Joint Institute for Nuclear Research

Analysis of coil and yoke design of the PANDA solenoid

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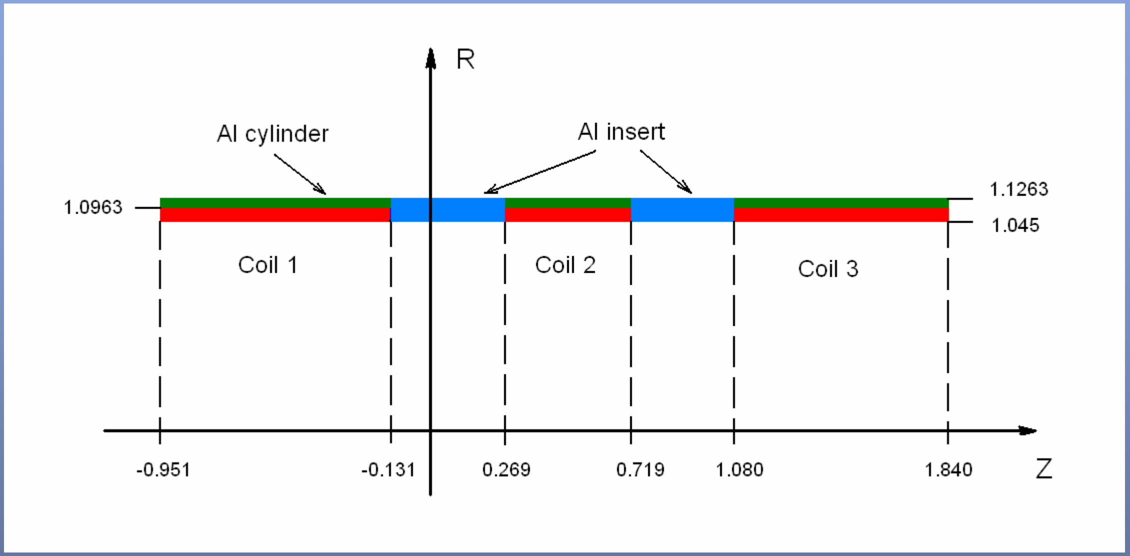
GSI, 08.11.2007

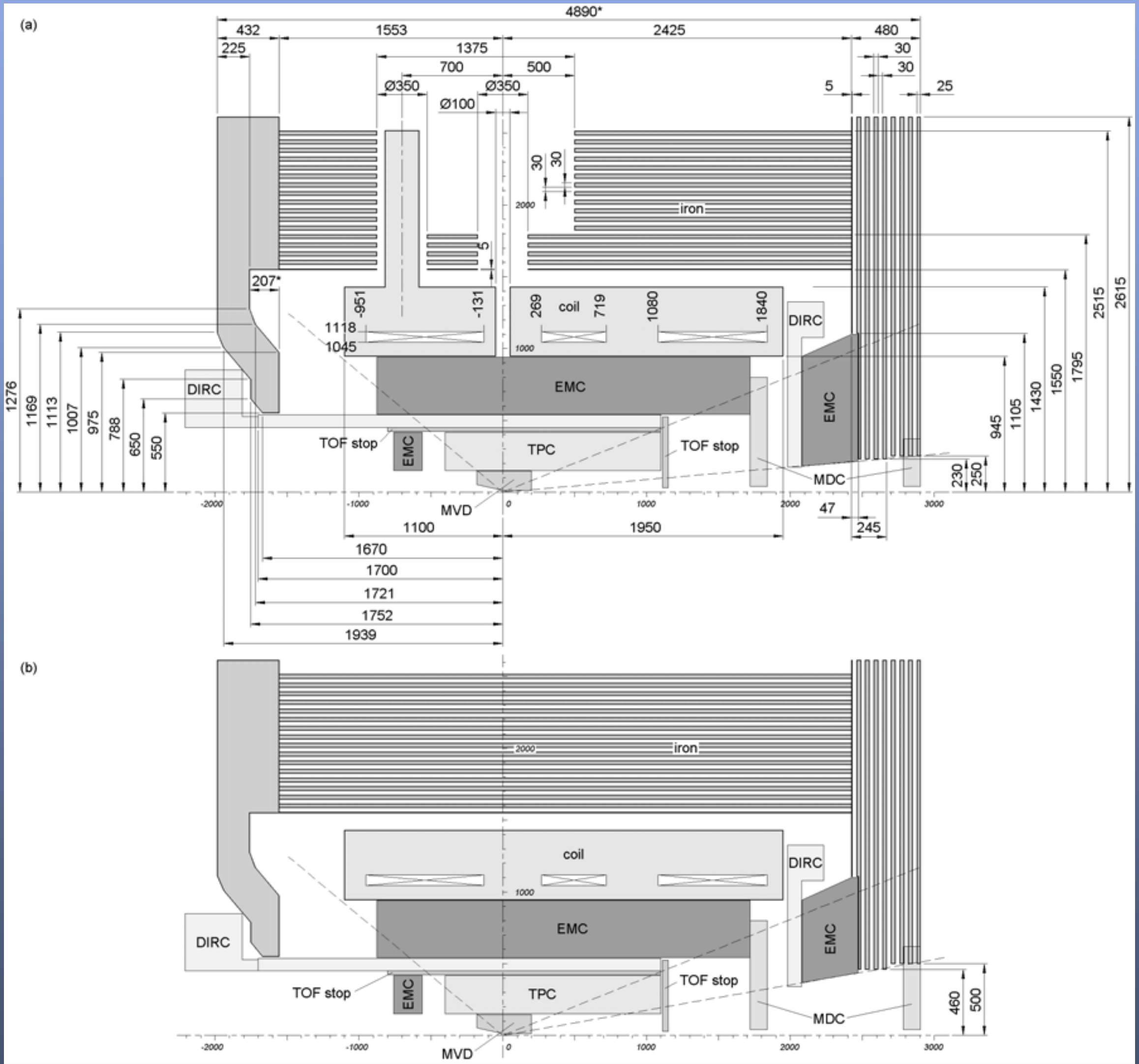
Coil layout and parameters



Coil number	Number of layers	Number of turns per layer
1	2	227
2	2	128
3	2	211
Total	1132 turns	

