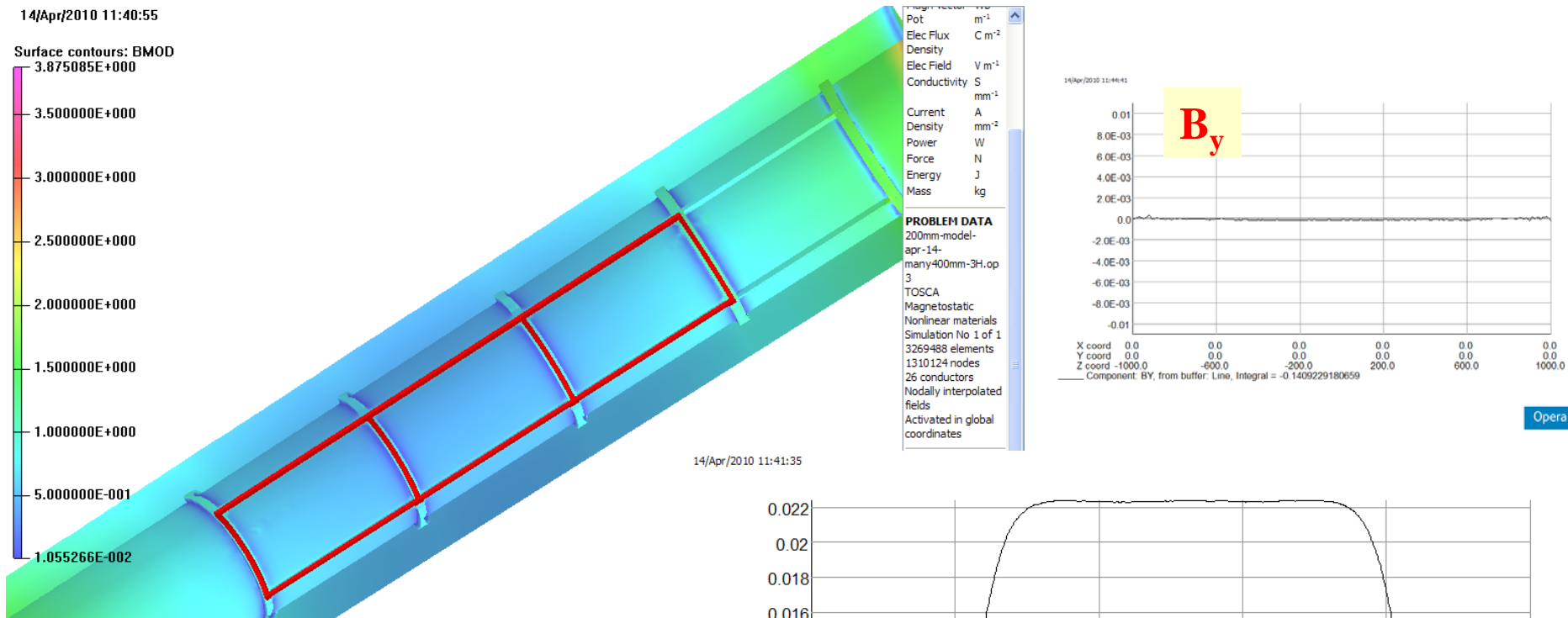
PROBLEM DATA
 200mm-model-agr-14-
 many400mm-1H1V-
 disp.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3269488 elements
 1310124 nodes

**Works well.
 Horizontal and vertical correctors are
 again put at the same radial space**



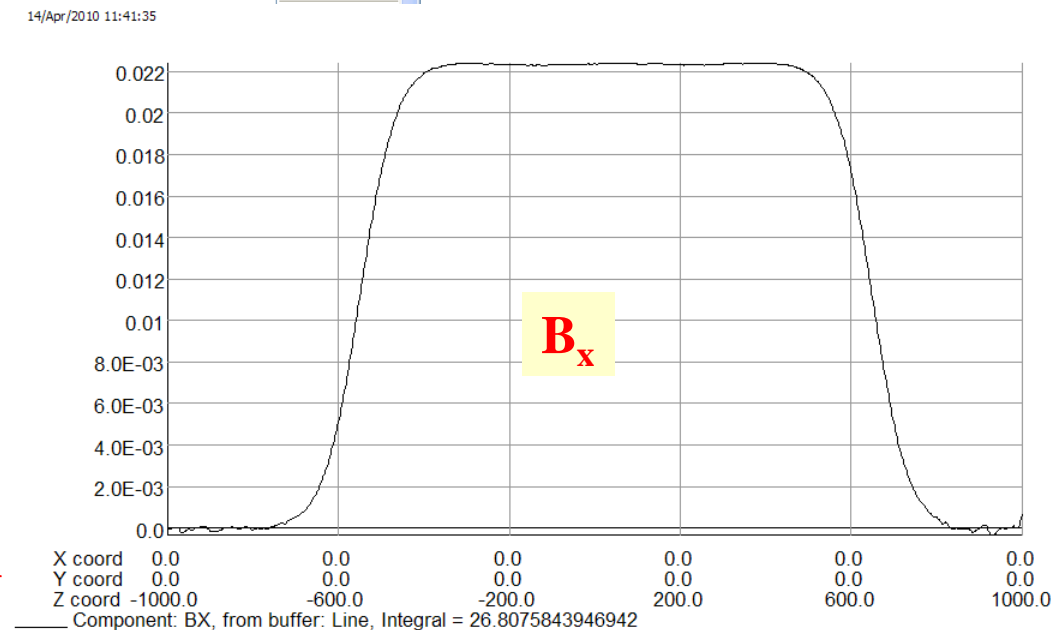
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Y coord	0.0	0.0	0.0	0.0	0.0	0.0
Z coord	-1000.0	-600.0	-200.0	200.0	600.0	1000.0
— Component: BY, from buffer: Line, Integral = 9.00970969542073						
- - - Component: BX, from buffer: Line, Integral = -8.9004308376253						

Three Horizontal Correctors at Full Strength

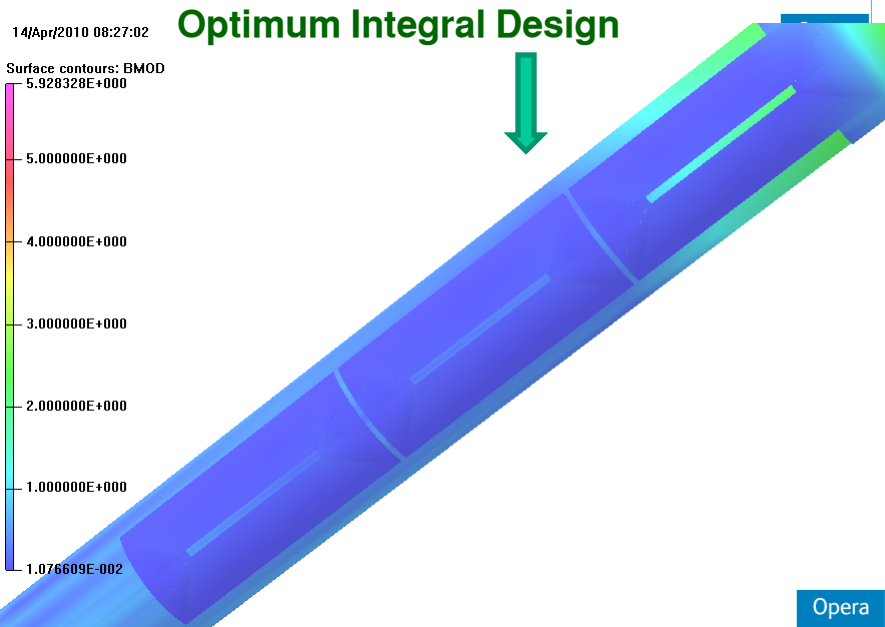
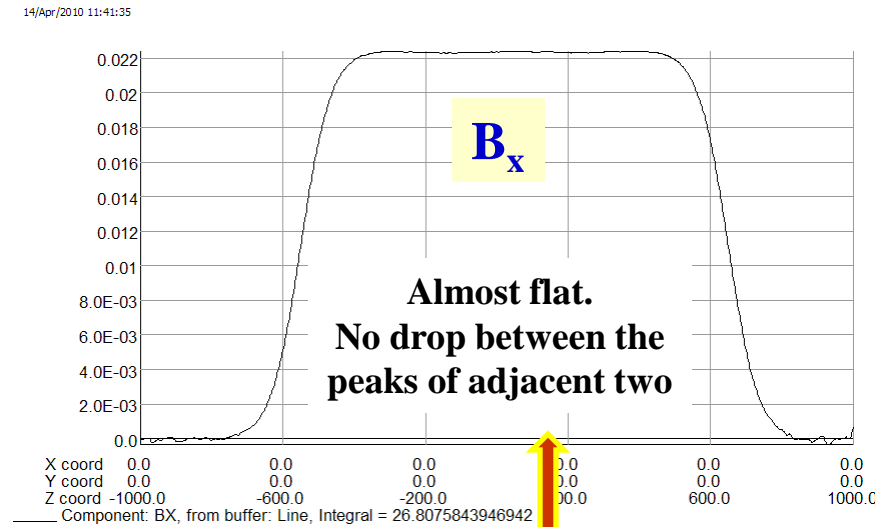
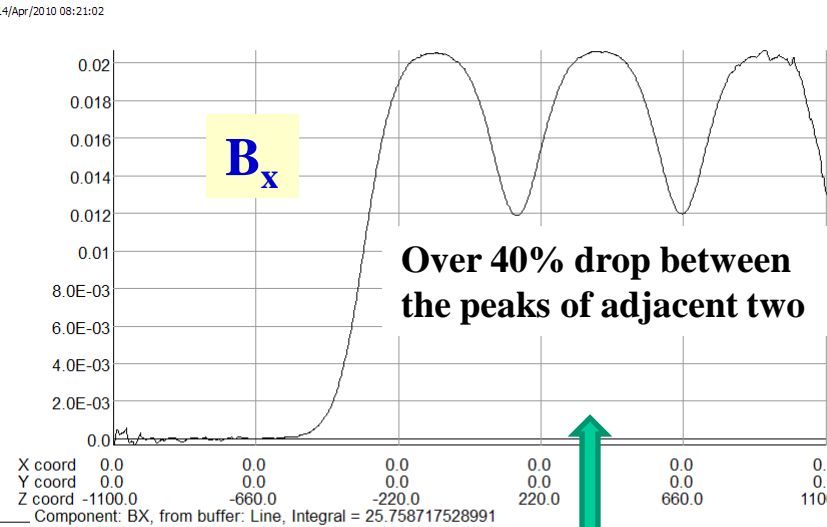


Works really well – even better than optimum integral design (field is very flat in this case).

