Development of High Gradient Hybrid PMQ for Petra-IV

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HELMHOLTZ

DESY.

Outline

High gradient PMQ design

01 Specification

02 Magnetic Design

- Geometry and materials
- Magnetic Force
- Gradient tuning
- Temperature Compensation
- Pole shape optimization
- Fringe field reduction

03 Magnetic Correction

- Harmonic shim

04 Perspective

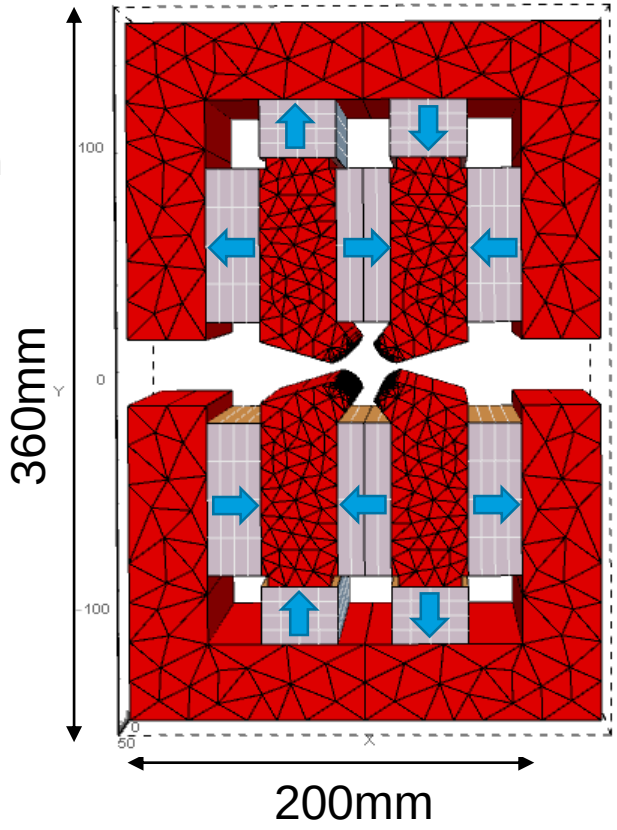
- Design Finalization
- Mechanical design
- Prototype

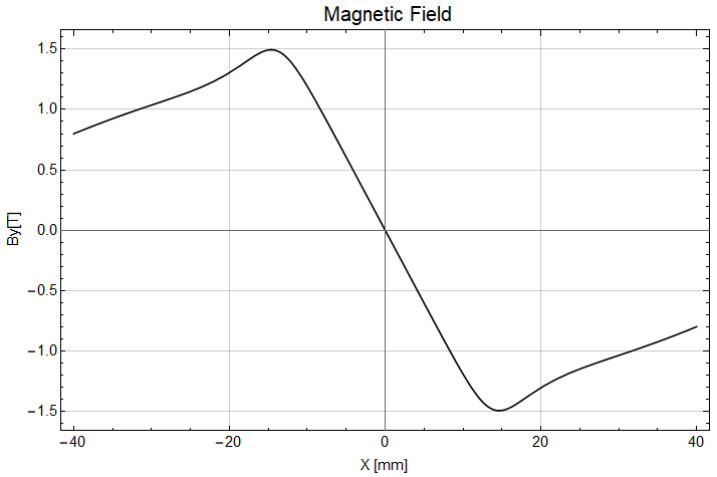
Specification and Preliminary Design

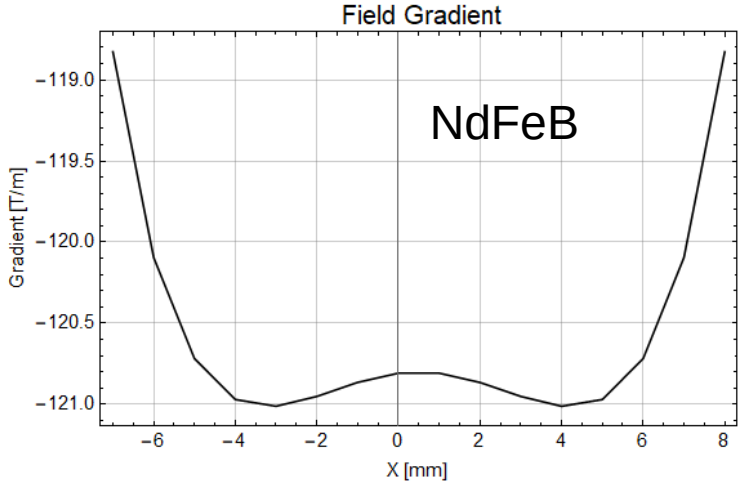
Specification for Petra IV PMQ

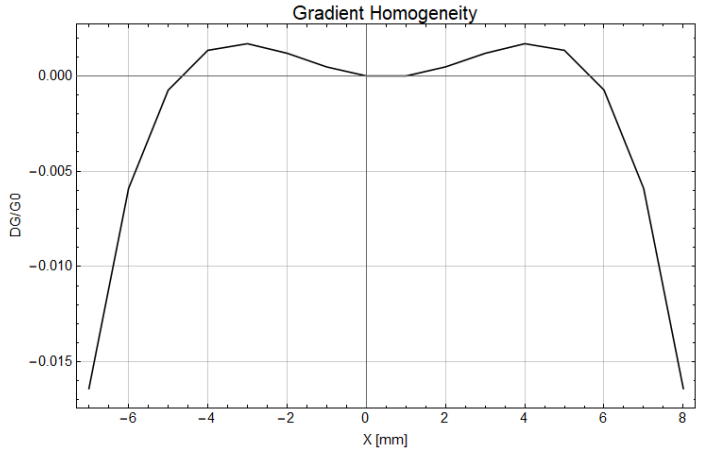
- Gradient: 120 T/m
- Gradient tuning: ~5 T/m
- Bore Radius: 11 mm
- GFR: +-6.5 mm
- DG/G0: 5.10^-4
- Length: 0.169 m
- Vertical gap: 8.8mm

