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

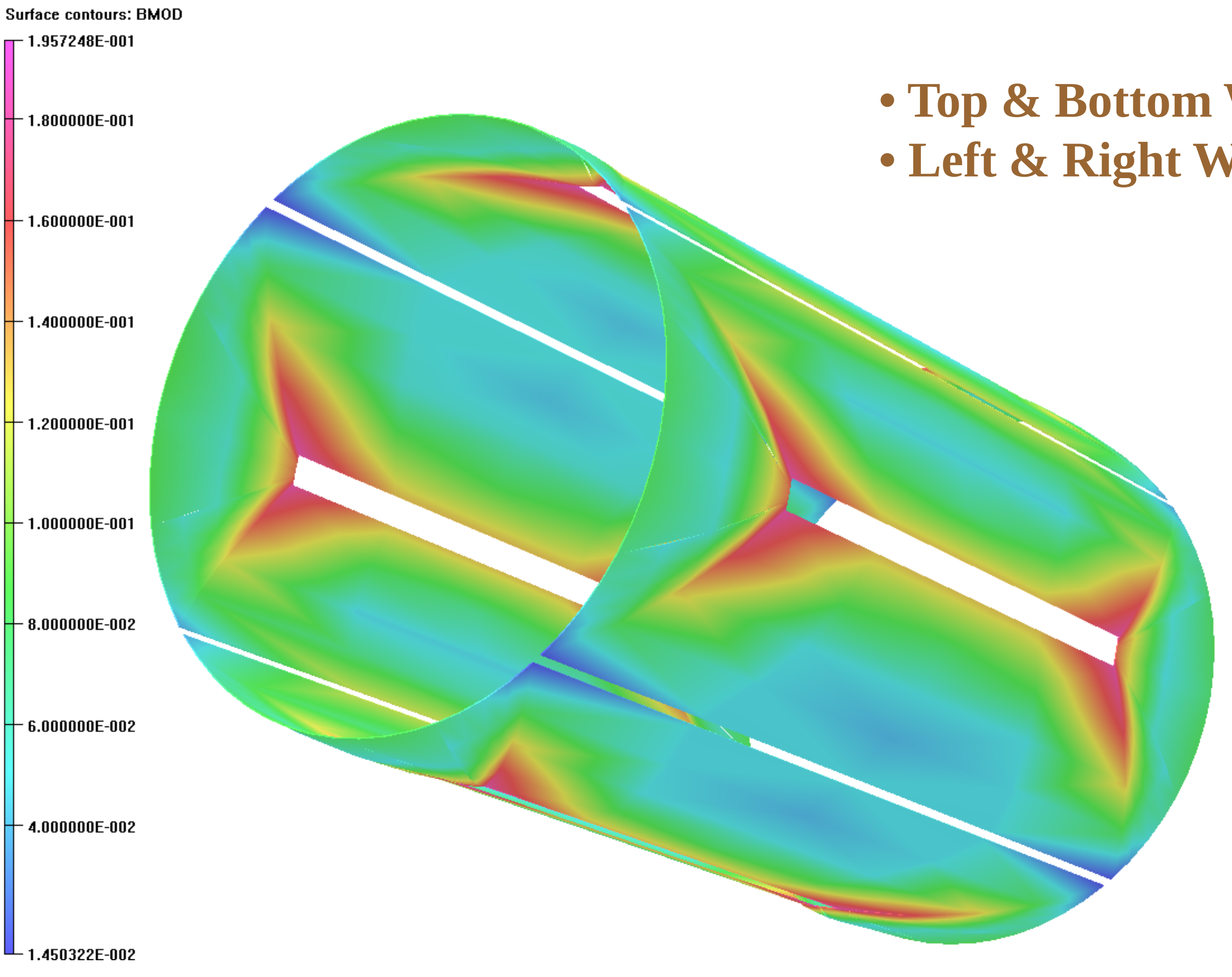
Design Types of Conductor Dominated Correctors

- 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**

Current Choice

Optimum Integral Design

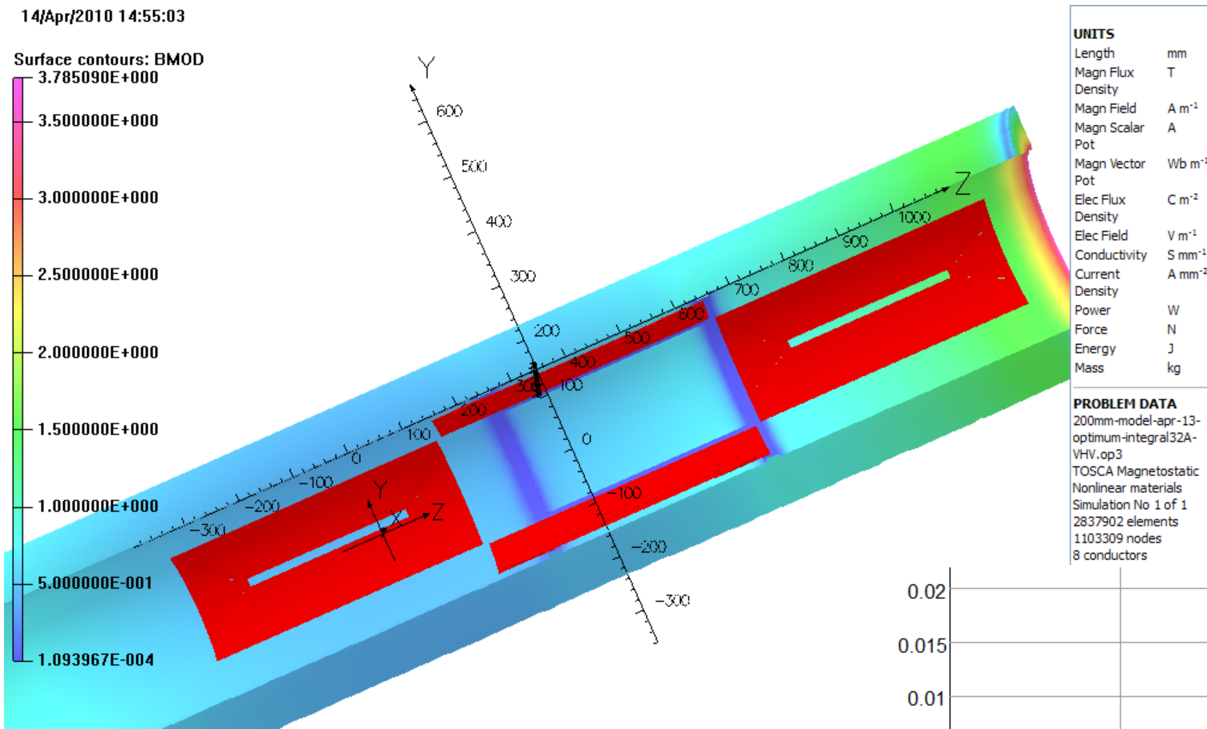
Both horizontal and vertical dipole correctors are accommodated in a single layer



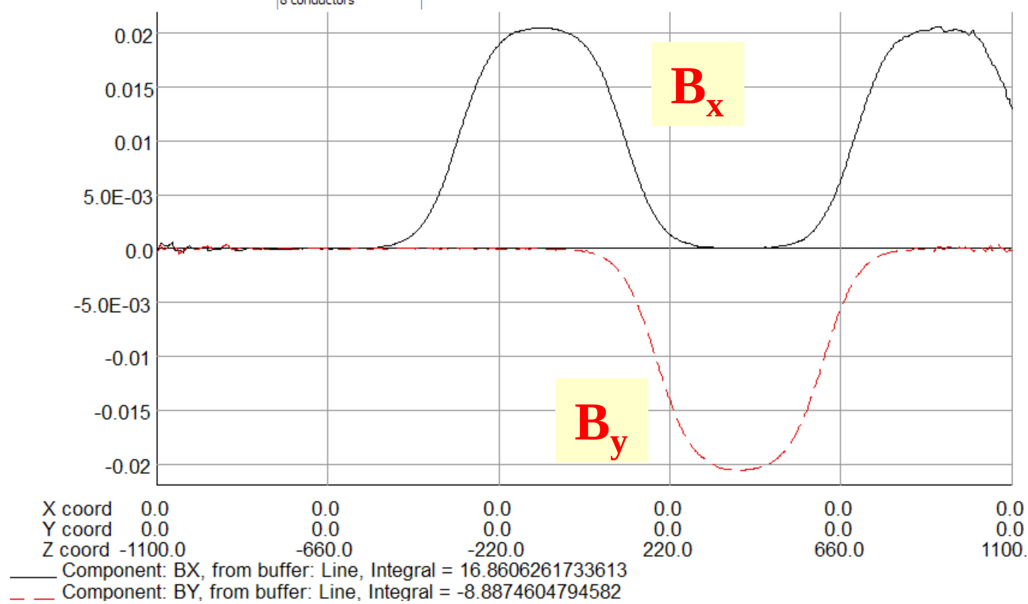
- **Top & Bottom Windings for Vertical**
- **Left & Right Windings for Horizontal**

