Magnetic field calculations and magnet design changes

Alexey Bragin

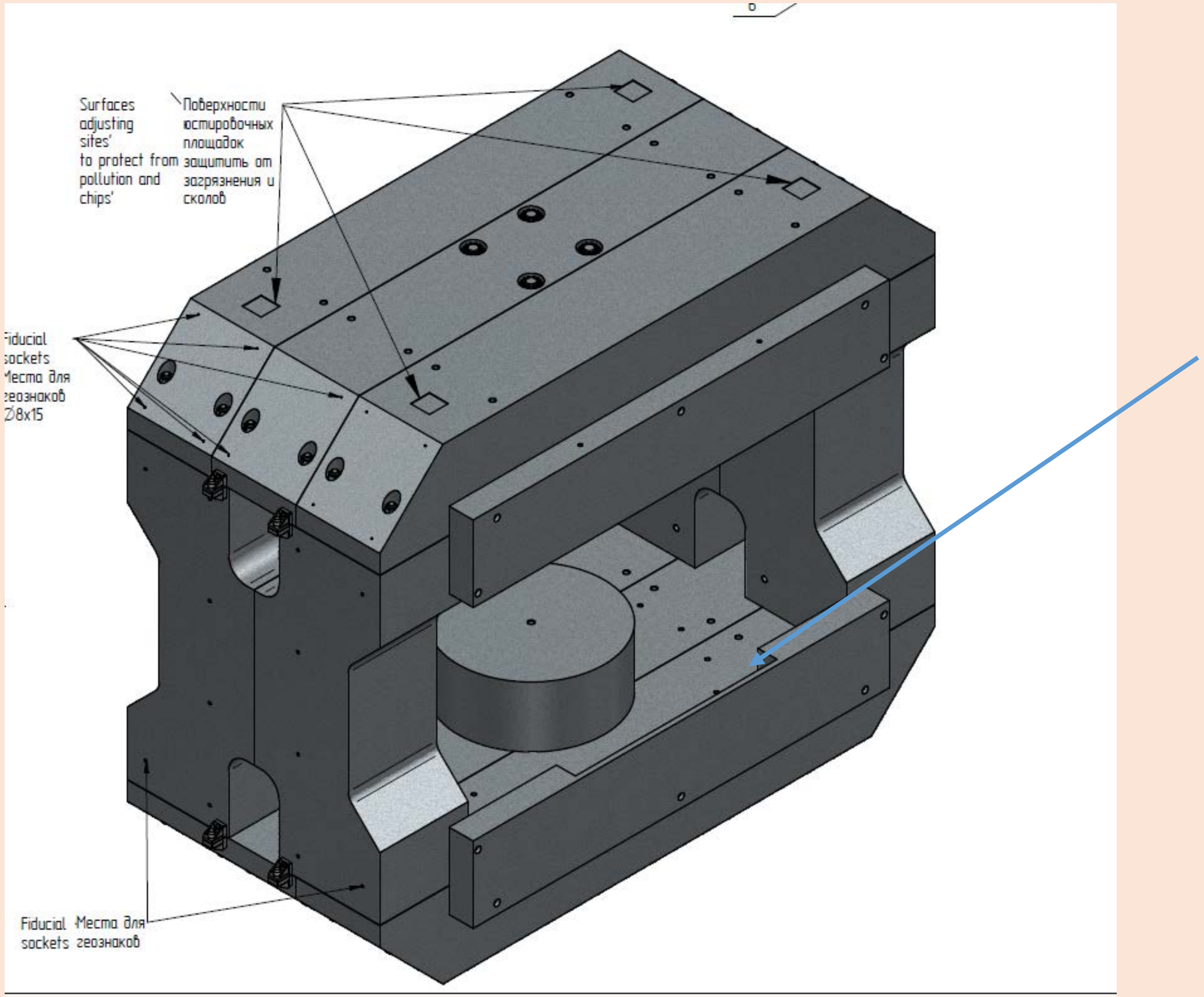
Budker Institute of Nuclear Physics, Novosibirsk, Russia

November, 2019

Outline

- Magnet design. Dimension.
- Calculation of the 3D model in Mermaid code
- ANSYS 3D calculations
- ANSYS 2D model for checking any inconsistencies in 3D calculations
- Discussion of the results

Total view of the iron yoke



The main dimensions of the iron yoke:
3700 mm of height
2380 mm of width
4400 mm of length.