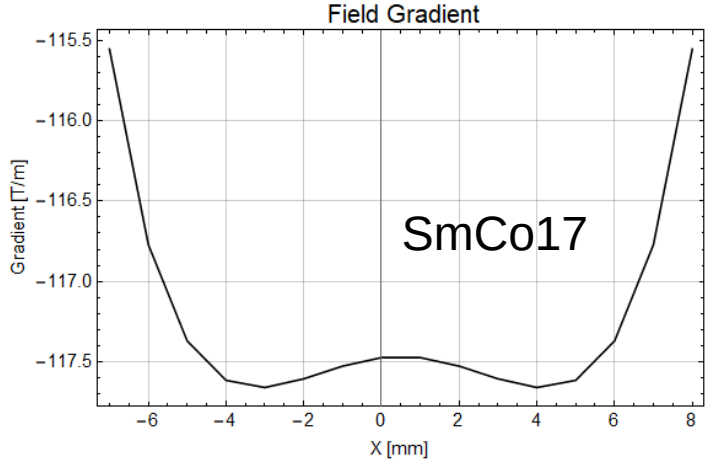
Radia model







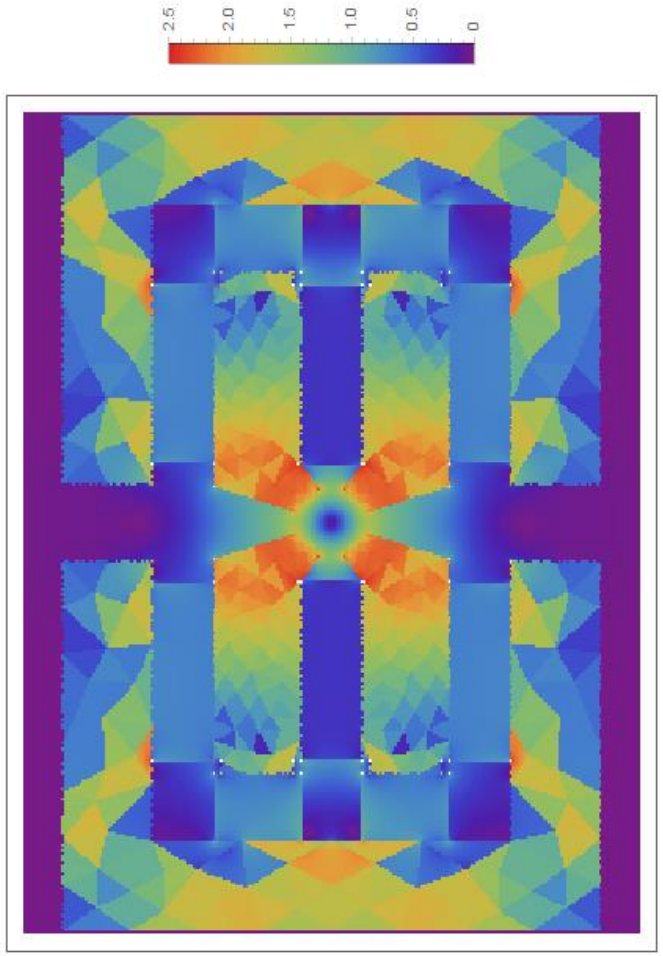


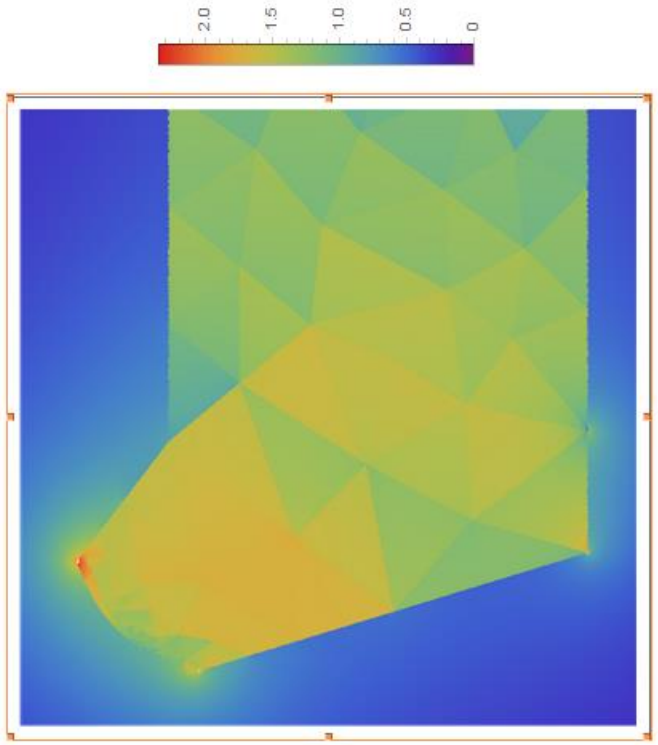


- Gradient: 117.5 T/m
- PM:SmCo17 Br=1.1T
- Iron ARMCO

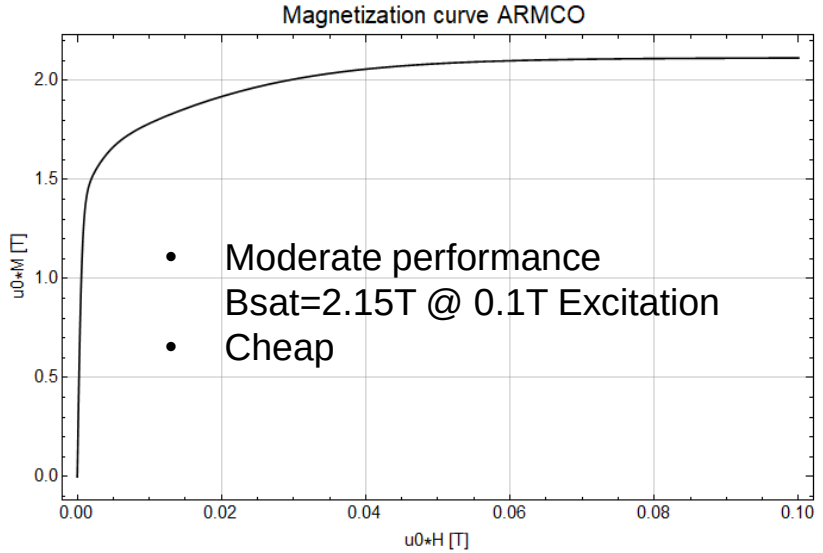
- Gradient: 120.8 T/m
- PM: NdFeB Br=1.25T
- Iron ARMCO

Specification and Preliminary Design

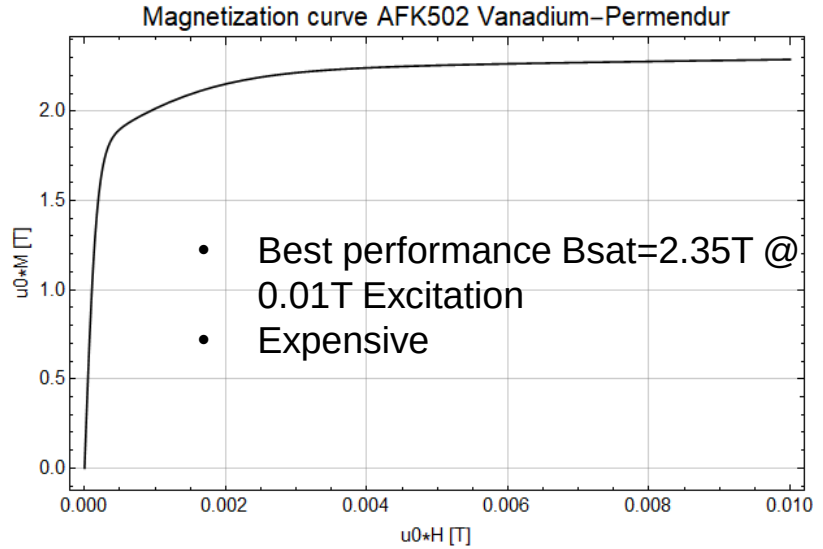




10 T/m Gradient gain using Vanadium Permendur Pole material (Vacoflux)

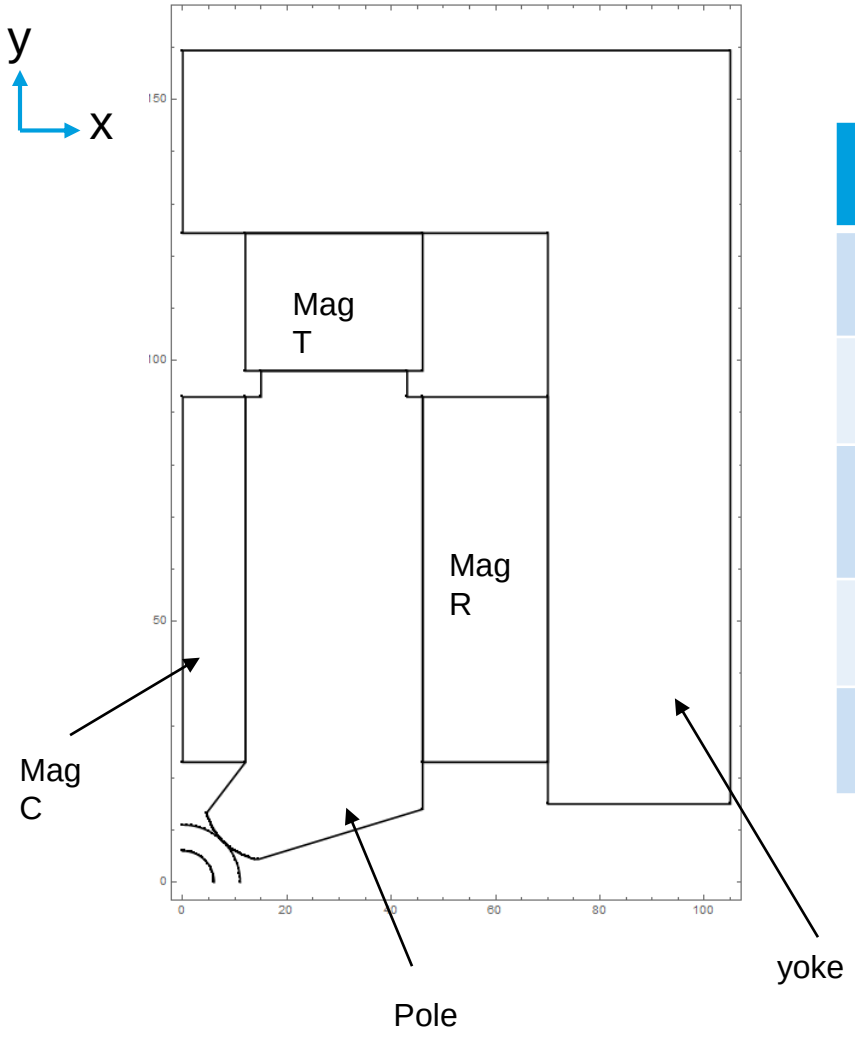


- Moderate performance Bsat=2.15T @ 0.1T Excitation
- Cheap



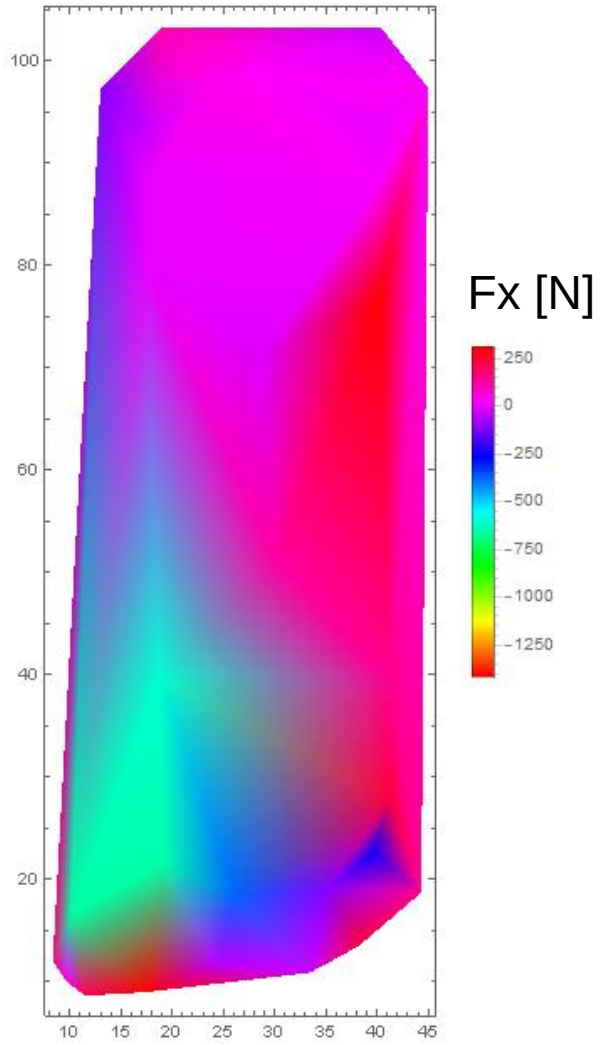
- Best performance Bsat=2.35T @ 0.01T Excitation
- Expensive