See comparison with the optimum integral design in the next slide



Comparison of Super-ferric Design with the Optimum Integral Design for e-lens Correctors in Series



Pot m⁻¹

Elec Flux C m⁻²

Density

Elec Field V m⁻¹

Conductivity S mm⁻¹

Current A

Density mm⁻²

Power W

Force N

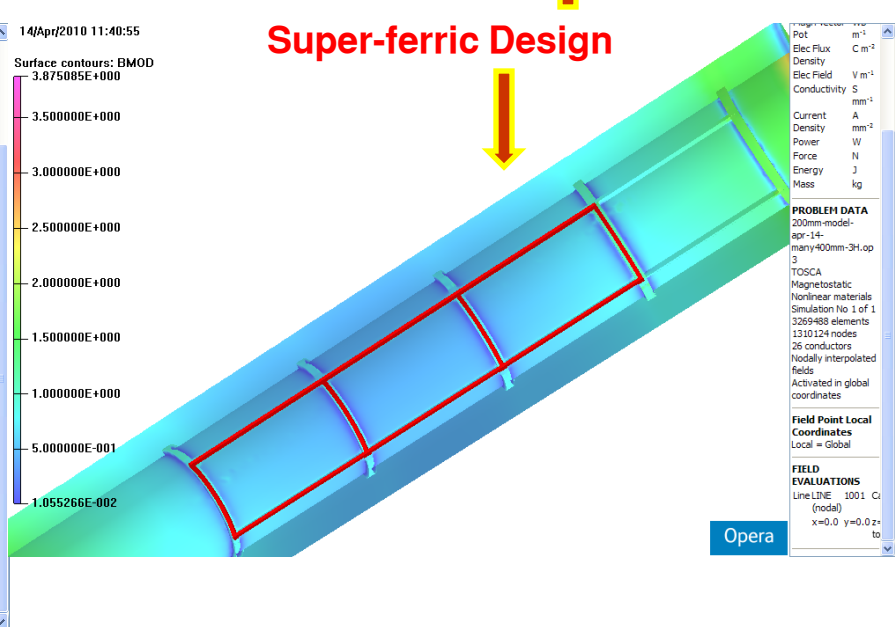
Energy J

Mass kg

PROBLEM DATA
200mm-model-apr-13-optimum-integrals24-three.op3
TOSCA
Magnetostatic
Nonlinear materials
Simulation No 1 of 1
2837902 elements
1103309 nodes
8 conductors
Nodally interpolated fields
Activated in global coordinates

Field Point Local Coordinates
Local = Global

FIELD EVALUATIONS
LineLINE 1001 C1 (nodal)
x=0.0 y=0.0 z=



Pot m⁻¹

Elec Flux C m⁻²

Density

Elec Field V m⁻¹

Conductivity S mm⁻¹

Current A

Density mm⁻²

Power W

Force N

Energy J

Mass kg

PROBLEM DATA
200mm-model-apr-14-many400mm-3H.op3
TOSCA
Magnetostatic
Nonlinear materials
Simulation No 1 of 1
3269488 elements
1310124 nodes
26 conductors
Nodally interpolated fields
Activated in global coordinates

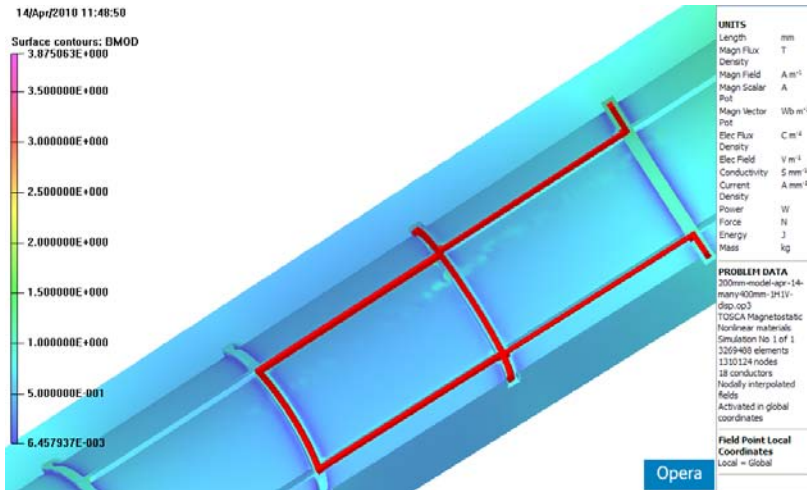
Field Point Local Coordinates
Local = Global

FIELD EVALUATIONS
LineLINE 1001 C1 (nodal)
x=0.0 y=0.0 z=

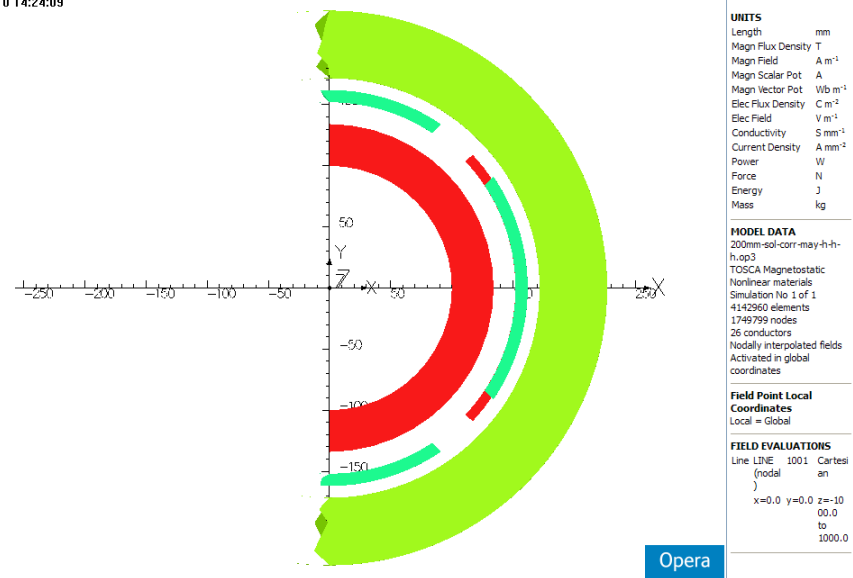
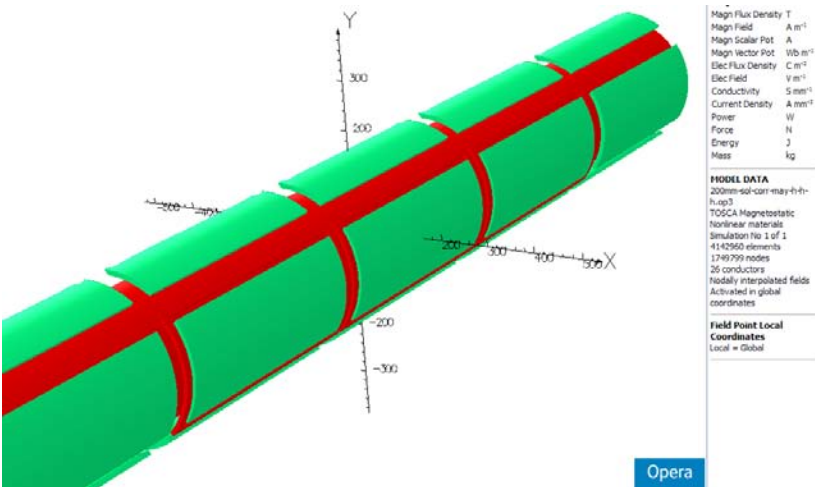
Iron Pole or NOT (Slotted Design)

In earlier Super-ferric design with coil around pole and pole connected to yoke

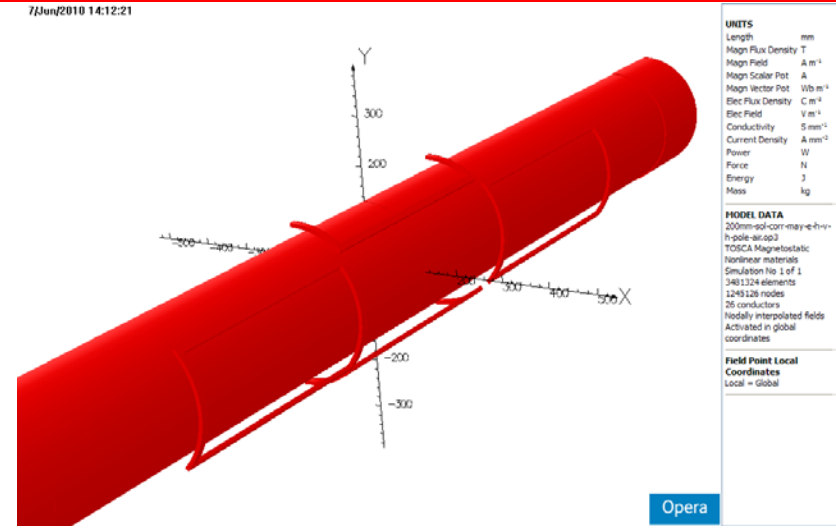
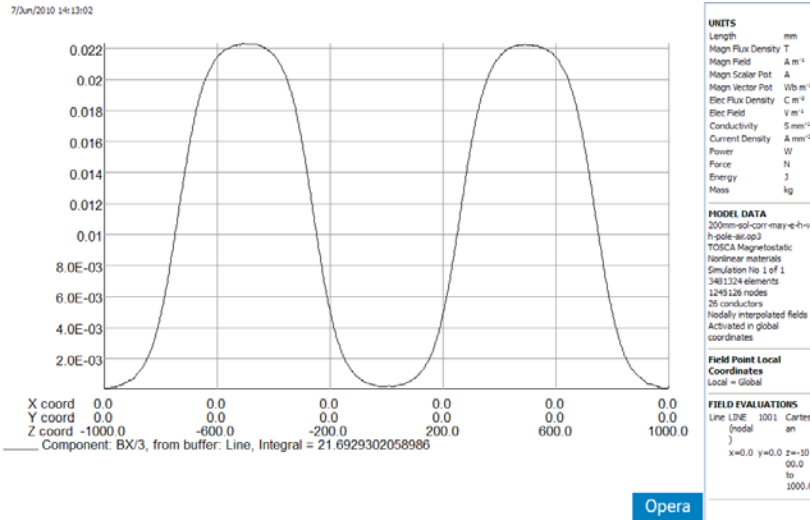
- In the present design, the iron pole is not connected to the yoke to allow space for helium.
- Iron pole is expensive (machining), it saturates fast (helium gap), thus the benefits are not clear.
- Therefore, the attempt here is to see if machined iron poles can be removed from the final design.
- If successful, the only remaining machined job => slots in the Aluminum tube for conductor.



