

Design of Q1BpF with Q1eF for 4K Operation

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BROOKHAVEN
NATIONAL LABORATORY

a passion for discovery

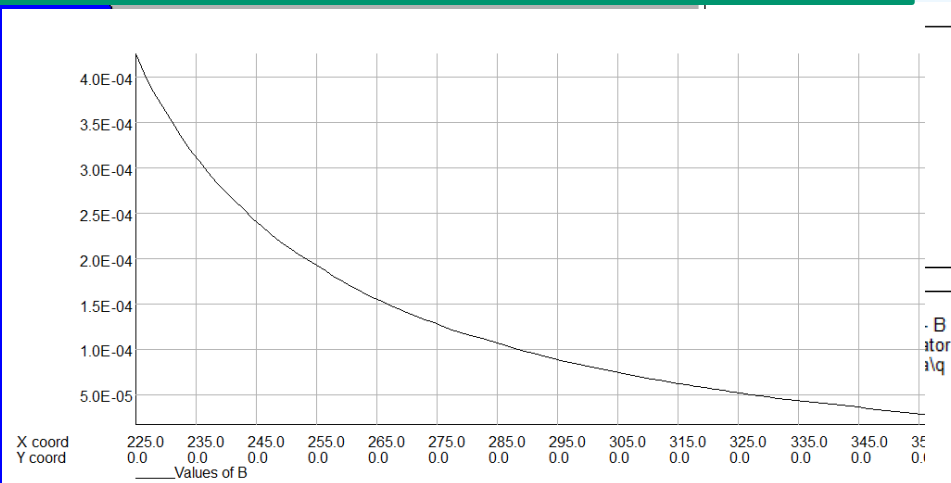
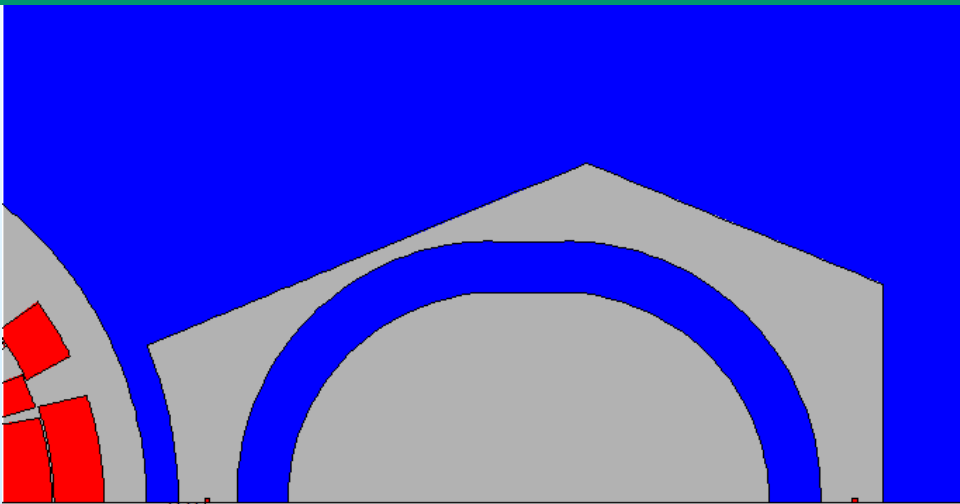
July 28, 2020

Overview

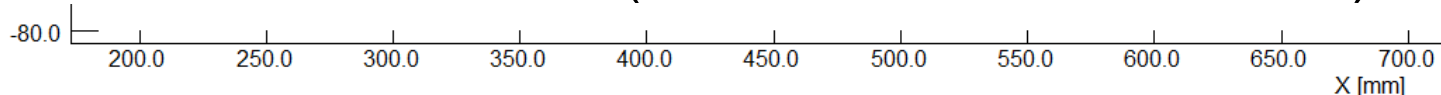
- **Goal: Check and optimize the design of Q1BpF with Q1eF to allow 4K operation**
- **Earlier we found a solution for Q2BpF 4 K operation without the introduction of Q1eF**
- **The addition of Q1eF may force yoke at the critical place more into saturation, possibly generating cross-talk induced errors between Q2BpF and Q1eF**
- **Several cases examined; only one each of above will be presented**
- **Next task?**

Shielding Solution that Worked in Q1BpF (in the absence of Q1eF)

Path of flux lines navigated with cutout in yoke and small coils on the two side of yoke over e-beam region added to further navigate flux lines (and reduce saturation) to significantly reduce field in the e-beam region



Hole @ $x = 288.3$ mm to 312.5 mm (with flat-top)
 Radius of hole = 83 mm (63 mm for electron beam)

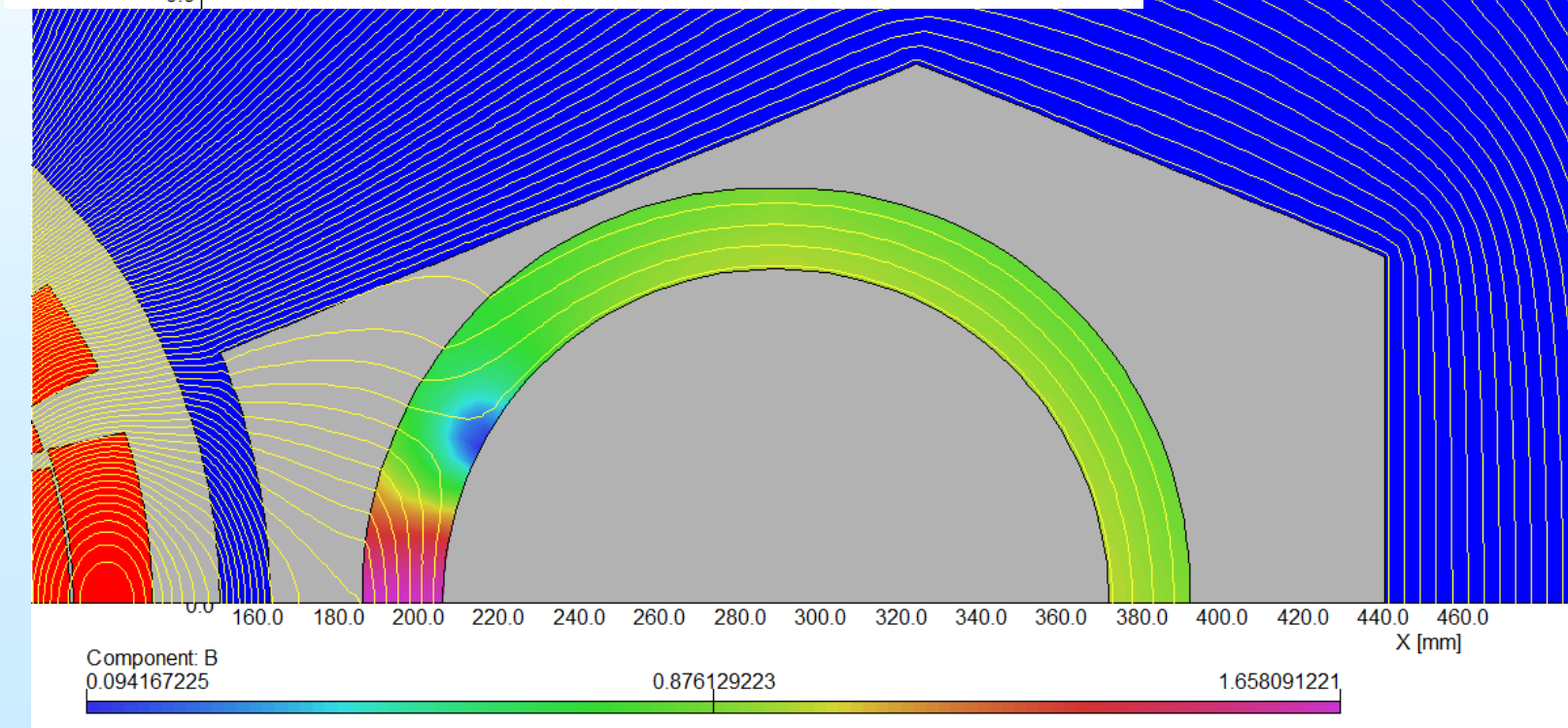
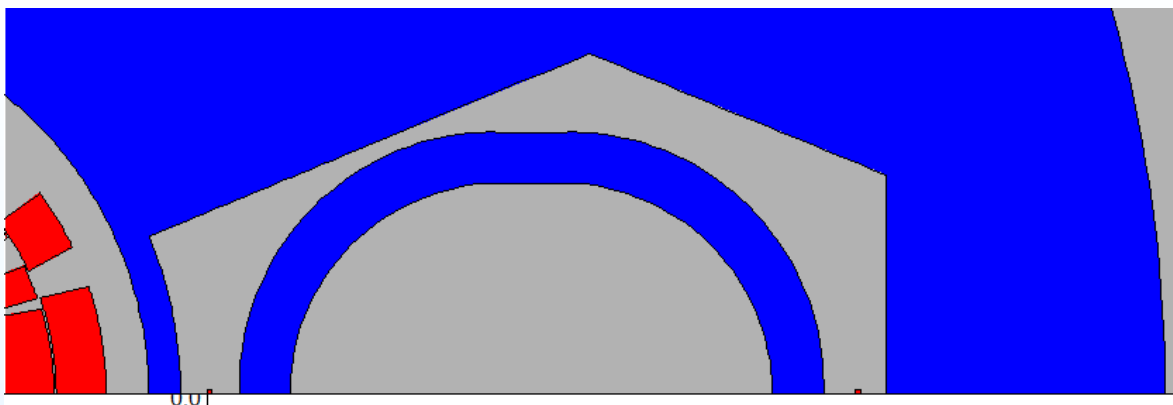