Magnetic Force



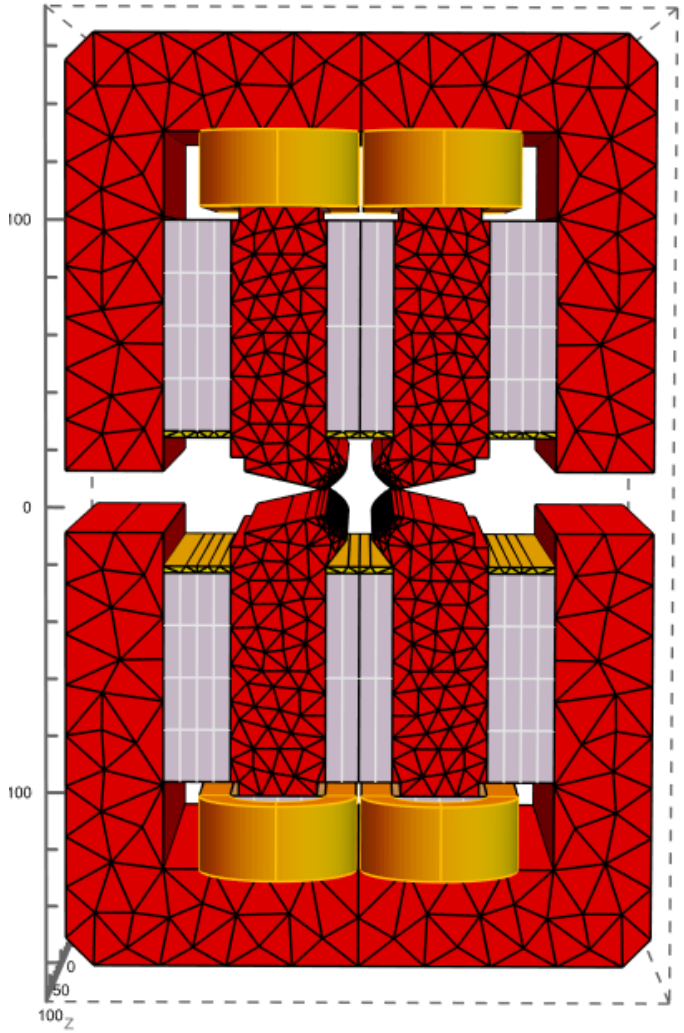
Name	Fx [N]	Fy [N]
Mag C	-594	-91
Mag R	551	59
Mag T	35	1240
Yoke	-300	-602
Pole	-1505	675