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

Optimum Integral Design for e-lens Correctors in Series

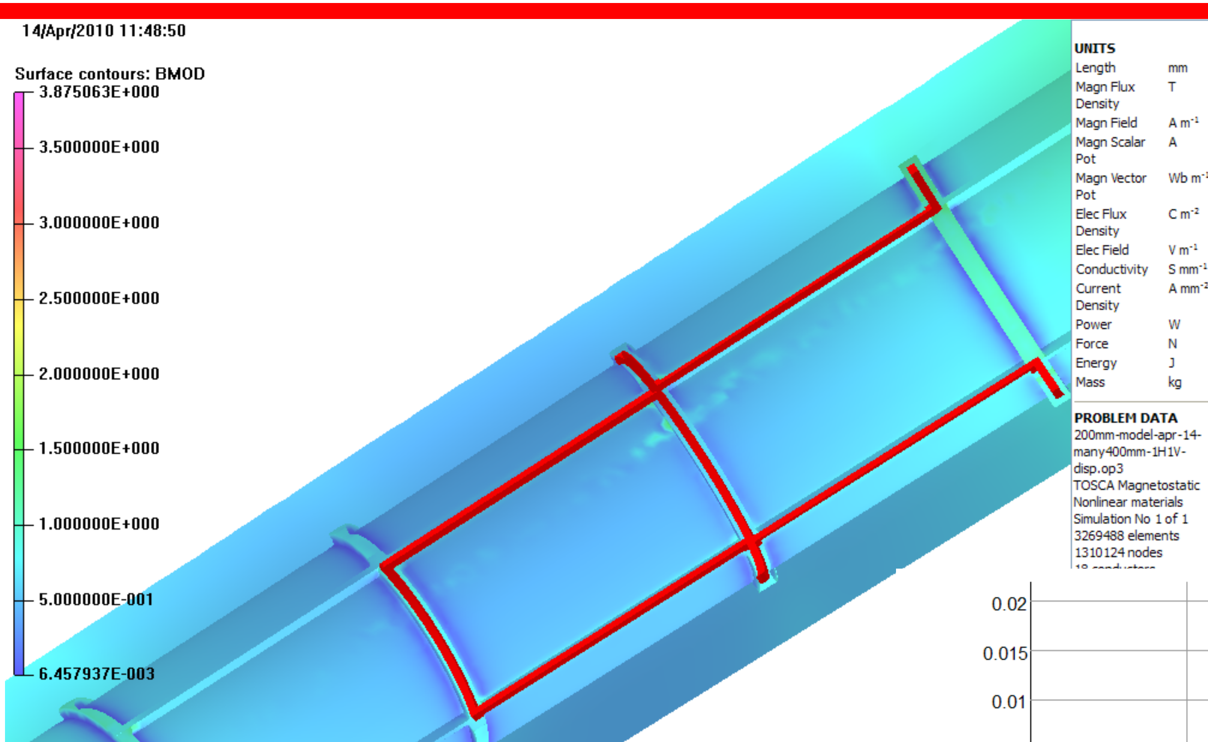


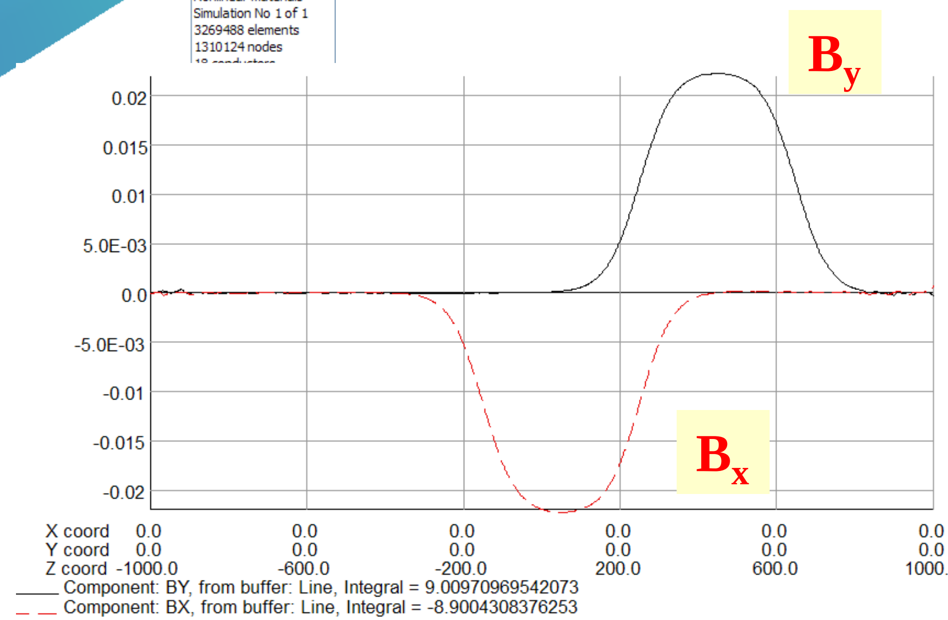
Powered alternately at full horizontal or full vertical field



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

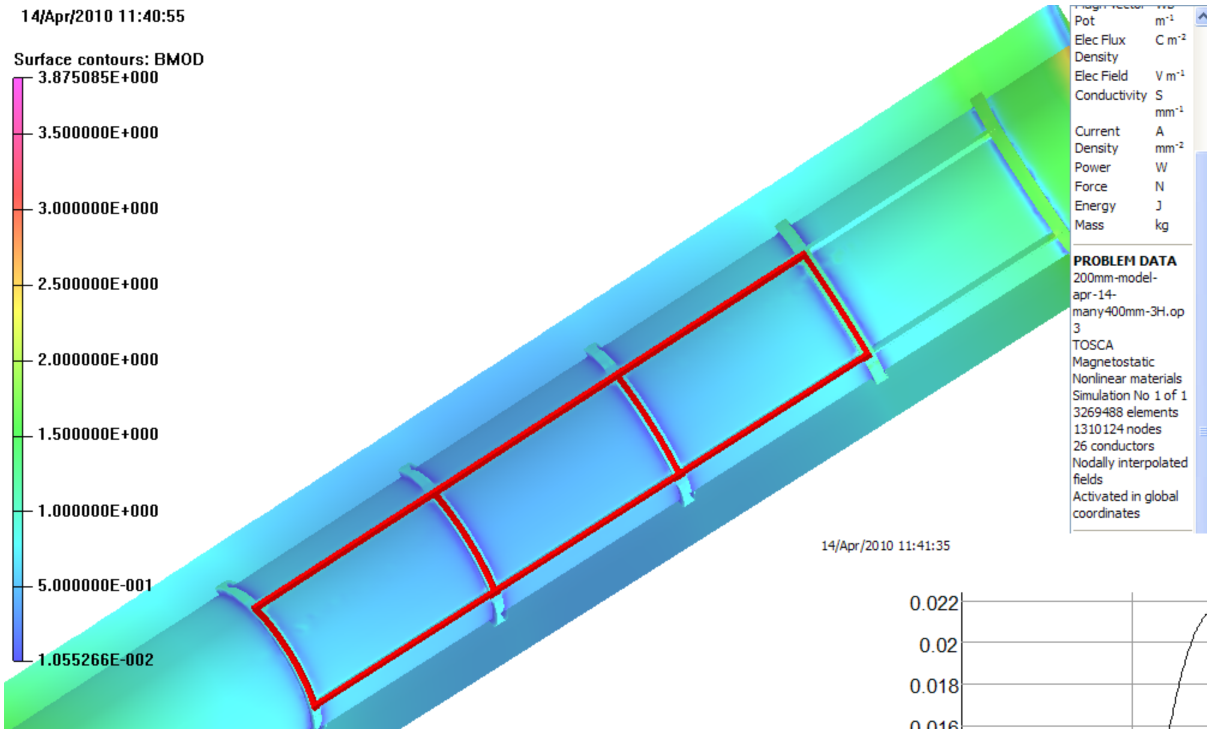
Super-ferric Design

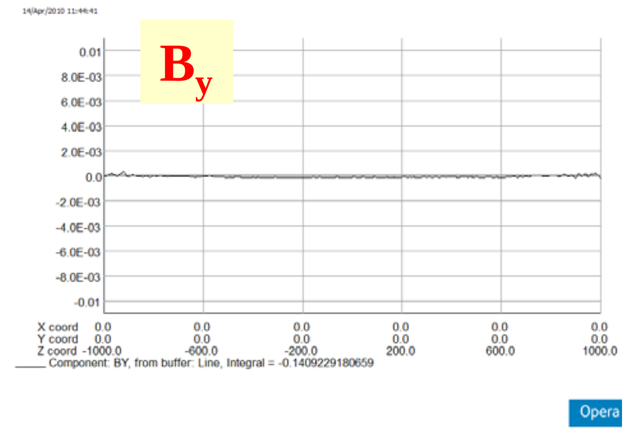


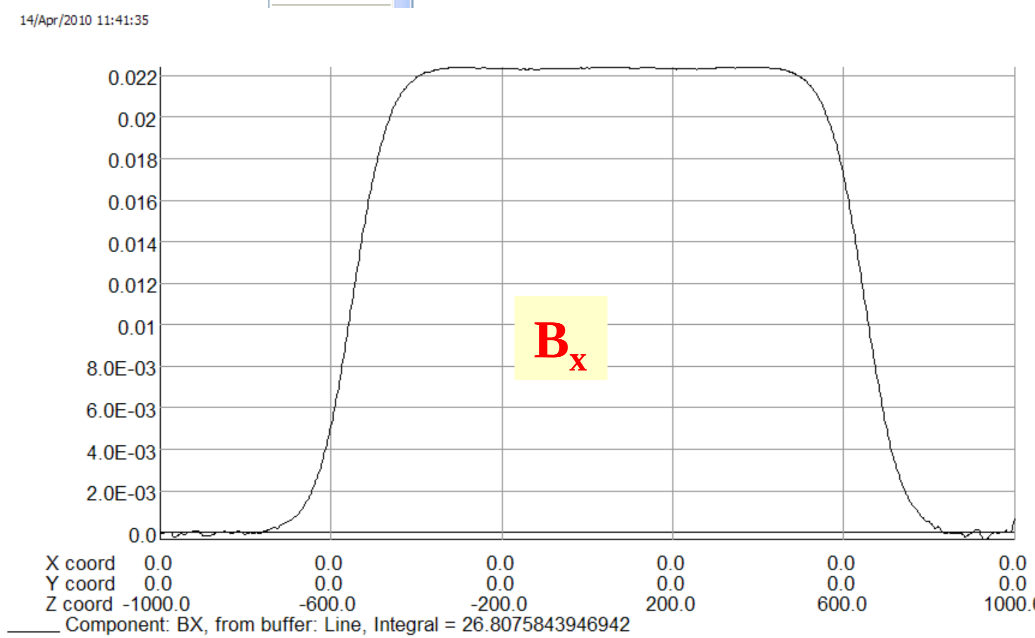


Works well.
Horizontal and vertical correctors are again put at the same radial space

Three Horizontal Correctors at Full Strength



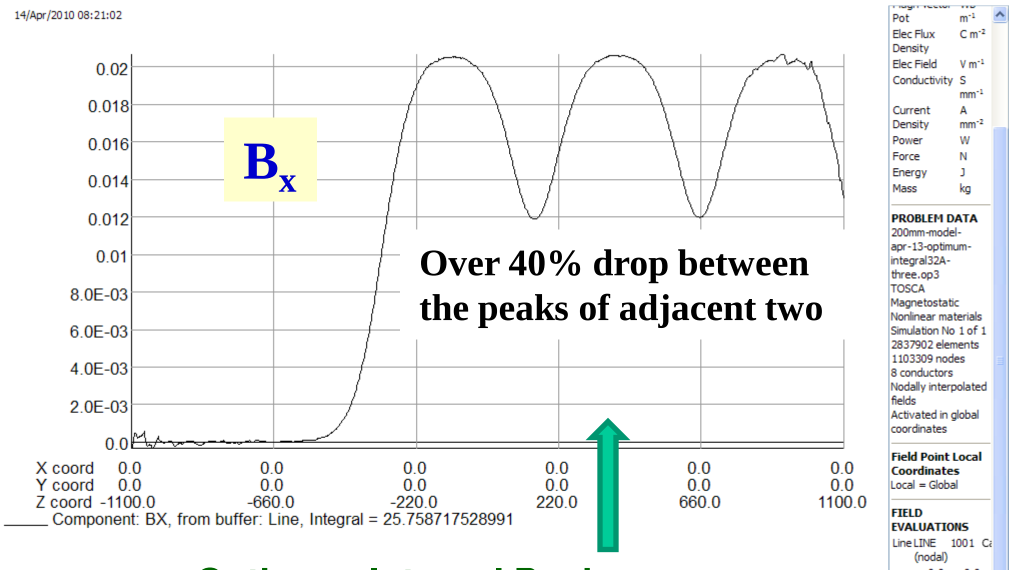


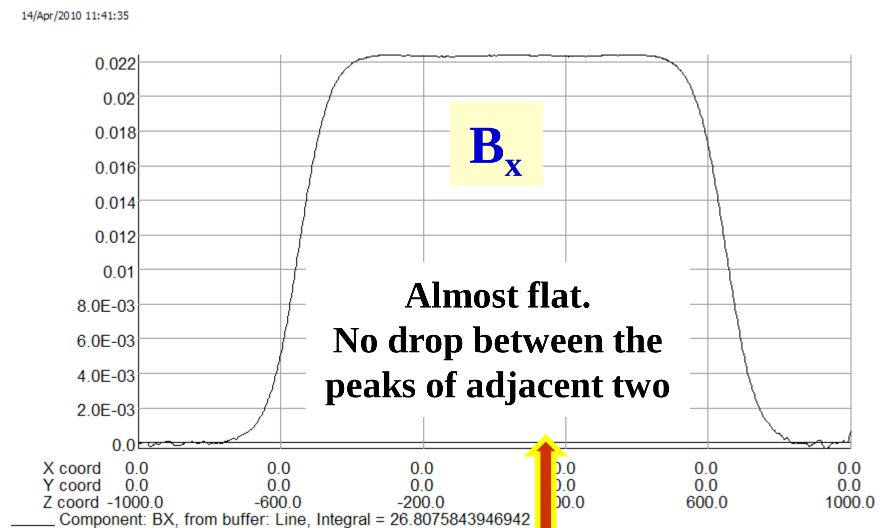


Works really well – even better than optimum integral design (field is very flat in this case).