82 regions

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Q1BpF with Q1eF (need to remove flat-top)

Flat-top creates non-allowed harmonics and takes away iron from the return yoke. therefore, it is removed for inserting Q1eF (see below)

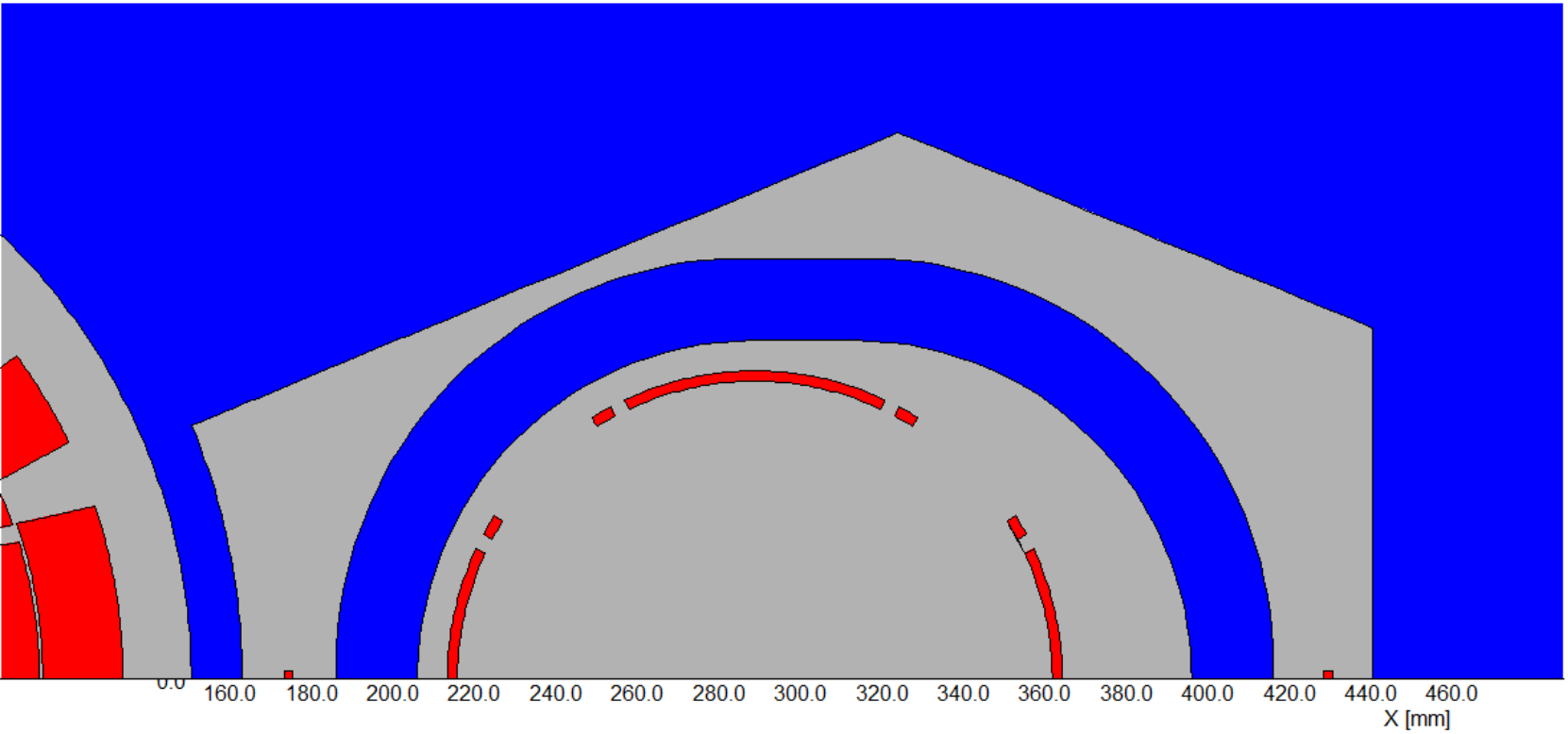


UNITS	
Length	: mm
Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻¹
Conductivity	: S m ⁻¹
Source density	: A mm ⁻²
Power	: W
Force	: N
Energy	: J
Mass	: kg

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Linear elements	
XY symmetry	
Vector potential	
Magnetic fields	
Static solution	
Case 2 of 2	
Scale factor: 2.4	
91805 elements	
46250 nodes	
96 regions	