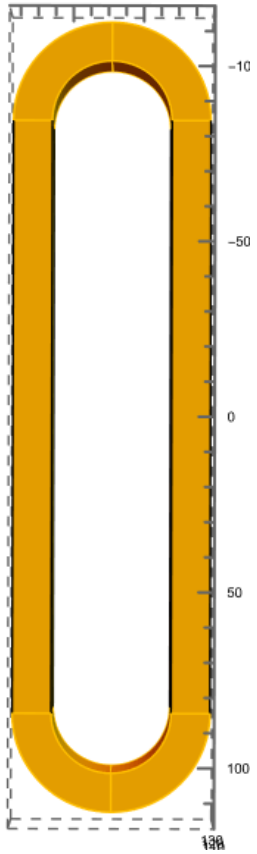
Pole Force (Fx) distribution



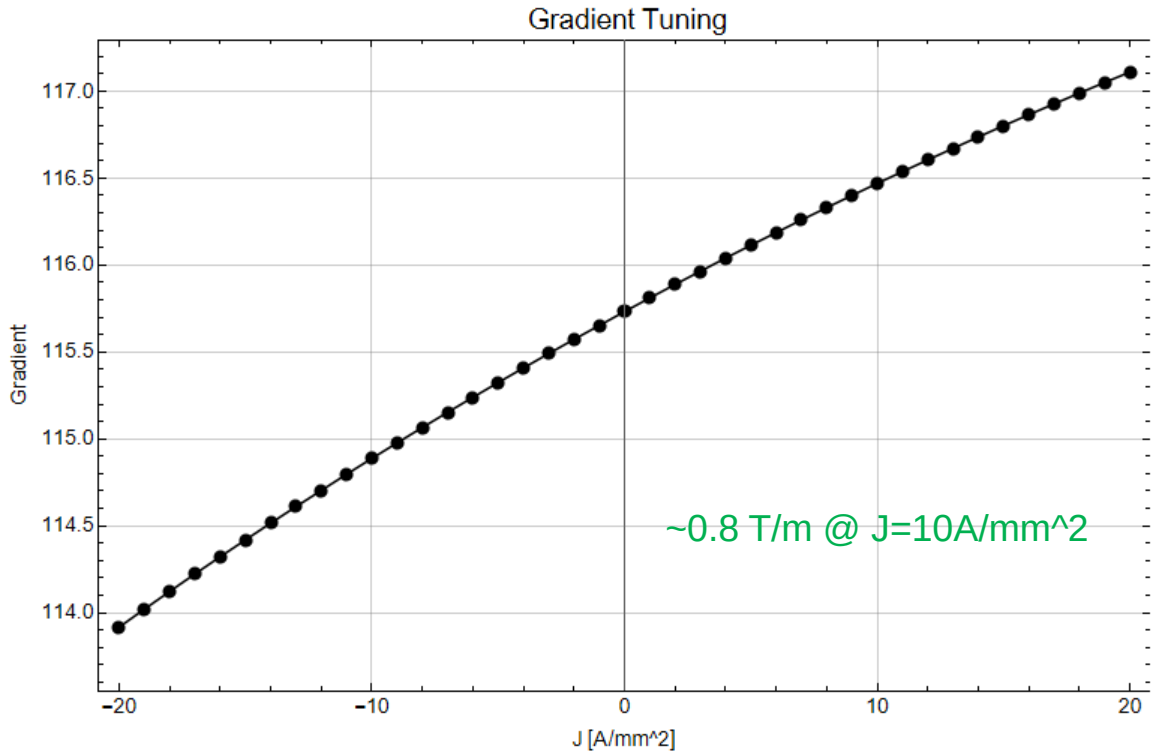
Gradient Tuning

Gradient Tuning with coils





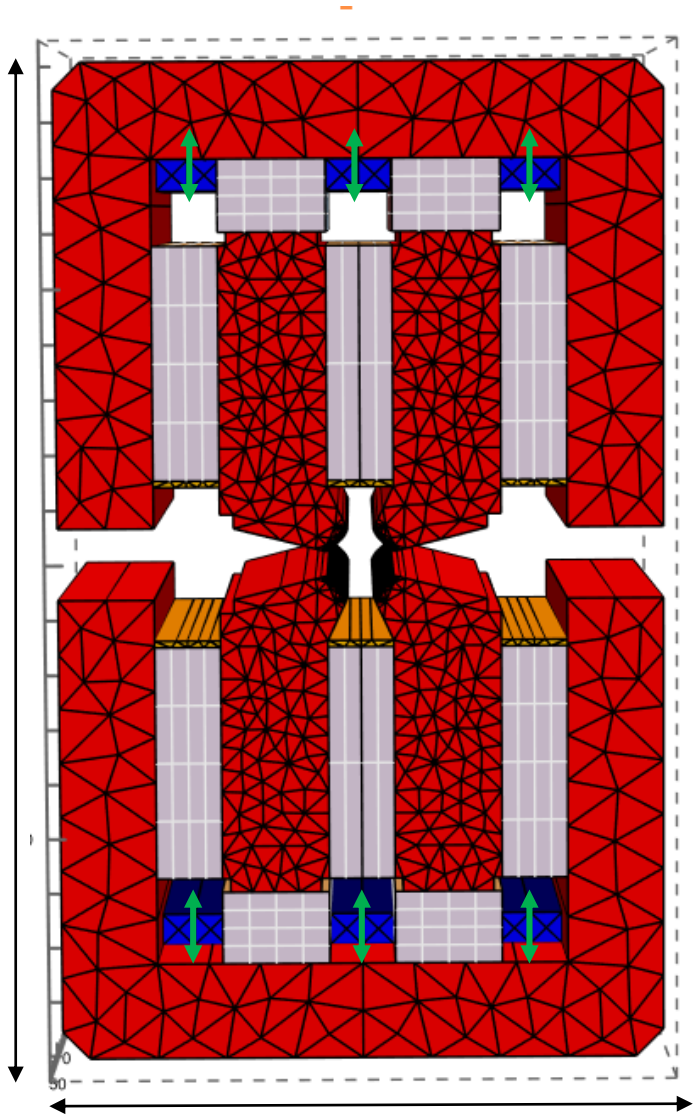
Tuning Coil

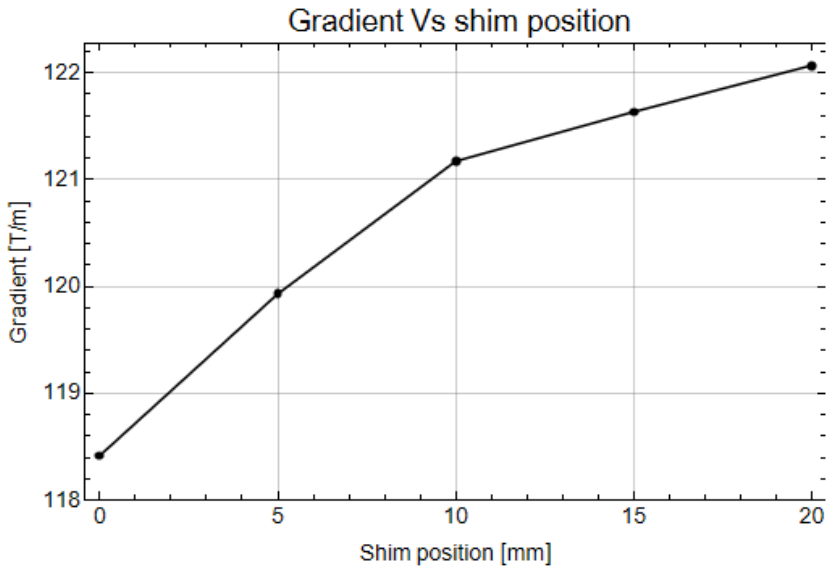


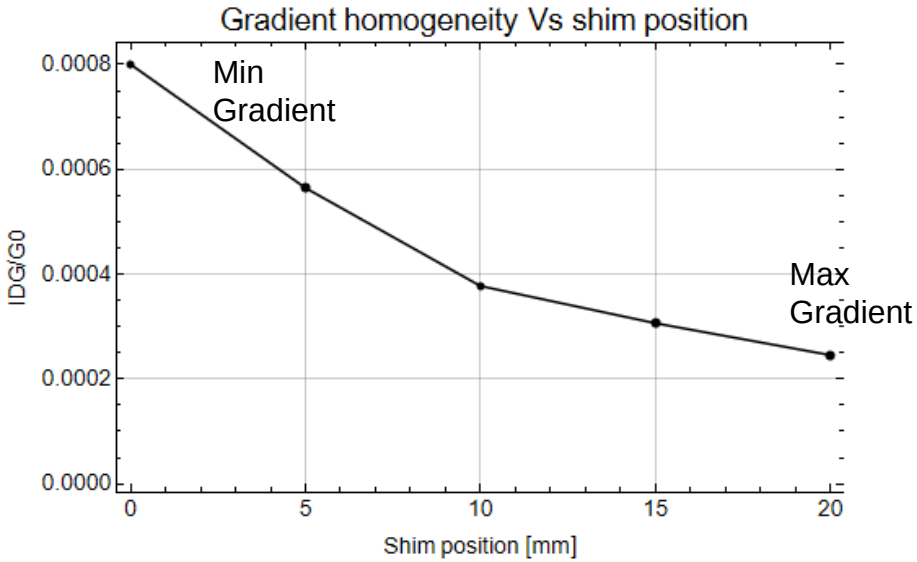
→ No efficient solution

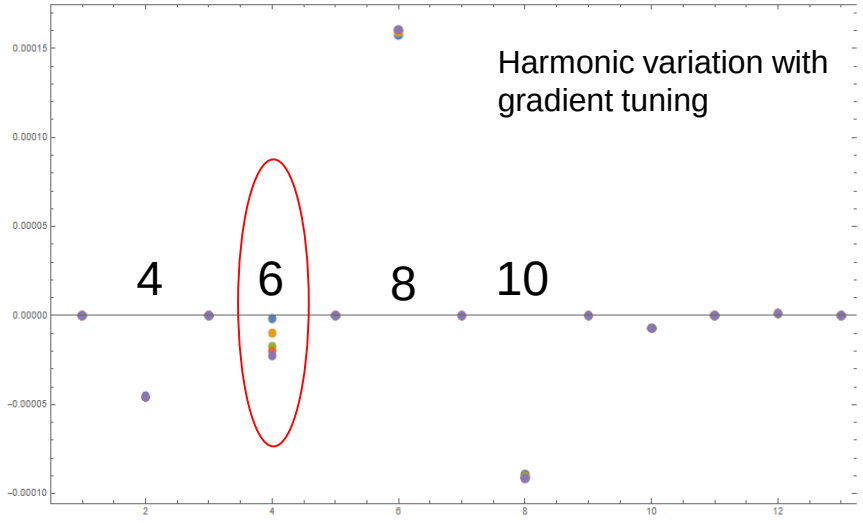
Gradient Tuning

Gradient Tuning with Shunt





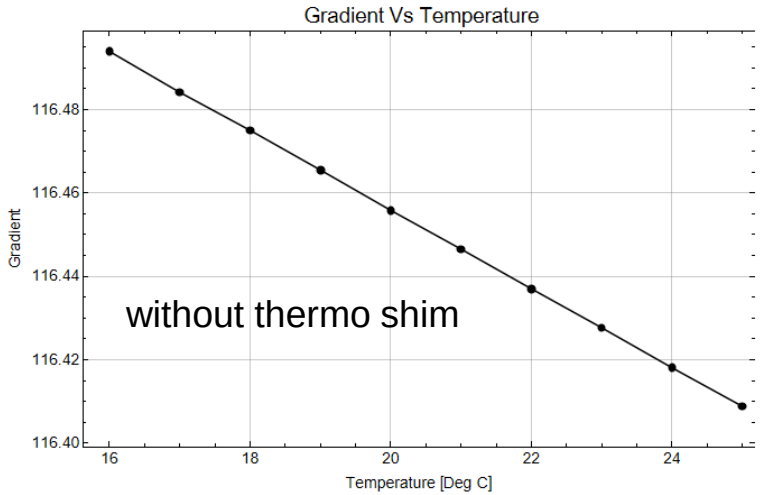


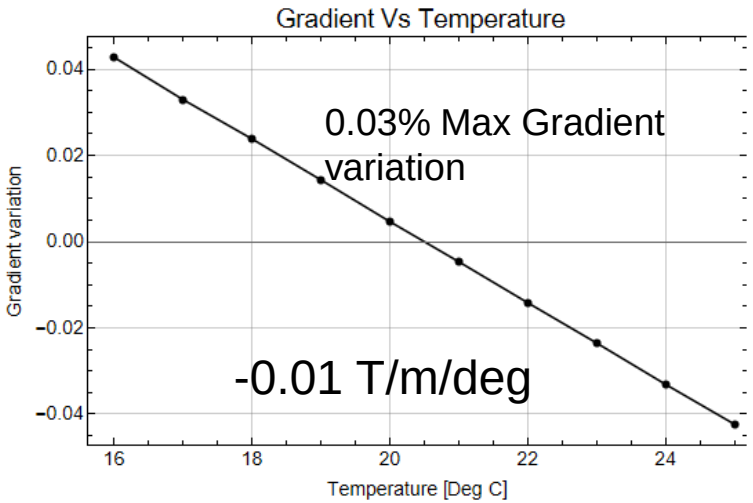


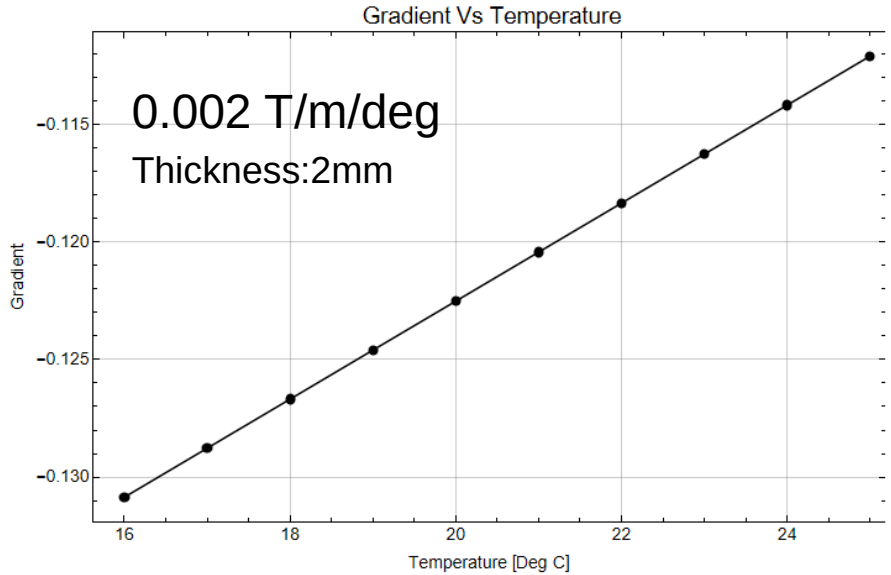
- Movable Iron shunt
- 5T/m gradient tuning range achievable
- Gradient homogeneity impact
- Required Correction of harmonic

Temperature compensation

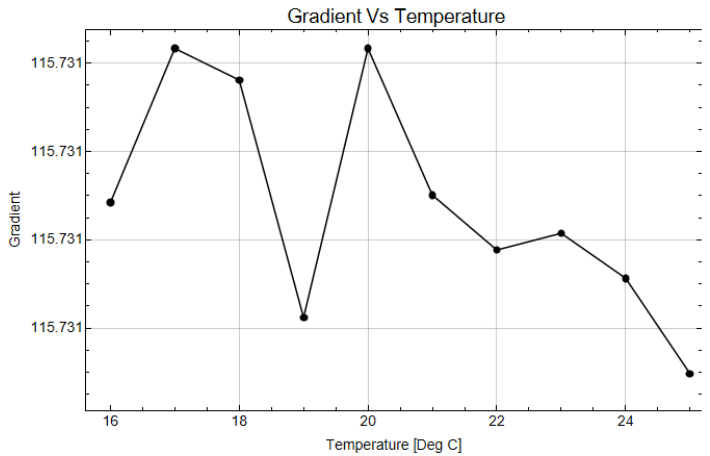
- Temperature coefficient PM SmCo17: -0.033 %/deg
- Temperature coefficient thermo shim(FeNi): -1.7 %/deg
- Thermal shim Thickness: 2mm