The field clamps have internal cuts.

Material – steel 10,
Cylinder poles - Armco

Calculation codes and models

Old model (2018) was calculated by different peoples and codes:

-ANSYS 3D code performed by Y. Goussakov and S. Farinon;

-MERMAID 3D code S. Khrushchev

-ANSYS 2D code A. Bragin

The last model (2019) was calculated by A. Bragin and Yu. Goussakov in ANSYS 3D code.

Parameter	Old model	New model
Current, A	686	666
Inner diameter, mm	1390	1396
Number of layers	53	52
Number of turns	1749	1716
Field clamps	The plates	The plates withinternal cuts

Mermaid 3D model

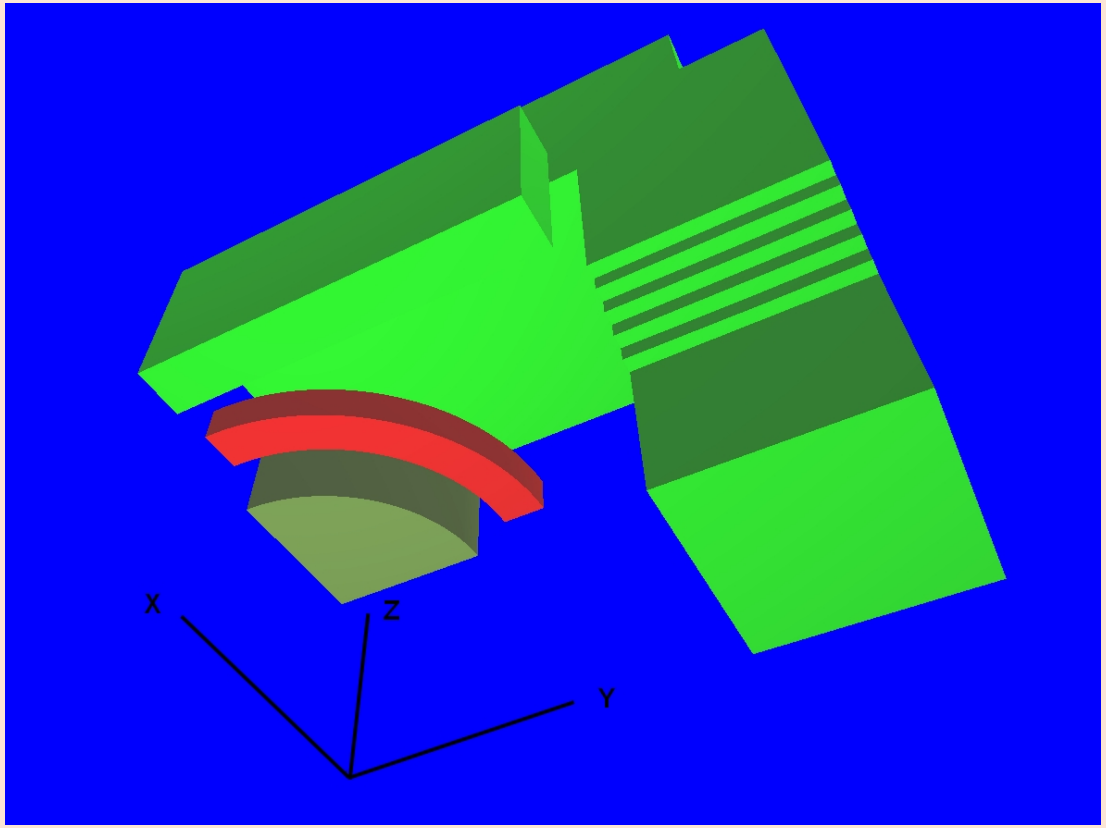
The total current in the coil is 1.2 MA (686 A of operating current).