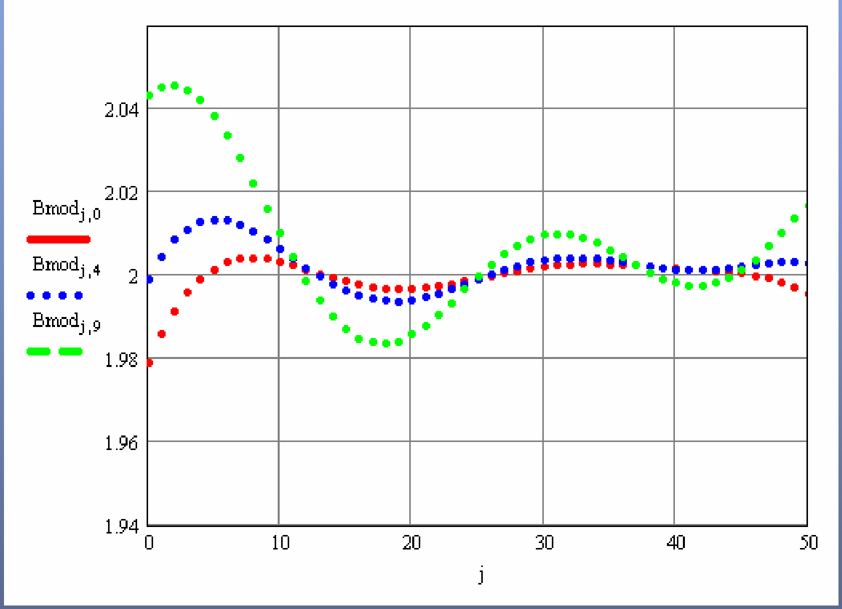
Current density
$j = 39\ MA/m^2$

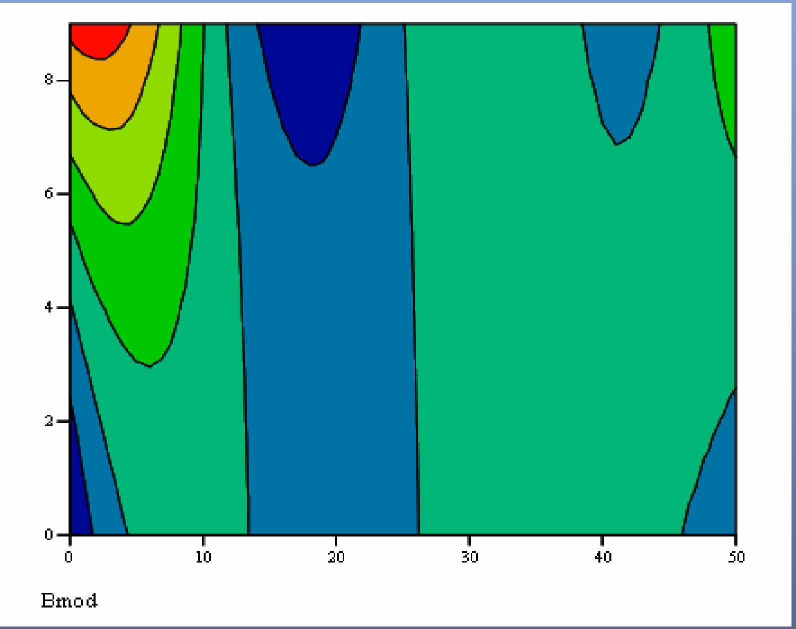
Solenoid cross-section



Field homogeneity

δ = 1.7%

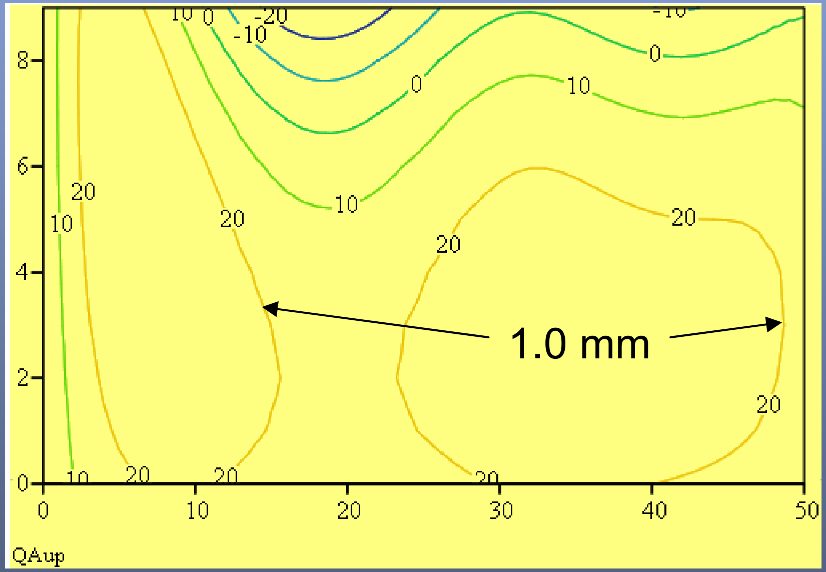




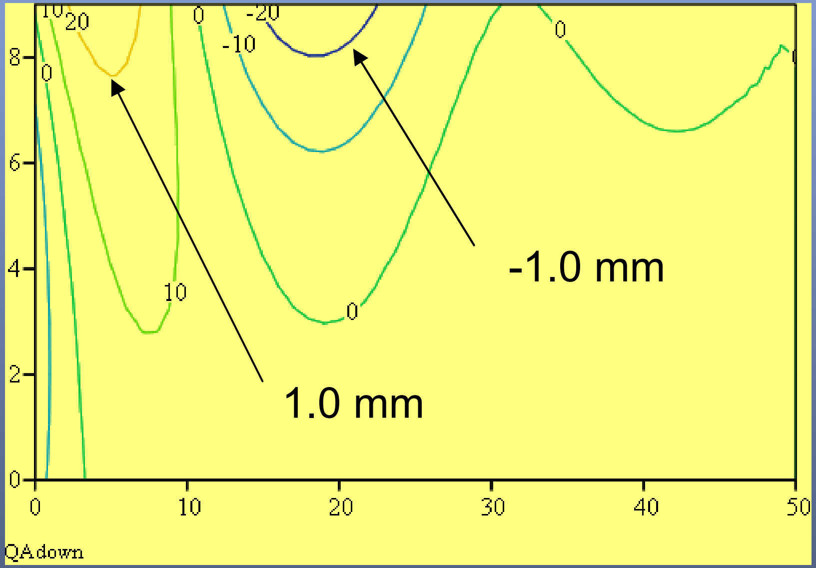
- Use of magnetization field from TOSCA calculations
- Calculation of coil fields in Mathcad
- Minimization of inhomogeneity by change of the turns numbers