**Q1BpF (Q1eF in flat-top yoke
 NOT GOOD)**



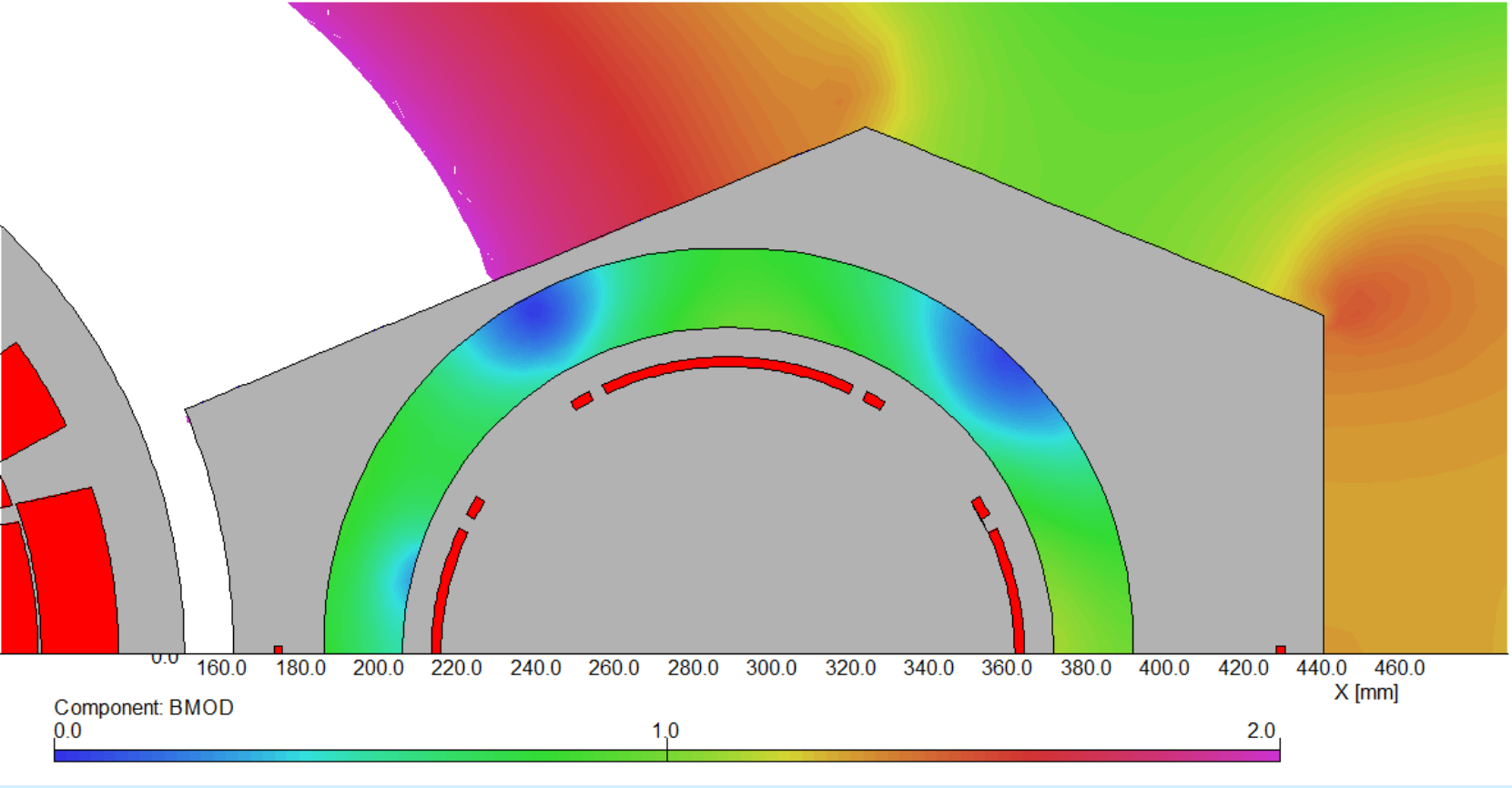
UNITS

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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

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 Linear elements
 XY symmetry
 Vector potential
 Magnetic fields
 Static solution
 Case 2 of 2
 Scale factor: 2.4
 92805 elements
 46758 nodes
 96 regions



Q1BpF (Q1eF with one polarity)



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

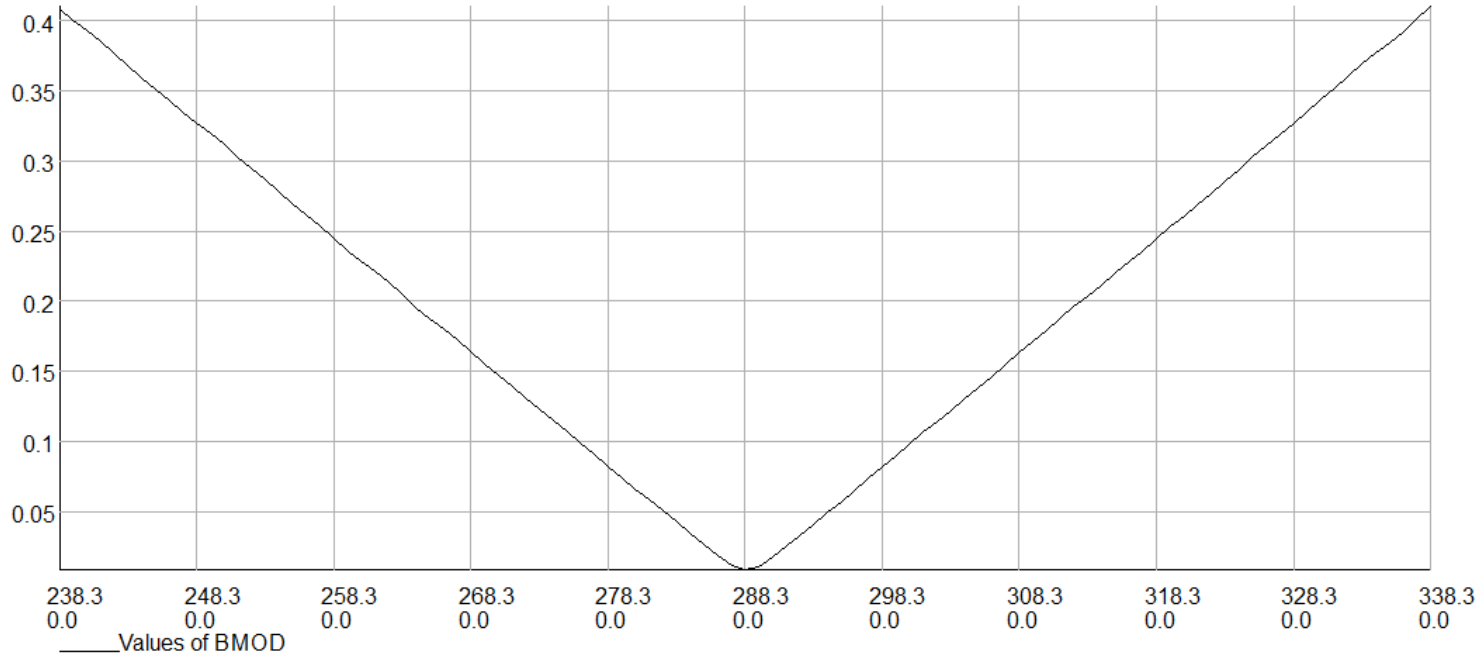
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 Linear elements
 XY symmetry
 Vector potential
 Magnetic fields
 Static solution
 Case 2 of 2
 Scale factor: 2.4
 91711 elements
 46211 nodes
 96 regions

