Joint Institute for Nuclear Research (Dubna)

Status of the PANDA cryostat design

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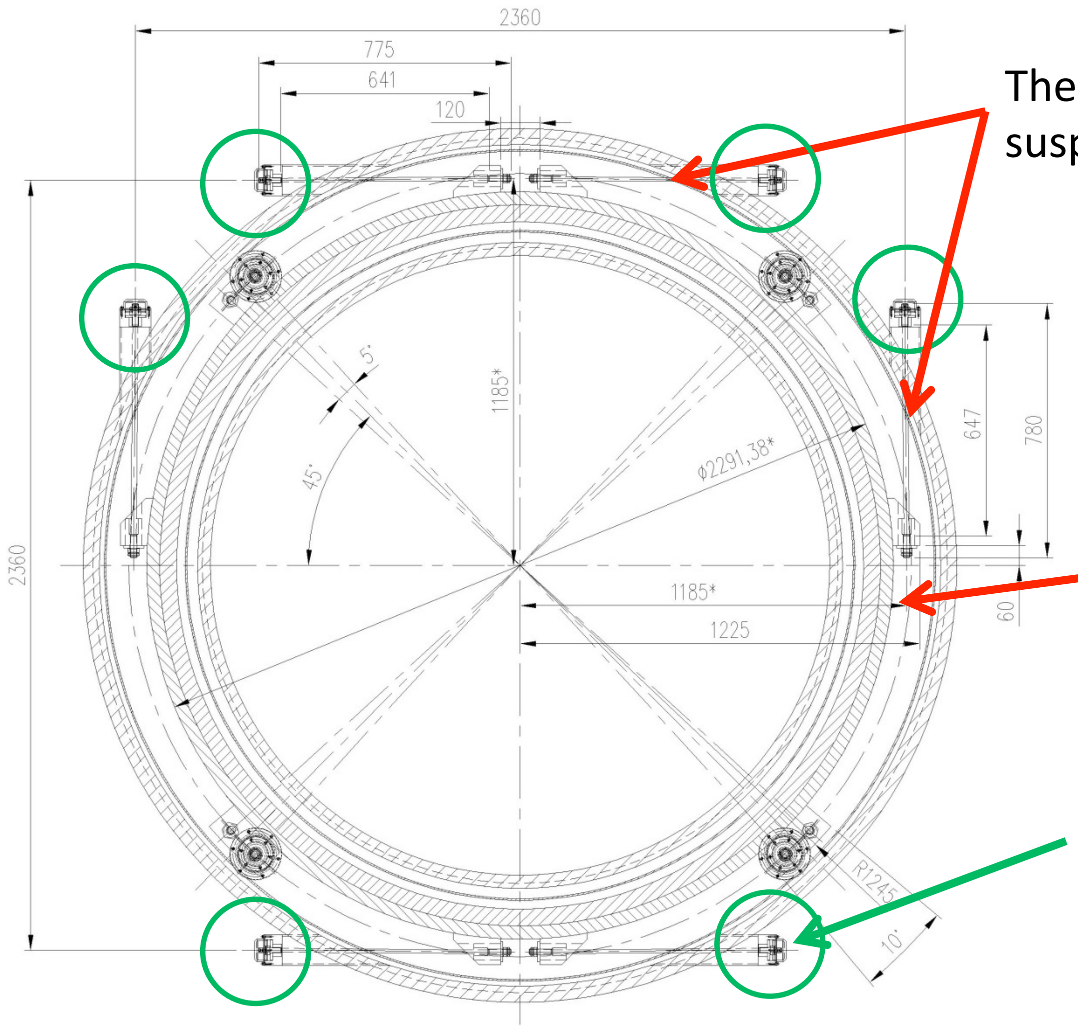
April 15, 2015

Design changes of the suspension system of the PANDA cryostat cold mass

The need of design changes of the suspension system was caused by

- development of the new design of the cold mass by CERN team
- the results of last year's mechanical calculations (despite the sufficient strength, the suspension system had excessive elasticity above the set limit 0.5 mm);
- manufacturing of the tie rods in accordance with the previous design required very time-consuming and costly machining;
- Belleville springs used in the suspension complicate the process of the cold mass installation into the vacuum volume .
- changing the weight of the cold mass from **42 kN** up to **5.9 kN** .