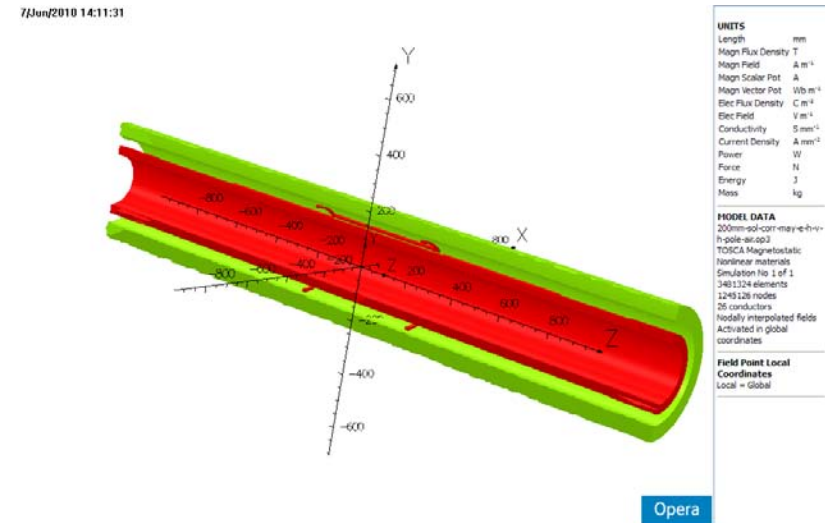
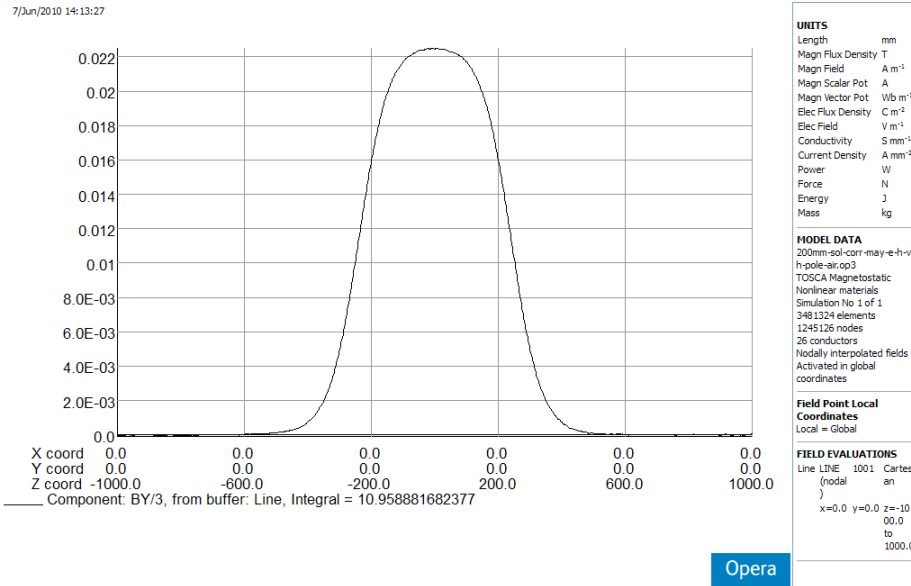
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Fields of Two Horizontal and One Vertical Short Correctors in Slotted Design without Iron Pole



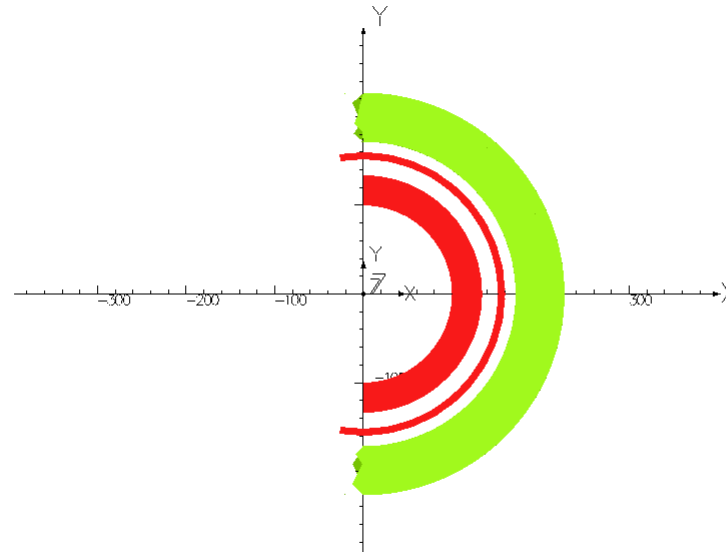
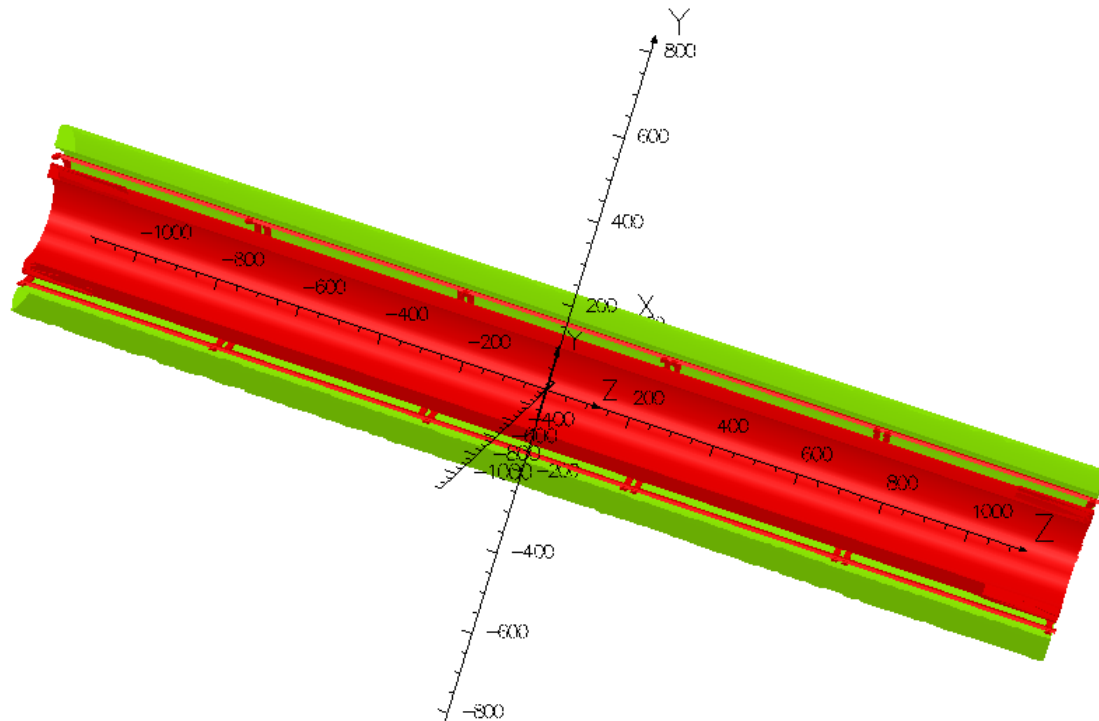
Looks OK



Model with Short and Long Correctors in Slotted Design without Iron Pole

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7/Jun/2010 13:23:05



UNITS

Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Wb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA
 200mm-sol-corr-all-scale-6T.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3481324 elements
 1245126 nodes
 66 conductors
 Nodally interpolated fields
 Activated in global coordinates

Field Point Local Coordinates
 Local = Global

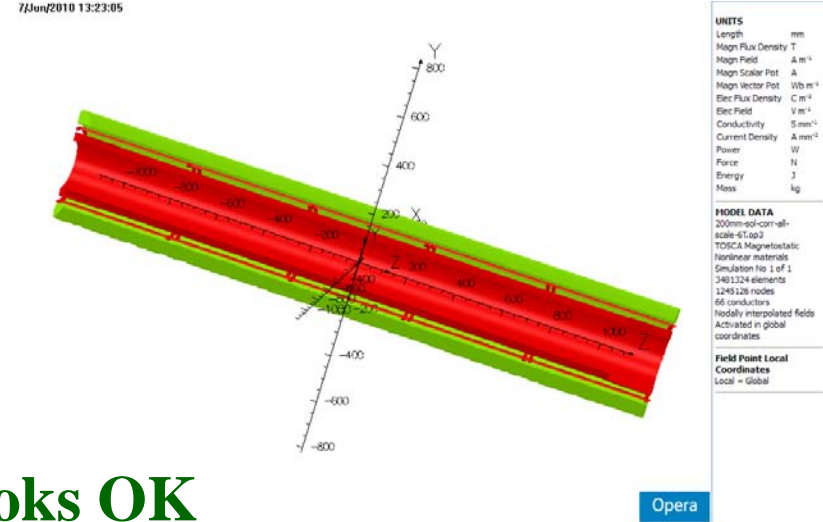
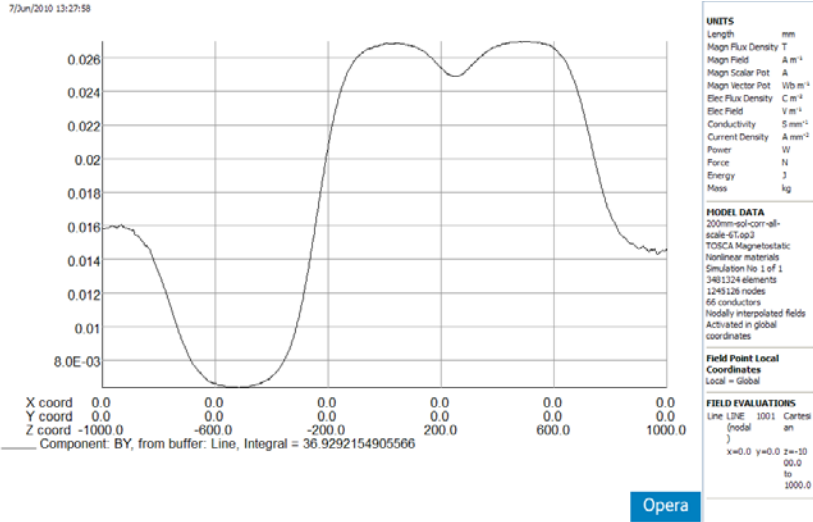
Opera