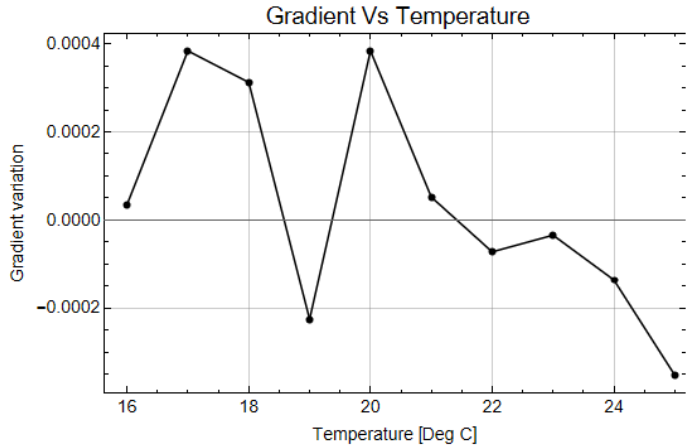




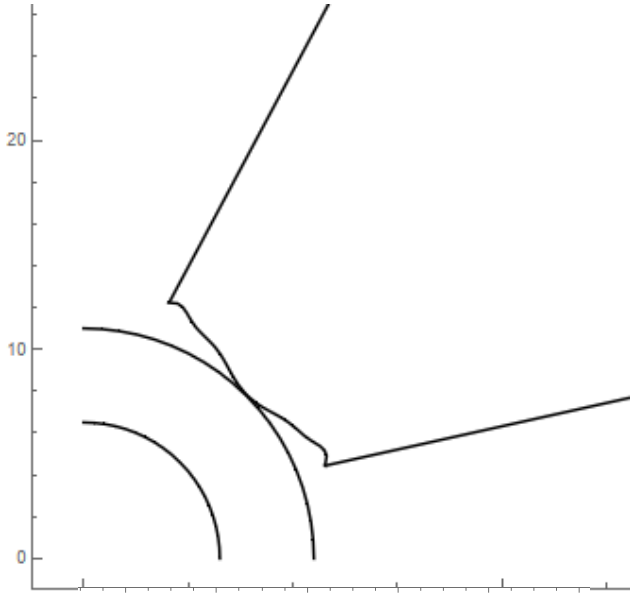


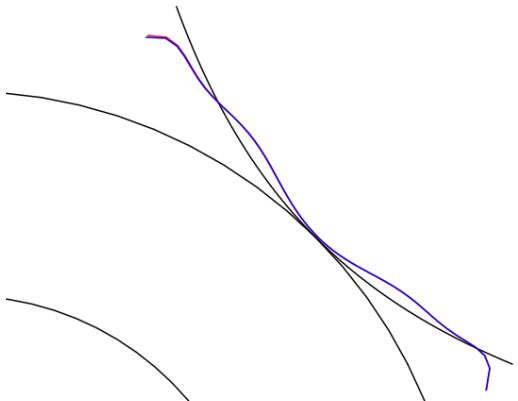
Correction (2.36mm thickness)



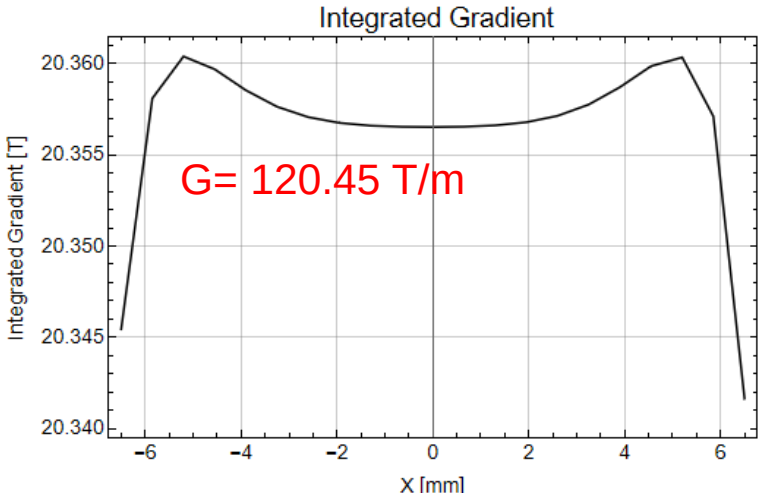


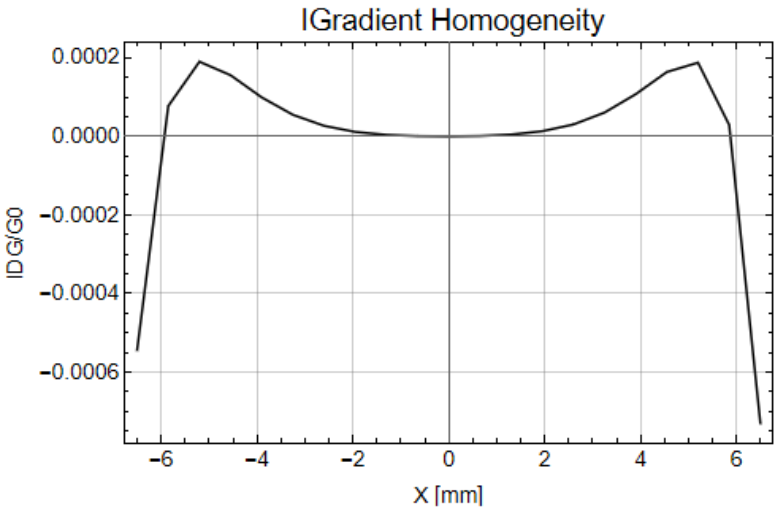
Pole Shape optimization (2D&3D)

