
Iterated Design of 200 mm, 6 T Superconducting Solenoid for e-lens

Ramesh Gupta

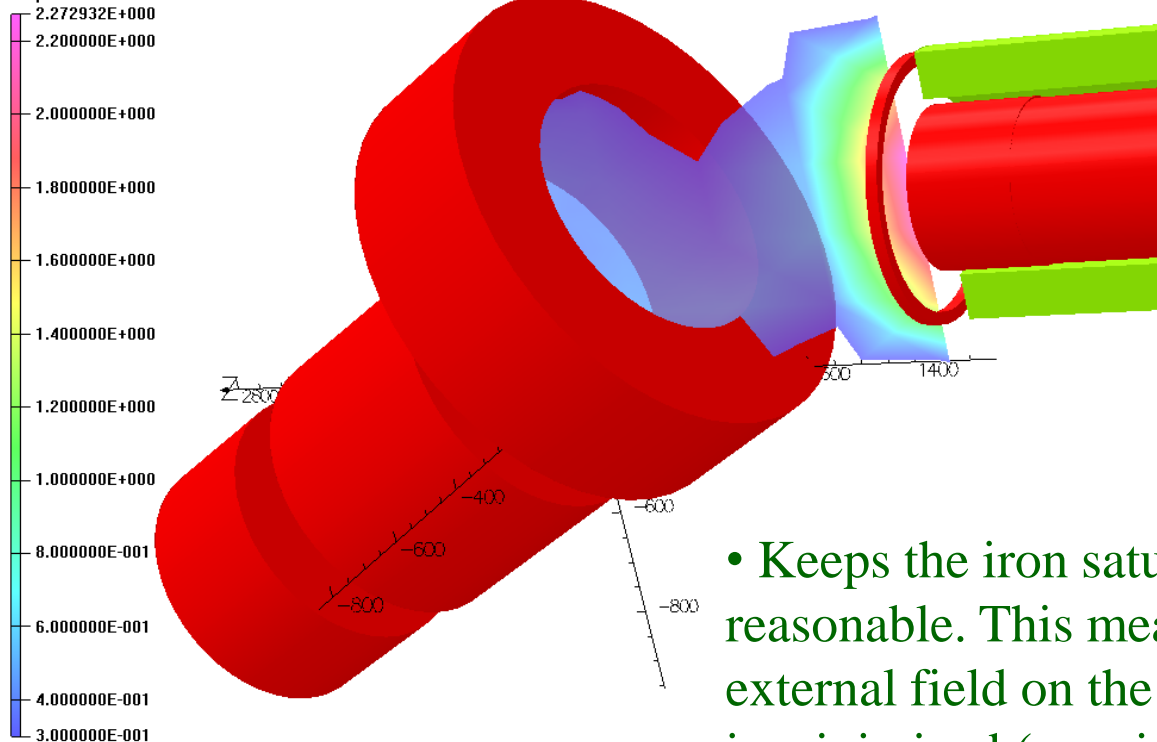
April 6, 2010

Small Superconducting Solenoid next to Main Solenoid (fringe field coil may be part of the same coldmass)

Size of the small sc solenoid : A few cm X a few cm - likely to be made of small corrector wire to keep current low.
(parameters are not yet optimized)

29/Mar/2010 15:07:42

Map contours: BMOD



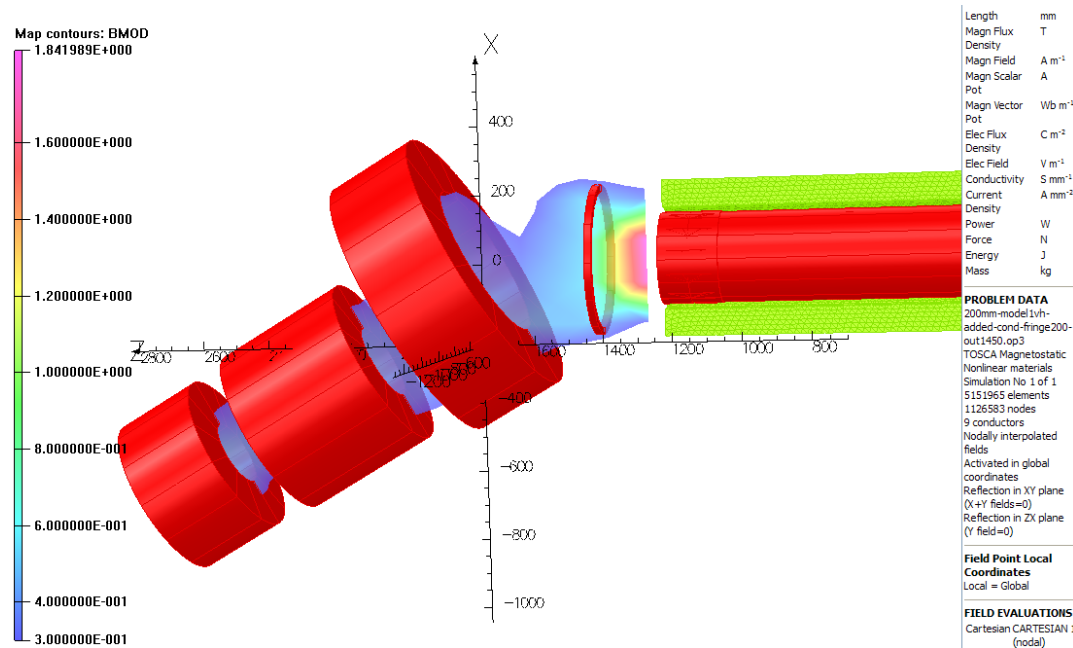
- There are several benefits of a separate solenoid to create field in the region between the superconducting and the copper solenoids.
- Provides an independent control (knob) to create the desired field, irrespective of what that desired field is, the field in the main solenoid and the field in the copper solenoid