Integral of the radial component of magnetic induction

$$I = \int B_r(z)\,dz / B$$

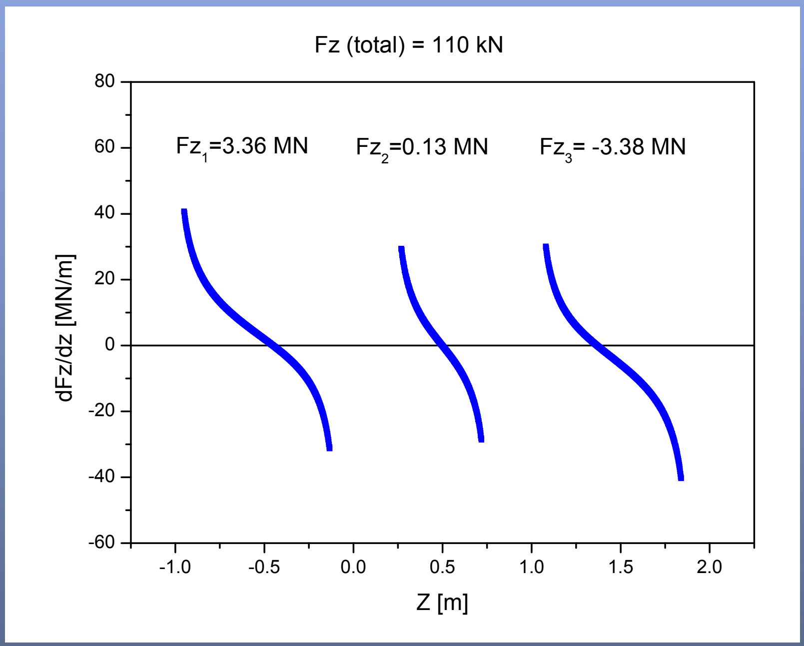


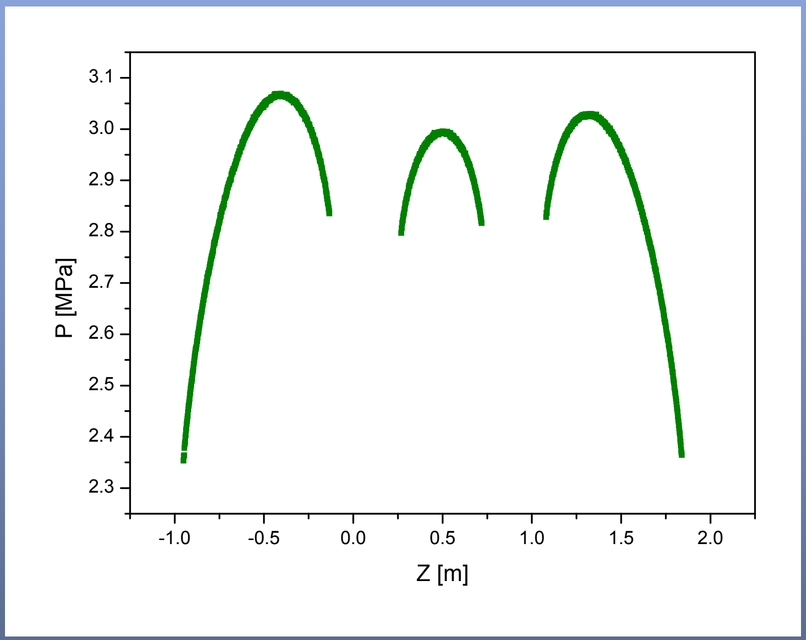
Upstream readout plane



Downstream readout plane

Magnetic forces at the solenoid coils





1. Net force at the coil is 110 kN
2. The attraction force between parts of the solenoid is at the level of 3.5 MN
3. The maximum radial pressure in the coil is 3.08 MPa

Material properties of the coil

inhomogeneous, anisotropic

Constituent materials properties (input data)

Material	T^0K	E, GPa	μ	$\Delta l/l$ 293-4.2^{0}K
Superconductor Cu/NbTi=1.09	4.2	130	0.3	0.00254
Fiberglass epoxy in plane	4.2	20	0.21	0.0024
Fiberglass epoxy normal to plane	4.2	12.5	0.21	0.0074

G=6 GPa ($T=4.2^0K$)

Aluminum: E=75 GPa, μ=0.33, $\Delta l/l$=0.0042

Material properties of the coil

Conductor cross-section: 3.2×25 mm^2,
with insulation 3.6×25.4 mm^2.

Filling factors:

Material	S, mm^2	Relative
Aluminum	71	0,78
Cu/NbTi	9,0	0,10
Insulation	11,4	0,12
Total	91,4	1,00

Calculated composite material properties:

Direction	E, GPa	$\Delta l/l$
Axial, Z	50	0.0044
Tangential, θ	74	0.0040
Radial, R	64	0.0041