Inner diameter of the winding is 1390 mm,

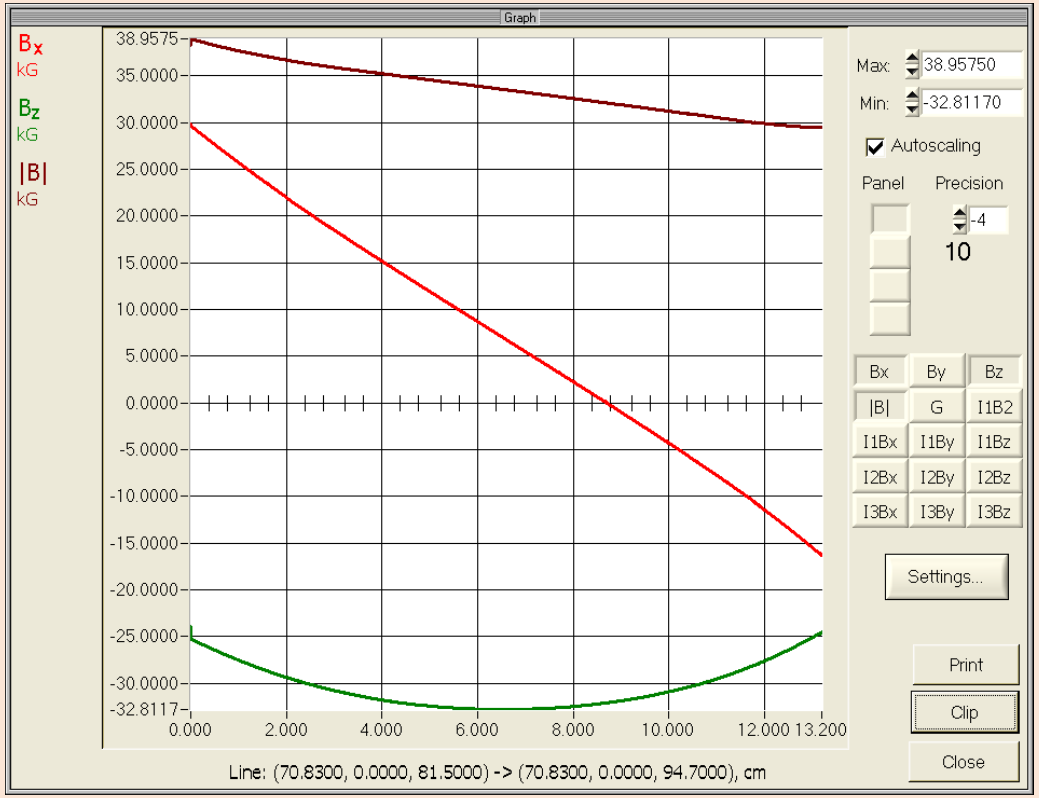
axial thickness is 131 mm,

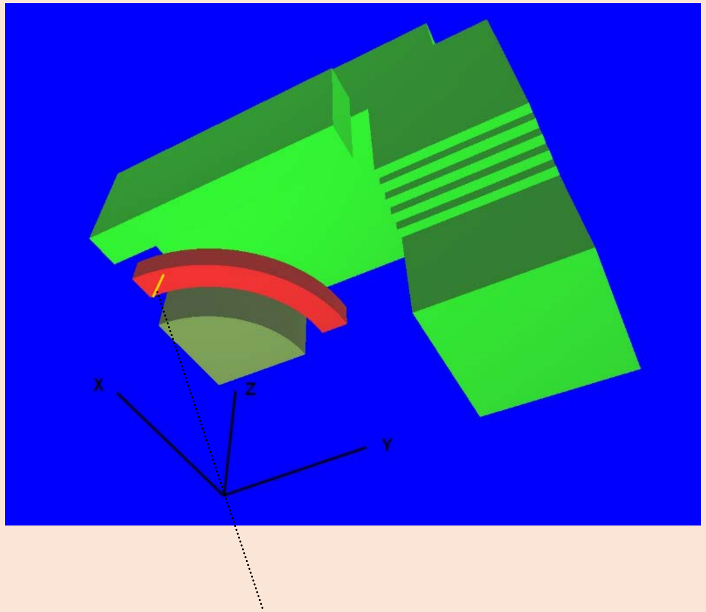
radial thickness is 160 mm

Vertical distance between the poles is 1440 mm.