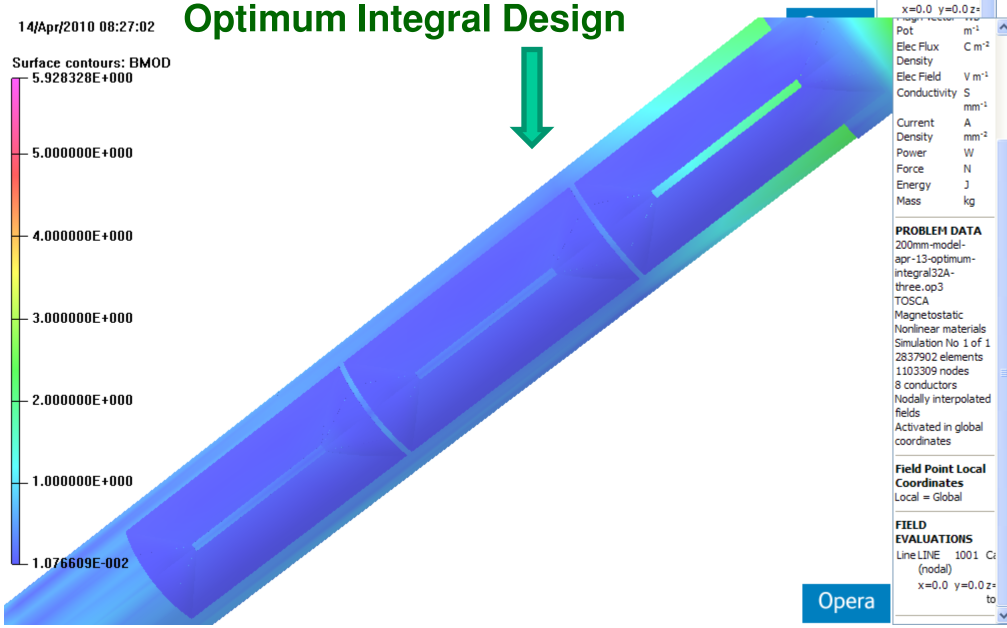
See comparison with the optimum integral design in the next slide

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

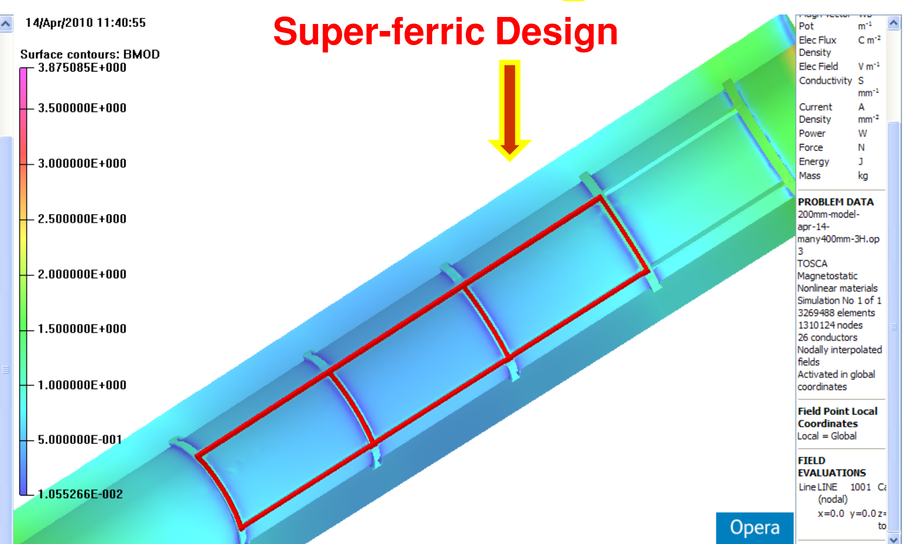




Optimum Integral Design

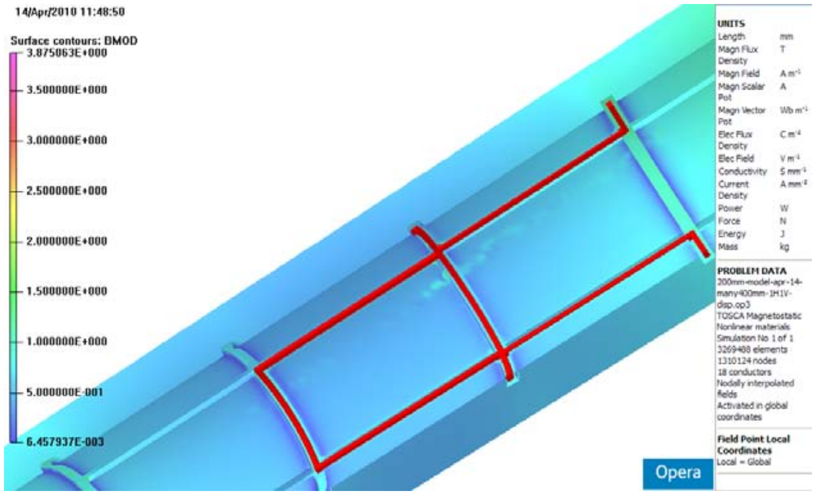


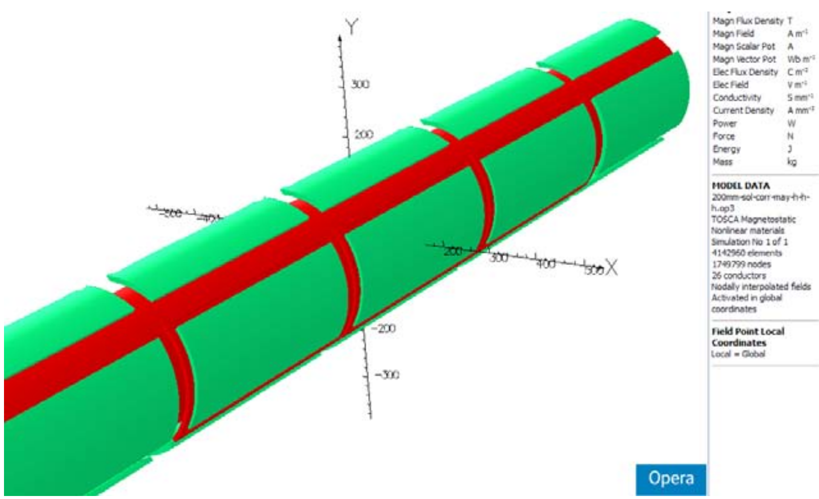
Super-ferric Design



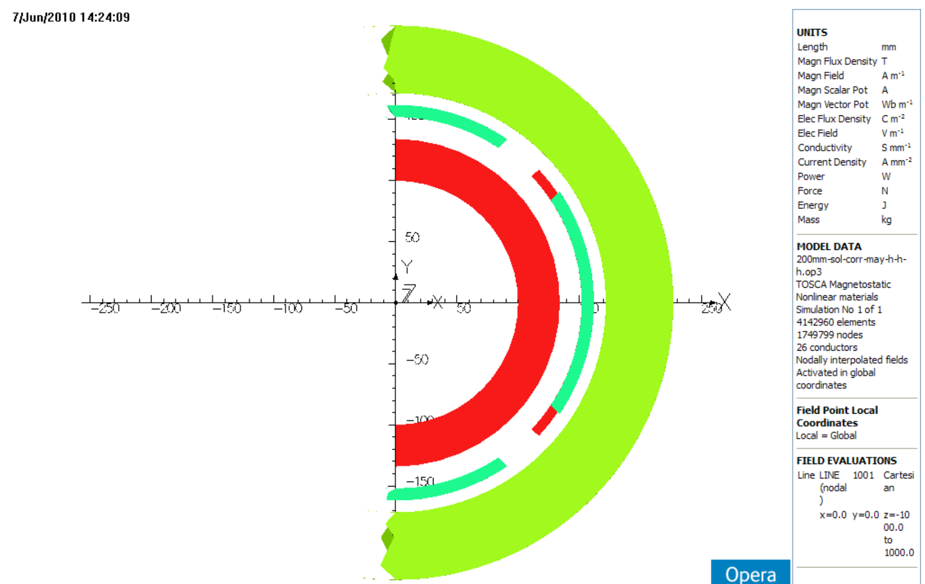
Iron Pole or NOT (Slotted Design)

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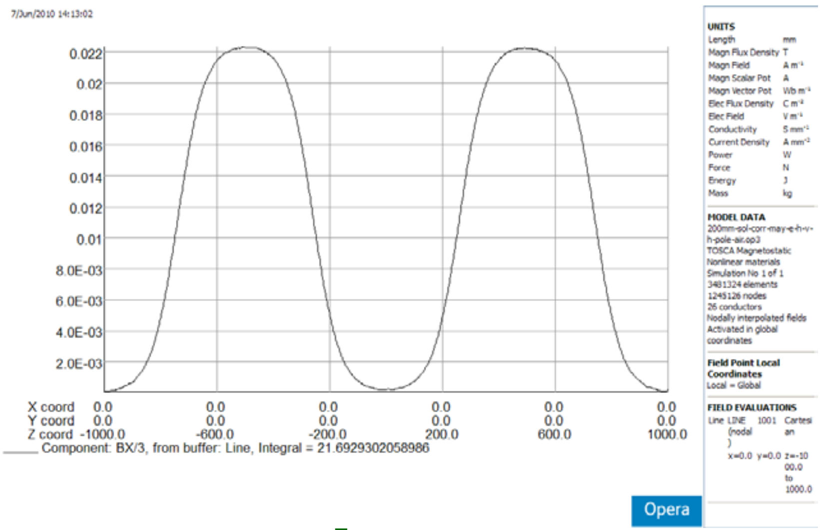
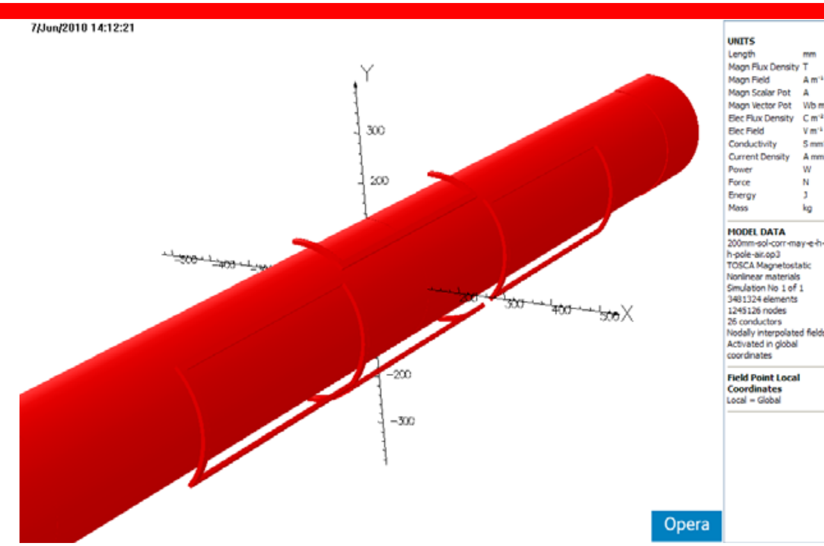
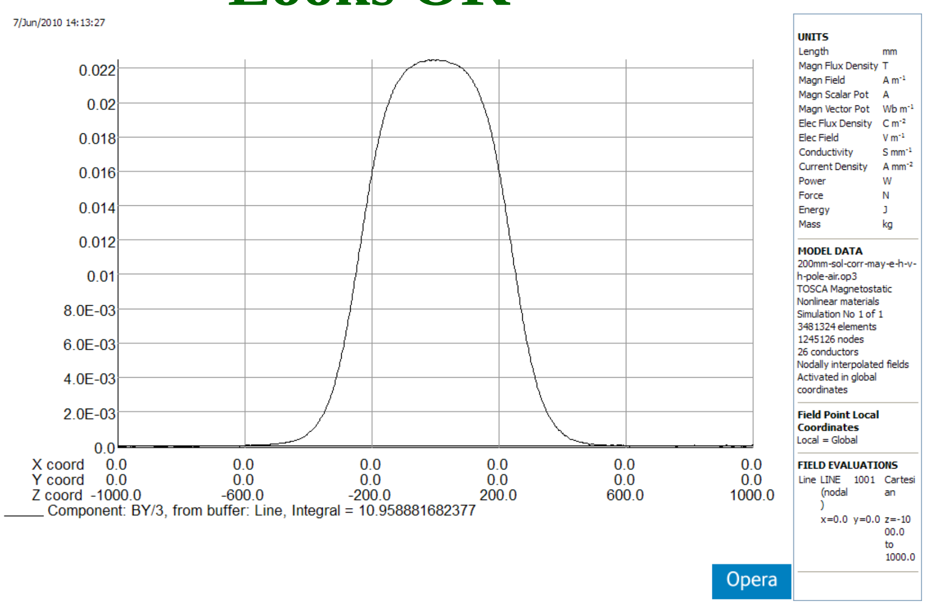
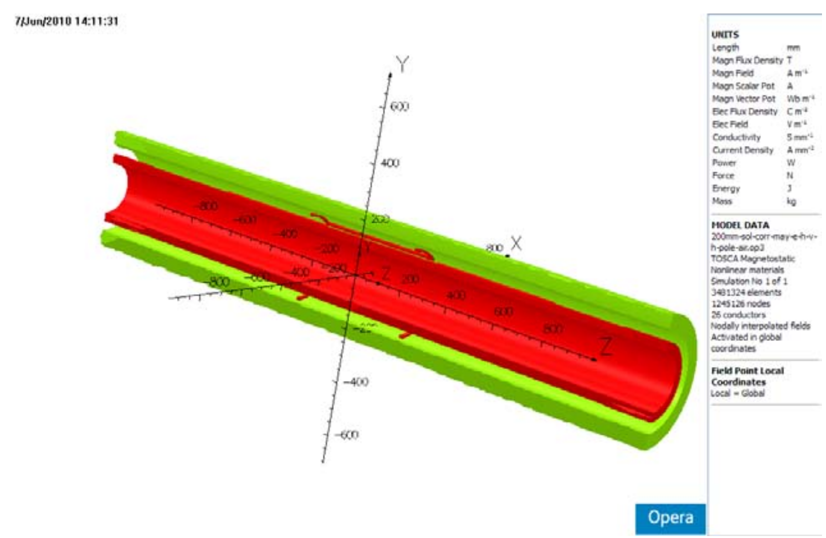
Fields of Two Horizontal and One Vertical Short Correctors in Slotted Design without Iron Pole