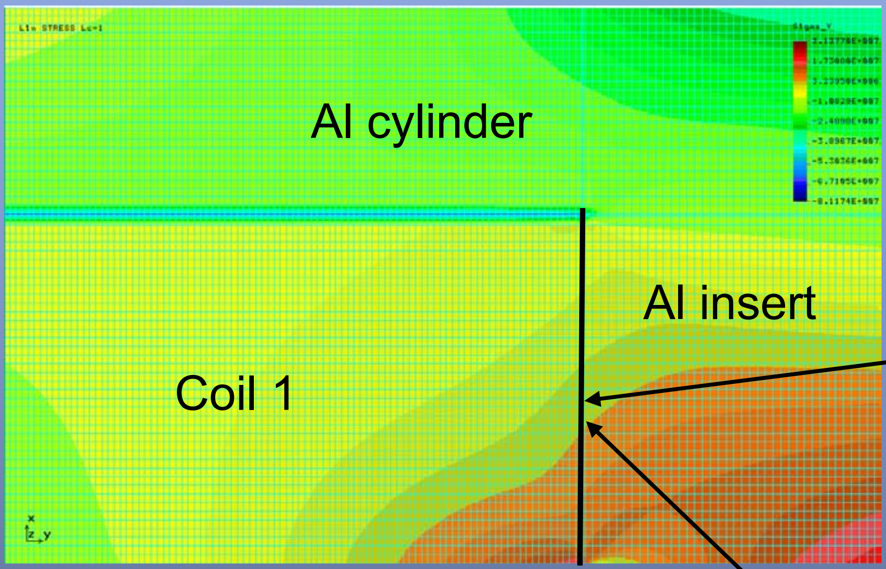
G = 20 GPa

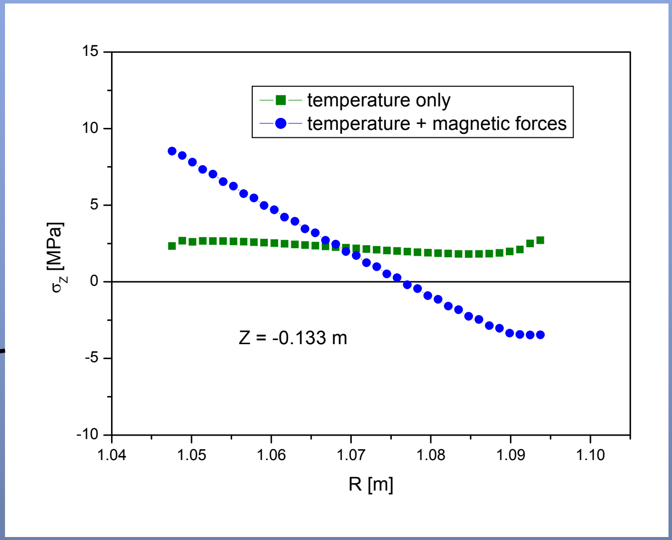
$\mu_{Z\theta} = 0.23$

$\mu_{ZR} = 0.22$

$\mu_{\theta R} = 0.31$

Calculated stresses in the coil

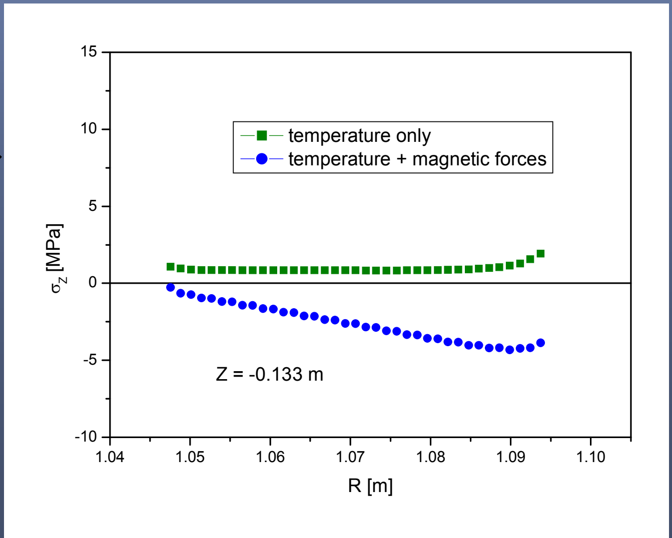




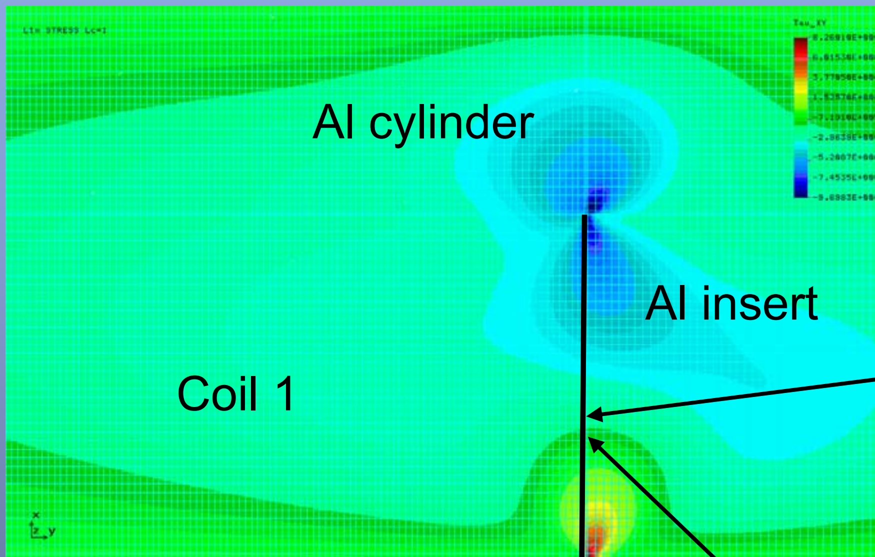
Axial stress distribution

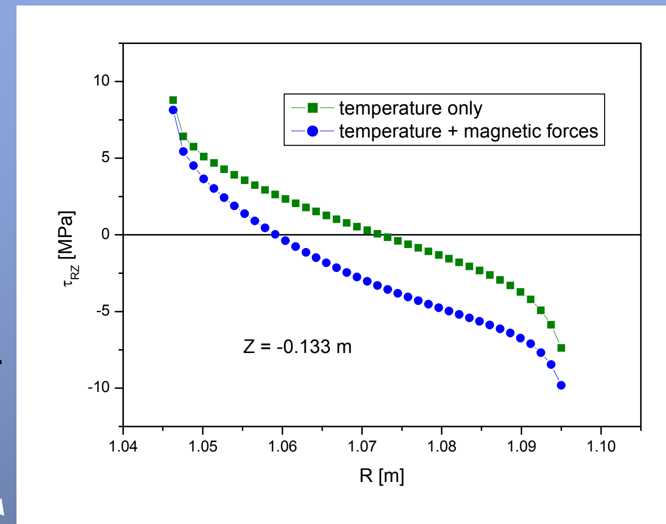
Rigid insert

Flexible insert (with cuts)