Magnetic field in the coil





The presented graph is along this yellow line.

The magnetic field values inside the SC winding as Mermaid result. The magnetic filed values are in kG, the distances are in cm. These filed values are highest in the coil as this winding part is closest to the iron field clamps.

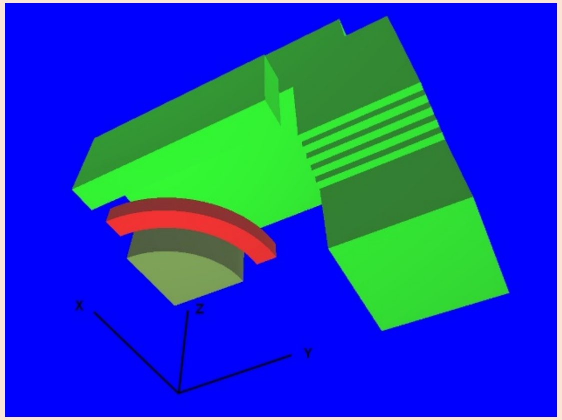
Forces in the coil – old design

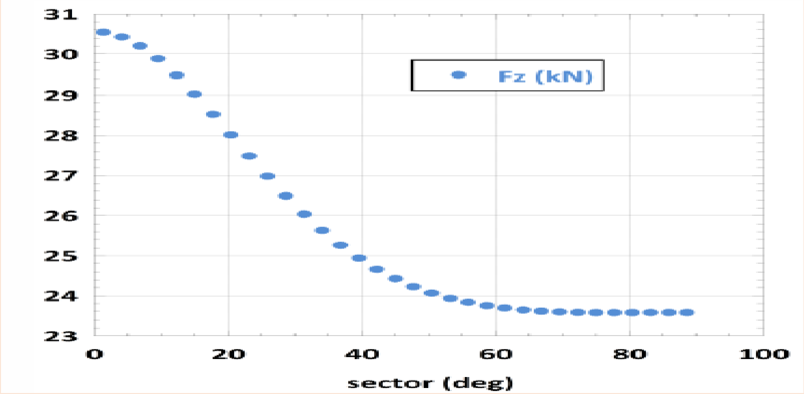
Lorentz forces in the coil

Inner pressure as p = I*Bz/(ax. thick.) ~ 5 MPa.

Vertical force Fz = I*Br*(πD) ~ 3.1-3.4 MN.

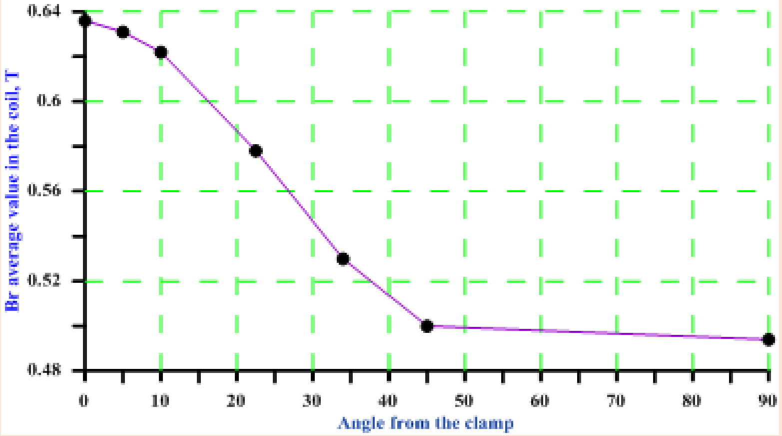
The vertical force is not uniformly distributed around the coil, the difference is ~ 22.5%. The highest value is by the field clamps.





The azimuthal distribution of vertical force along the sector of 90 grades. ANSYS 3D by Stefania.