MODEL DATA
 200mm-sol-corr-all-scale-6T.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3481324 elements
 1245126 nodes
 66 conductors
 Nodally interpolated fields
 Activated in global coordinates

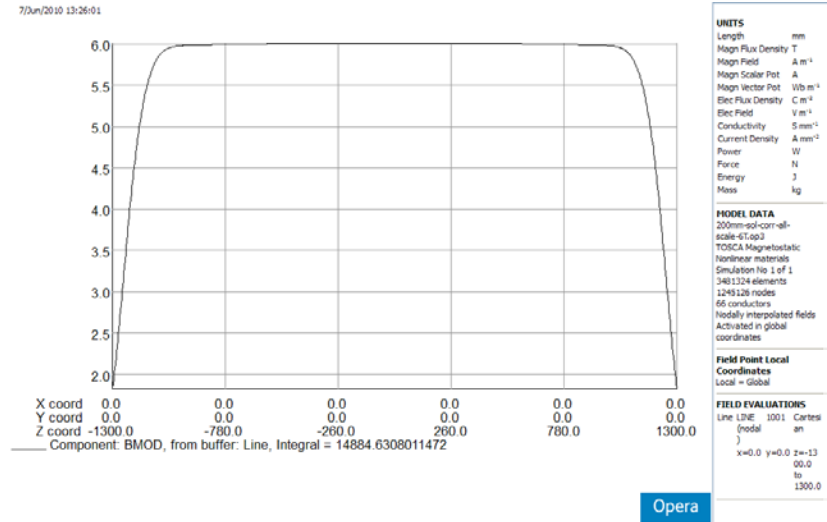
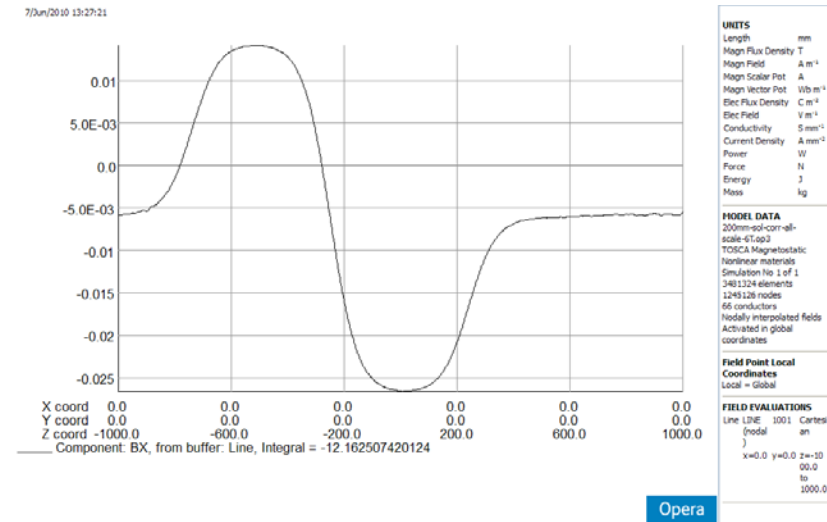
Field Point Local Coordinates
 Local = Global

Opera

Field with Short and Long Correctors in Slotted Design without Iron Pole



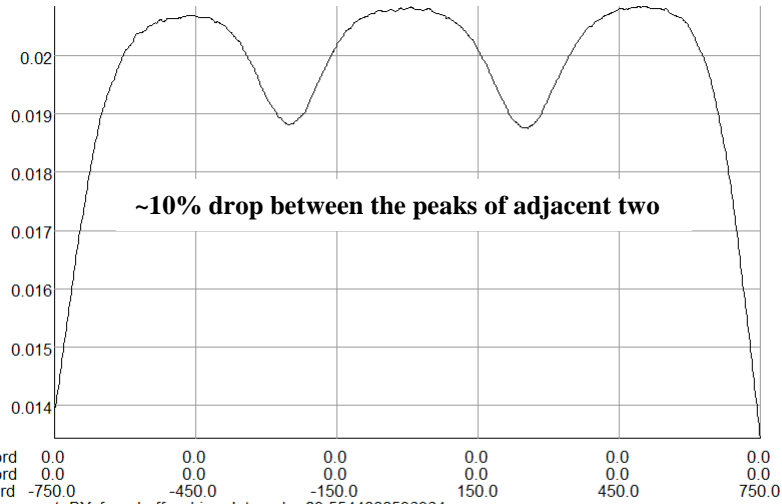
Looks OK



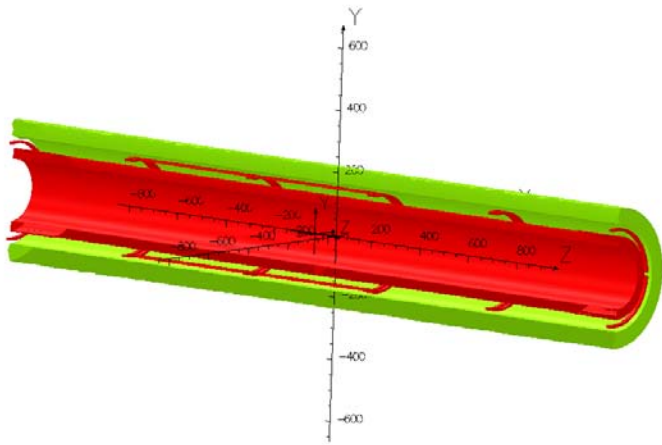
Comparison of Field between the Slotted Design and the Optimum Integral Design

Slotted Design

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7/Jun/2010 13:34:34



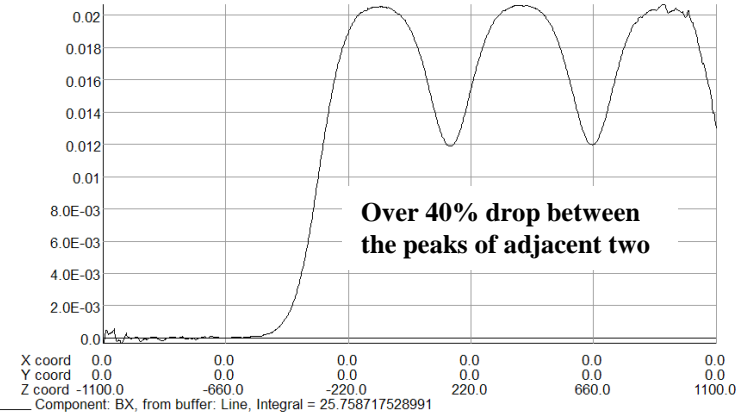
UNITS
 Length mm
 Magn Flux Density T
 Magn Field A m⁻¹
 Magn Scalar Pot A
 Magn Vector Pot Wb m⁻¹
 Elec Flux Density C m⁻²
 Elec Field V m⁻¹
 Conductivity S mm⁻¹
 Current Density A mm⁻²
 Power W
 Force N
 Energy J
 Mass kg

MODEL DATA
 200mm-sol-corr-v-all-h-some-scale-6T.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3481324 elements
 1245126 nodes
 58 conductors
 Nodally interpolated fields
 Activated in global coordinates

Field Point Local Coordinates
 Local = Global

FIELD EVALUATIONS
 Line LINE 1001 Cartesian
 (nodal) an
)
 x=0.0 y=0.0 z=75
 0.0 to 750.0

14/Apr/2010 08:21:02



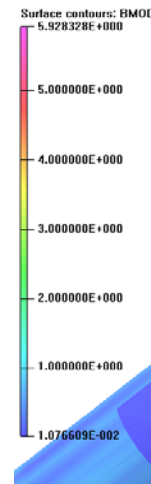
PROBLEM DATA
 200mm-model-apr-13-optimum-integral32A-three.op3
 TOSCA
 Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 2837902 elements
 1103309 nodes
 8 conductors
 Nodally interpolated fields
 Activated in global coordinates

Field Point Local Coordinates
 Local = Global

FIELD EVALUATIONS
 Line LINE 1001 Cartesian
 (nodal) an
)
 x=0.0 y=0.0 z= to

Slotted design is much better

14/Apr/2010 08:27:02



PROBLEM DATA
 200mm-model-apr-13-optimum-integral32A-three.op3
 TOSCA
 Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 2837902 elements
 1103309 nodes
 8 conductors
 Nodally interpolated fields
 Activated in global coordinates

Field Point Local Coordinates
 Local = Global

FIELD EVALUATIONS
 Line LINE 1001 Cartesian
 (nodal) an
)
 x=0.0 y=0.0 z= to

Opera

Opera

Benefits of Slotted Design over Optimum Integral and Super-ferric Design

- Slotted design is the least expensive of all.
- Slotted design also uses a significantly less superconductor than optimum integral.
- Ends of the slotted design takes much less space.
- This makes the drop in field between the peaks of two correctors small.
- Correctors based on the slotted design takes less time to build and poses less conflict with other projects (see Mike Anerella's presentation).
- This, the slotted design is superior to the optimum integral design.
- Slotted design is less expensive than super-ferric design because it does not require machining of the pole and extra complications arising from inserting poles in the Aluminum tube (which may require additional machining).
- The drop in field between two correctors is larger in slotted design when compared to the super-ferric design, however, it is still significantly smaller than that in the optimum integral design.

all dimensions are in mm unless noted

support tube ID	300
support tube OD / coil ID	304
circumference	955
# of windings	1504.635 mm (.025 inch) wire spacing assumes horizontal and vertical coils are on the same layer, 100% fill, i.e. each block is 1/8
max. # of windings per block	188 of circumference
block width	12.7
windings per layer	20
# of layers	4
final # of windings per block	80
block height	3
block insulator - pushers	3
over-wrap after last layer	1.30 per A. Marone
total block height	7.30
corrector assembly OD	318.59
yoke ID	324.6

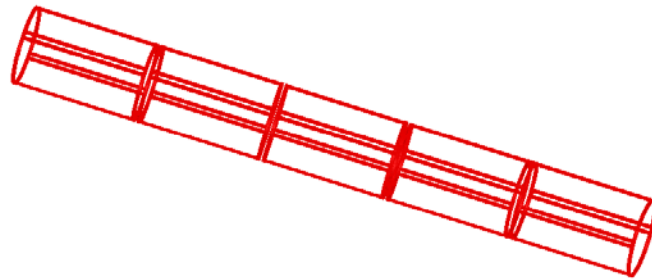
conductor length per 0.5m coil (2 blocks)	160 length in meters
total length of 10 coils	1600 length in meters
conductor length per 2.5m coil (2 blocks)	800 length in meters
total length of 2 coils	1600 length in meters

Total conductor length, ONE MAGNET	3200 length in meters
------------------------------------	-----------------------