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Looks good as iron providing the shielding is not saturated

Q1BpF (Q1eF with one polarity)



UNITS

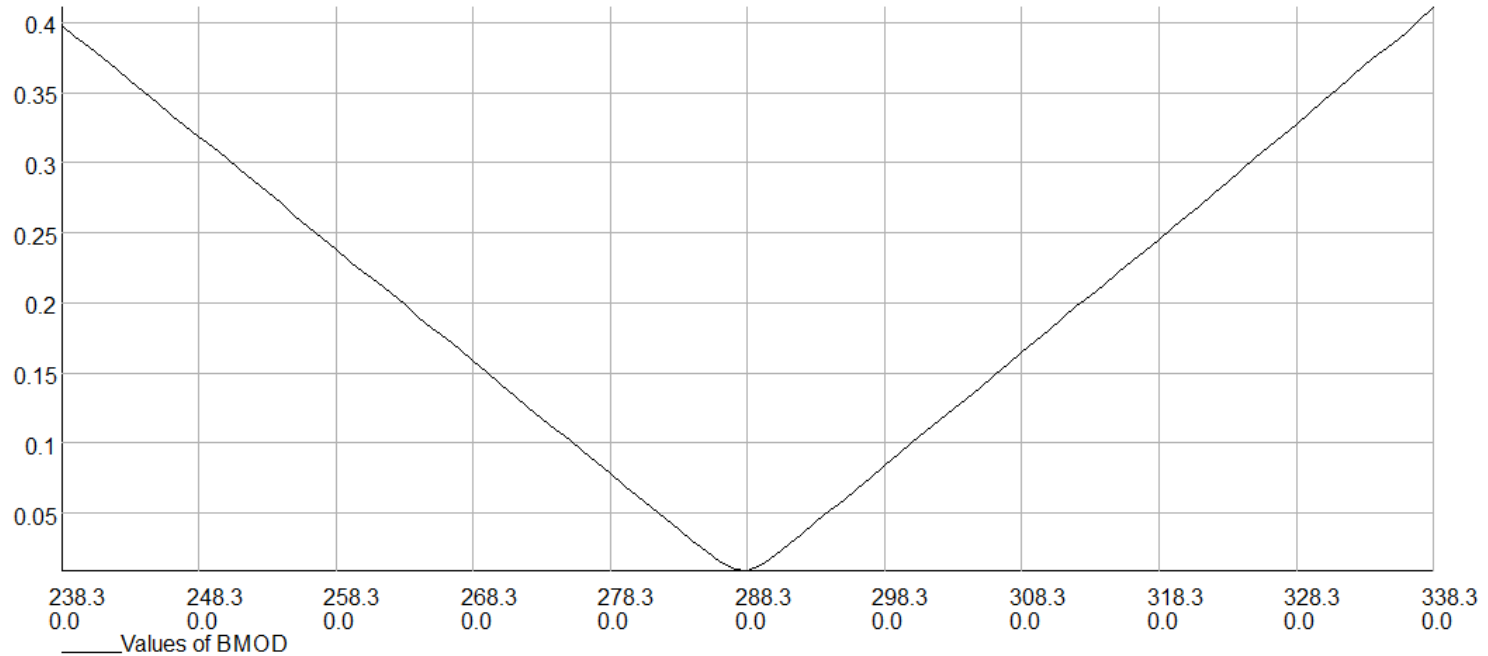
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Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻¹
Conductivity	: S m ⁻¹
Source density	: A mm ⁻²
Power	: W
Force	: N
Energy	: J
Mass	: kg

MODEL DATA
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 Linear elements
 XY symmetry
 Vector potential
 Magnetic fields
 Static solution
 Case 2 of 2
 Scale factor: 2.4
 91711 elements
 46211 nodes
 96 regions



Looks good as gradient is symmetric around the center of Q1eF (x=288.3)

Q1BpF (Q1eF with opposite polarity)



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

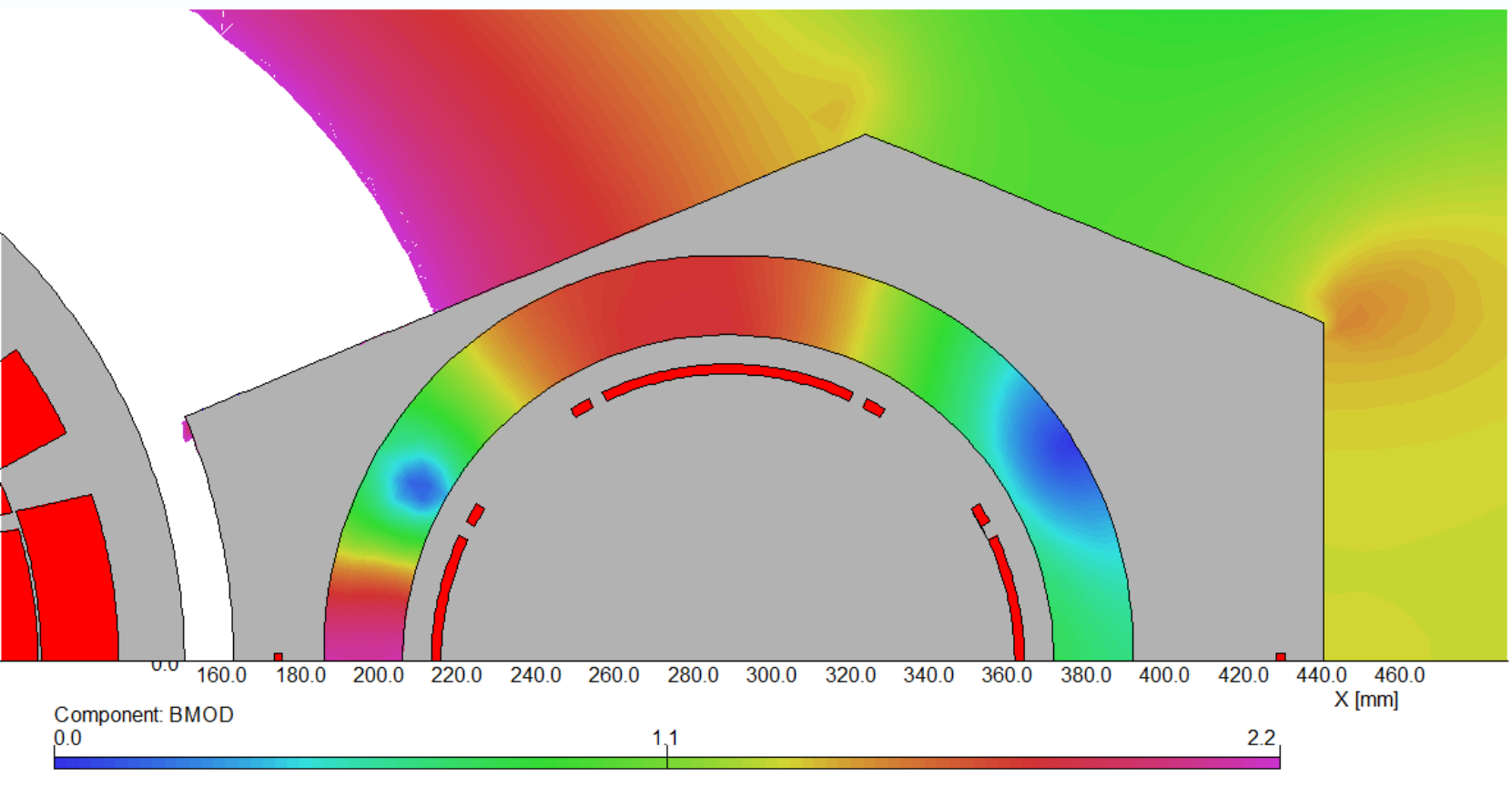
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 Linear elements
 XY symmetry
 Vector potential
 Magnetic fields
 Static solution
 Case 2 of 2
 Scale factor: 2.4
 91711 elements
 46211 nodes
 96 regions