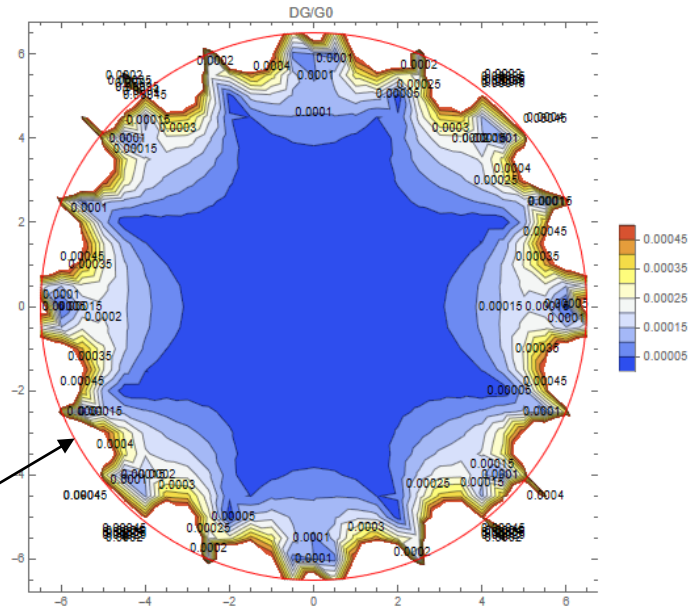




2D &3D shape -> tiny difference







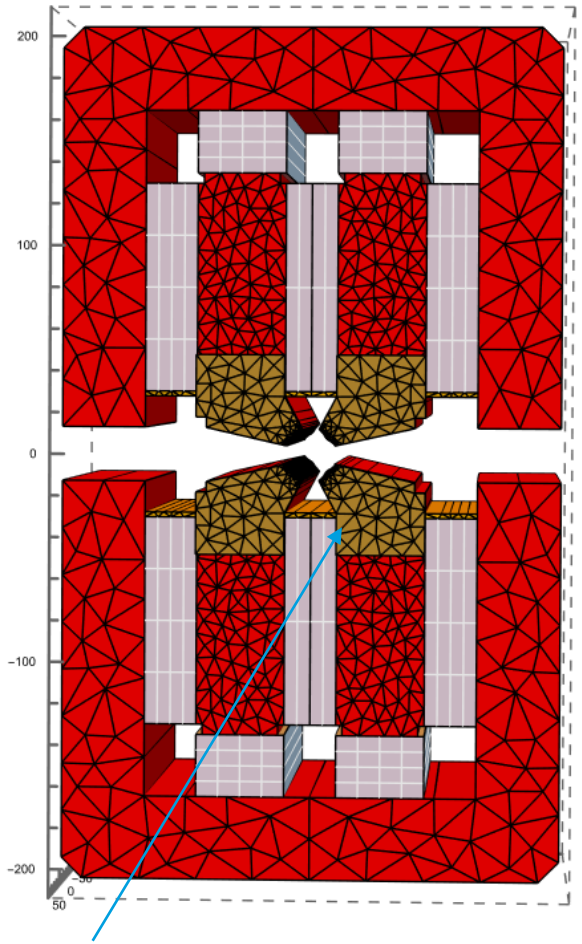
GFR

Integrated Harmonics

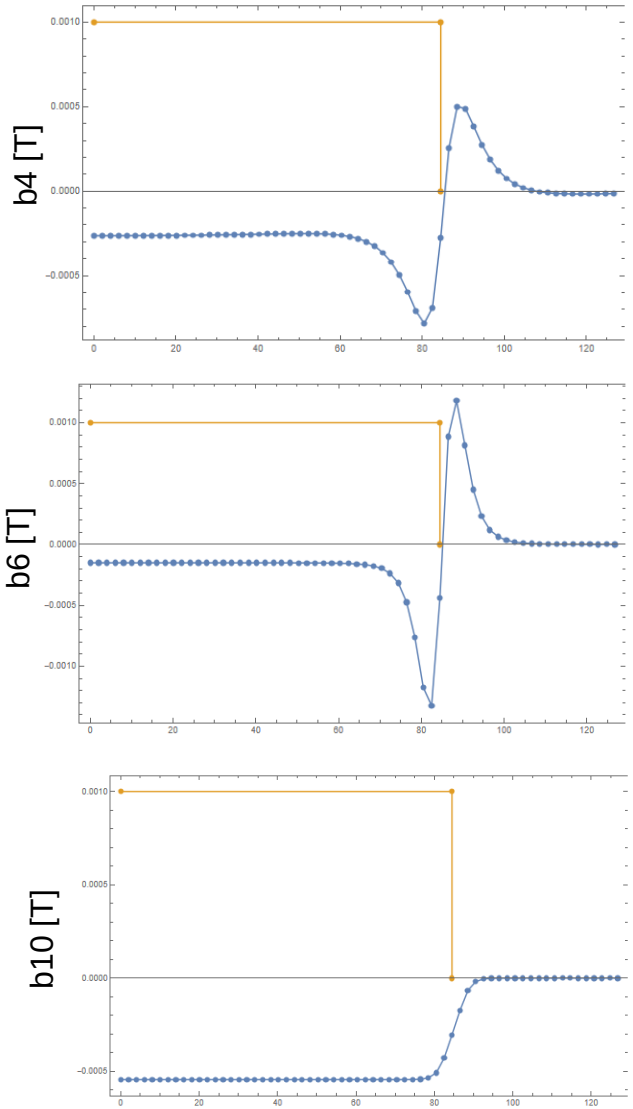
1	0	0
2	0.132317	10000.
3	0	0
4	3.3517×10^{-6}	0.253307
5	0	0
6	0.0000170568	1.28908
7	0	0
8	-1.11112×10^{-6}	-0.0839738
9	0	0
10	-2.14325×10^{-6}	-0.161978
11	0	0
12	1.67678×10^{-7}	0.0126723
13	0	0
14	-0.0000131667	-0.995089
15	0	0