Item	thickness	Dimension (mm)	
		inner diameter	outer diameter
inner cryostat (assumes 60mm aperture)	3	148	154
radial insulating space	5	154	164
Heat shield	4	164	172
radial insulating space	4	172	180
helium vessel / support tube	10	180	200
solenoid, 26 layers	37	200	274
G-10 buildup (max., tapered)	10	274	294
support shell (max., tapered)	5	294	304
assembly clearance (min., at max. taper)	1	304	306
corrector tube wall (to bottom of grooves)	2	306	310
corrector layers (4) + overwrap	7.3	310	324.6
helium space	3	324.6	330.6
yoke	61.7	330.6	454
assembly clearance thickness	1.5	454	457
helium vessel	19	457	495
insulation thickness	24	495	543
heat shield	3	543	549
insulation thickness	24	549	597
cryostat	6.35	597	610

Examining Possible Configuration of Short Correctors

Jun/2010 14:36:15



Case examined

Vertical: $V/8, V, V, V/2, V/4$ of maximum 0.02 T

Horizontal: $-7/8H, -H, -H, +H, +3/4H$ of 0.02 T

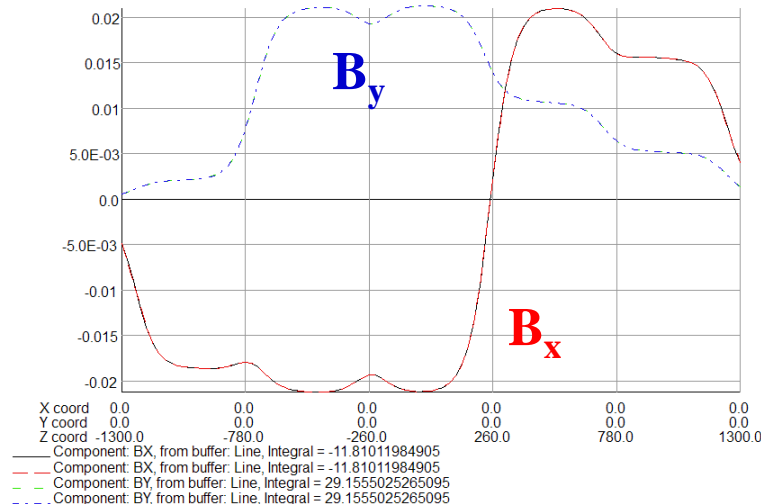
An obvious but important thing to remember:

Actual error may not follow this physical pattern. e.g., there could be a change in sign just in the middle of a short corrector. The error due to that could be much larger than the dip between two short corrector having same strength.

However, correction does not have to be perfect. As long as the net error is <50 micron, it should be OK.

Op

15/Jun/2010 14:31:03



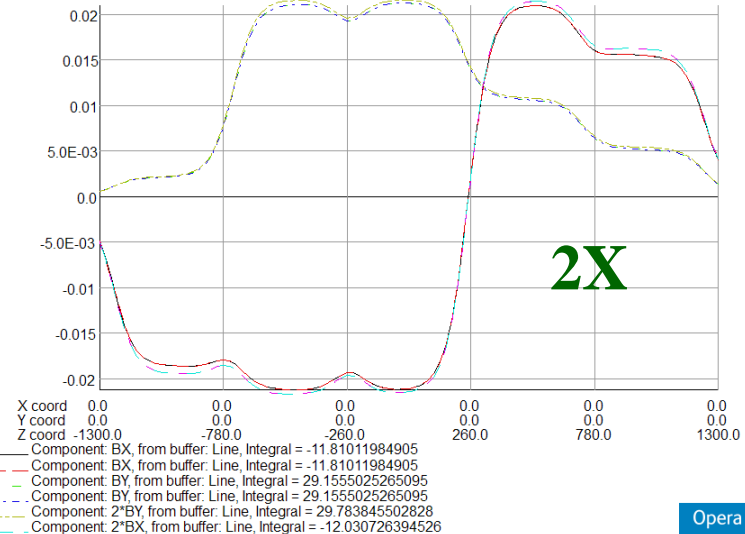
UNITS	
Length	mm
Magn Flux Density T	
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Wb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
sol-corr-v3-short-3t.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
3623048 elements	
1307561 nodes	
82 conductors	
Fields by integration	
Activated in global coordinates	

Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Line	LINE 101 Cartesian (integral)
x=0.0	y=0.0 z=-1300.0 to 1300.0

15/Jun/2010 14:34:15



UNITS	
Length	mm
Magn Flux Density T	
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Wb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
sol-corr-v3-short-3t.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
3623048 elements	
1307561 nodes	
82 conductors	
Fields by integration	
Activated in global coordinates	

Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Line	LINE 101 Cartesian (integral)
x=0.0	y=0.0 z=-1300.0 to 1300.0

Opera

Opera

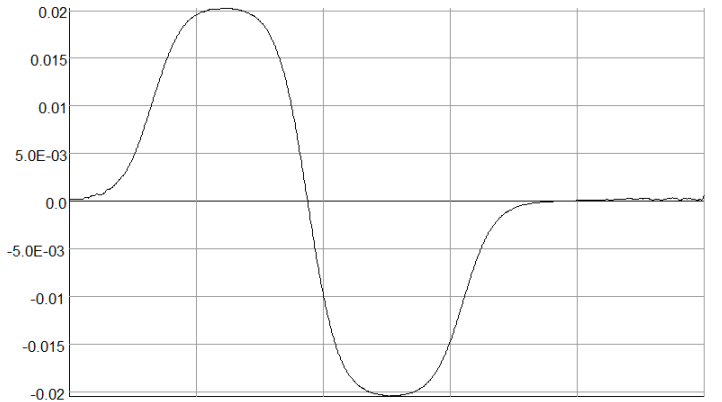
Change in error correction due to non-linearity (1)

- Main solenoid will operate from 3 T to 6 T.
- Correctors (both short and long) must correct for the position error at each field.
- Since the iron saturation is significant at 6 T, currents will not scale linearly.
- Moreover, each short corrector, in general, will have a different value of current (field).
- In addition, there may be a significant influence of persistent currents also. The influence of persistent currents needs to be properly estimated.
- Since the correctors in the proposed design occupy a significantly small angular space than that in the conventional correctors, simple scaling from the measurements may not be representative for persistent current purpose (do not be surprised if the persistent current induced errors in the slotted design is significantly smaller).
- A linear scaling of current in correctors with solenoid field (3 T to 6 T) could, therefore, may create some error. If these errors can not be tolerated, then a more sophisticated scaling will be necessary.
- Next few slides will examine this issue in more details.

Change in error correction due to non-linearity (2)

(Correction at 6 T)

7/Jun/2010 13:44:41



X coord 0.0 0.0 0.0 0.0 0.0 0.0
 Y coord 0.0 0.0 0.0 0.0 0.0 0.0
 Z coord -1000.0 -600.0 -200.0 200.0 600.0 1000.0
 Component: BX, from buffer: Line, Integral = 0.04690665802994

UNITS
 Length mm
 Magn Flux Density T
 Magn Field A m⁻¹
 Magn Scalar Pot A
 Magn Vector Pot Vb m⁻¹
 Elec Flux Density C m⁻²
 Elec Field V m⁻¹
 Conductivity S mm⁻¹
 Current Density A mm⁻²
 Power W
 Force N
 Energy J
 Mass kg

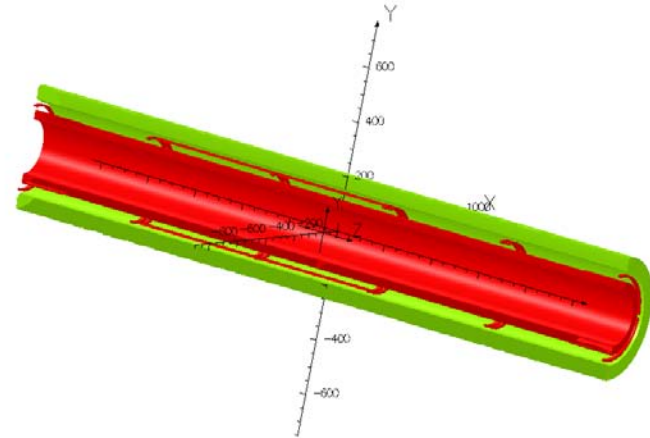
MODEL DATA
 200mm-sol-corr-many-
 scale-1_0.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3481324 elements
 1245126 nodes
 50 conductors
 Nodally interpolated fields
 Activated in global
 coordinates

**Field Point Local
 Coordinates**
 Local = Global

FIELD EVALUATIONS
 Line LINE 1001 Cartesi
 (nodal
)
 x=0.0 y=0.0 z=-10
 00.0
 to
 1000.0

Opera

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UNITS
 Length mm
 Magn Flux Density T
 Magn Field A m⁻¹
 Magn Scalar Pot A
 Magn Vector Pot Vb m⁻¹
 Elec Flux Density C m⁻²
 Elec Field V m⁻¹
 Conductivity S mm⁻¹
 Current Density A mm⁻²
 Power W
 Force N
 Energy J
 Mass kg

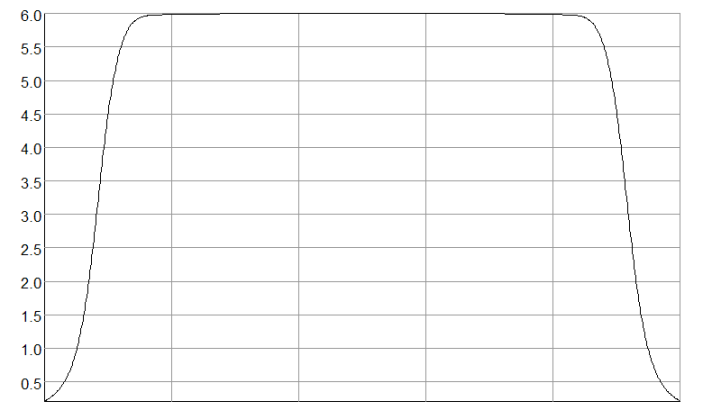
MODEL DATA
 200mm-sol-corr-many-
 scale-1_0.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3481324 elements
 1245126 nodes
 50 conductors
 Nodally interpolated fields
 Activated in global
 coordinates

**Field Point Local
 Coordinates**
 Local = Global

FIELD EVALUATIONS
 Line LINE 1001 Cartesi
 (nodal
)
 x=0.0 y=0.0 z=-15
 00.0
 to
 1500.0