Changes in radial suspension



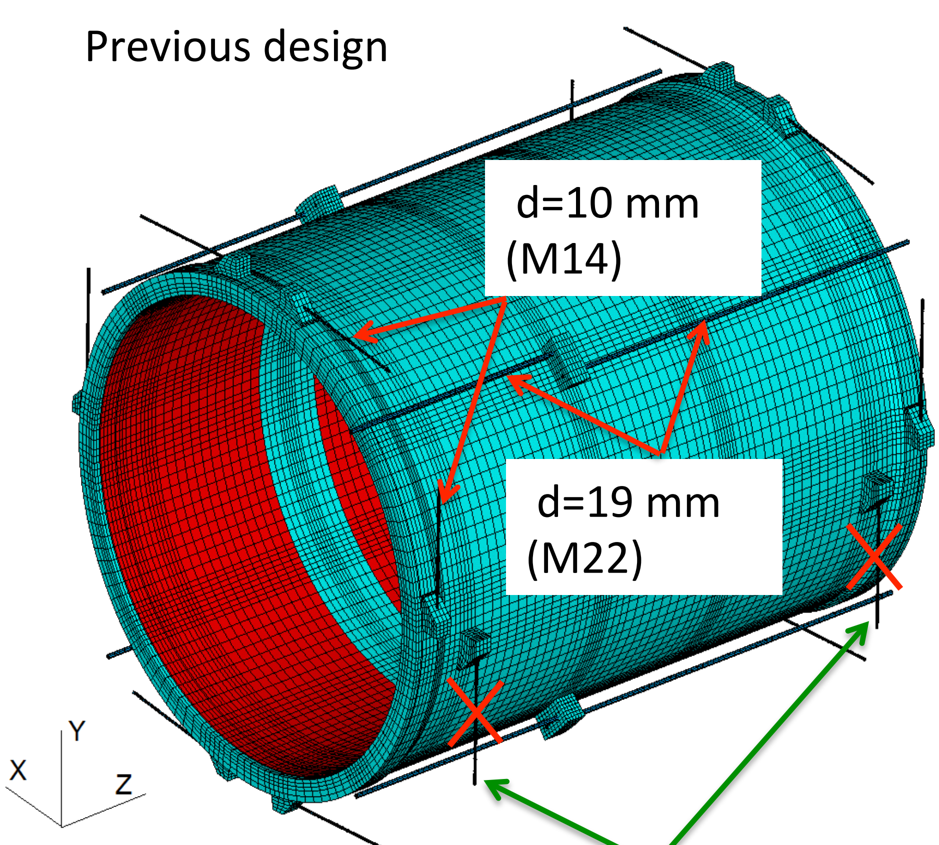
The thickness of all rods of the radial suspension is increased up to 16 mm.

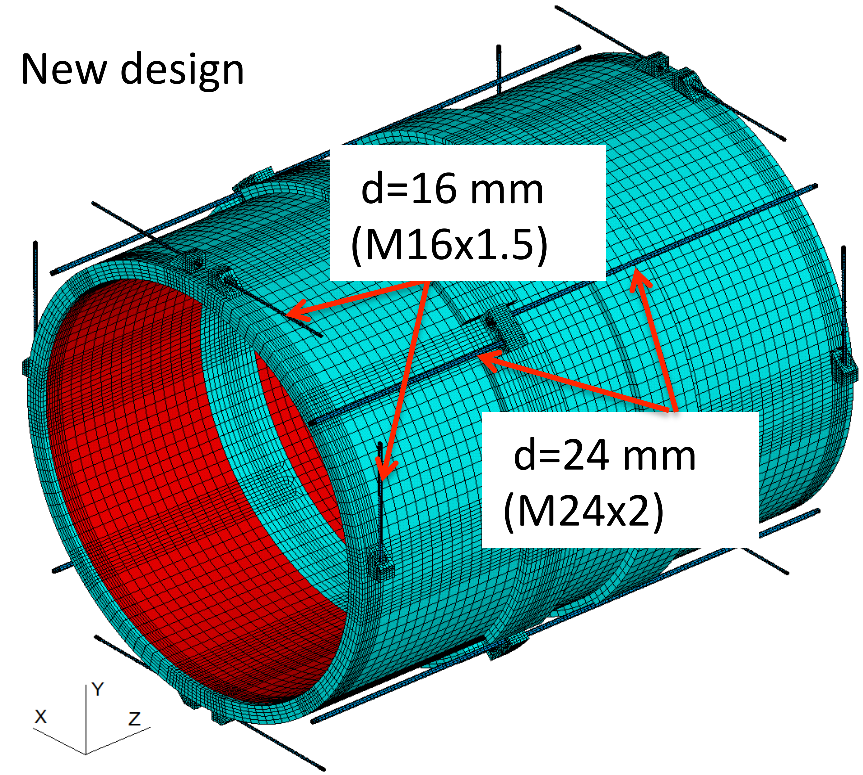
Now vertical rods are able to bear the maximal load applied to two diagonal rods only