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Does NOT look good as gradient is not symmetric around the center of Q1eF

Q1BpF (Q1eF with opposite polarity)



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

MODEL DATA
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 Linear elements
 XY symmetry
 Vector potential
 Magnetic fields
 Static solution
 Case 2 of 2
 Scale factor: 2.4
 91711 elements
 46211 nodes
 96 regions

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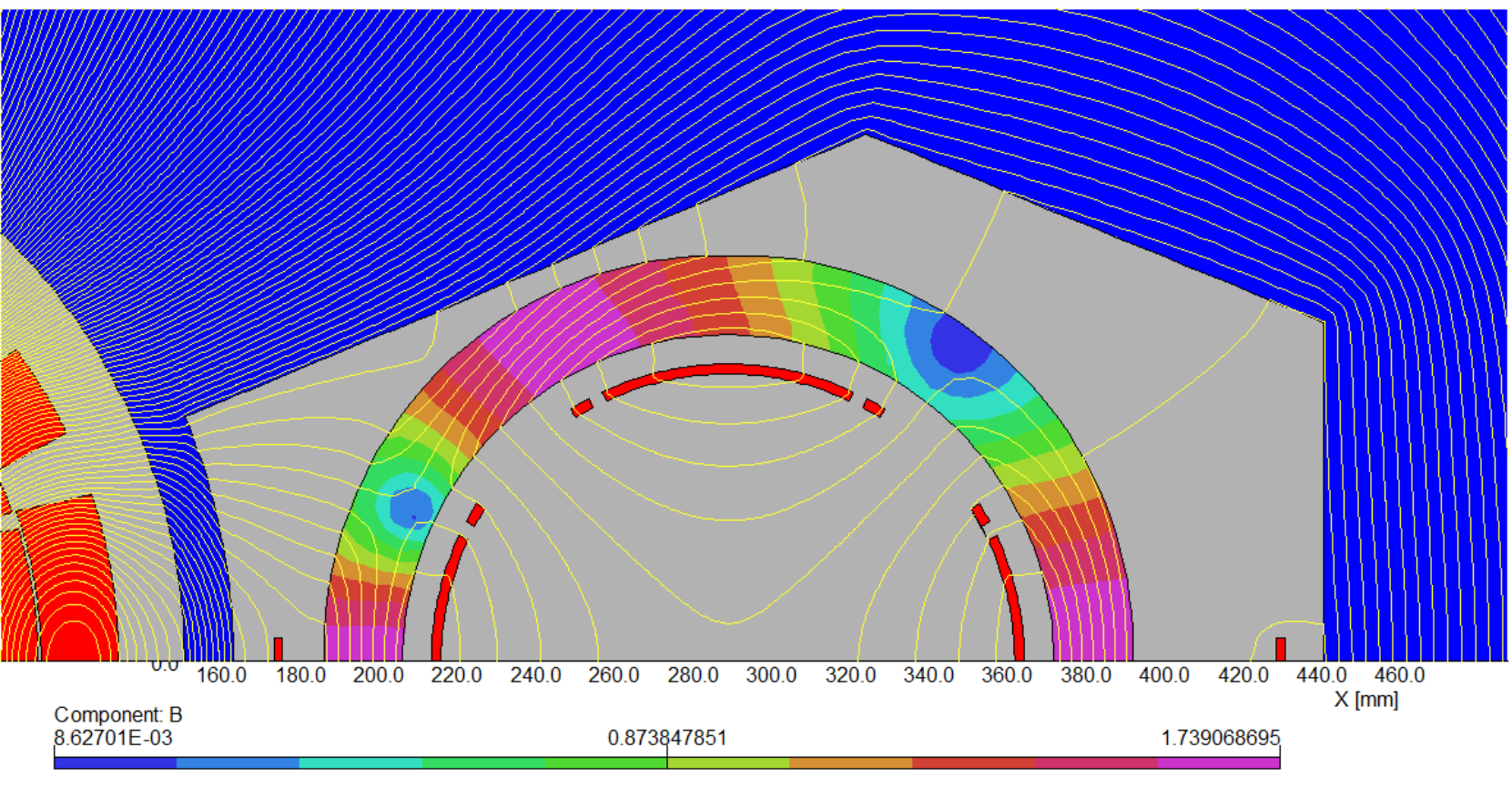


Does not look good as the iron providing the shielding is highly saturated on one side (>2T)

Solution

Use the technique that
we recently invented
(strengthen the coils
around the iron to
reduce saturation)

Q1BpF (Q1eF with opposite polarity AND stronger control coils)



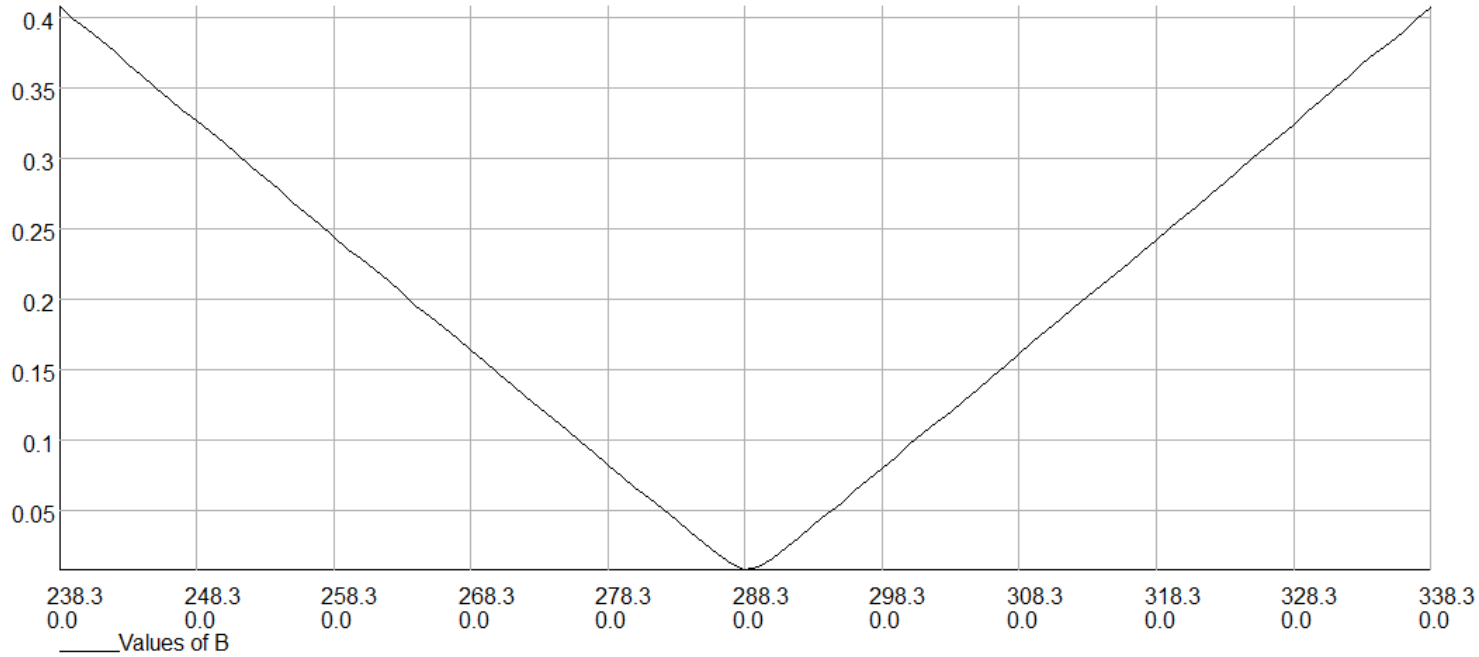
UNITS	
Length	: mm
Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻¹
Conductivity	: S m ⁻¹
Source density	: A mm ⁻²
Power	: W
Force	: N
Energy	: J
Mass	: kg