- Keeps the iron saturation in the main solenoid reasonable. This means that the influence of the external field on the field inside the main solenoid is minimized (a major consideration in this design).

➤ **Another design: Fringe field coils further out where they are more effective**

Development since last presentation

- Request to increase power of fringe field (or exterior field coil).
- Exterior field coils can't be as out (axially) as previously thought.
- Finding it difficult to put all in 2.8 meter slot allocated
- Axial forces could cause significant design and protection issue.



Note:

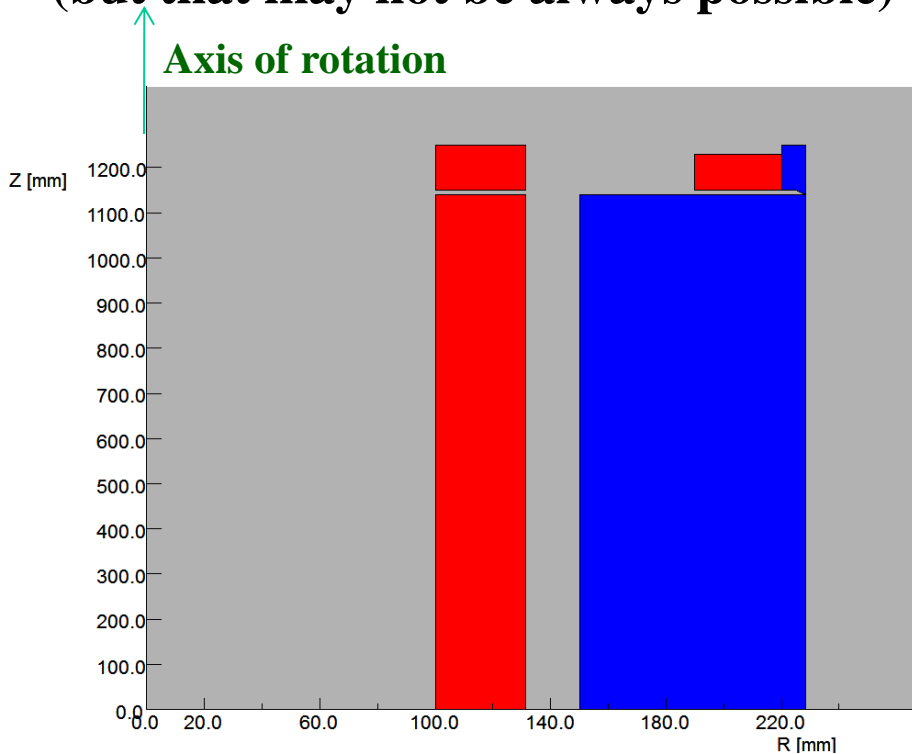
The following slides show the design work (design ideas) that are being investigated and is not the final design.