Opera

7/Jun/2010 13:45:25



X coord 0.0 0.0 0.0 0.0 0.0 0.0
 Y coord 0.0 0.0 0.0 0.0 0.0 0.0
 Z coord -1500.0 -900.0 -300.0 300.0 900.0 1500.0
 Component: BMOD, from buffer: Line, Integral = 15164.084478158

UNITS
 Length mm
 Magn Flux Density T
 Magn Field A m⁻¹
 Magn Scalar Pot A
 Magn Vector Pot Vb m⁻¹
 Elec Flux Density C m⁻²
 Elec Field V m⁻¹
 Conductivity S mm⁻¹
 Current Density A mm⁻²
 Power W
 Force N
 Energy J
 Mass kg

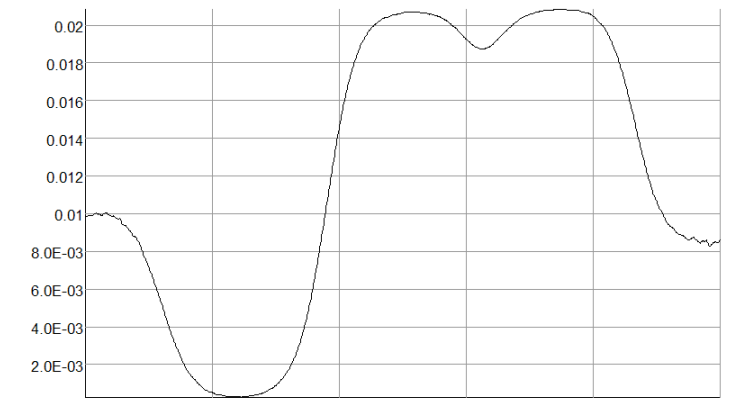
MODEL DATA
 200mm-sol-corr-many-
 scale-1_0.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3481324 elements
 1245126 nodes
 50 conductors
 Nodally interpolated fields
 Activated in global
 coordinates

**Field Point Local
 Coordinates**
 Local = Global

FIELD EVALUATIONS
 Line LINE 1001 Cartesi
 (nodal
)
 x=0.0 y=0.0 z=-15
 00.0
 to
 1500.0

Opera

7/Jun/2010 13:43:55



X coord 0.0 0.0 0.0 0.0 0.0 0.0
 Y coord 0.0 0.0 0.0 0.0 0.0 0.0
 Z coord -1000.0 -600.0 -200.0 200.0 600.0 1000.0
 Component: BY, from buffer: Line, Integral = 24.7187005598561

UNITS
 Length mm
 Magn Flux Density T
 Magn Field A m⁻¹
 Magn Scalar Pot A
 Magn Vector Pot Vb m⁻¹
 Elec Flux Density C m⁻²
 Elec Field V m⁻¹
 Conductivity S mm⁻¹
 Current Density A mm⁻²
 Power W
 Force N
 Energy J
 Mass kg

MODEL DATA
 200mm-sol-corr-many-
 scale-1_0.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3481324 elements
 1245126 nodes
 50 conductors
 Nodally interpolated fields
 Activated in global
 coordinates

**Field Point Local
 Coordinates**
 Local = Global

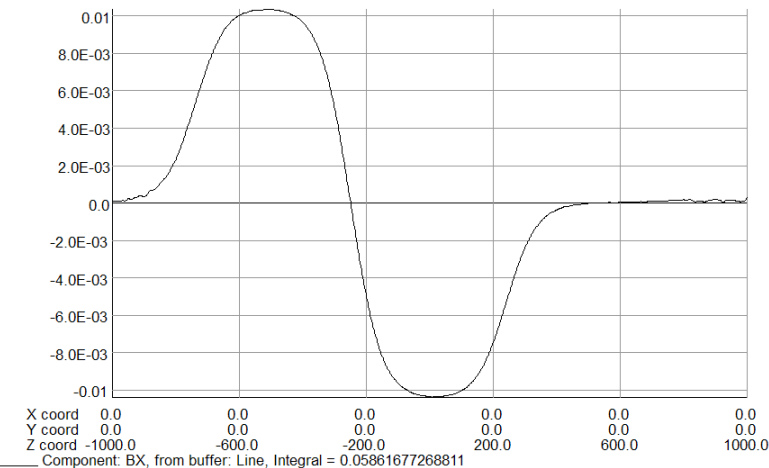
FIELD EVALUATIONS
 Line LINE 1001 Cartesi
 (nodal
)
 x=0.0 y=0.0 z=-10
 00.0
 to
 1000.0

Opera

Change in error correction due to non-linearity (3)

(Correction at 3 T)

7/Jun/2010 13:49:48



Component: BX, from buffer: Line, Integral = 0.05861677268811

Opera

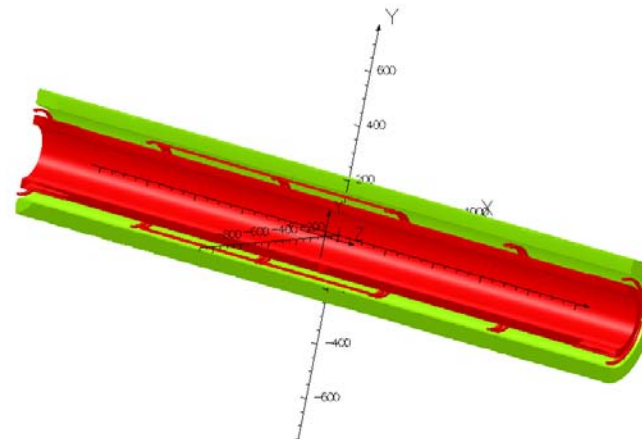
UNITS	
Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Vb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
200mm-sol-corr-many-scale-3T.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
3481324 elements	
1245126 nodes	
50 conductors	
Nodally interpolated fields	
Activated in global coordinates	

Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Line LINE	1001 Cartesian
(nodal)	an
x=0.0	y=0.0 z=-10.00.0
to	1000.0

7/Jun/2010 13:48:24



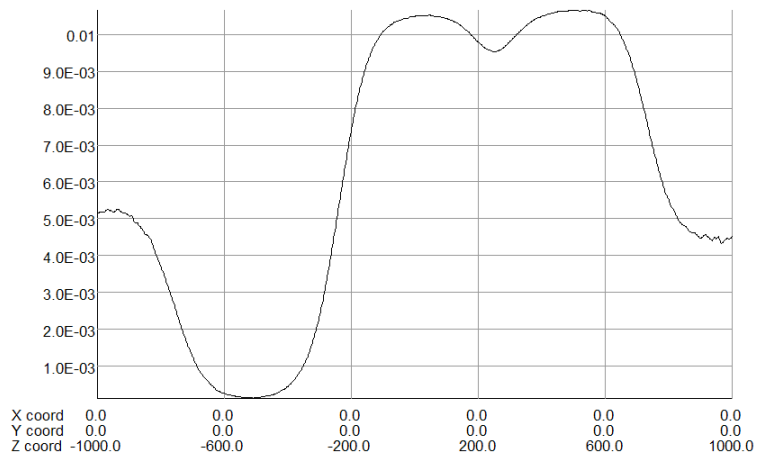
Opera

UNITS	
Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Vb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
200mm-sol-corr-many-scale-3T.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
3481324 elements	
1245126 nodes	
50 conductors	
Nodally interpolated fields	
Activated in global coordinates	

Field Point Local Coordinates	
Local = Global	

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Component: BY, from buffer: Line, Integral = 12.6528192439561

Opera

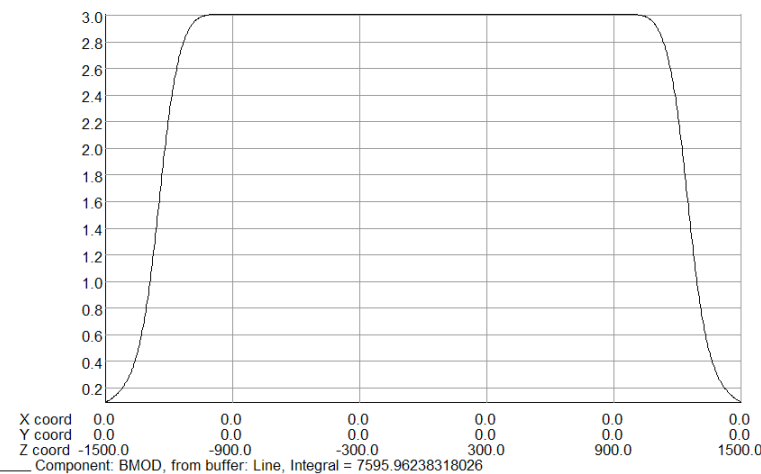
UNITS	
Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Vb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
200mm-sol-corr-many-scale-3T.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
3481324 elements	
1245126 nodes	
50 conductors	
Nodally interpolated fields	
Activated in global coordinates	

Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Line LINE	1001 Cartesian
(nodal)	an
x=0.0	y=0.0 z=-15.00.0
to	1000.0

7/Jun/2010 13:48:55



Component: BMOD, from buffer: Line, Integral = 7595.96238318026

Opera

UNITS	
Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Vb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
200mm-sol-corr-many-scale-3T.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
3481324 elements	
1245126 nodes	
50 conductors	
Nodally interpolated fields	
Activated in global coordinates	

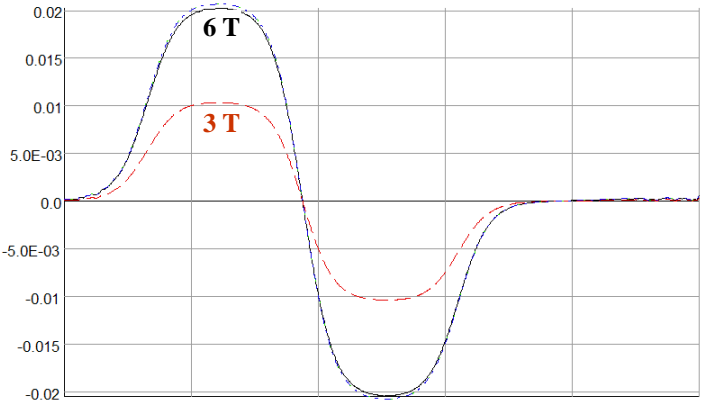
Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Line LINE	1001 Cartesian
(nodal)	an
x=0.0	y=0.0 z=-15.00.0
to	1500.0

Influence of Iron Saturation in short correctors (either accept small errors or adjust correction)

7/Jun/2010 13:56:30

2*3 T



X coord 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 Y coord 0.0 0.0 -600.0 0.0 -200.0 0.0 200.0 0.0 1000.0
 Z coord -1000.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