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Linear elements	
XY symmetry	
Vector potential	
Magnetic fields	
Static solution	
Case 2 of 2	
Scale factor: 2.4	
91725 elements	
46218 nodes	
96 regions	



Looks better as the iron providing the shielding is less saturated (1.7 T rather than over 2 T)

Q1BpF (Q1eF with opposite polarity AND stronger control coils)



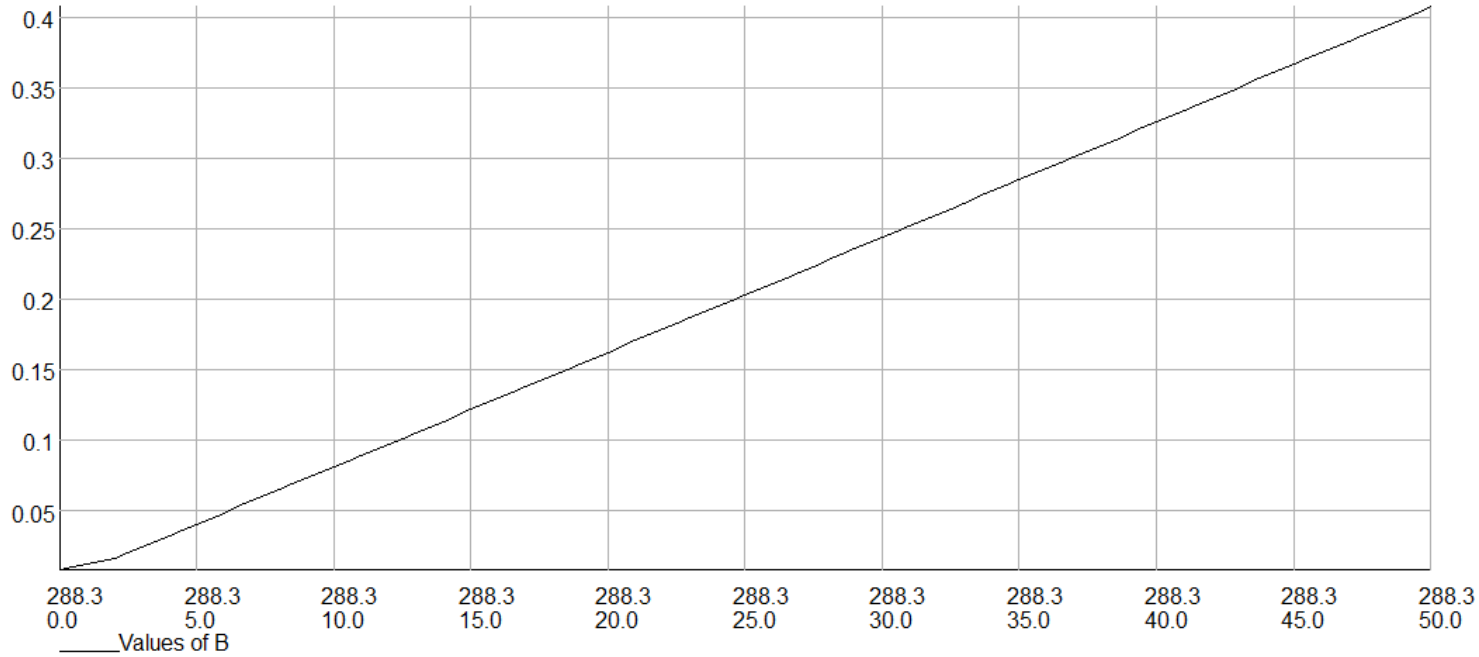
UNITS	
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Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻¹
Conductivity	: S m ⁻¹
Source density	: A mm ³
Power	: W
Force	: N
Energy	: J
Mass	: kg

MODEL DATA
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 Linear elements
 XY symmetry
 Vector potential
 Magnetic fields
 Static solution
 Case 2 of 2
 Scale factor: 2.4
 91725 elements
 46218 nodes
 96 regions



Still looks good as gradient is symmetric around the center of Q1eF (x=288.3)

Q1BpF (Q1eF with opposite polarity AND stronger control coils)