One of the design presented last week

Iterated Design Concept

- Structure is introduced between the coil to take large axial Lorentz forces
- Exterior field (fringe field) coil is brought within 2500 mm yoke
- Exterior field coil is made with the same conductor as main coil and is connected in series to save on number of leads
- Strength of exterior field coil is increased for > 0.3 T in region of interest
- In this case trim coil in the end were avoided by iterating various parameters (but that may not be always possible)

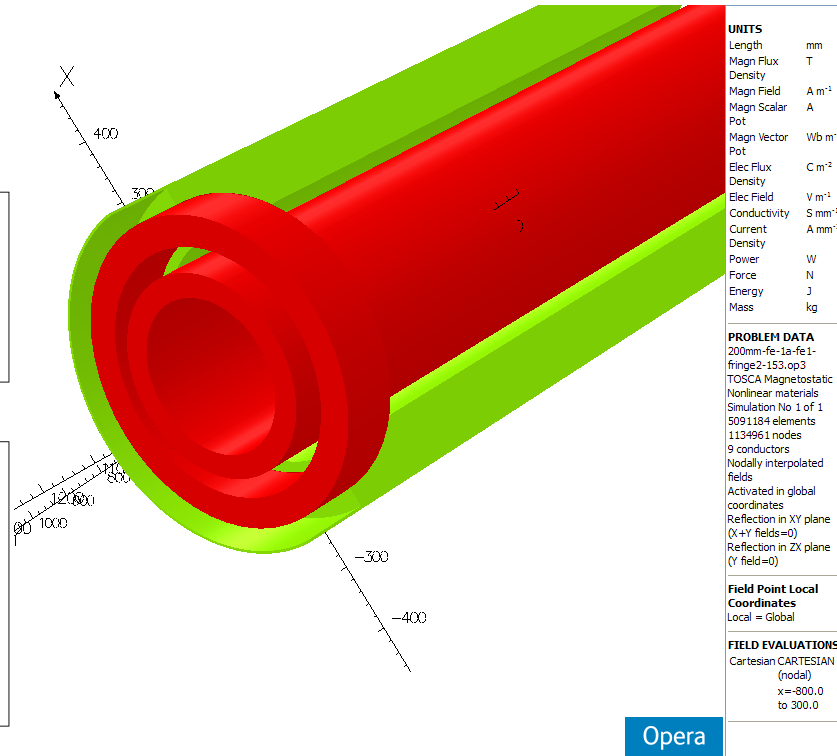
6/Apr/2010 15:04:48



UNITS	
Length	: mm
Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻²
Conductivity	: S m ⁻¹
Source density	: A mm ⁻²
Power	: W
Force	: N
Energy	: J
Mass	: kg

PROBLEM DATA	
O:\opera\sc-solenoid\2	
00-c45x70-t7d-save.st	
Quadratic elements	
Axi-symmetry	
R*vector potential	
Magnetic fields	
Static solution	
Case 5 of 6	
Scale factor: 1.0	
11013 elements	
22486 nodes	
25 regions	

06/Apr/2010 14:06:12 Page 218



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-fe-1a-fe-1-	
fringe2-153.op3	
TOSCA Magnetostatic	
Nonlinear materials	
Simulation No 1 of 1	
5091184 elements	
1134961 nodes	
9 conductors	
Nodally interpolated fields	
Activated in global coordinates	
Reflection in XY plane (X=+1 fields=0)	
Reflection in ZX plane (Y field=0)	