There are no bottom vertical rods since now the weight of the cold mass exceeds the permissible radial decentering force **45 kN**

Belleville springs are removed from the construction. This should increase the predictability of the behavior of the suspension - wrong adjustment of the springs increases suspension elasticity under the action of the magnetic forces

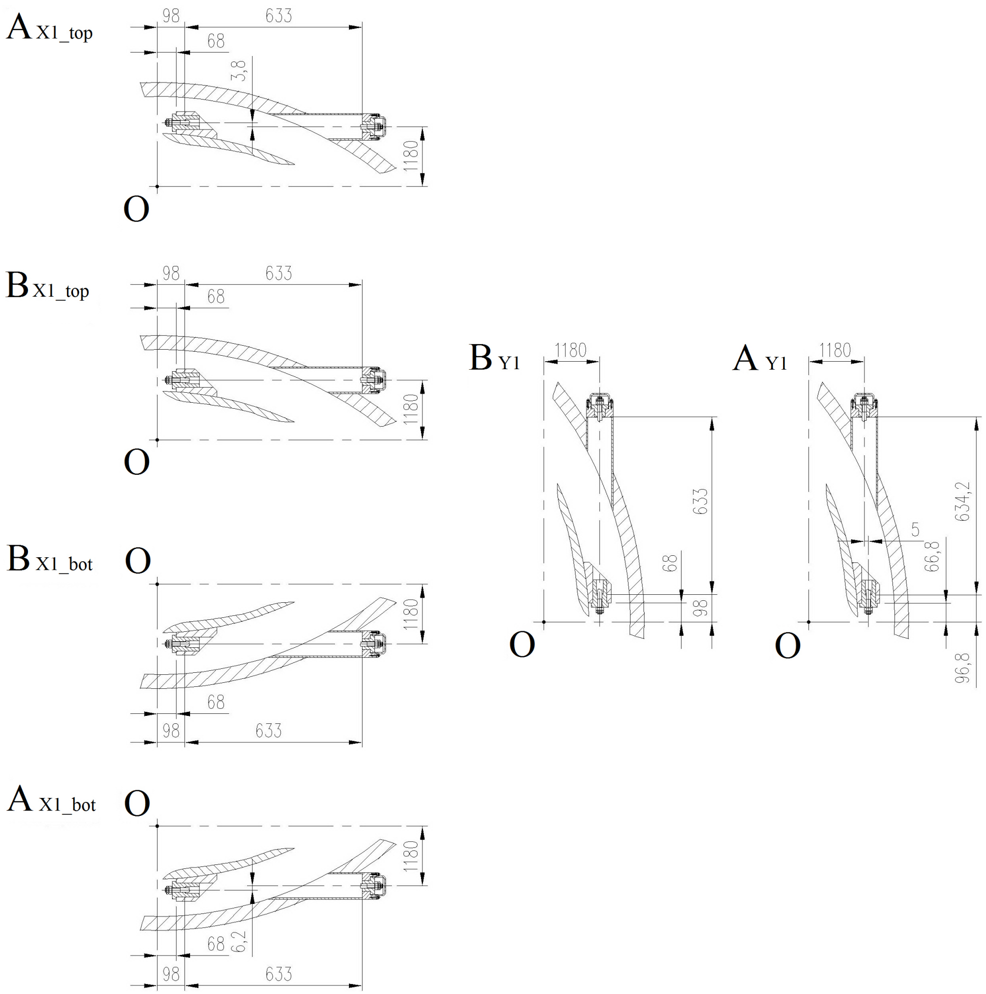
Changes of the diameters of the suspension rods