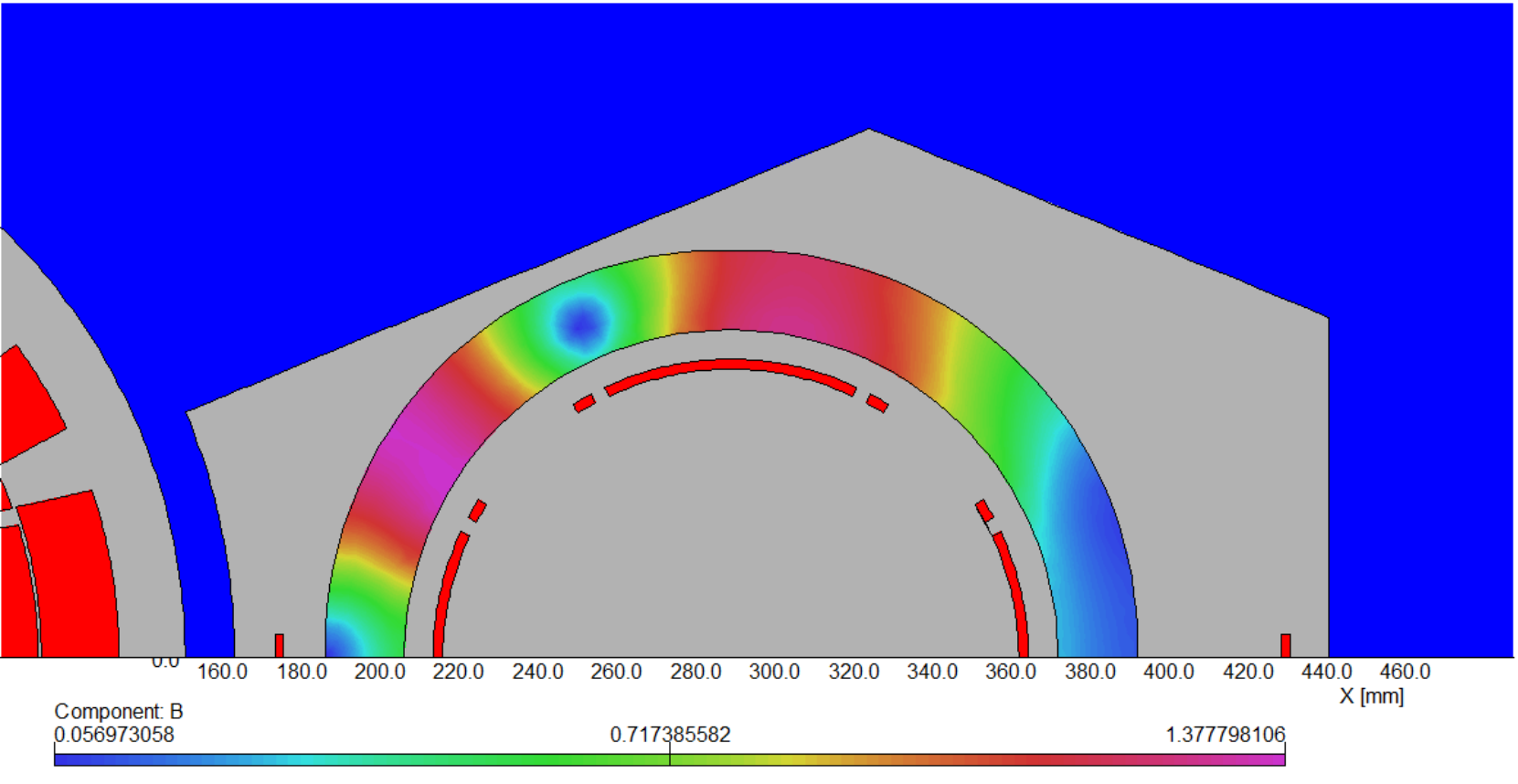
UNITS	
Length	: mm
Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻¹
Conductivity	: S m ⁻¹
Source density	: A mm ³
Power	: W
Force	: N
Energy	: J
Mass	: kg

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 Linear elements
 XY symmetry
 Vector potential
 Magnetic fields
 Static solution
 Case 2 of 2
 Scale factor: 2.4
 91725 elements
 46218 nodes
 96 regions



Field (gradient) on vertical axis looks good as well around the center of Q1eF (x=288.3)

Q1BpF (Q1eF with good polarity AND stronger control coils)



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

MODEL DATA

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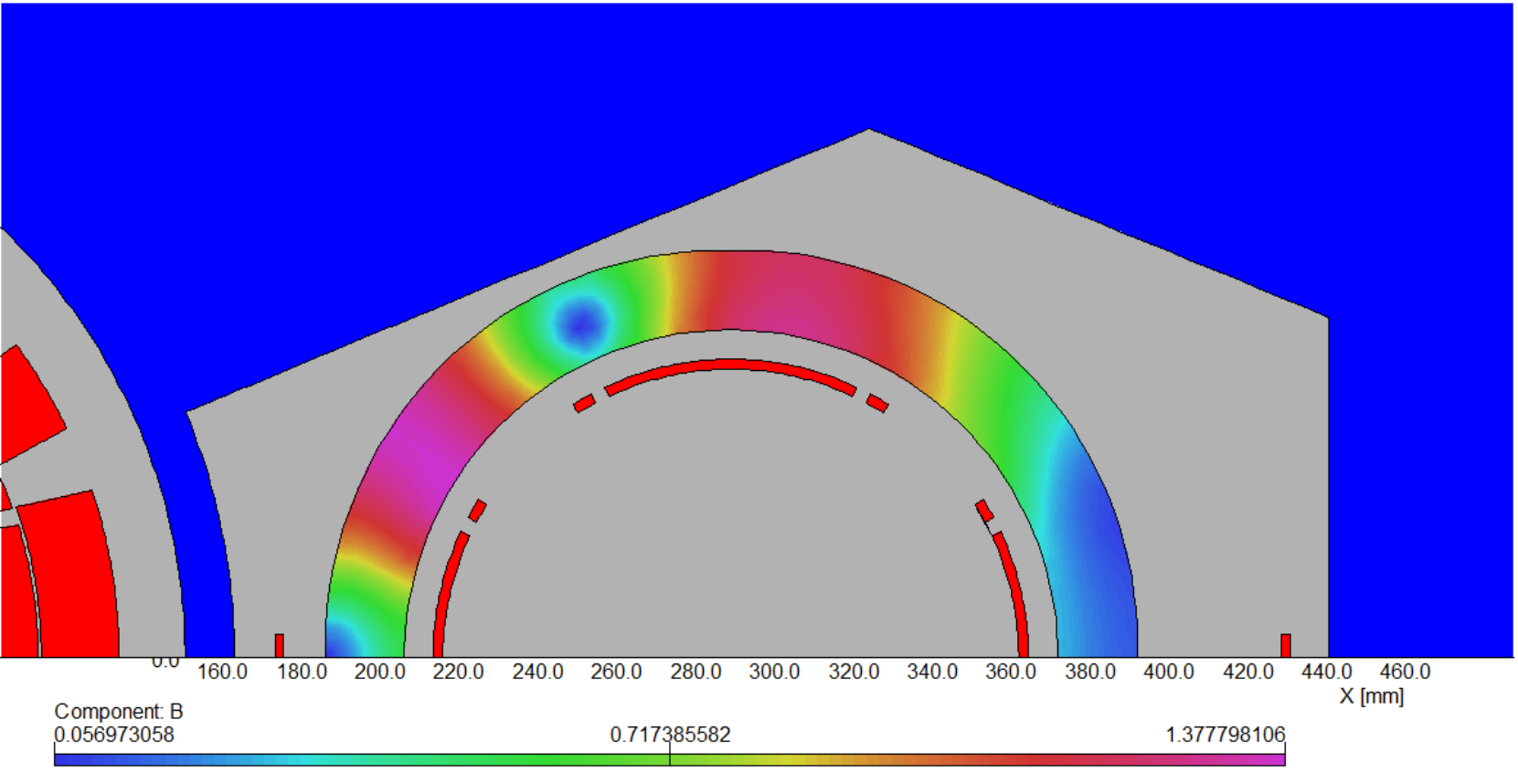
- Linear elements
- XY symmetry
- Vector potential
- Magnetic fields
- Static solution
- Case 2 of 2
- Scale factor: 2.4
- 91725 elements
- 46218 nodes
- 96 regions

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Looks good as the iron providing the shielding is less saturated (1.3 T)

Q1BpF (Q1eF with good polarity AND stronger control coils)