Field Point Local Coordinates	
Local = Global	

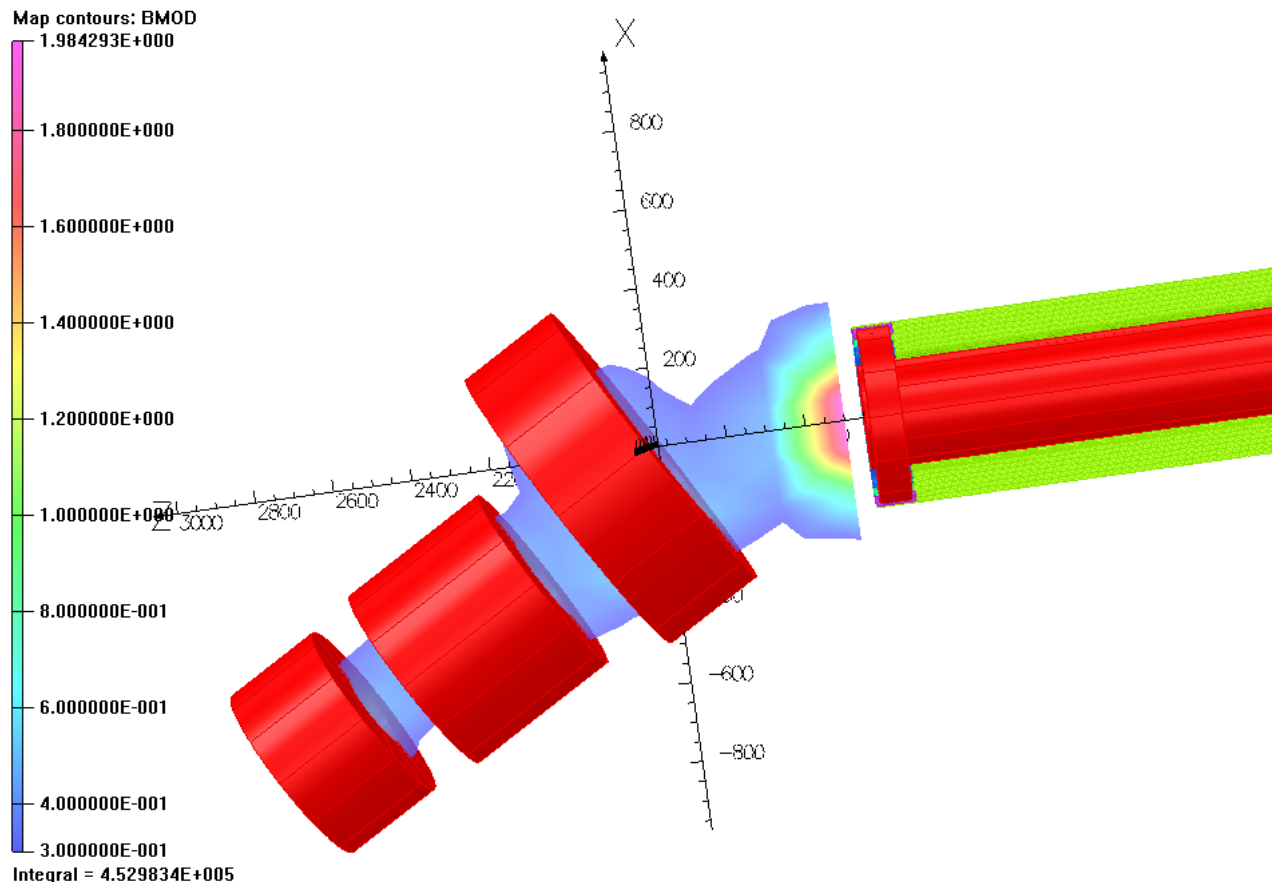
FIELD EVALUATIONS	
Cartesian CARTESIAN 10 (nodes)	
x=-800.0 y= to 300.0	

Opera

Field in the intermediate region

- It is possible to obtain a field > 0.3 T in the region of interest.