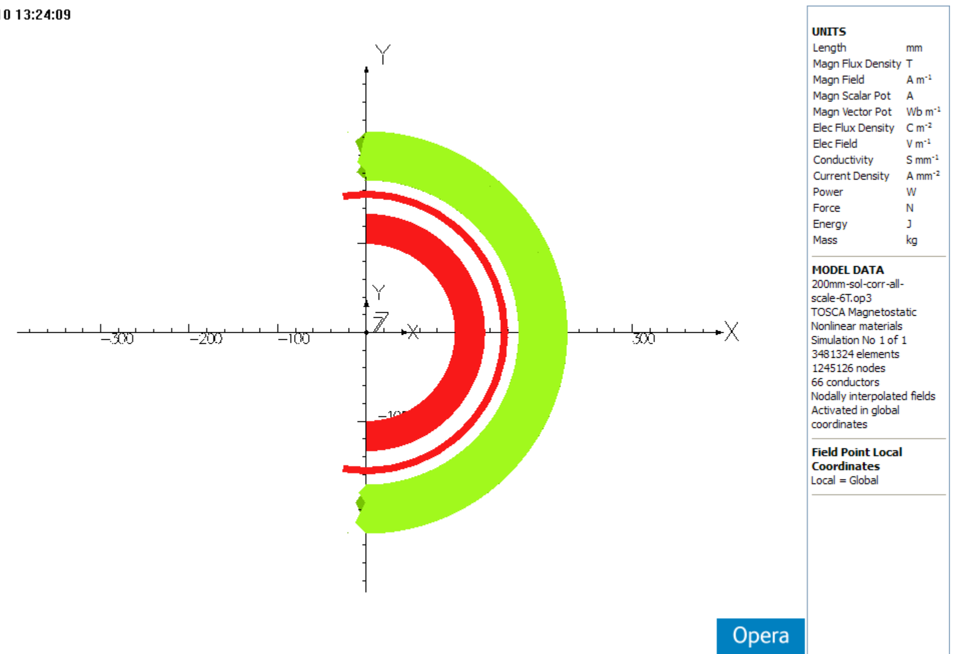


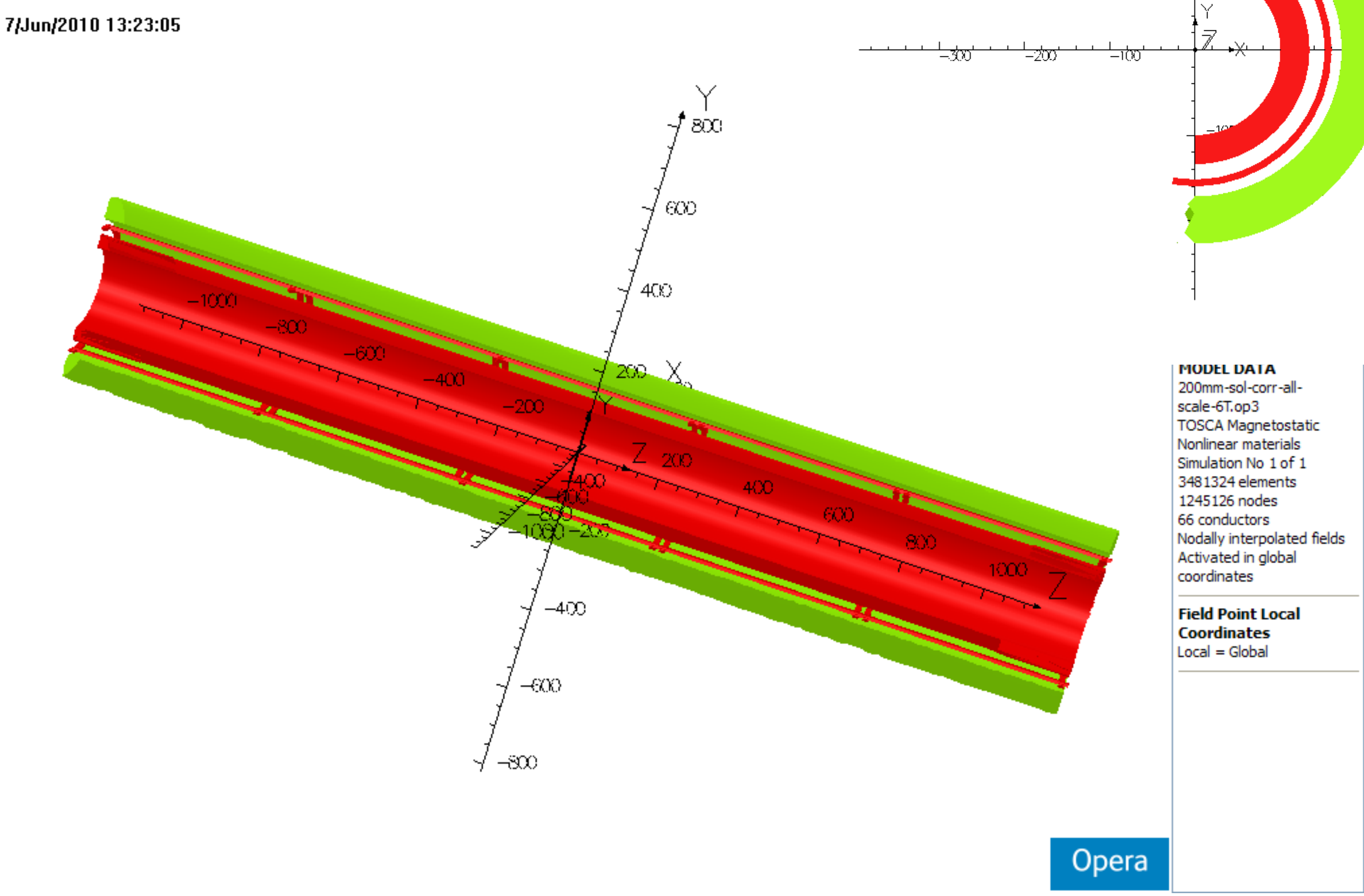
Looks OK



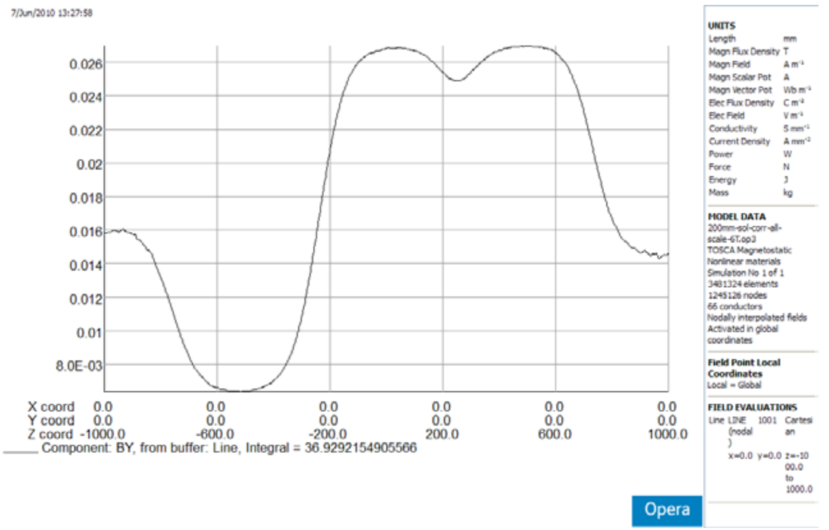


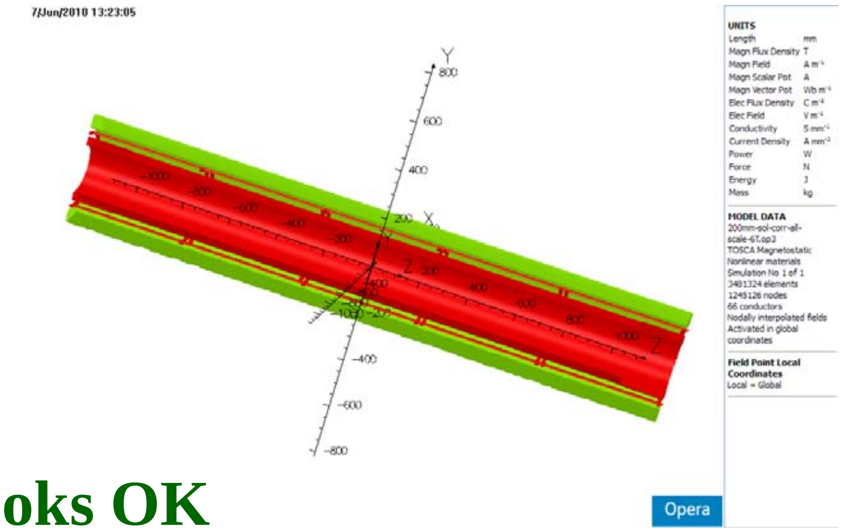
Model with Short and Long Correctors in Slotted Design without Iron Pole