Component: BX, from buffer: Line, Integral = 0.04690665802994
 Component: BX, from buffer: Line, Integral = 0.05861677268811
 Component: 2*Bx, from buffer: Line, Integral = 0.11723354537623
 Component: 2*Bx, from buffer: Line, Integral = 0.11723354537623

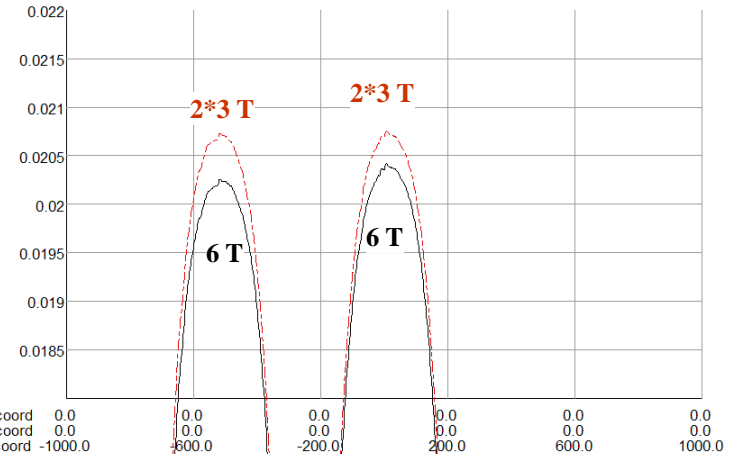
UNITS	
Length	mm
Magn Flux Density T	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Vb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
200mm-sol-corr-many-scale-3T.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
3481324 elements	
1245126 nodes	
50 conductors	
Nodally interpolated fields	
Activated in global coordinates	

Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Line LINE 1001 Cartesian (nodal) an	
x=0.0 y=0.0 z=-10.00.0	

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X coord 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 Y coord 0.0 0.0 -600.0 0.0 -200.0 0.0 200.0 0.0 1000.0
 Z coord -1000.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

Component: ABS(BX), from buffer: Line, Integral = 17.6474874759232
 Component: 2*ABS(BX), from buffer: Line, Integral = 18.0054594450578

UNITS	
Length	mm
Magn Flux Density T	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Vb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA	
200mm-sol-corr-many-scale-3T.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
3481324 elements	
1245126 nodes	
50 conductors	
Nodally interpolated fields	
Activated in global coordinates	

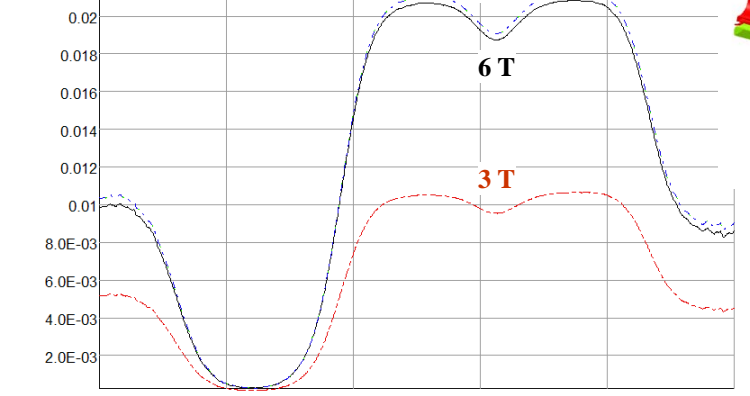
Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Line LINE 1001 Cartesian (nodal) an	
x=0.0 y=0.0 z=-10.00.0	
to 1000.0	

Opera

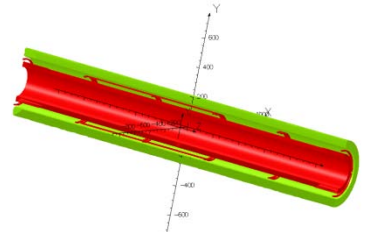
7/Jun/2010 13:58:12

2*3 T



X coord 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 Y coord 0.0 0.0 -600.0 0.0 -200.0 0.0 200.0 0.0 1000.0
 Z coord -1000.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

Component: BY, from buffer: Line, Integral = 24.7187005598561
 Component: BY, from buffer: Line, Integral = 12.6528192439561
 Component: 2*BY, from buffer: Line, Integral = 25.3056384879123
 Component: 2*BY, from buffer: Line, Integral = 25.3056384879123

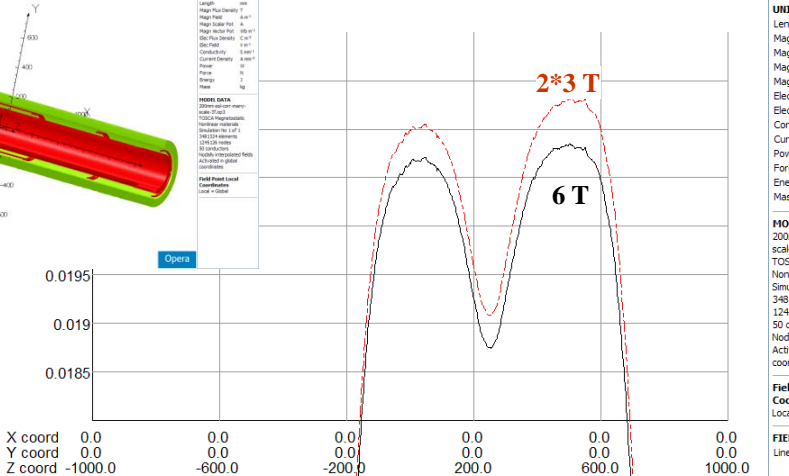


7/Jun/2010 13:58:24

MODEL DATA	
200mm-sol-corr-many-scale-3T.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
3481324 elements	
1245126 nodes	
50 conductors	
Nodally interpolated fields	
Activated in global coordinates	

Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Line LINE 1001 Cartesian (nodal) an	
x=0.0 y=0.0 z=-10.00.0	
to 1000.0	



X coord 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 Y coord 0.0 0.0 -600.0 0.0 -200.0 0.0 200.0 0.0 1000.0
 Z coord -1000.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

Component: ABS(BY), from buffer: Line, Integral = 24.7187005598561
 Component: 2*ABS(BY), from buffer: Line, Integral = 25.3056384879123

UNITS	
Length	mm
Magn Flux Density T	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Vb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

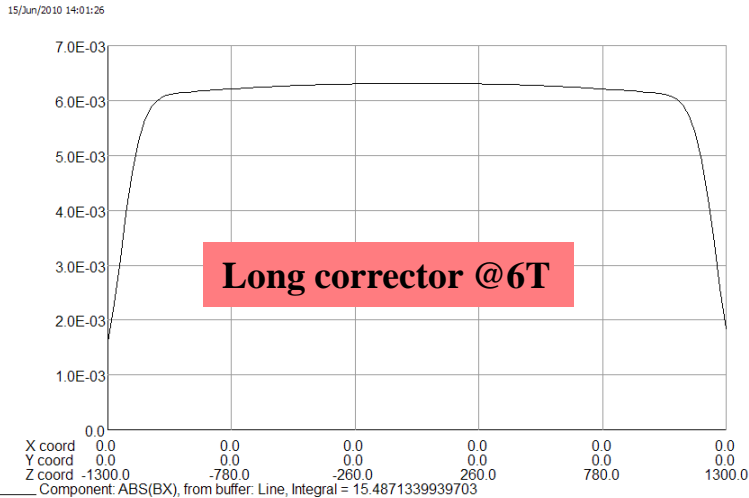
MODEL DATA	
200mm-sol-corr-many-scale-3T.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
3481324 elements	
1245126 nodes	
50 conductors	
Nodally interpolated fields	
Activated in global coordinates	

Field Point Local Coordinates	
Local = Global	

FIELD EVALUATIONS	
Line LINE 1001 Cartesian (nodal) an	
x=0.0 y=0.0 z=-10.00.0	
to 1000.0	

Opera

Change in error correction in Long Correctors due to non-linearity



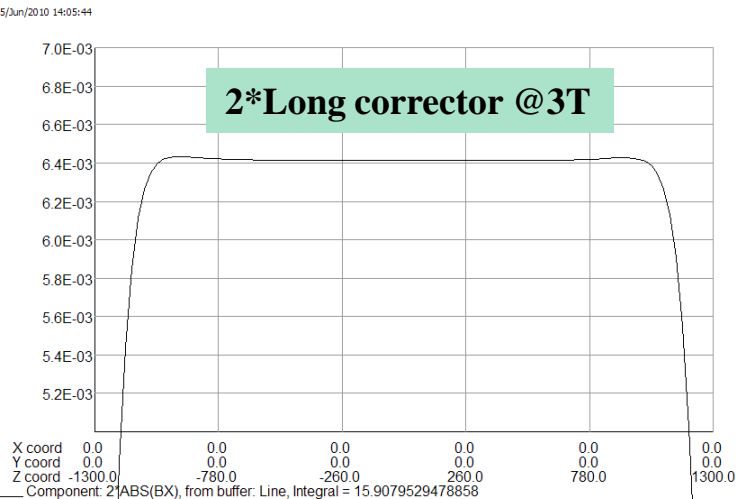
15/Jun/2010 14:05:44

UNITS
 Length mm
 Magn Flux Density T
 Magn Field A m⁻¹
 Magn Scalar Pot A
 Magn Vector Pot Wb m⁻¹
 Elec Flux Density C m⁻²
 Elec Field V m⁻¹
 Conductivity S mm⁻¹
 Current Density A mm⁻²
 Power W
 Force N
 Energy J
 Mass kg

MODEL DATA
 sol-corr-v3-long-6t.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3623048 elements
 1307561 nodes
 18 conductors
 Fields by integration
 Activated in global coordinates

Field Point Local Coordinates
 Local = Global

FIELD EVALUATIONS
 Line LINE 101 Cartesian (integral)
 x=0.0 y=0.0 z=-1300.0 to 1300.0