6/Apr/2010 14:51:59

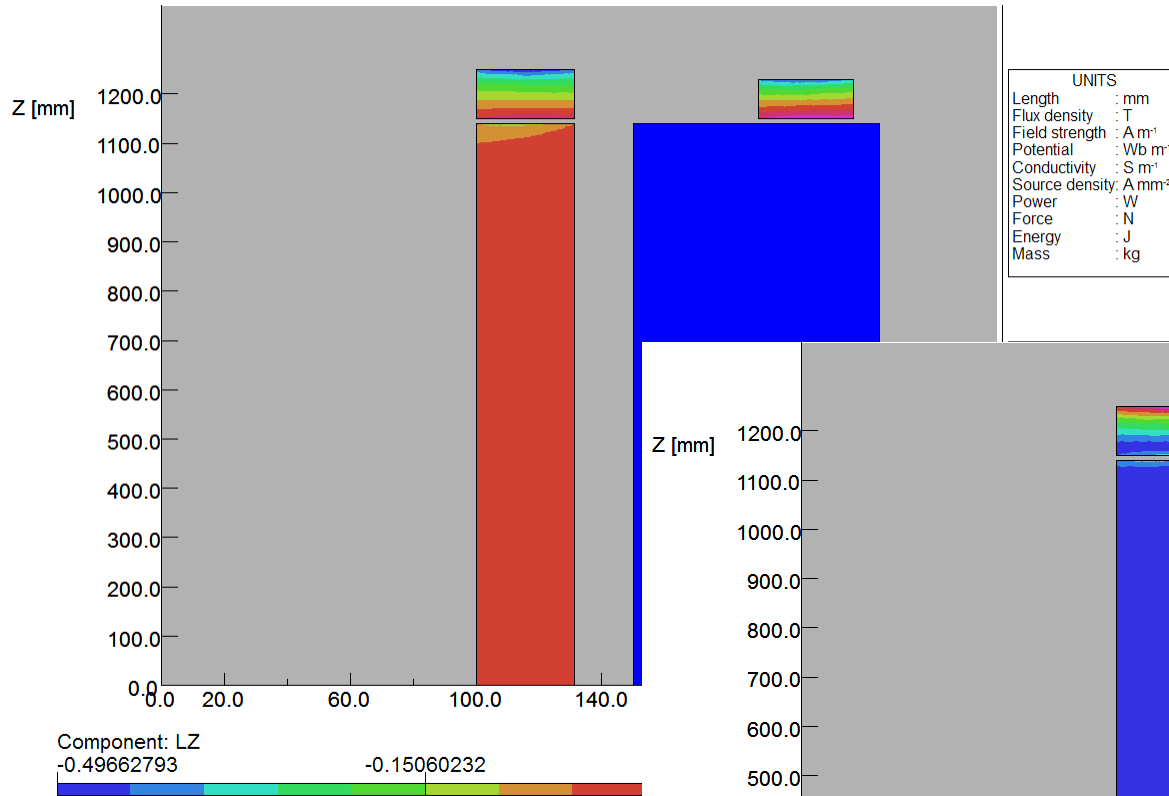


- However, it is @6T main field. If one wants >0.3 T independent of the main field, then the exterior field coils may have to be independently powered.

- This means the extra lead can't be eliminated.

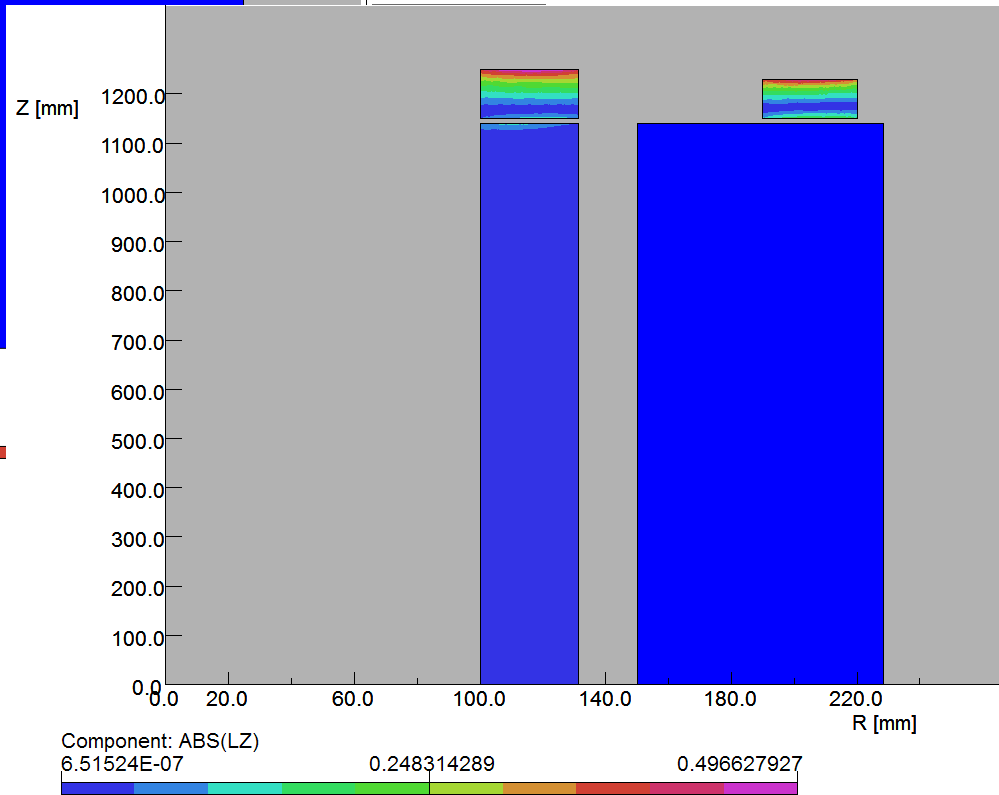
Opera

Axial Forces



UNITS	
Length	: mm
Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻¹
Conductivity	: S m ⁻¹
Source density	: A mm ⁻²
Power	: W
Force	: N
Energy	: J
Mass	: kg