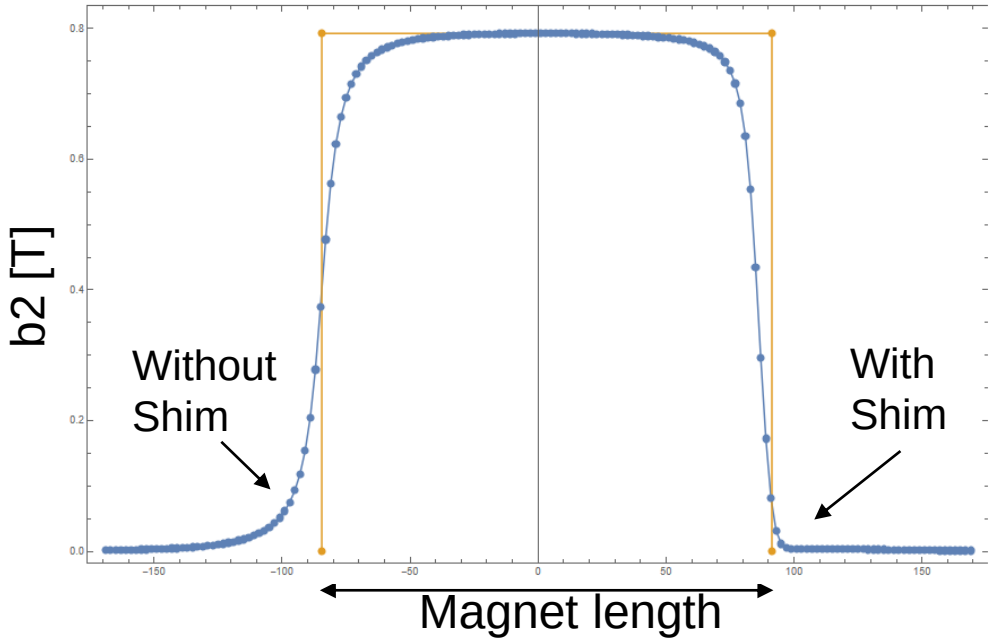
$$\sqrt{\sum bn^2} = 2 \cdot 10^{-5}$$

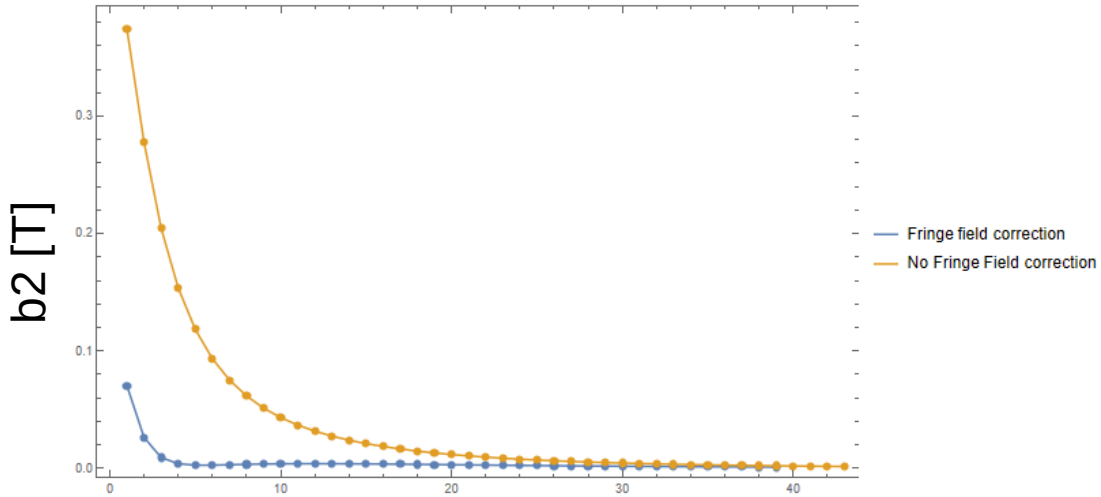
Fringe Field Reduction



PM shim
6.85mm Thickness

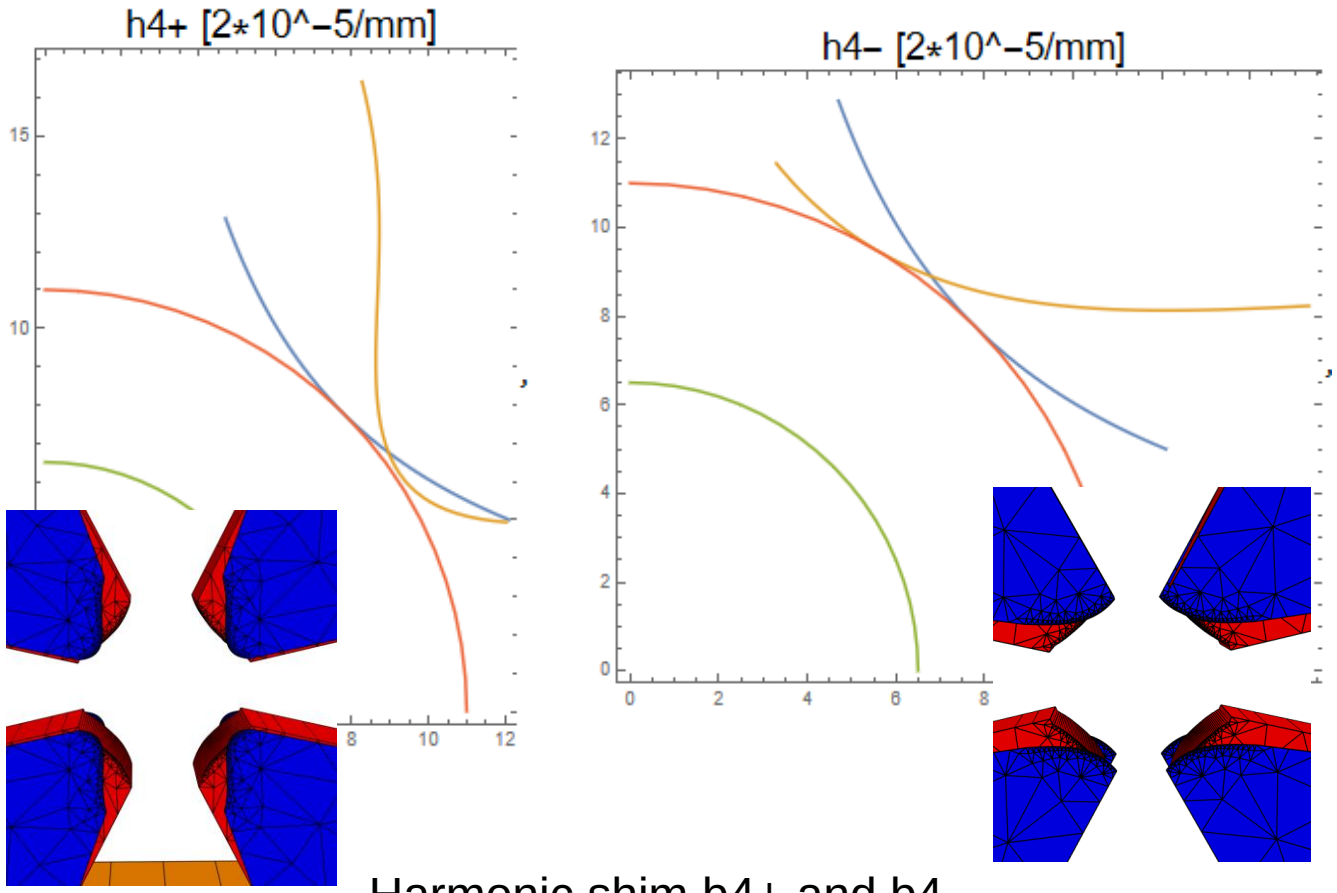


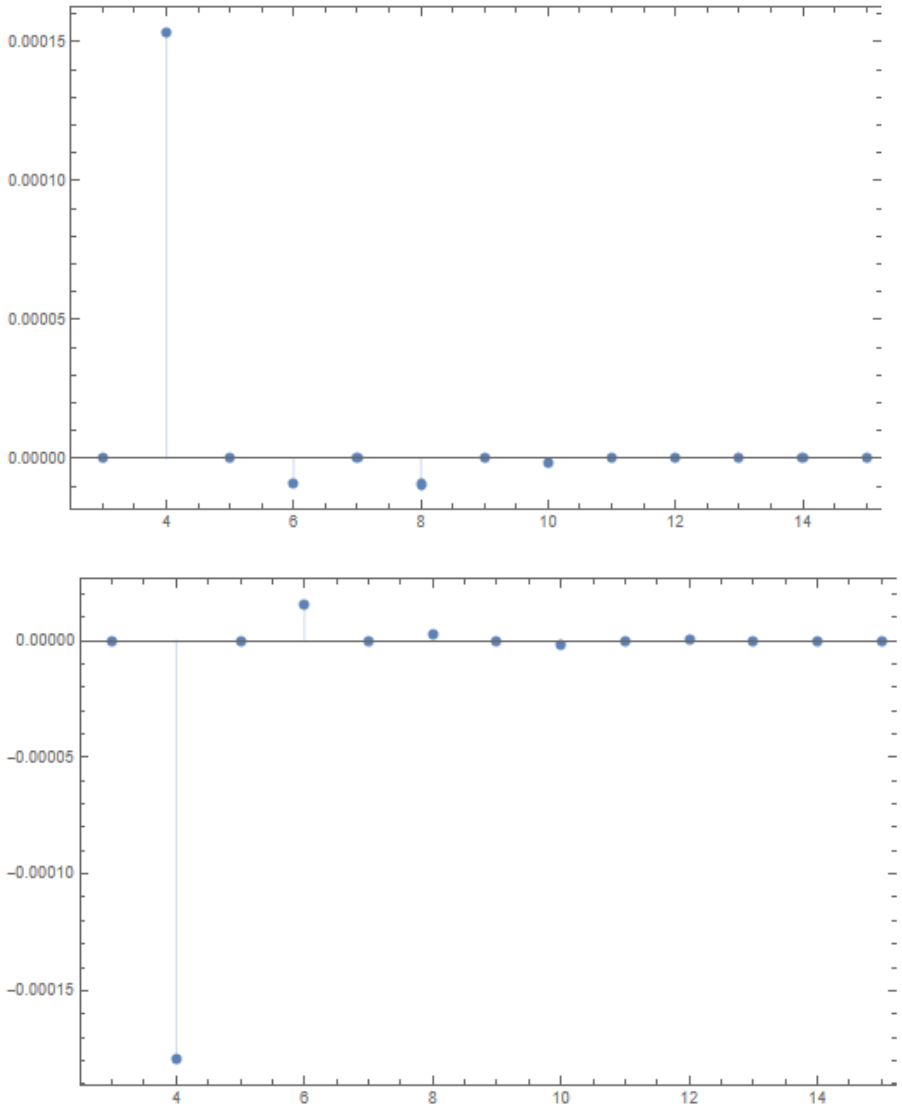




Magnetic Correction

Harmonic Shim



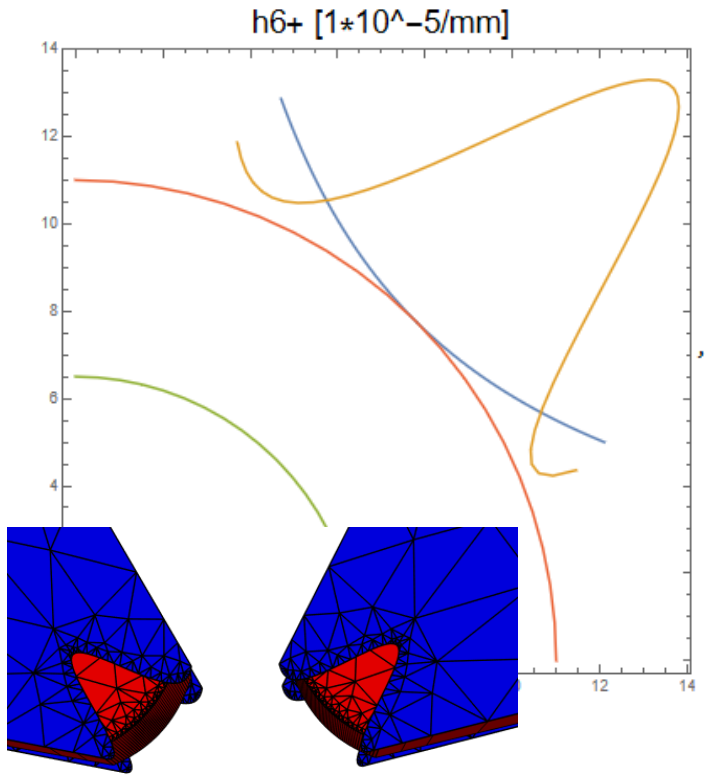


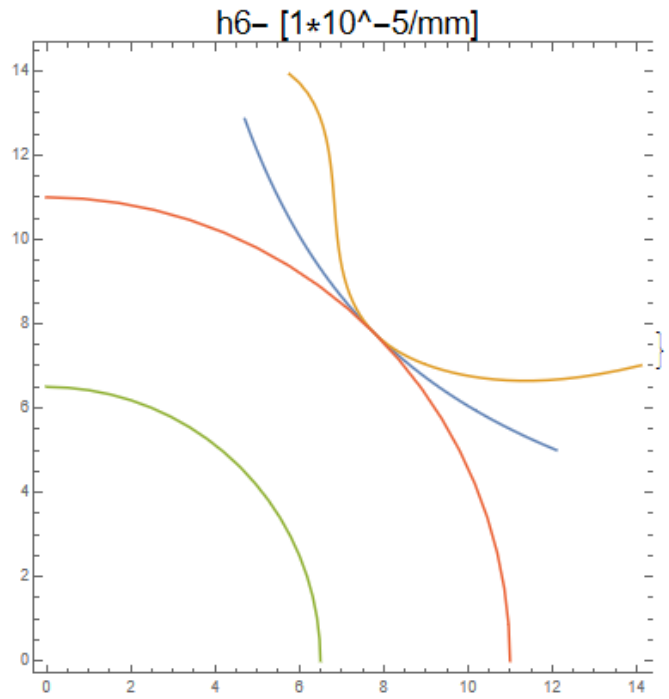
Harmonic shim b4+ and b4-

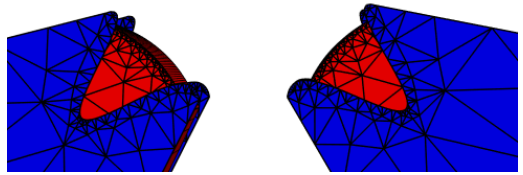
15*10^-5 → ~15 units/mm shim thickness

Magnetic Correction

Harmonic Shim

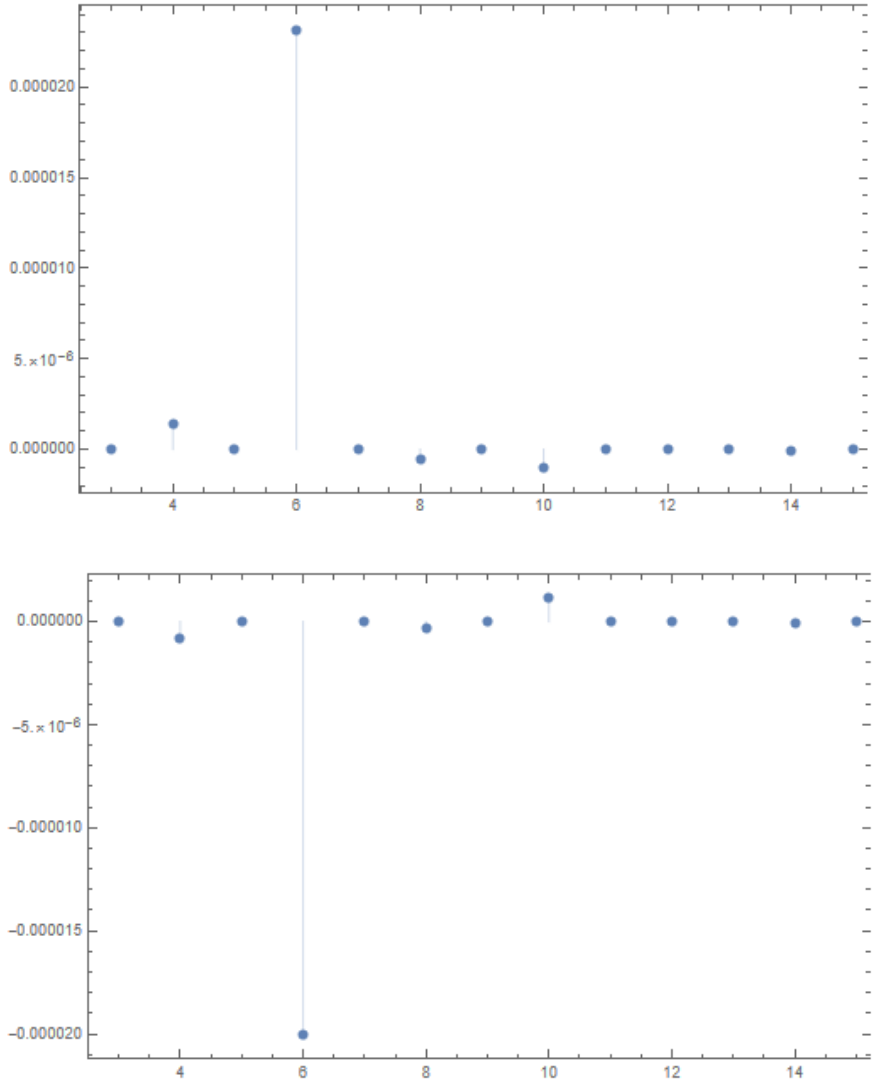




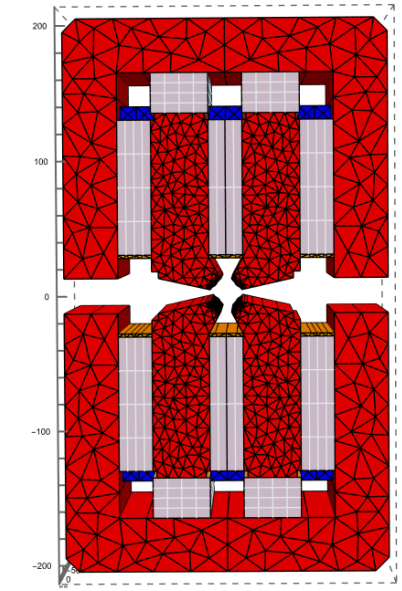


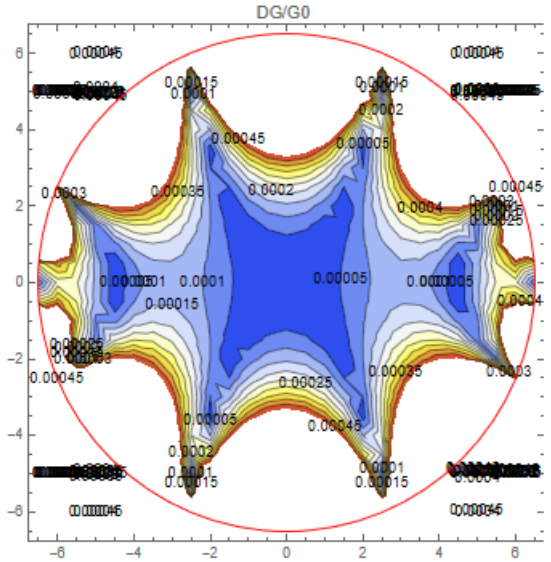
Harmonic shim b6+ and b6-

2*10^-5 → ~2 units/mm shim thickness

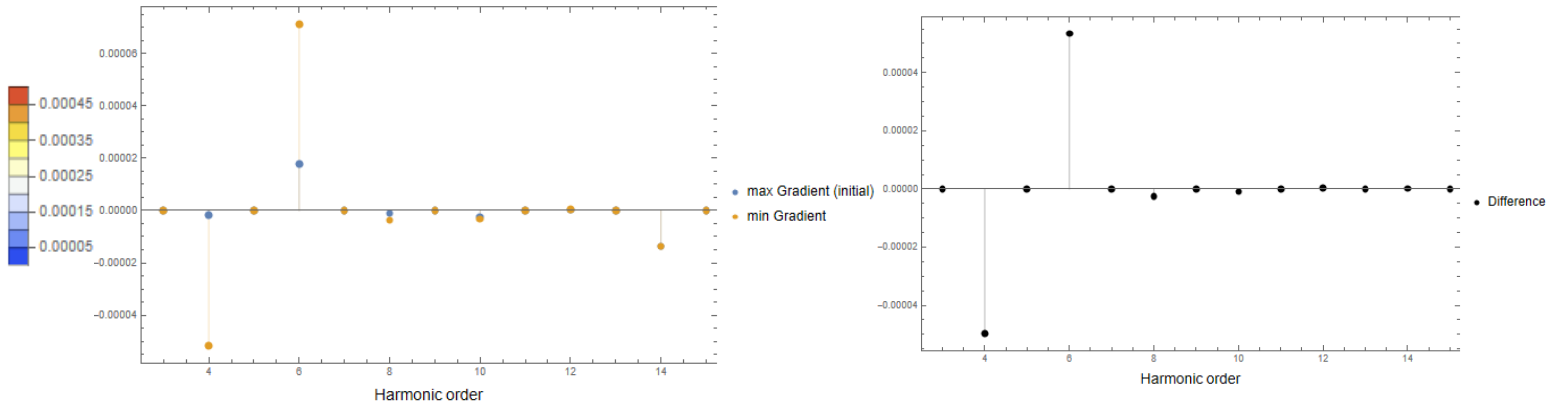


Magnetic correction test