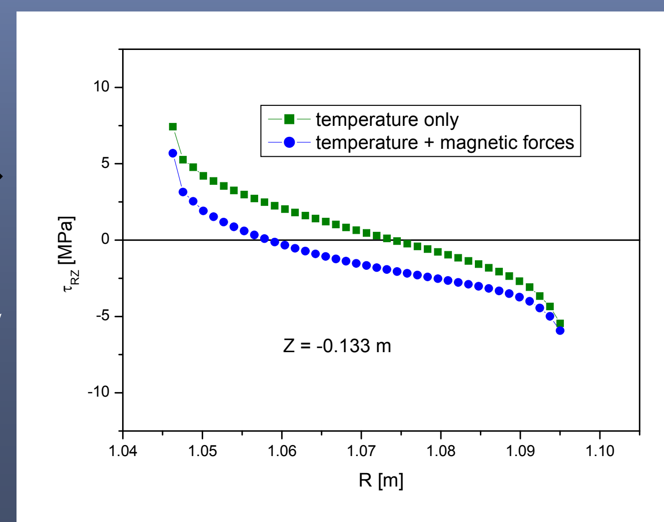
Calculated stresses in the coil



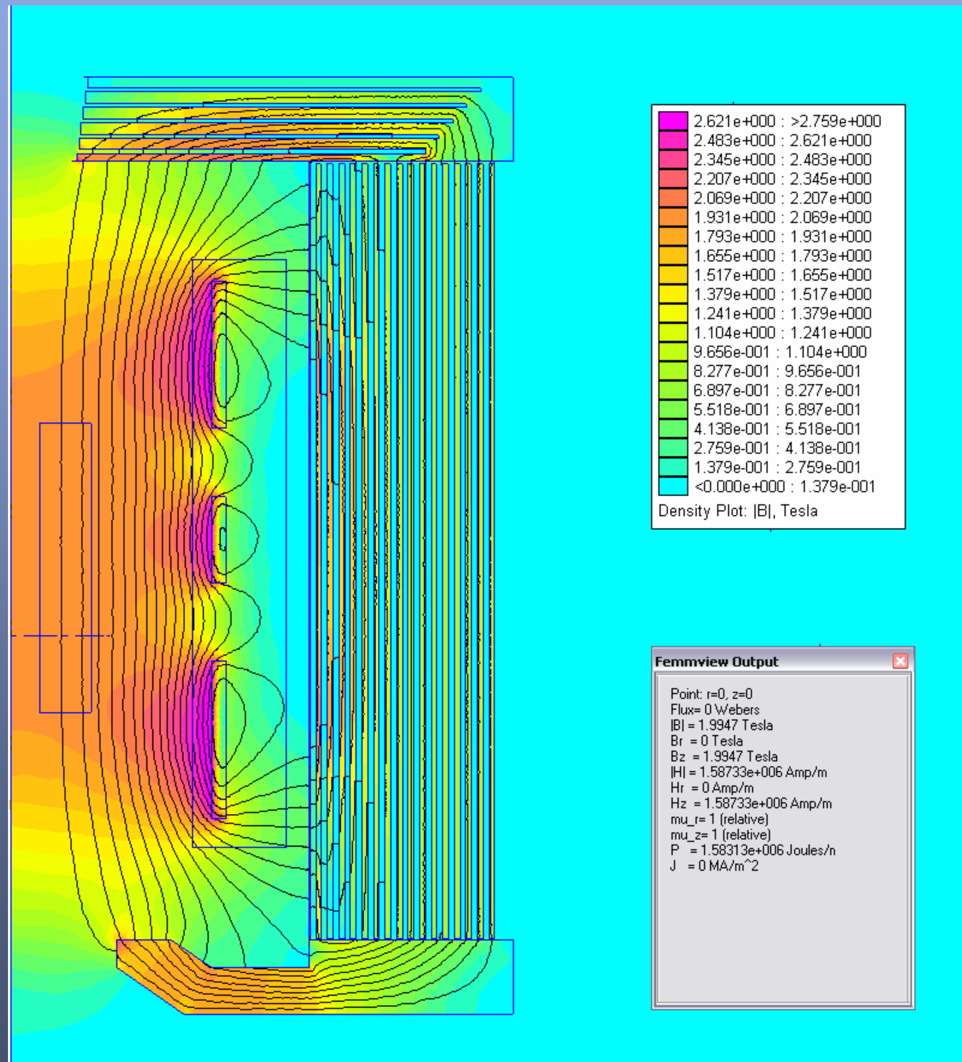


Shear stress distribution

τ_{equiv} [MPa]	Temperature only	Temperature + mag. forces
Rigid insert	9.2	13.1
Flexible insert	7.4	5.7