It is possible to segment the axial Lorentz forces



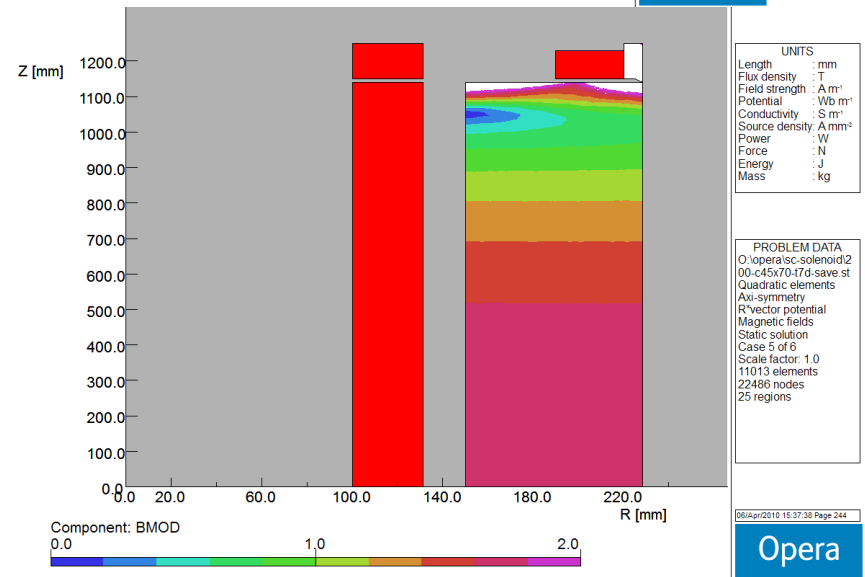
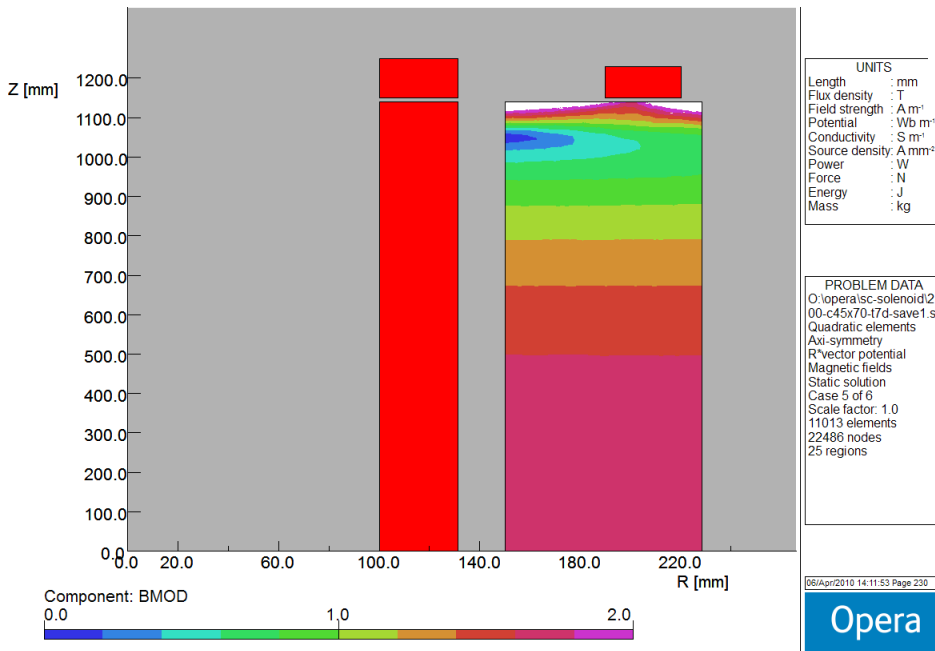
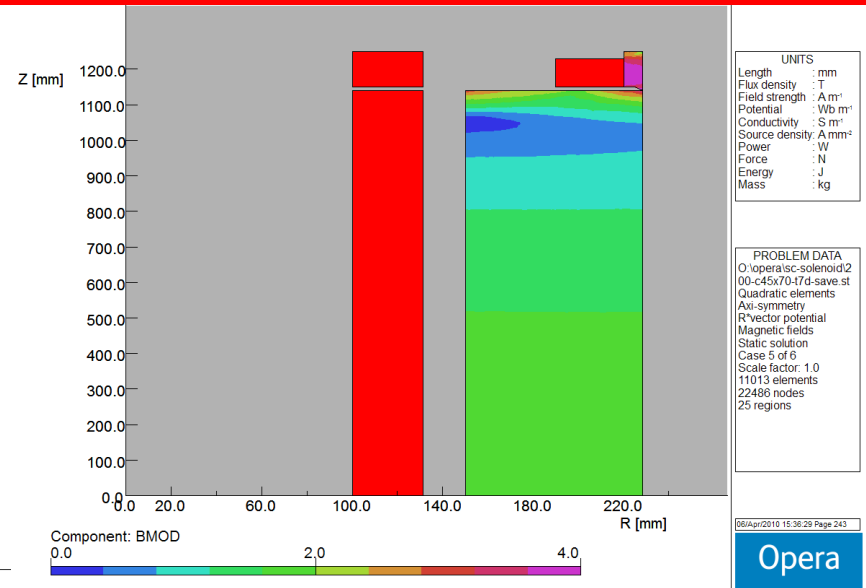
UNITS	
Length	: mm
Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻¹
Conductivity	: S m ⁻¹
Source density	: A mm ⁻²
Power	: W
Force	: N
Energy	: J
Mass	: kg