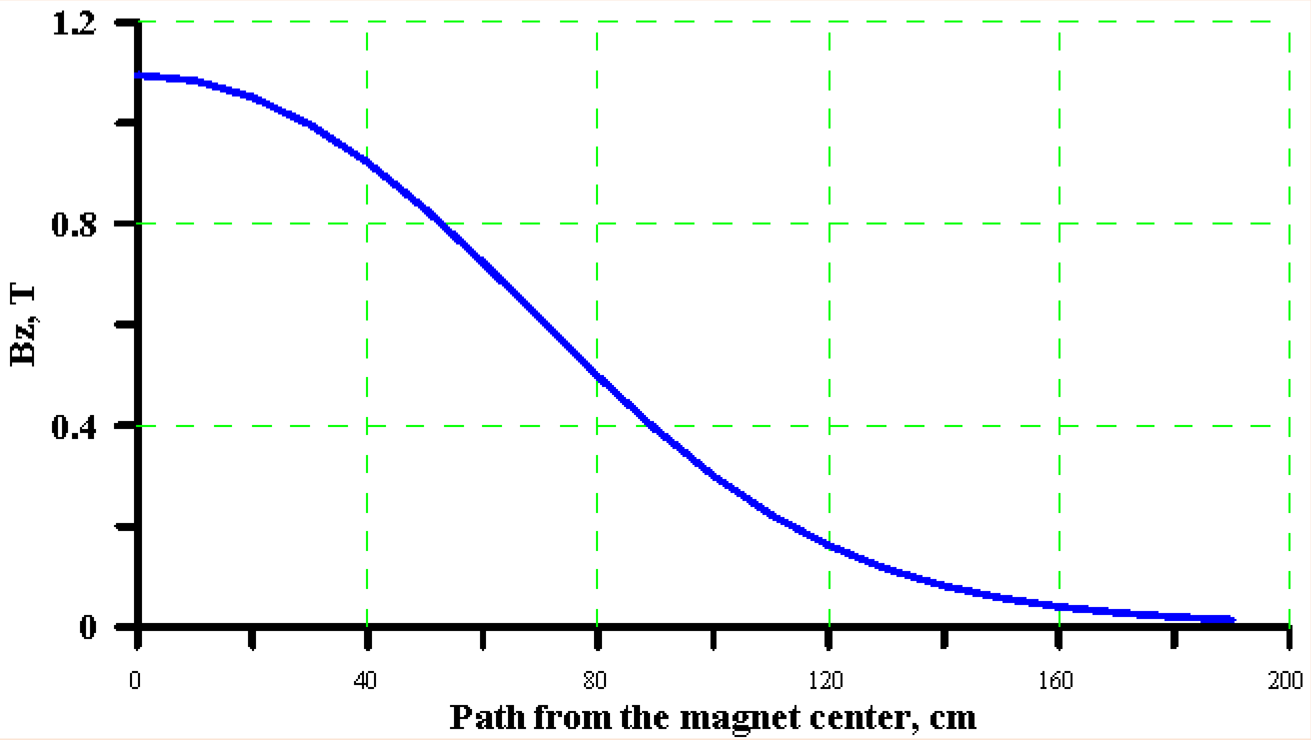
Fz = 3.4 MN.



The azimuthal distribution of average radial magnetic field along the sector of 90 grades. Mermaid 3D in BINP.

Fz = 3.1 MN.

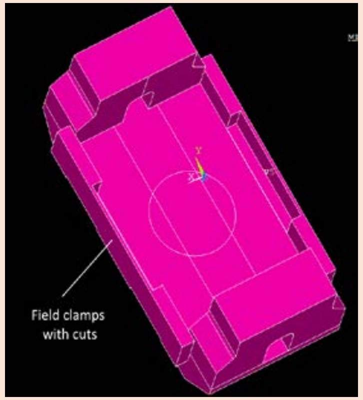
Magnetic field distribution – old design



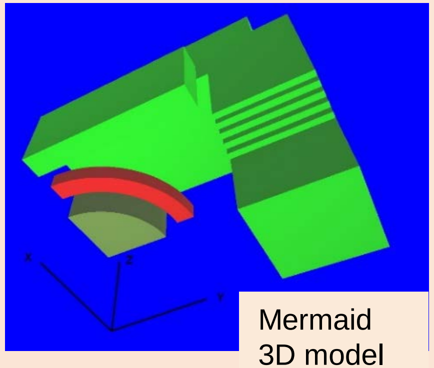
Magnetic field integral is 1.004 T*m about the center of the magnet on the length of 1 m in Mermaid calculation.