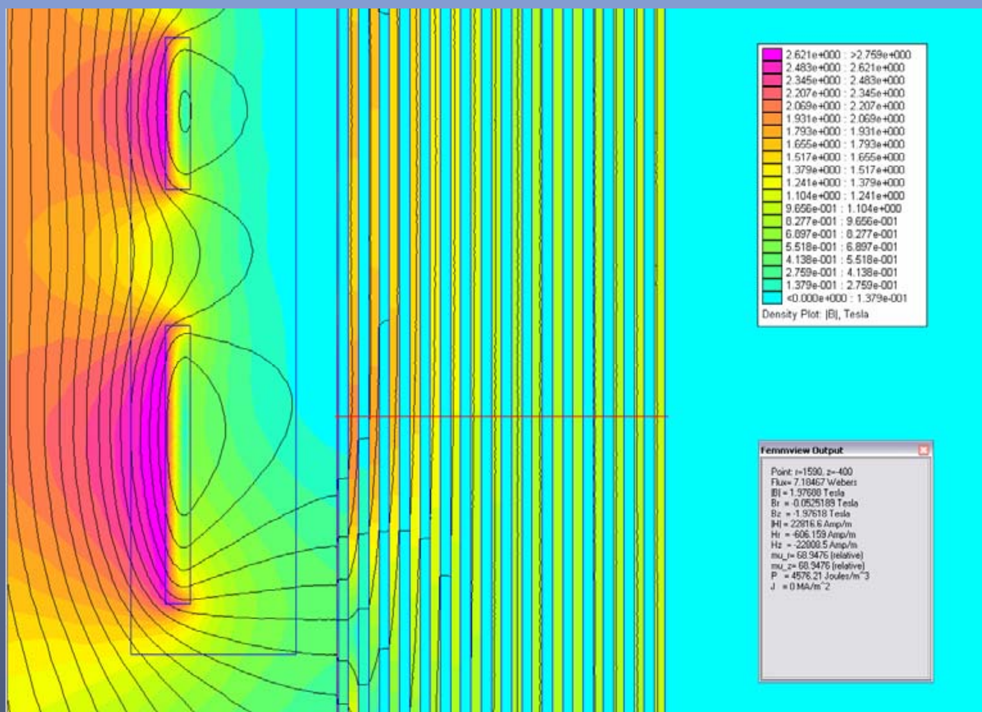


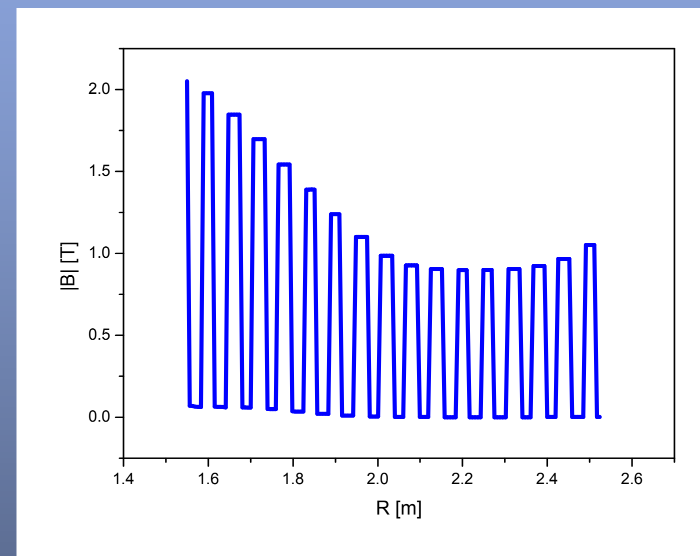
Magnetic flux density distribution



Magnetic flux density distribution

central part



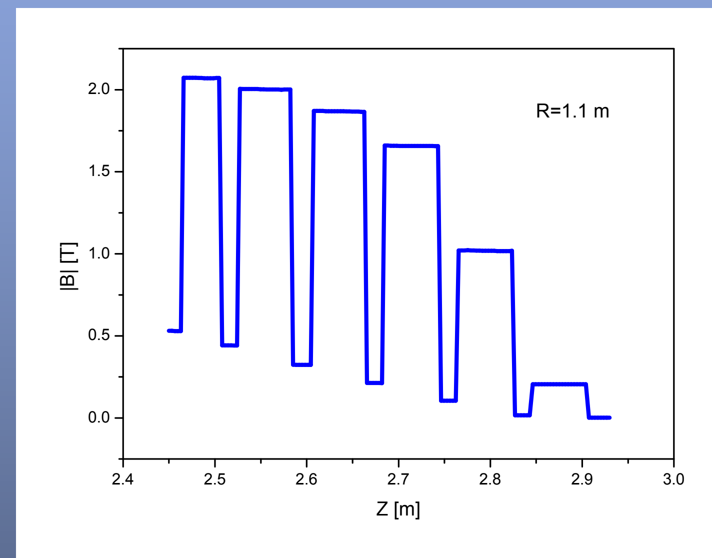


Flux density in the yoke (Z=-400 mm) as a function of radius

Axial magnetic force on the barrel part F_Z = -160 kN

Magnetic flux density distribution

downstream part

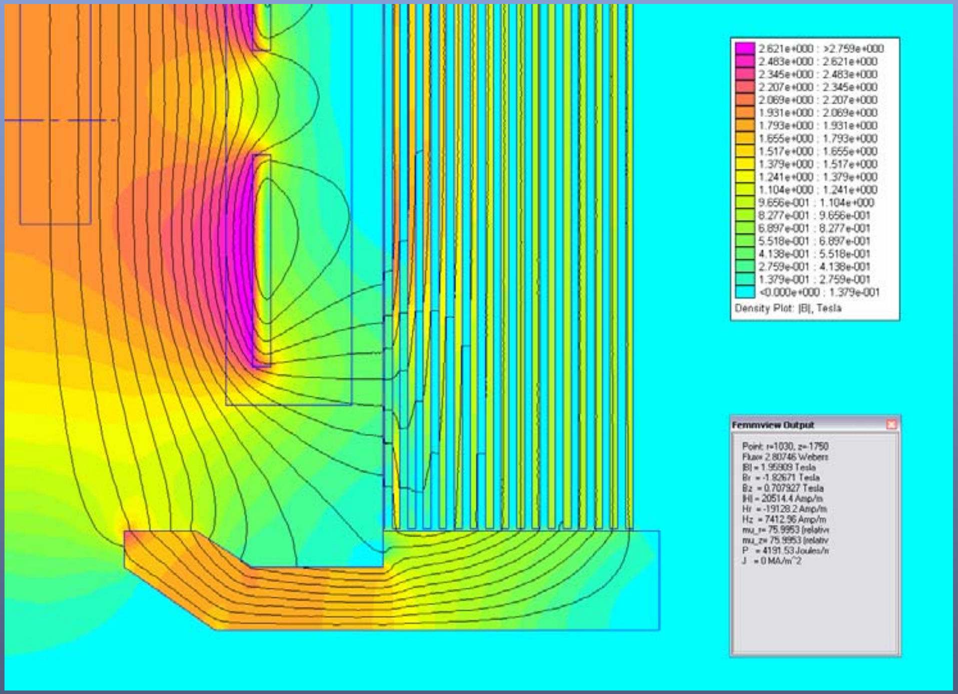


Flux density in the downstream end cap (R=1.1 m)

Axial magnetic force on the downstream end cap F_Z = -2.24 MN

Magnetic flux density distribution

upstream part



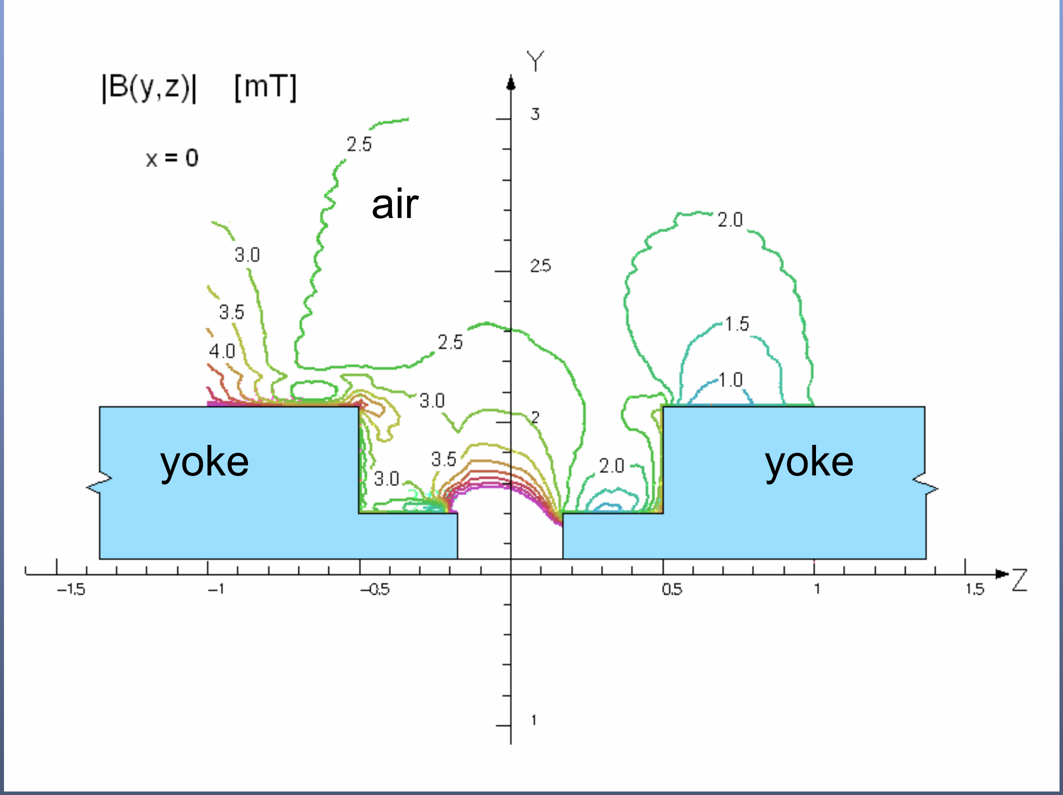
Saturation of the upstream end cap:

$|B| < 1.9$ T

Axial magnetic force on the upstream end cap $F_Z = 2.29$ MN

Stray fields near the target orifice
(from 3D TOSCA model)