PROBLEM DATA
O:\opera\sc-solenoid\2
00-c45x70-t7d-save1.st
Quadratic elements
Axi-symmetry
R^vector potential
Magnetic fields
Static solution
Case 5 of 6
Scale factor: 1.0
11013 elements
22486 nodes
25 regions

The layers of end coils should run in series to main coil to avoid uneven force distribution during quench

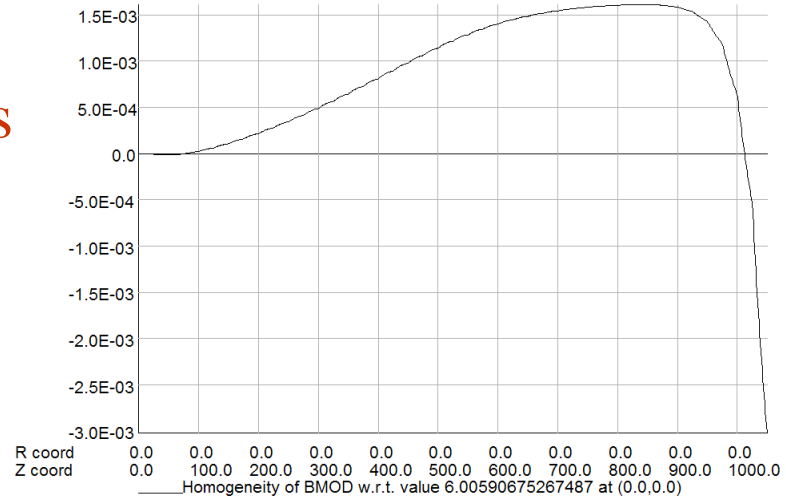
Field in the Iron Yoke

Field in yoke is primarily below 2T



Field Quality

It is possible to obtain field errors $< 5 \times 10^{-3}$ despite a little gap.

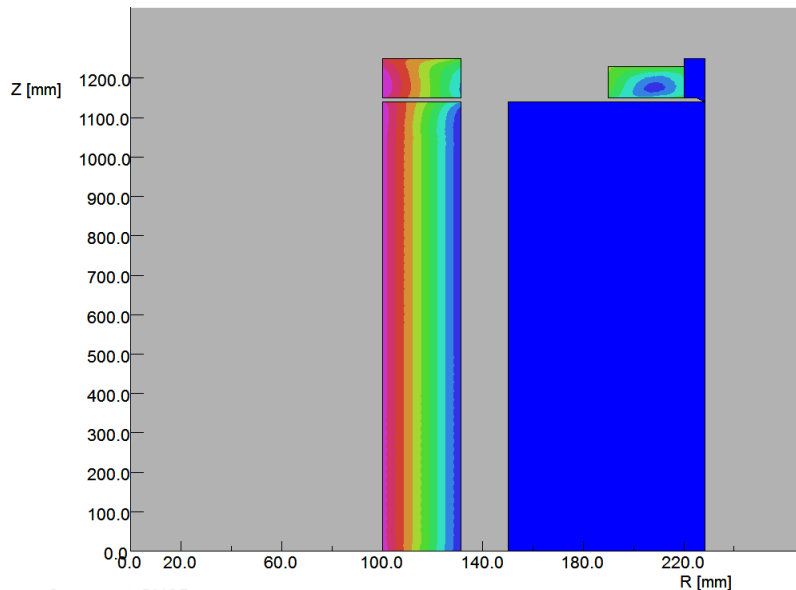


UNITS	
Length	: mm
Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻¹
Conductivity	: S m ⁻¹
Source density	: A mm ⁻²
Power	: W
Force	: N
Energy	: J
Mass	: kg

PROBLEM DATA
 O:\opera\sc-solenoid2
 00-c45x70-t7d-save.st
 Quadratic elements
 Axi-symmetry
 R^vector potential
 Magnetic fields
 Static solution
 Case 5 of 6
 Scale factor: 1.0
 11013 elements
 22486 nodes
 25 regions

06/Apr/2010 14:06:32 Page 219

Opera



UNITS	
Length	: mm
Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻¹
Conductivity	: S m ⁻¹
Source density	: A mm ⁻²
Power	: W
Force	: N
Energy	: J
Mass	: kg

PROBLEM DATA
 O:\opera\sc-solenoid2
 00-c45x70-t7d-save.st
 Quadratic elements
 Axi-symmetry
 R^vector potential
 Magnetic fields
 Static solution
 Case 5 of 6
 Scale factor: 1.0
 11013 elements
 22486 nodes
 25 regions