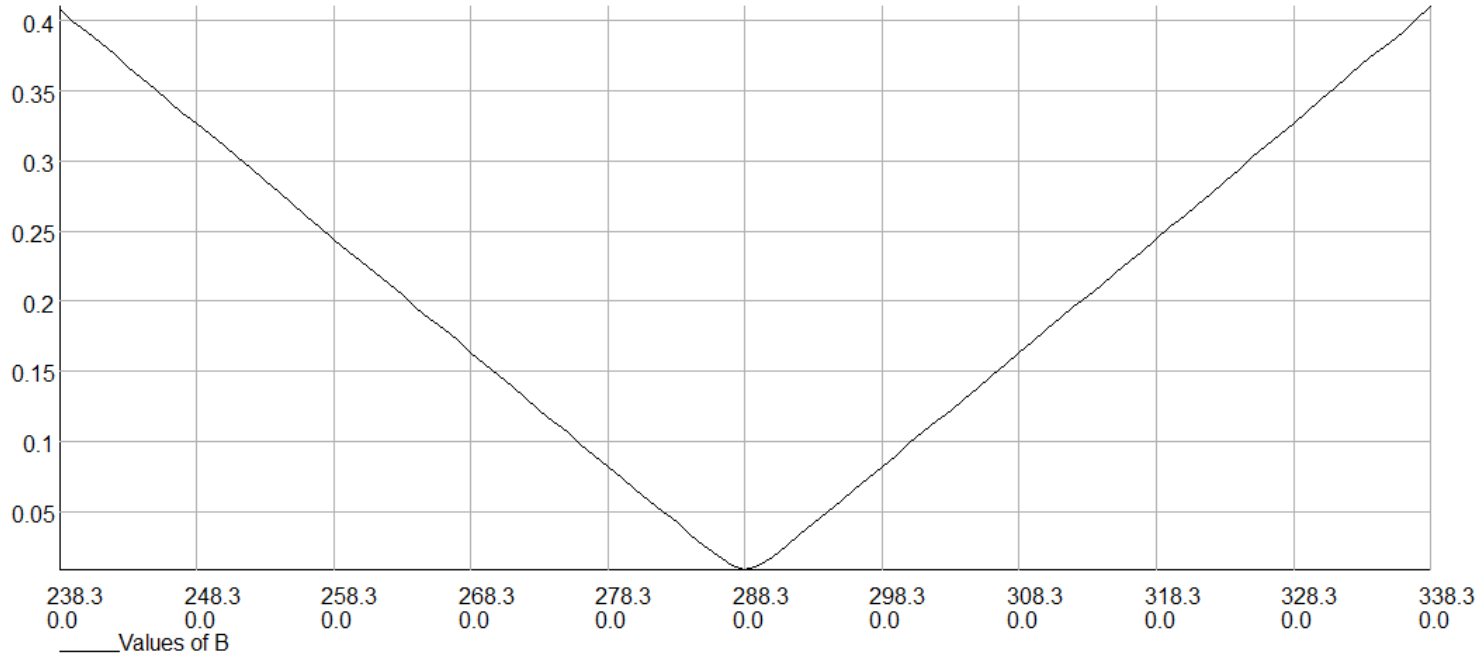
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Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻¹
Conductivity	: S m ⁻¹
Source density	: A mm ²
Power	: W
Force	: N
Energy	: J
Mass	: kg

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Q1BpF (Q1eF with good polarity AND stronger control coils)



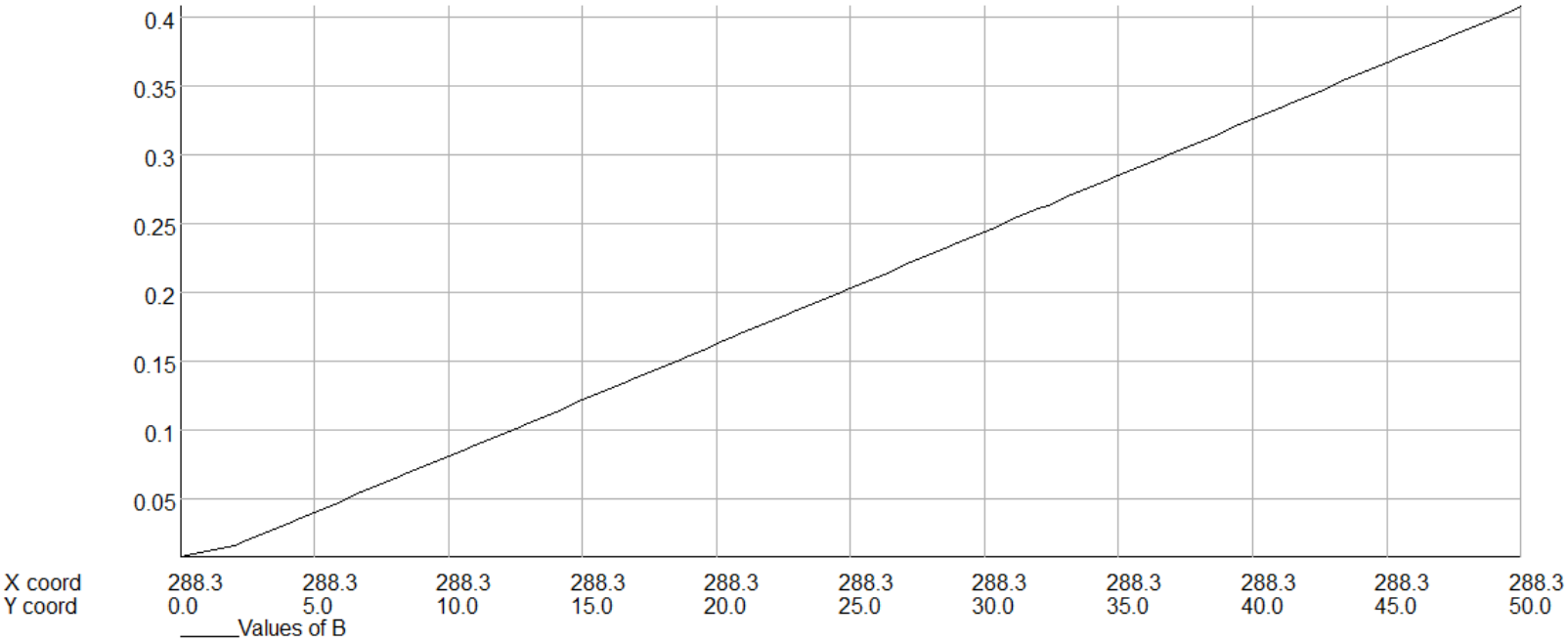
UNITS	
Length	: mm
Flux density	: T
Field strength	: A m ⁻¹
Potential	: Wb m ⁻¹
Conductivity	: S m ⁻¹
Source density	: A mm ²
Power	: W
Force	: N
Energy	: J
Mass	: kg

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Field (gradient) on vertical axis looks good as well around the center of Q1eF (x=288.3)

Q1BpF (Q1eF with good polarity AND stronger control coils)



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

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Field (gradient) on vertical axis looks good as well around the center of Q1eF (x=288.3)

Discussion and Conclusions

- **More detail analysis and further optimization needs to be performed; however, it appears that we have a solution.**
- **We are still good for 4 K operation**
- **Next task?**
 - **3d-design of above magnets?**
 - **Examine other magnets?**