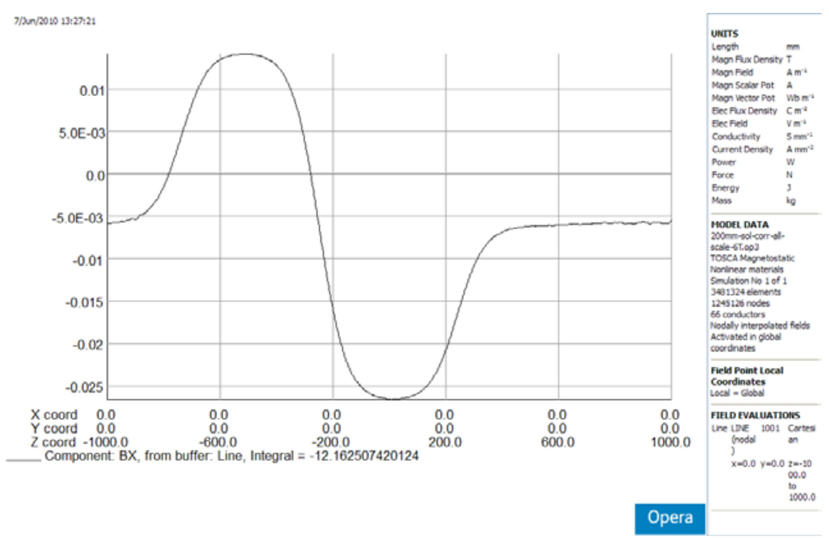


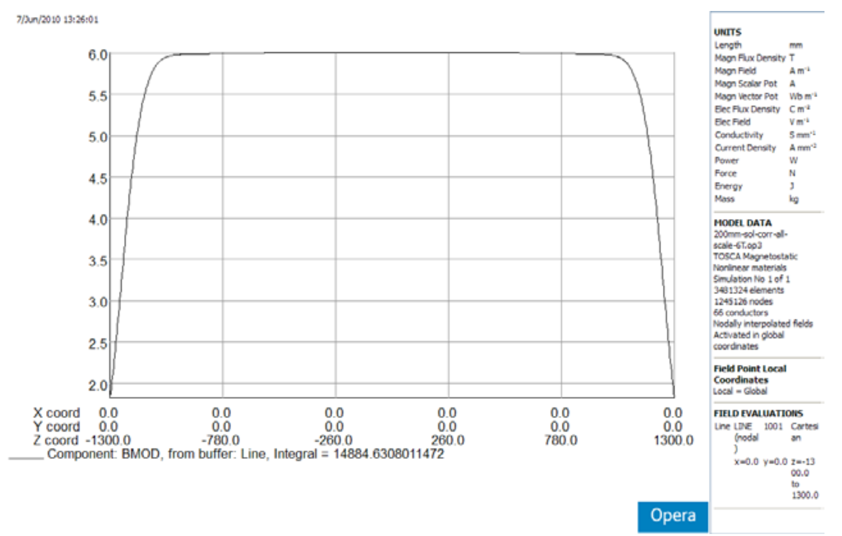
Field with Short and Long Correctors in Slotted Design without Iron Pole





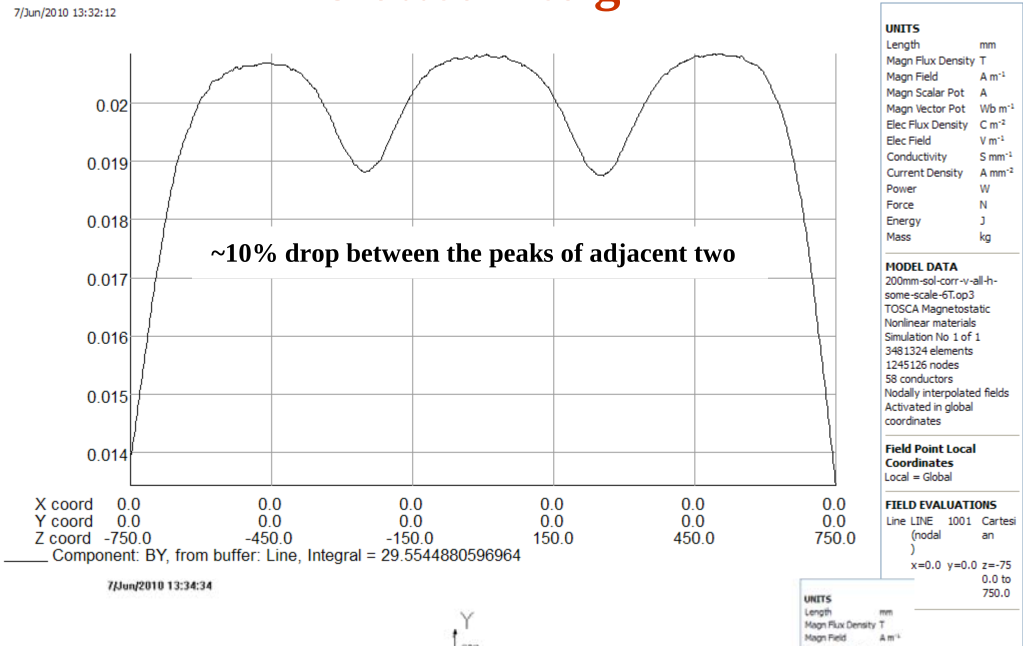
Looks OK



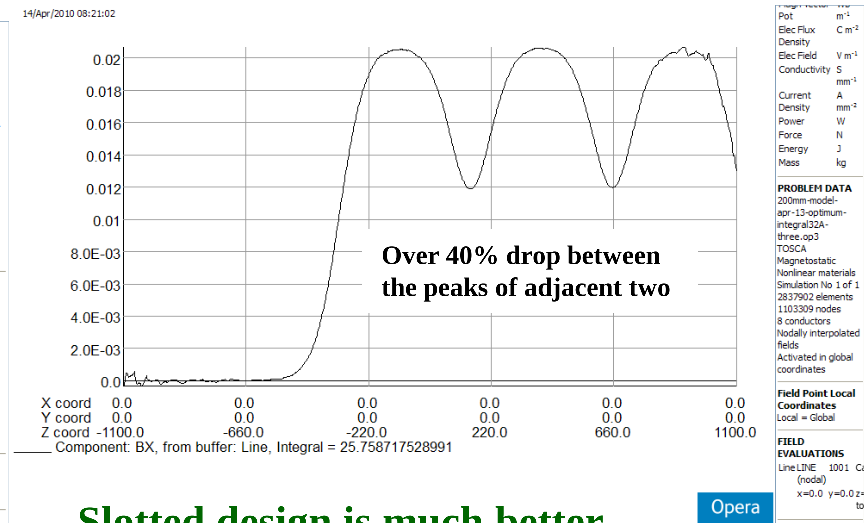


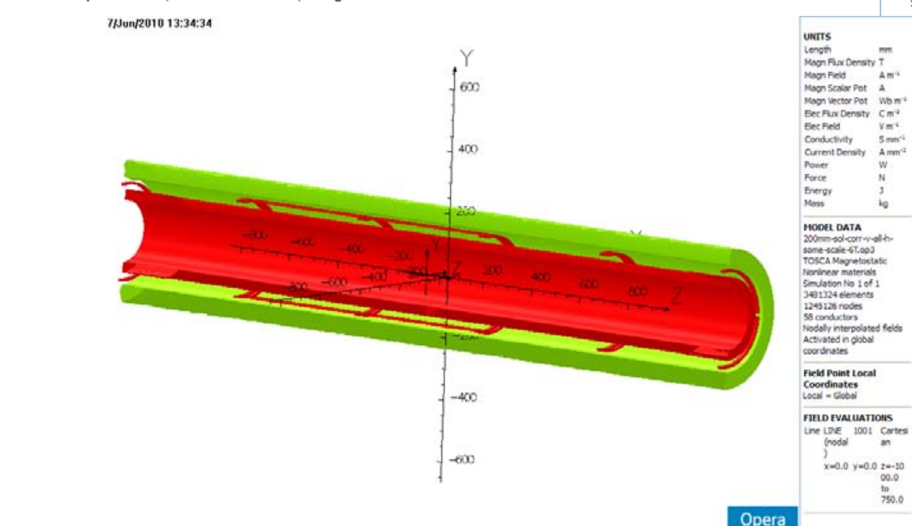
Comparison of Field between the Slotted Design and the Optimum Integral Design

Slotted Design

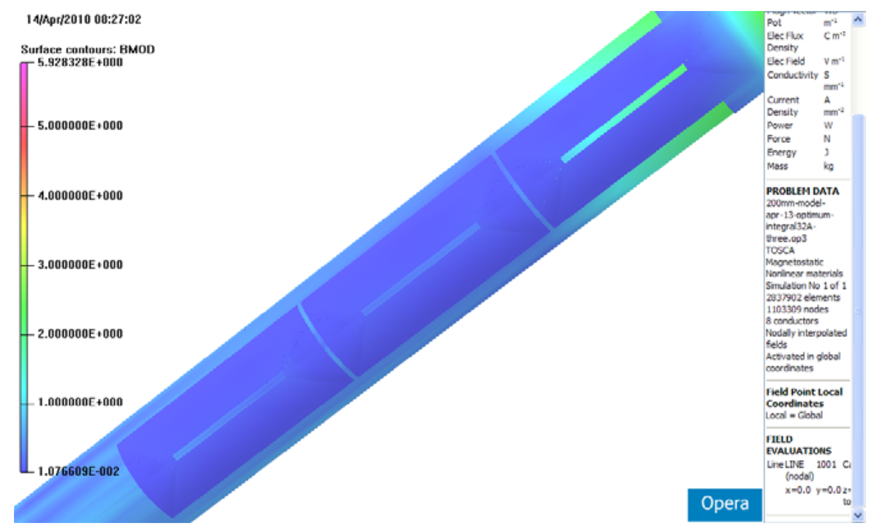


Optimum Integral Design





Slotted design is much better



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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.

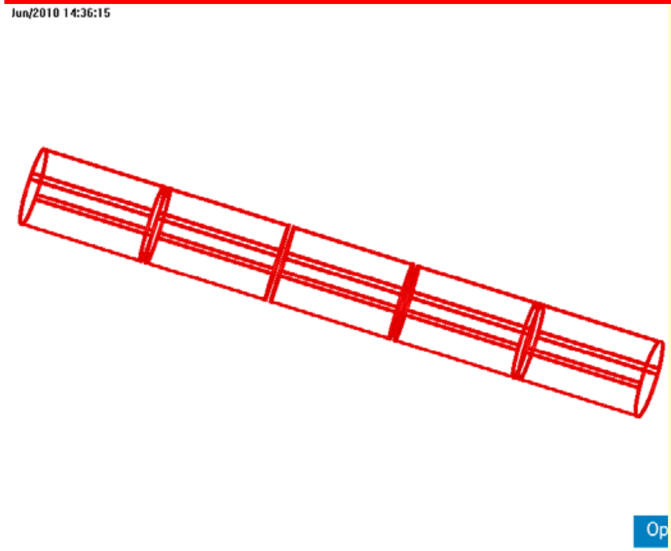
all dimensions are in mm unless noted

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 is1/8
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