Influence of steel and field clamps on the main parameters: how new design was calculated

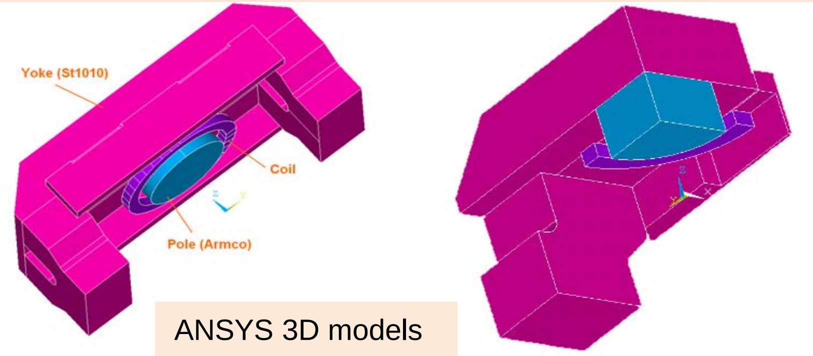
Parameters	Yoke: Steel 1010, Pole: Armco, the current design	The current design without the field clamps	The current design with field clamps having the cuts like in Fig. 3	Yoke: Steel 1010, Pole: Armco, the 52 layers and with FC cuts,	Yoke: Steel 1010, Pole: Armco, the 52 layers and with FC cuts, the new design
B in the center, T	1.125	1.138	1.138	1.124	1.099
Bmax on the coil, T	3.888	~3.8	~3.76	3.70	3.59
Int. Bds± 0.5 m, T*m	1.031	1.048	1.047	1.034	1.012
Operating current, A	686	686	686	686	666
Number of turns	1749	1749	1749	1716	1716
E stored energy, MJ	5.33	5.28	5.31	5.14	4.90



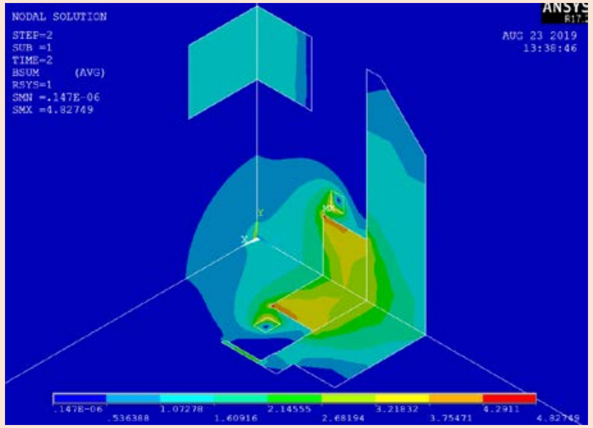
Magnetic field calculations – final results