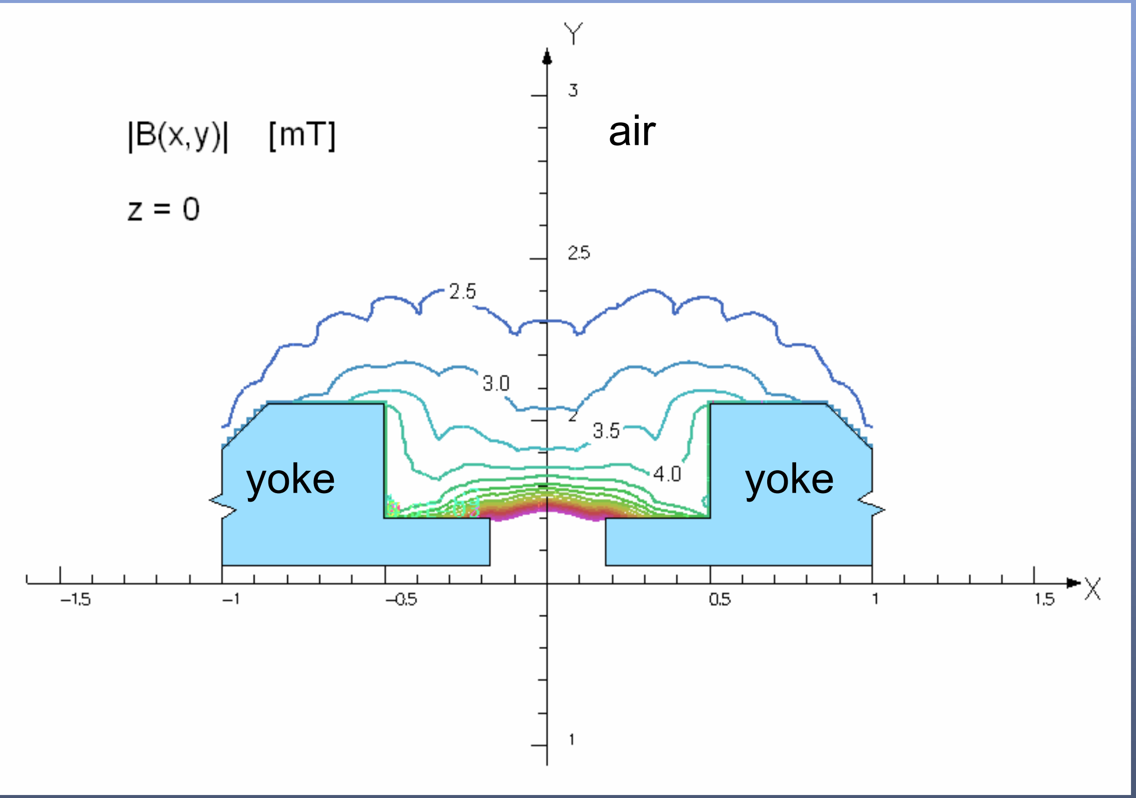
Longitudinal section



The stray fields are at the level of 5 mT.

Stray fields near the target orifice
(from 3D TOSCA model)

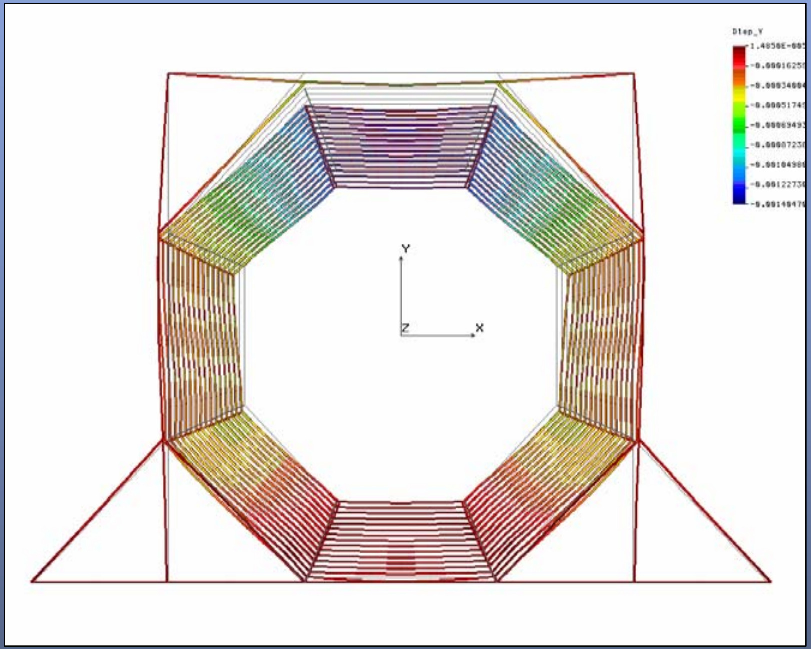
Cross-section



The stray fields are at the level of 5 mT.

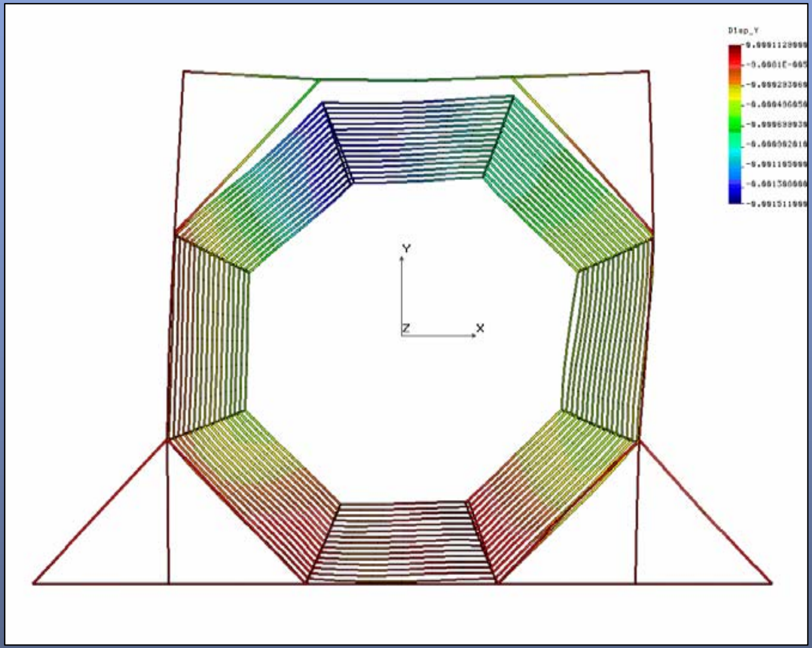
Barrel deformation in the cross section

Yoke barrel gravity load G = 2100 kN



Maximal value of the deformation: u_y = 1.4 mm
Absence of outer support frames would lead
to deformation u_y = 6.5 mm.

gravity load and horizontal load:
Px = 0.25 G (seismic load)