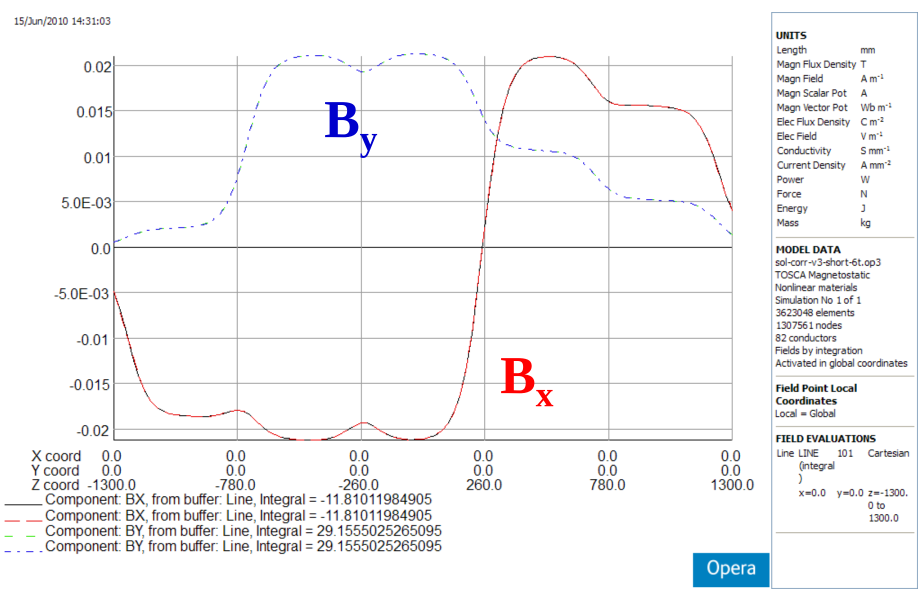
Item	Dimension (mm) thickness	inner diameter	outer diameter
inner cryostat (assumes 60mm aperture)	3	148	154
radial insulating space	5	154	164
Heat shield	4	164	172
radial insulating space	4	172	180
helium vessel / support tube	10	180	200
solenoid, 26 layers	37	200	274
G-10 buildup (max., tapered)	10	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

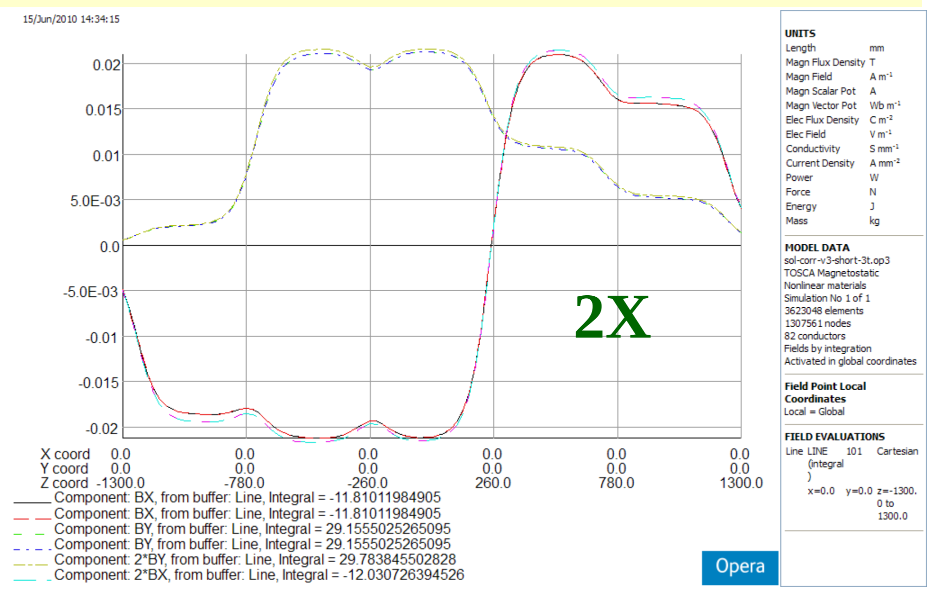
Examining Possible Configuration of Short Correctors



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 0.02T

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.





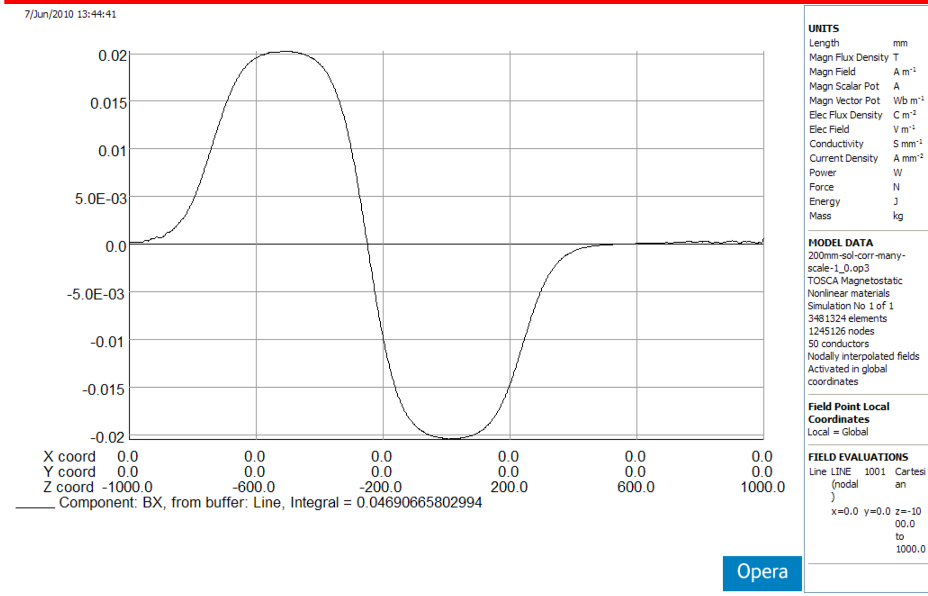
Change in error correction due to non-linearity (1)

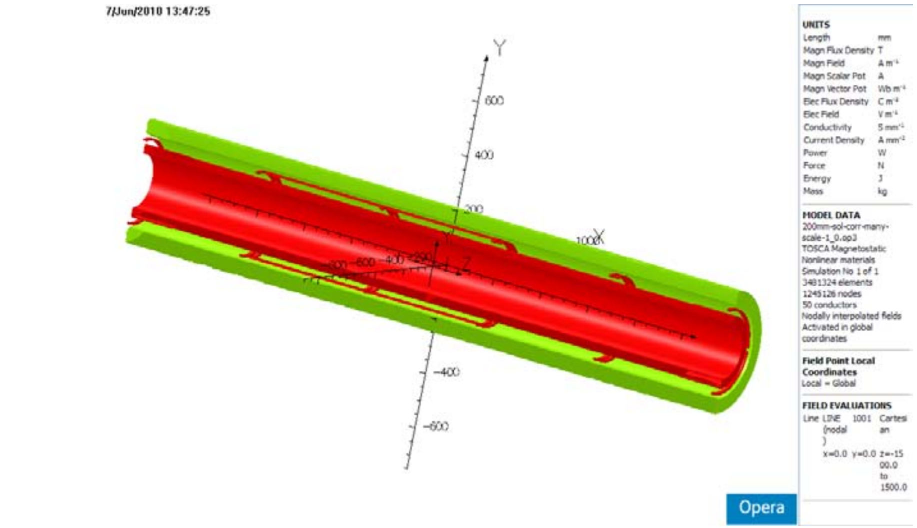
- Main solenoid will operate from 3 T to 6 T.
- Correctors (both short and long) must correct for the position error at each field.
- Since the iron saturation is significant at 6 T, currents will not scale linearly.
- Moreover, each short corrector, in general, will have a different value of current (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.

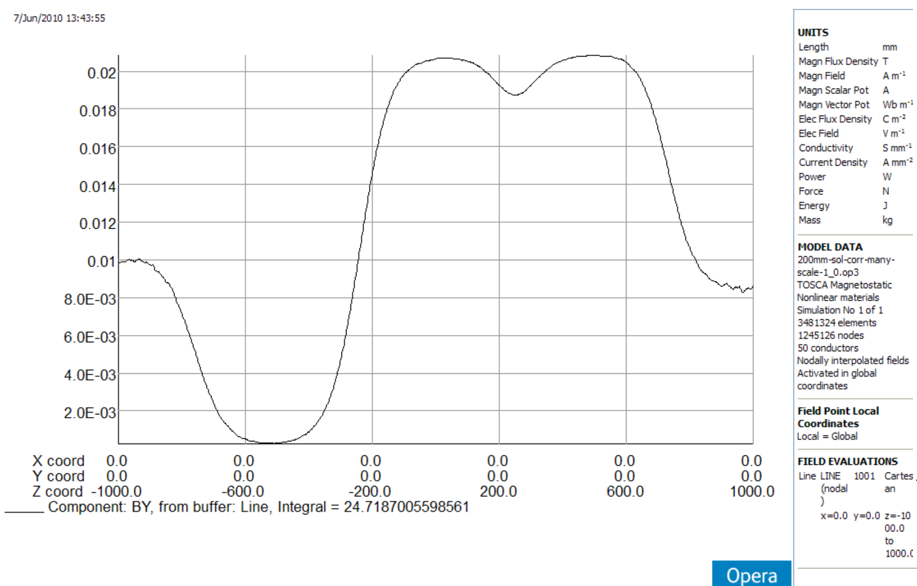
- Next few slides will examine this issue in more details.

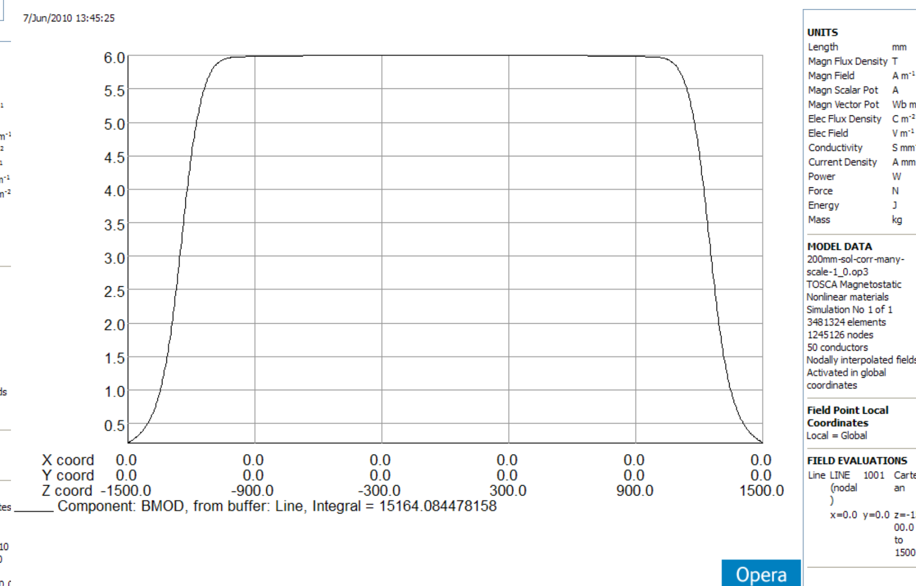
Change in error correction due to non-linearity (2)

(Correction at 6 T)