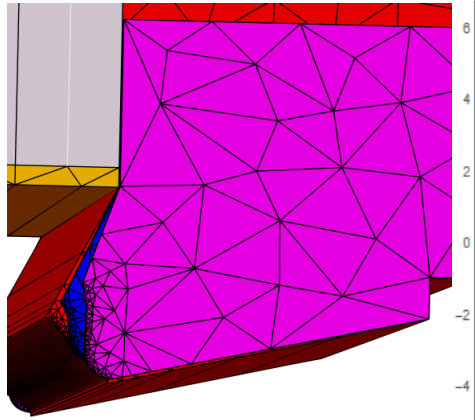


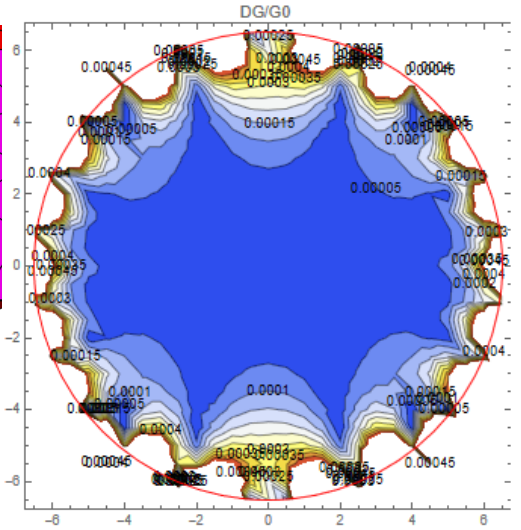


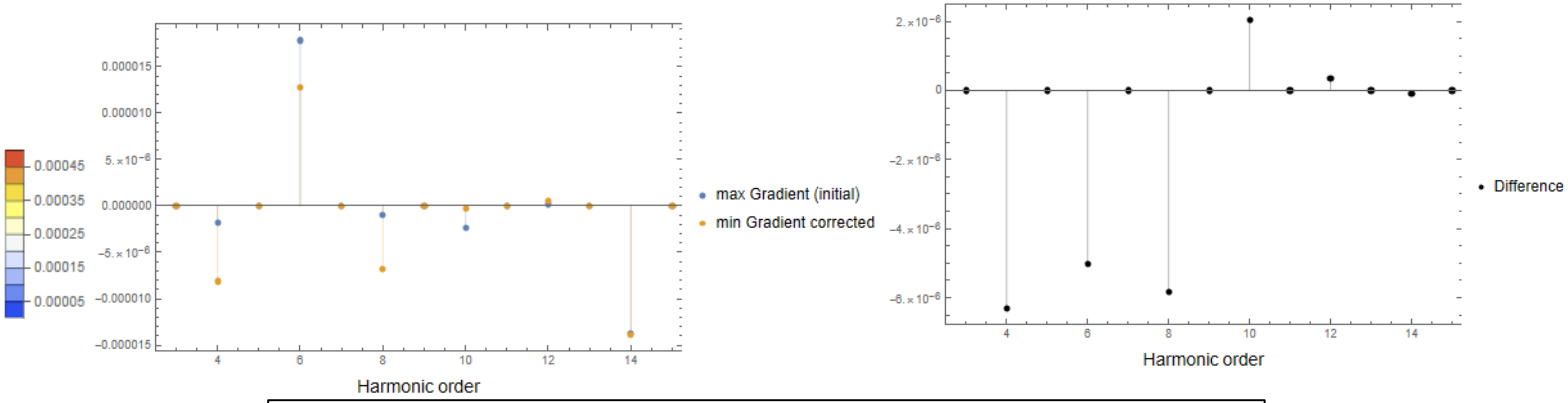
Field perturbation at minimum gradient with tuning shunt
(negligible perturbation at max gradient with shunt on the top)



Field correction







Stack of two shim

b6- ; 2.5mm thickness
b4+ ; 0.35mm thickness

Field error correction with ‘’harmonic shim”

- Generation of a specific harmonic order(b4+,b4-,b6+,b6-)
- Correction of gradient tuning error (b6 harmonic variation)
- Correction of possible mechanical error
- Flexible correction: stack of correction shim

Perspective

- Magnetic design finalization
  - Parameter update, model improvement
  - Study of the final magnet model
- Mechanical design
  - On progress, first CAD model
  - Prototype afterward

Thank you