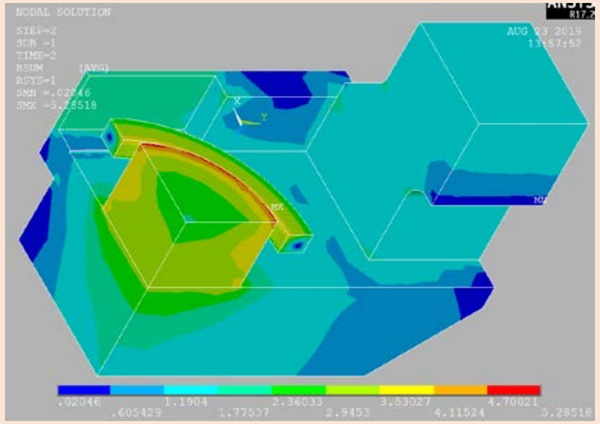
Mermaid 3D model



ANSYS 3D models



Magnetic field in the whole model



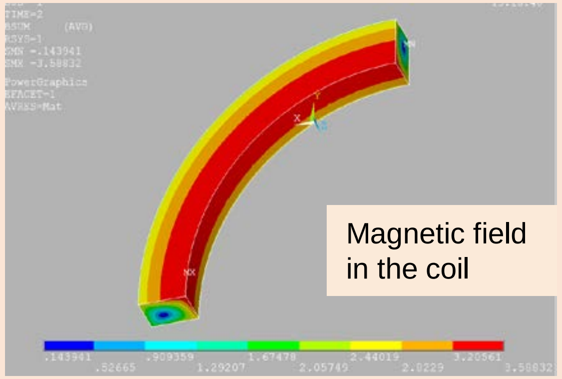
Magnetic field in the iron and the coil

The magnetic filed was calculated using Mermaid (BINP developed) and ANSYS codes. Several models were used for calculations, including 2D model. The calculations purposes are:

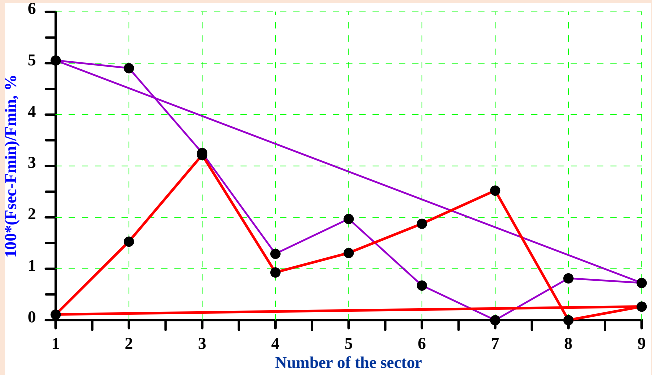
- Magnetic field integral
- Magnetic field on the coil
- Lorentz forces, and with coil misalignments
- Optimization of the field clamps of the iron yoke
- Stray field values by the RICH detector

Lorentz forces values due to misalignments of the coil from its position.

Shifts	Fx, N	Fy, N	Fz, MN
Δz = 5 mm (opp. to the center)	~ 0	~ 0	3.21
Δz = -5 mm (to the center)	~ 0	~ 0	3.07
Δx = 5 mm	$2.56*10^4$	~ 0	3.207
Δx = 10 mm	$4.77*10^4$	~ 0	3.12
Δy = 5 mm	~ 0	$1.81*10^4$	3.218



Magnetic field in the coil



Azimuthal variation of vertical and horizontal forces in the coil due to non axial symmetry.

Main results of the magnetic field calculations:

1. The integrals around the center of the magnet is 1.012 T*m for 666 A of the current in last design of the field clamps.
2. Maximal magnetic field on the coil is ~ 3.6 T at 666 A current.
3. The vertical force on one coil toward the yoke is ~ 3.05 MN at 700 A current. The horizontal forces of de-centered coil are about 20 kN per 5 mm shift that is not much. Azimuthal variation of the forces values along the coil is below 5%.
4. The force on the poles is about 0.7 MN and it is opposite to the center of the magnet. The neat force toward the center on the horizontal iron beams subtracting the vertical coil force is about 50 tones.

Forces, inductances

- **The forces on the coils are:**

- 3.3 MN (highest) in vertical direction to the nearest horizontal yoke beams. It is not uniform azimuthally with 22% of difference.

- 5 MPa of internal pressure.

- **Force on the pole iron attractive toward the nearest horizontal yoke beams ~ 0.7 MN (70 tones).**
- **Mutual inductance between the coils is 0.21 H – very low. Calculated from stored energies of separately charged coils in ANSYS 2D.**

Results

- The magnetic field was calculated in different codes: ANSYS 3D, MERMAID 3D.
- The field integral is satisfying to be 1 T*m – the main parameter.
- Maximal magnetic field on the winding is 3.9 T
- Coil support struts should be placed properly with respect to the non uniform distribution of vertical force around azimuth.
- The number of struts will be reconsidered to be 8.
- Force on the pole is attractive to the nearest horizontal beams of the yoke, about 70 tones.
- The stray field by the RICH detector is not high.