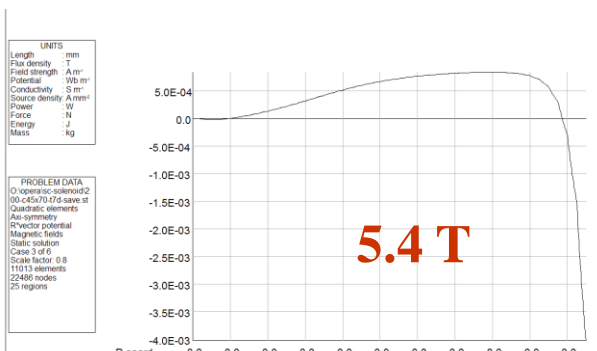
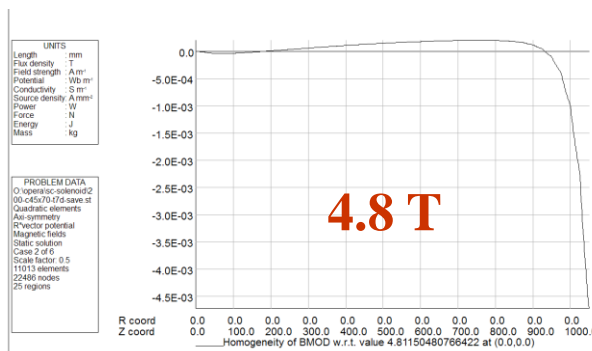
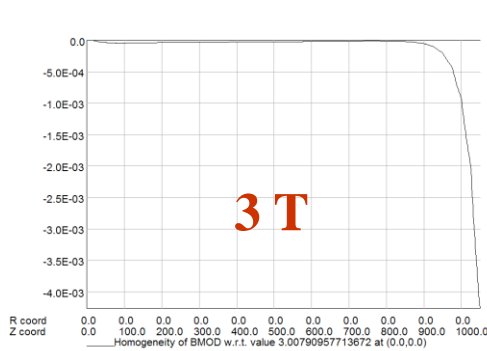
06/Apr/2010 15:40:57 Page 245

Opera

Component: BMOD
 0.013729206 3.134696805 6.255664403

Field Errors at Different Fields

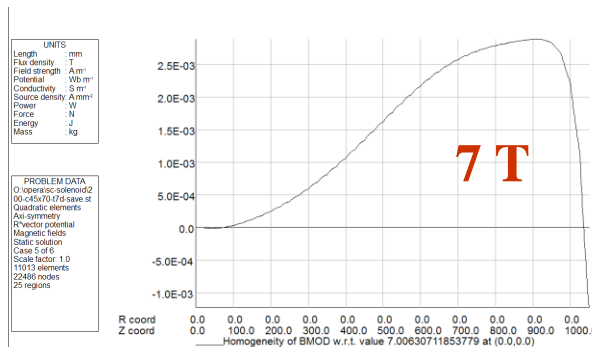
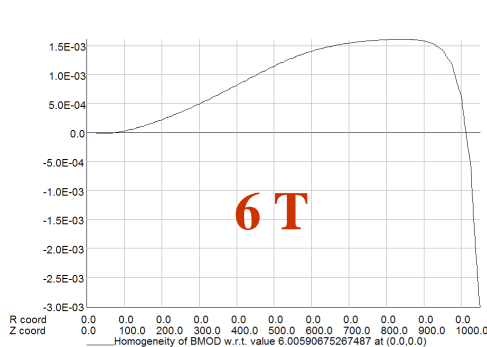
- Proof of principle design to show relative errors $< 10^{-3}$
- Relative field errors are plotted from center to 1050 mm axially



Opera

Opera

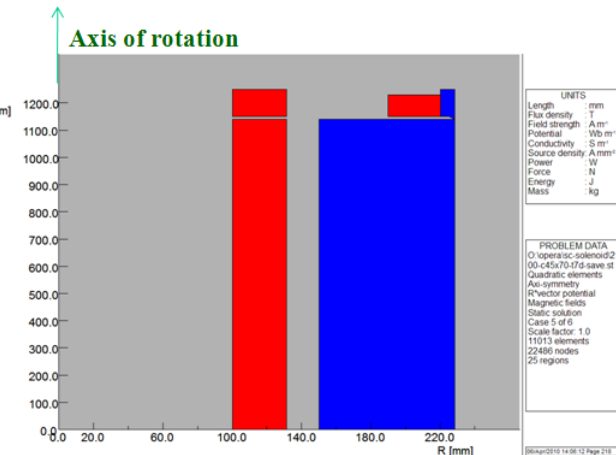
Opera



Opera

Opera

Opera



Summary

- Work in progress
- The design is in reasonable stage to move forward – no show stoppers
- It is possible to obtain >0.3 T field with superconducting coil inside the coldmass.