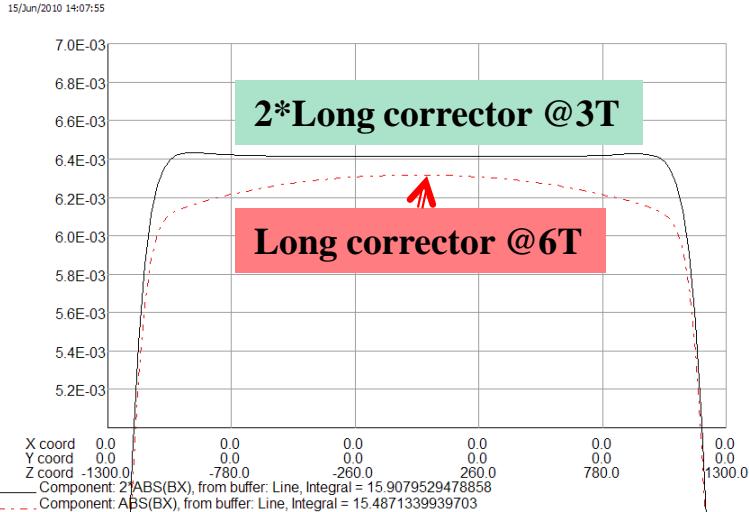


UNITS
 Length mm
 Magn Flux Density T
 Magn Field A m⁻¹
 Magn Scalar Pot A
 Magn Vector Pot Wb m⁻¹
 Elec Flux Density C m⁻²
 Elec Field V m⁻¹
 Conductivity S mm⁻¹
 Current Density A mm⁻²
 Power W
 Force N
 Energy J
 Mass kg

MODEL DATA
 sol-corr-v3-long-3t.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3623048 elements
 1307561 nodes
 18 conductors
 Fields by integration
 Activated in global coordinates

Field Point Local Coordinates
 Local = Global

FIELD EVALUATIONS
 Line LINE 101 Cartesian (integral)
 x=0.0 y=0.0 z=-1300.0 to 1300.0



UNITS
 Length mm
 Magn Flux Density T
 Magn Field A m⁻¹
 Magn Scalar Pot A
 Magn Vector Pot Wb m⁻¹
 Elec Flux Density C m⁻²
 Elec Field V m⁻¹
 Conductivity S mm⁻¹
 Current Density A mm⁻²
 Power W
 Force N
 Energy J
 Mass kg

MODEL DATA
 sol-corr-v3-long-6t.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3623048 elements
 1307561 nodes
 18 conductors
 Fields by integration
 Activated in global coordinates

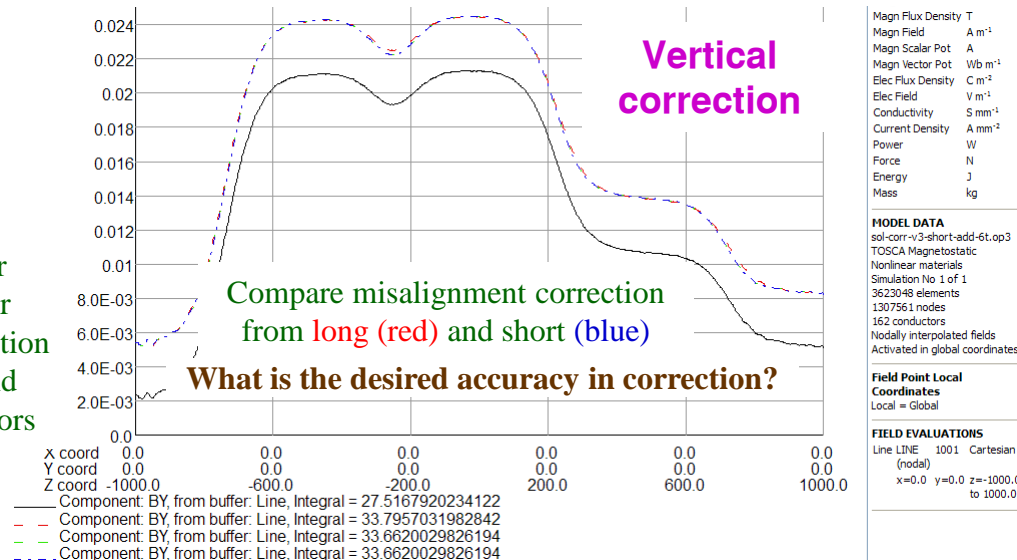
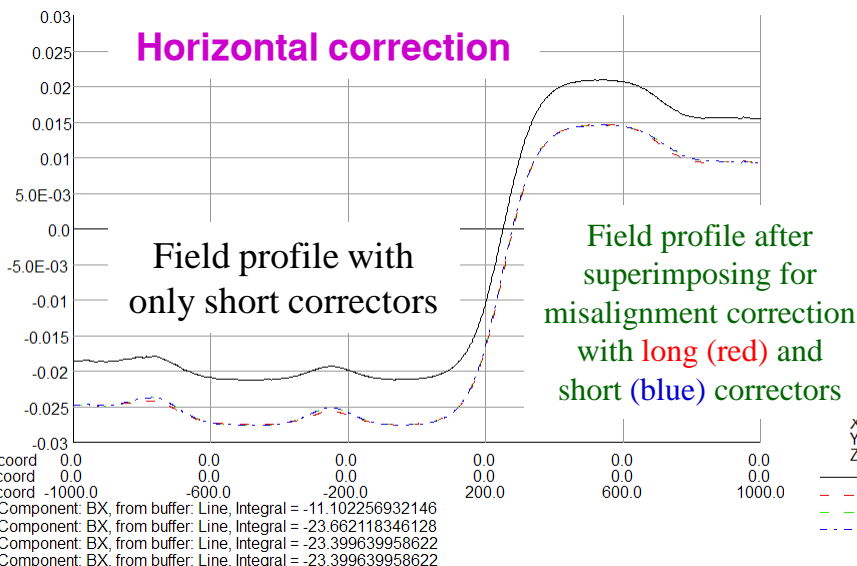
Field Point Local Coordinates
 Local = Global

FIELD EVALUATIONS
 Line LINE 101 Cartesian (integral)
 x=0.0 y=0.0 z=-1300.0 to 1300.0

- Using long corrector for global alignment error, causes additional error due to saturation.
- It can be corrected by adjusting short corrector.
- But then why not use short corrector completely?

Overall Correction of Proton Beam Angle with respect to Solenoid (alignment correction)

- There may be misalignment between the proton beam and solenoid axis.
- Long correctors (horizontal and vertical) with a maximum strength of 0.006 T are planned for achieving overall alignment of proton beam with respect to solenoid axis within 50(?) micron.
- In principle this field may also be provided by short correctors. The benefit of the slotted corrector design is that there is very small drop in field between two short correctors.
- Example below is for mis-alignment correction with a field of $B_x = -0.006$ T & $B_y = +0.003$ T by **long (red)** or **short (blue)** correctors. Instruction to computer => change current by ~4 Amp (horizontal) & ~2 Amp (vertical) for **case (a) in additional long corrector** or **case (b) in all short correctors - same amount**.
- There appears to be little to no difference in the end result (field profile) between the two cases.
- However, there may be a significant difference in the cost, heat load, etc.
- Remember, error correction is not perfect and does not have to be perfect (these are correctors).



Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Wb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA
 sol-corr-v3-short-add-6t.op3
 TOSCA Magnetostatic
 Nonlinear materials
 Simulation No 1 of 1
 3623048 elements
 1307561 nodes
 162 conductors
 Nodally interpolated fields
 Activated in global coordinates

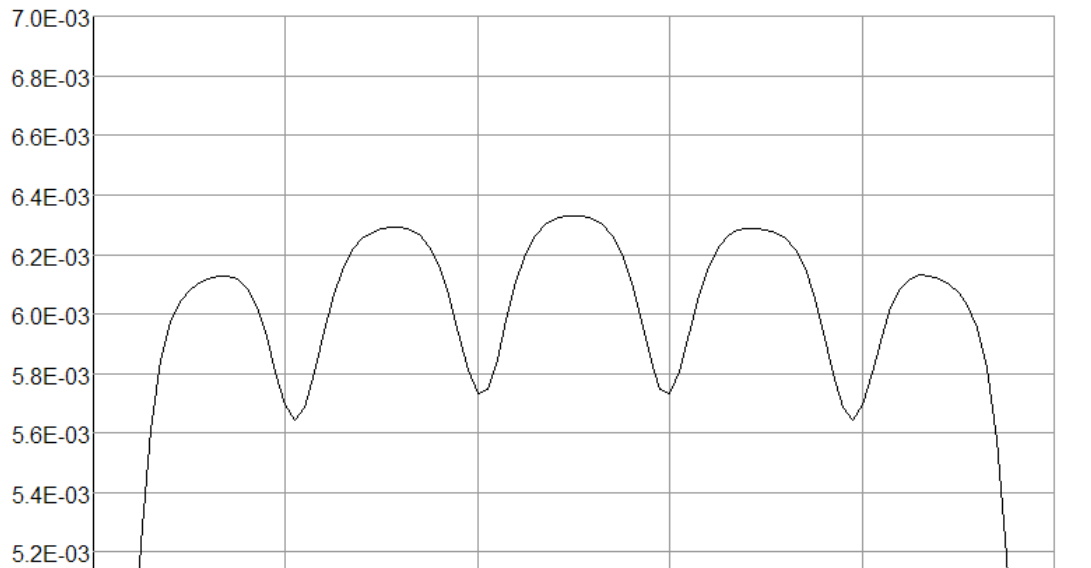
Field Point Local Coordinates
 Local = Global

FIELD EVALUATIONS
 Line LINE 1001 Cartesian (nodal)
 x=0.0 y=0.0 z=-1000.0 to 1000.0

Summary

- Slot design of correctors seems to be working well .
- Iron pole is eliminated (as it does not give much benefit). Removing it saves cost with practically no penalty.
- Question to cost sensitive experts:
 - ❑ Are short corrector good enough to do the job of both long and short?
 - ❑ Can computer control algorithm allow short correctors (with slightly increased amp-turns) to serve the purpose of both?
 - ❑ If yes, then there could be significant saving in cost, schedule, leads and heat load, etc.

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X coord 0.0 0.0 0.0 0.0 0.0 0.0
Y coord 0.0 0.0 0.0 0.0 0.0 0.0
Z coord -1300.0 -780.0 -260.0 260.0 780.0 1300.0
Component: ABS(BX), from buffer: Line, Integral = 15.0393910494821

UNITS

Length	mm
Magn Flux Density	T
Magn Field	A m ⁻¹
Magn Scalar Pot	A
Magn Vector Pot	Wb m ⁻¹
Elec Flux Density	C m ⁻²
Elec Field	V m ⁻¹
Conductivity	S mm ⁻¹
Current Density	A mm ⁻²
Power	W
Force	N
Energy	J
Mass	kg

MODEL DATA

sol-corr-v3-short-add099-6t.op3
TOSCA Magnetostatic
Nonlinear materials
Simulation No 1 of 1
3623048 elements
1307561 nodes
82 conductors
Fields by integration
Activated in global coordinates

Field Point Local Coordinates

Local = Global

FIELD EVALUATIONS

Line LINE 101 Cartesian
(integral)
x=0.0 y=0.0 z=-1300.0 to 1300.0

Opera