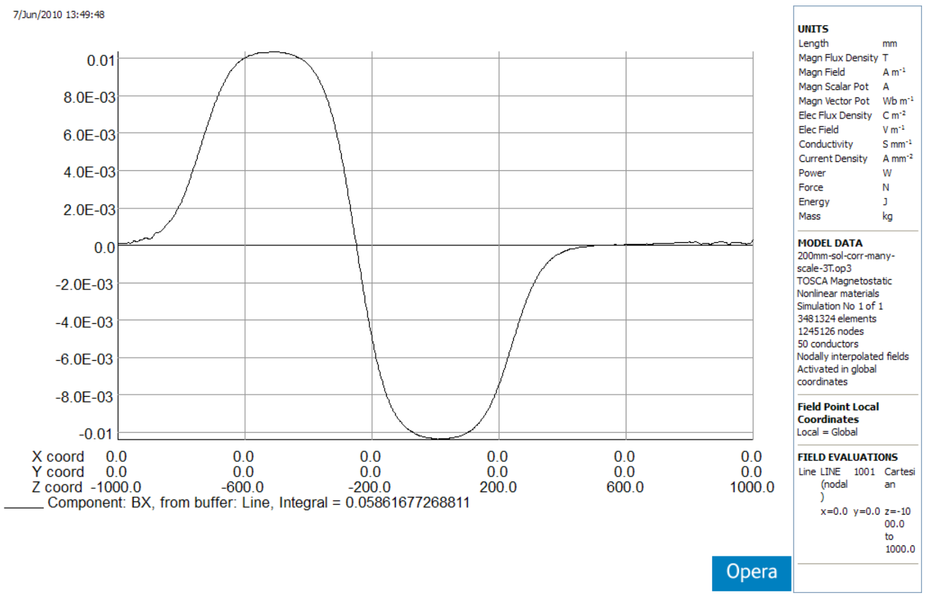


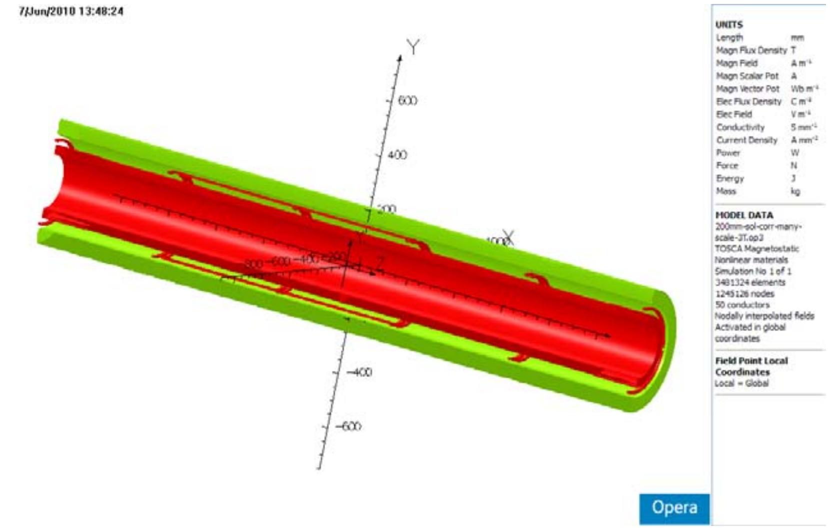


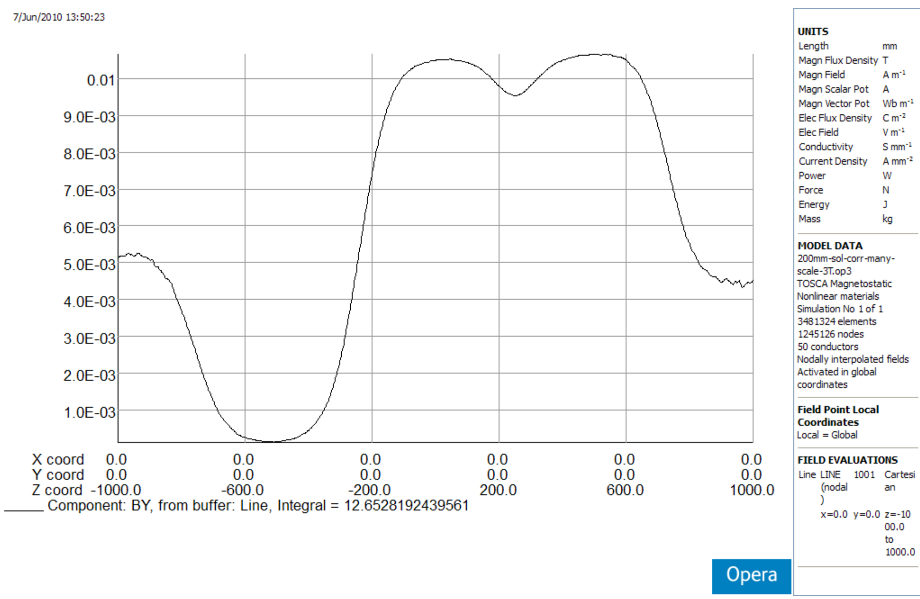


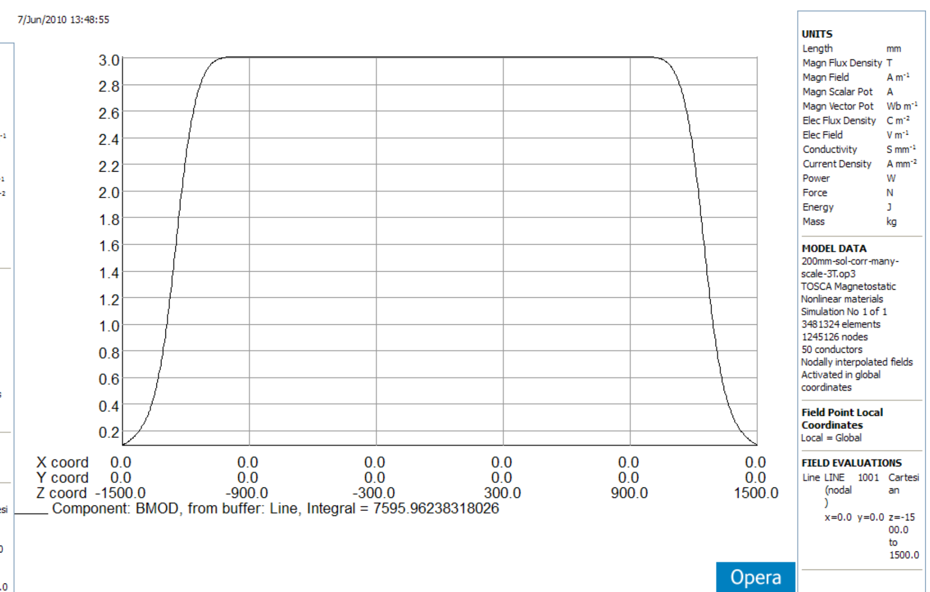
Change in error correction due to non-linearity (3)

(Correction at 3 T)









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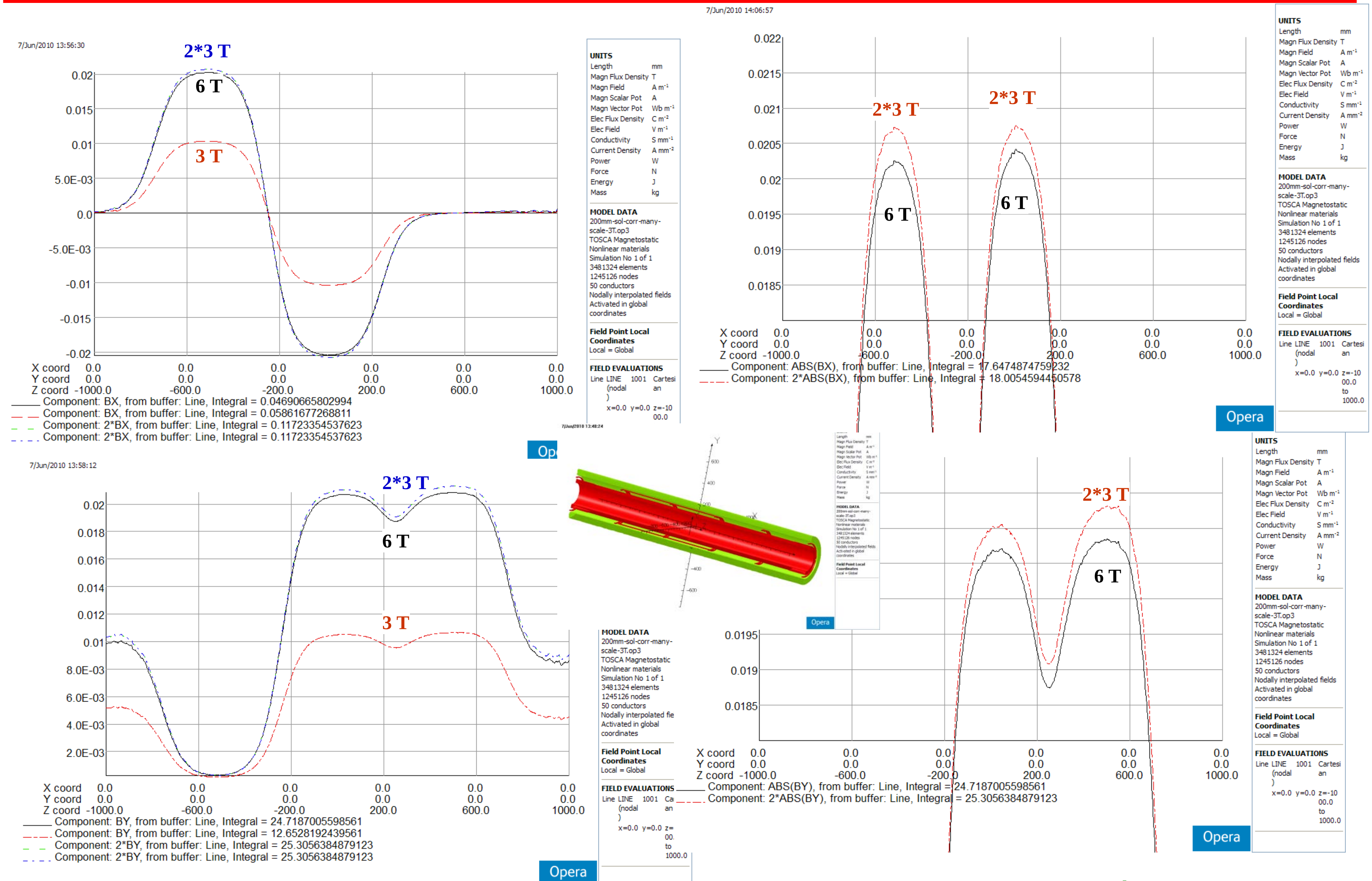
Influence of Iron Saturation in short correctors (either accept small errors or adjust correction)