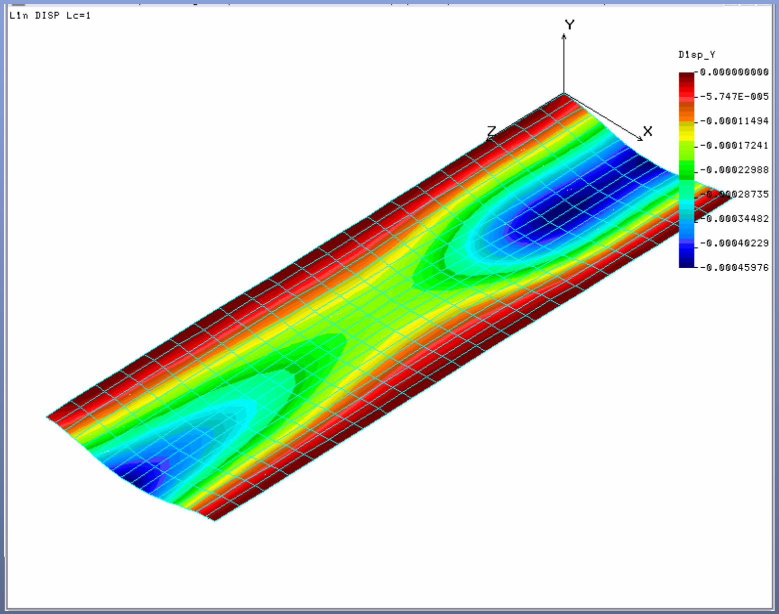


Maximal vertical and horizontal deformations are u_y = 1.5 mm and u_x = 2.0 mm

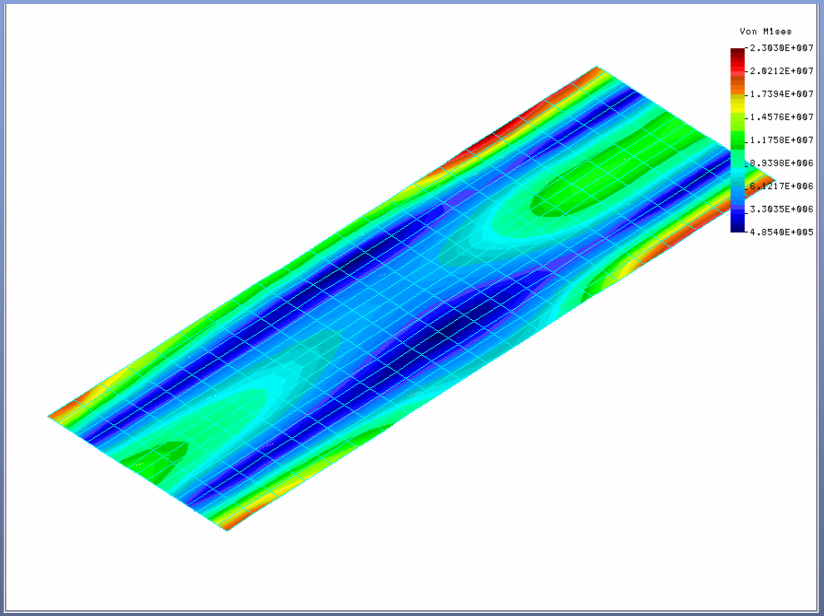
The maximal stress in the plates due to weight and seismic load is σ_{max} = 14 MPa < [σ]
[σ] = 140 MPa

Stresses and deformations in the yoke beams due to magnetic load

(longitudinal section)



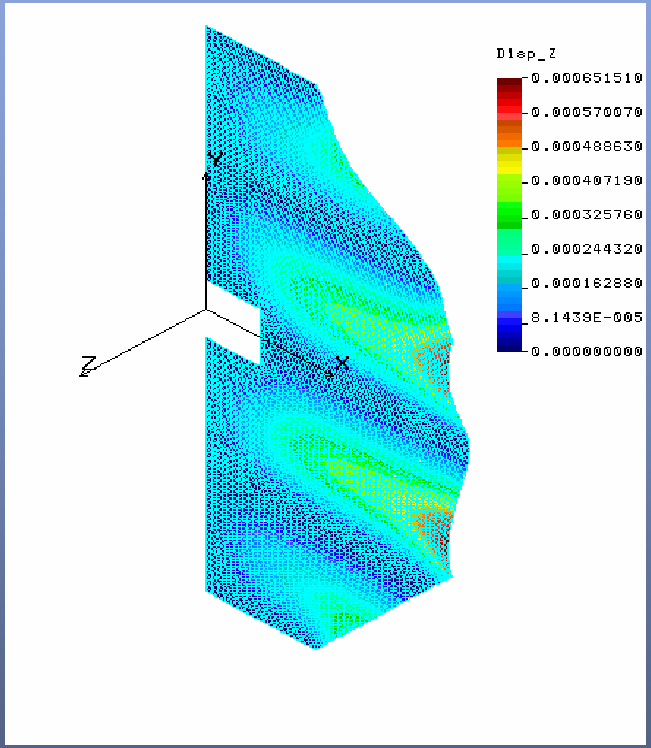
Bending deformation of the inner plate.



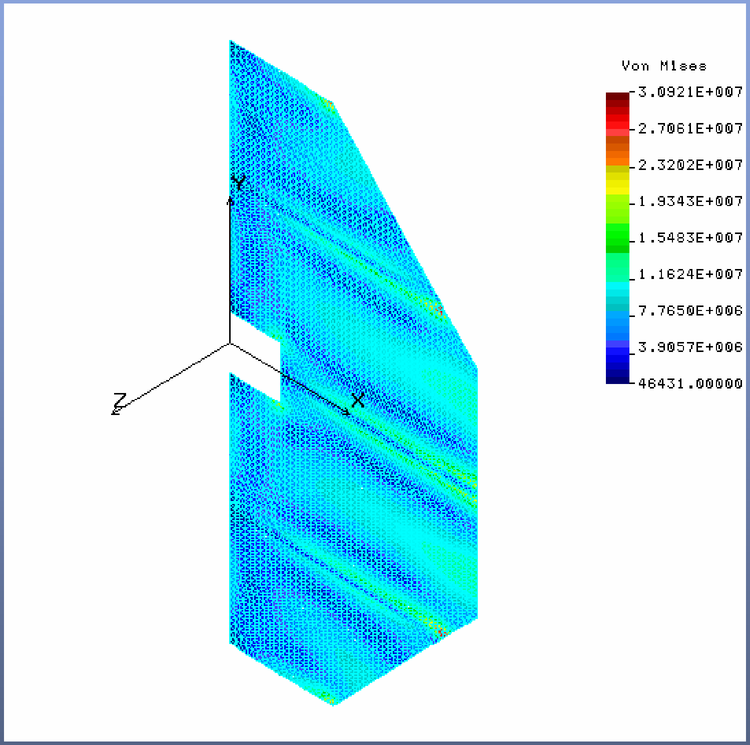
Von Mises stresses in the inner yoke plate

The maximal plate deflection is 0.5 mm, the maximal stress is σ = 28 MPa

Stresses and deformations in the yoke end cap (due to magnetic forces)



Deformation of 40 mm plate in the downstream end cap



Von Mises stresses in 40 mm plate of the downstream end cap

The bending deformation of the mostly loaded 40 mm plate in the downstream end cap: u=0.5 mm, the maximal stress: σ = 31 MPa