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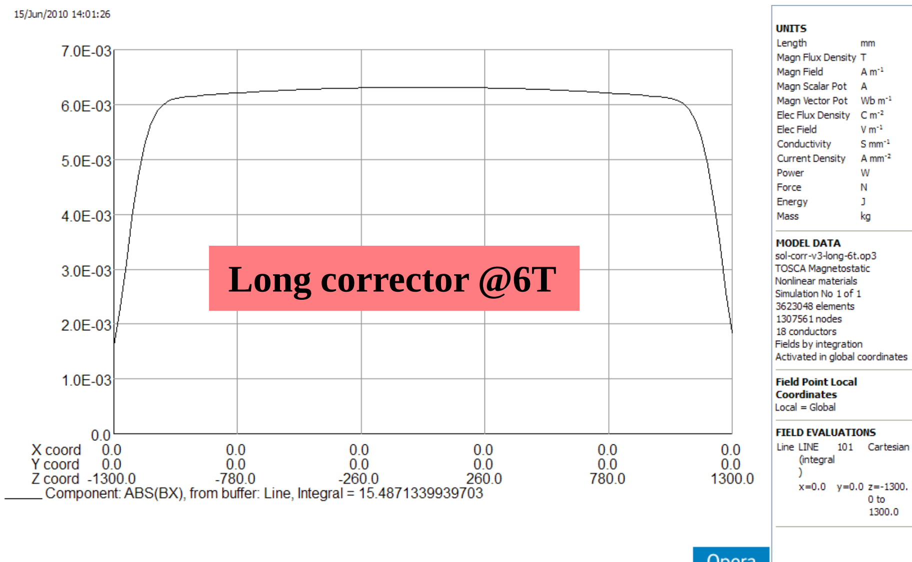
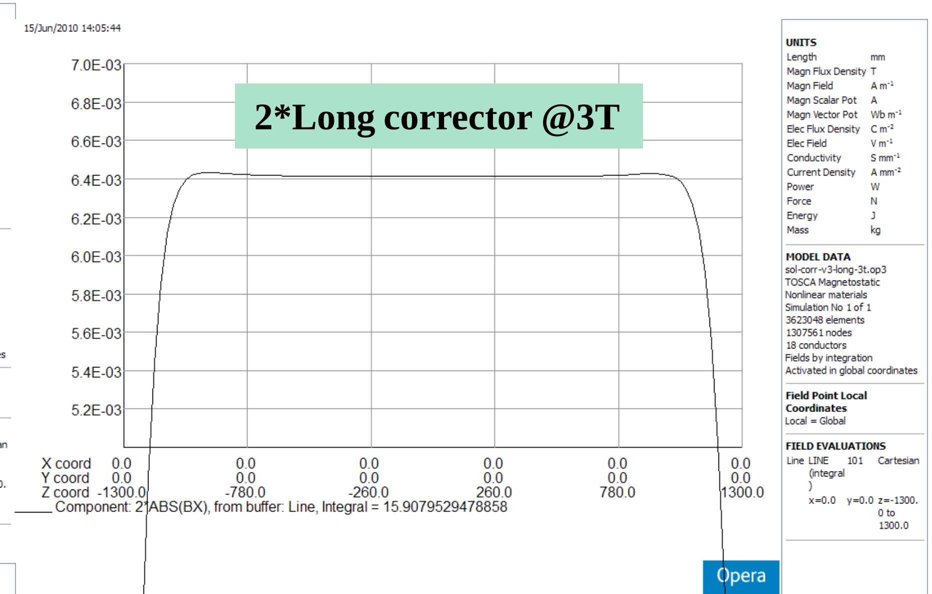
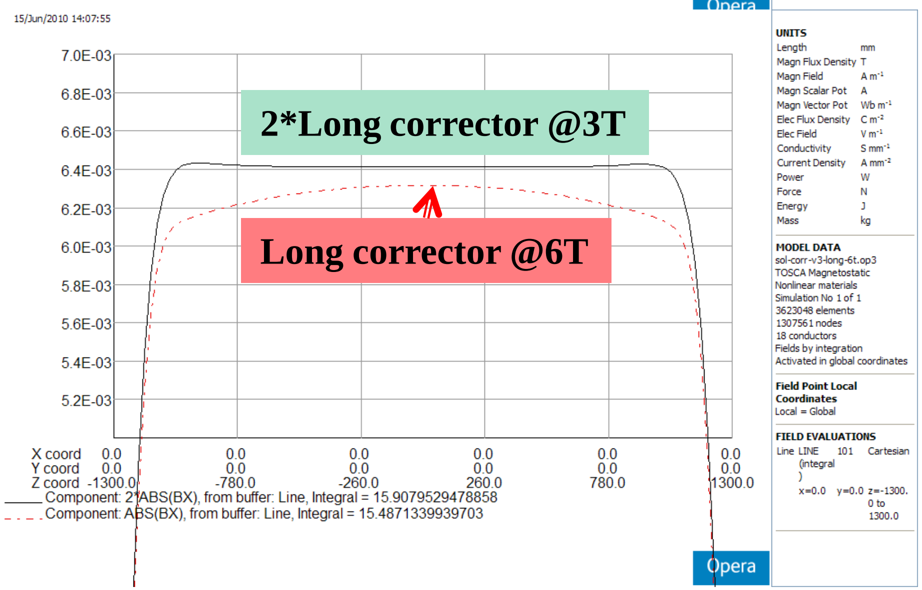
Change in error correction in Long Correctors due to non-linearity



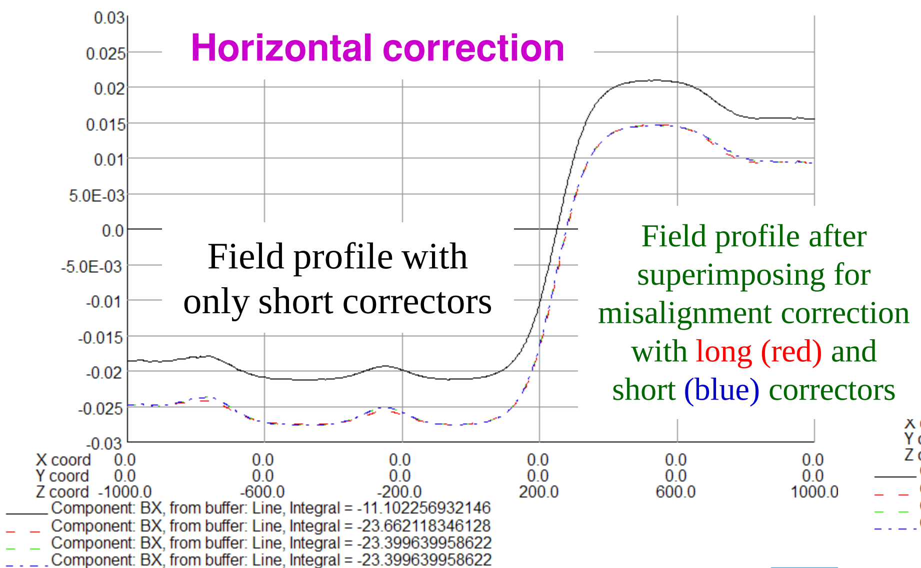


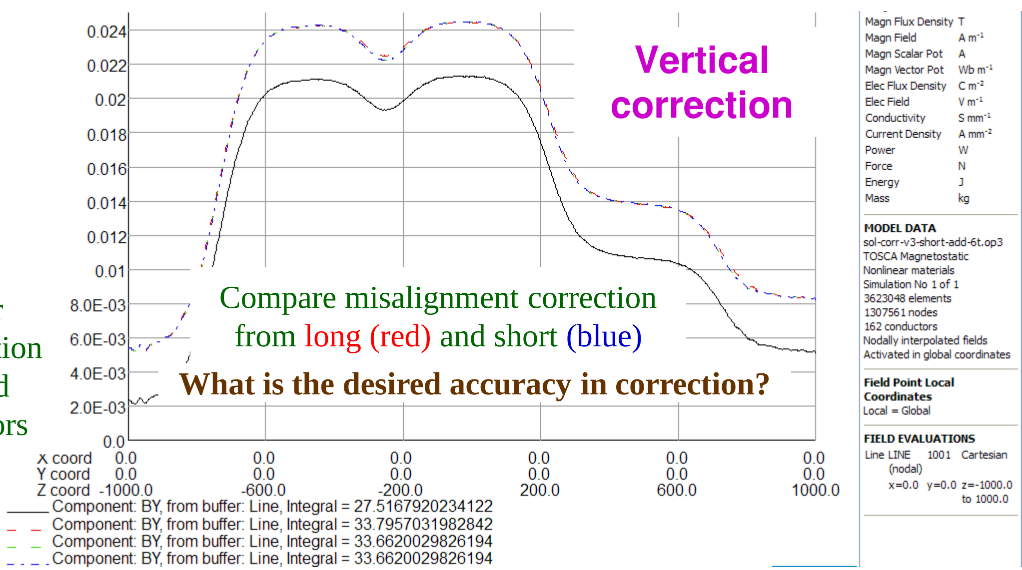


- Using long corrector for global alignment error, causes additional error due to saturation.
- It can be corrected by adjusting short corrector.
- But then why not use short corrector completely?

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

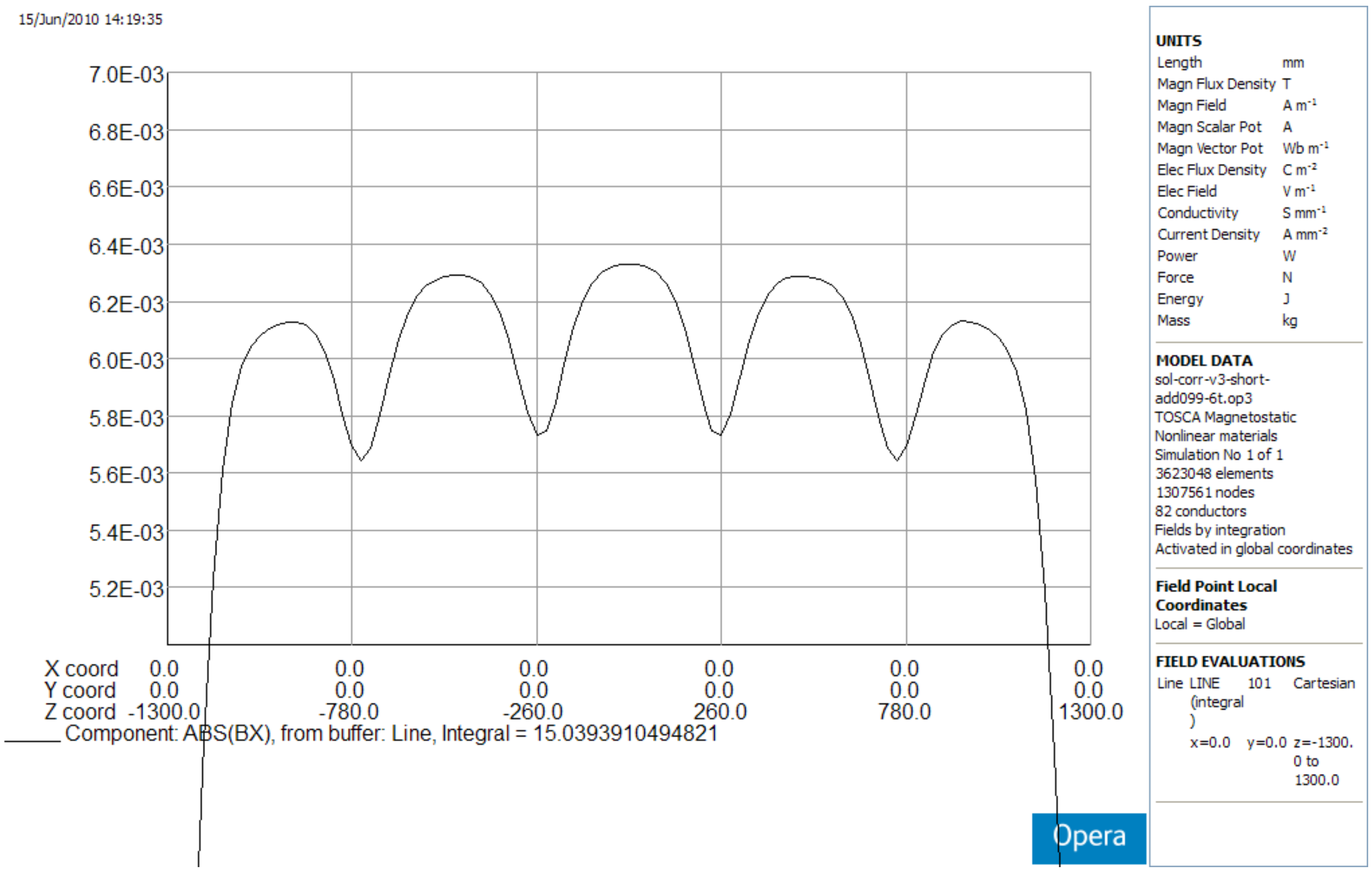
- There may be misalignment between the proton beam and solenoid axis.
- Long correctors (horizontal and vertical) with a maximum strength of 0.006 T are planned for achieving overall alignment of proton beam with respect to solenoid axis within 50(?) micron.
- In principle this field may also be provided 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 Bx = -0.006 T & By = +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).





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.



15/Jun/2010 14:19:35
7.0E-03
6.8E-03
6.6E-03
6.4E-03
6.2E-03
6.0E-03
5.8E-03
5.6E-03
5.4E-03
5.2E-03
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
Opera
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