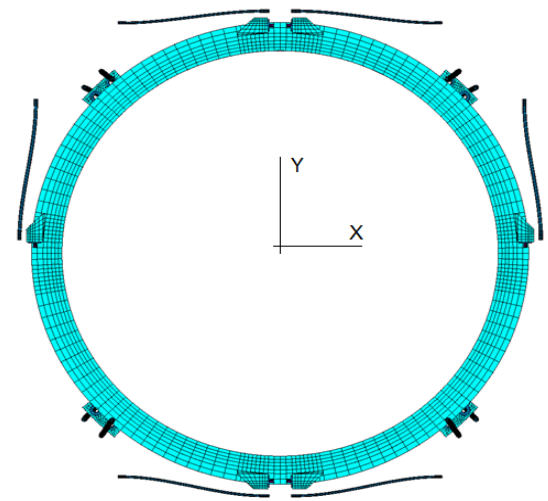
Difficulty in accessing these ties during
Cold mass installation

Pre-bending of the rods of the radial suspension in the XY plane

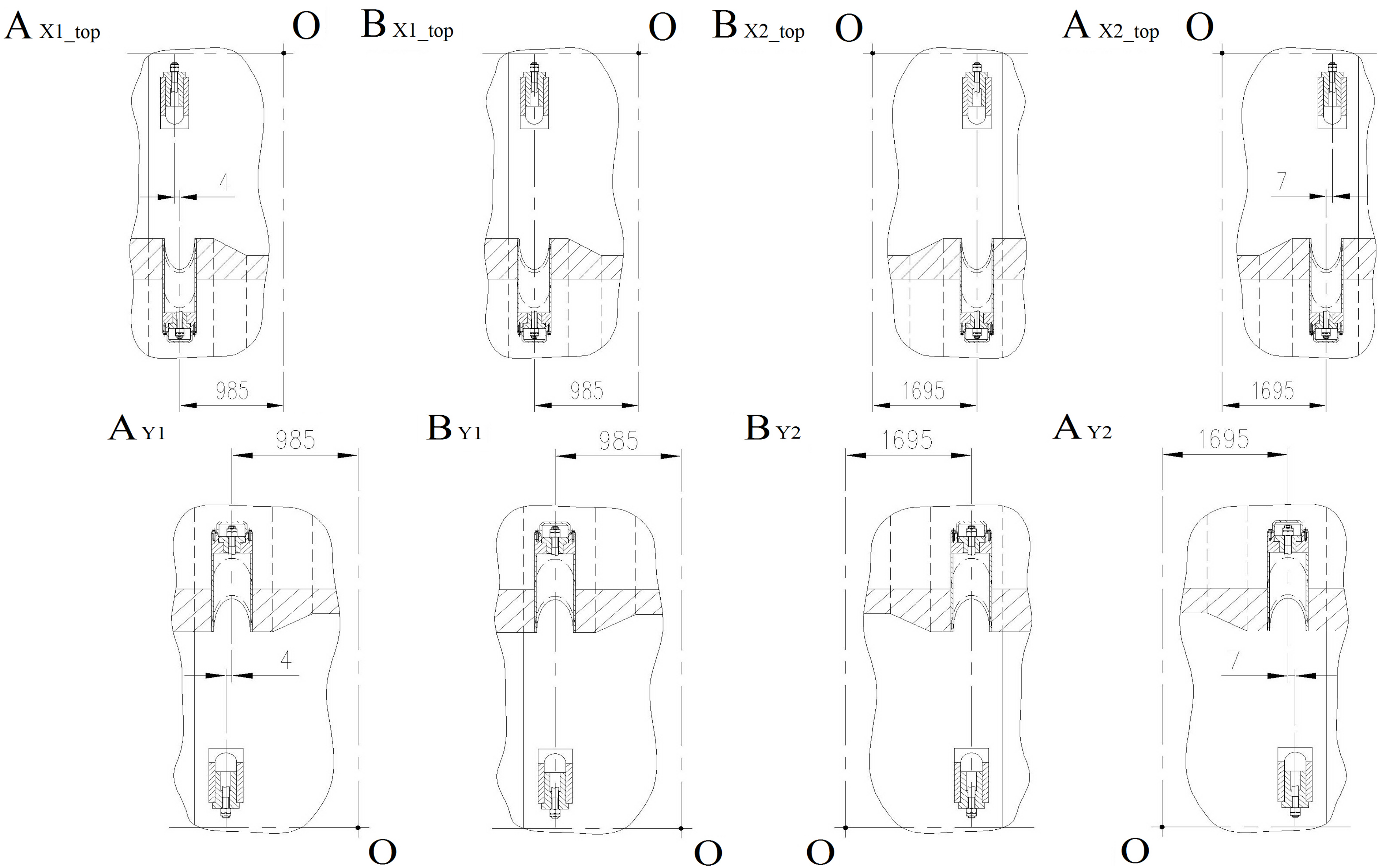


A - corresponds to the warm state of the cold mass

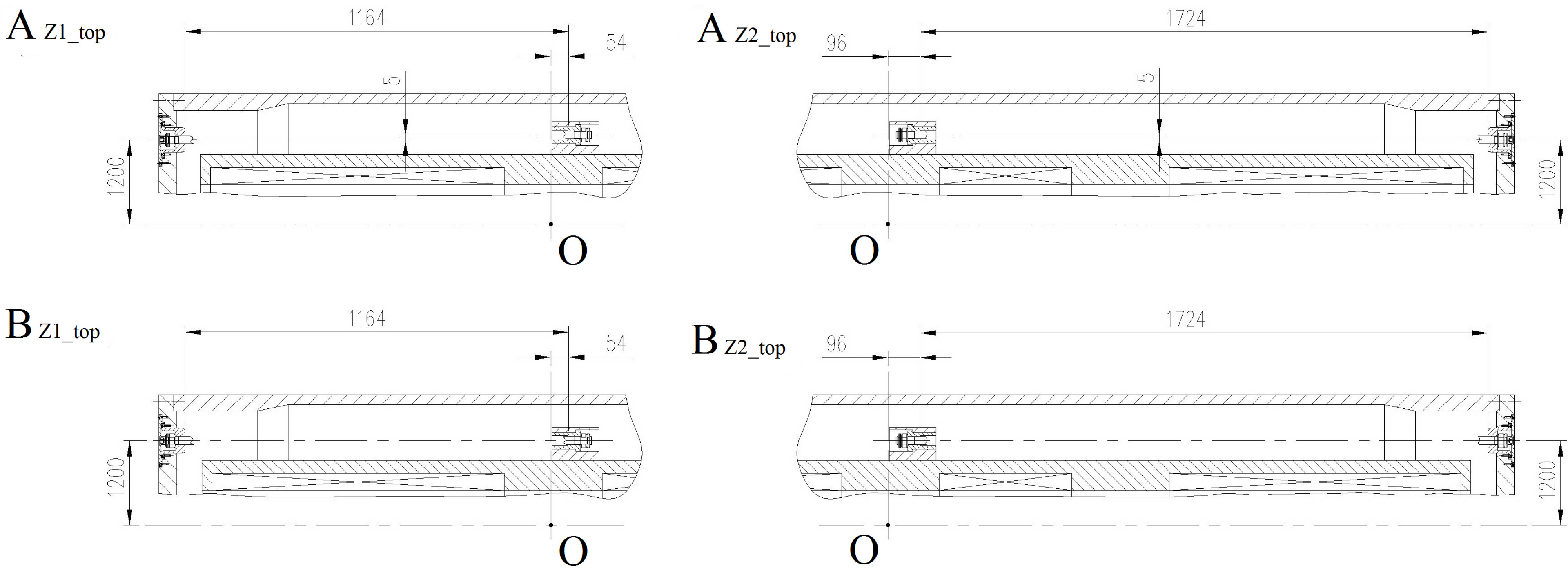
B - corresponds to the cold state of the cold mass



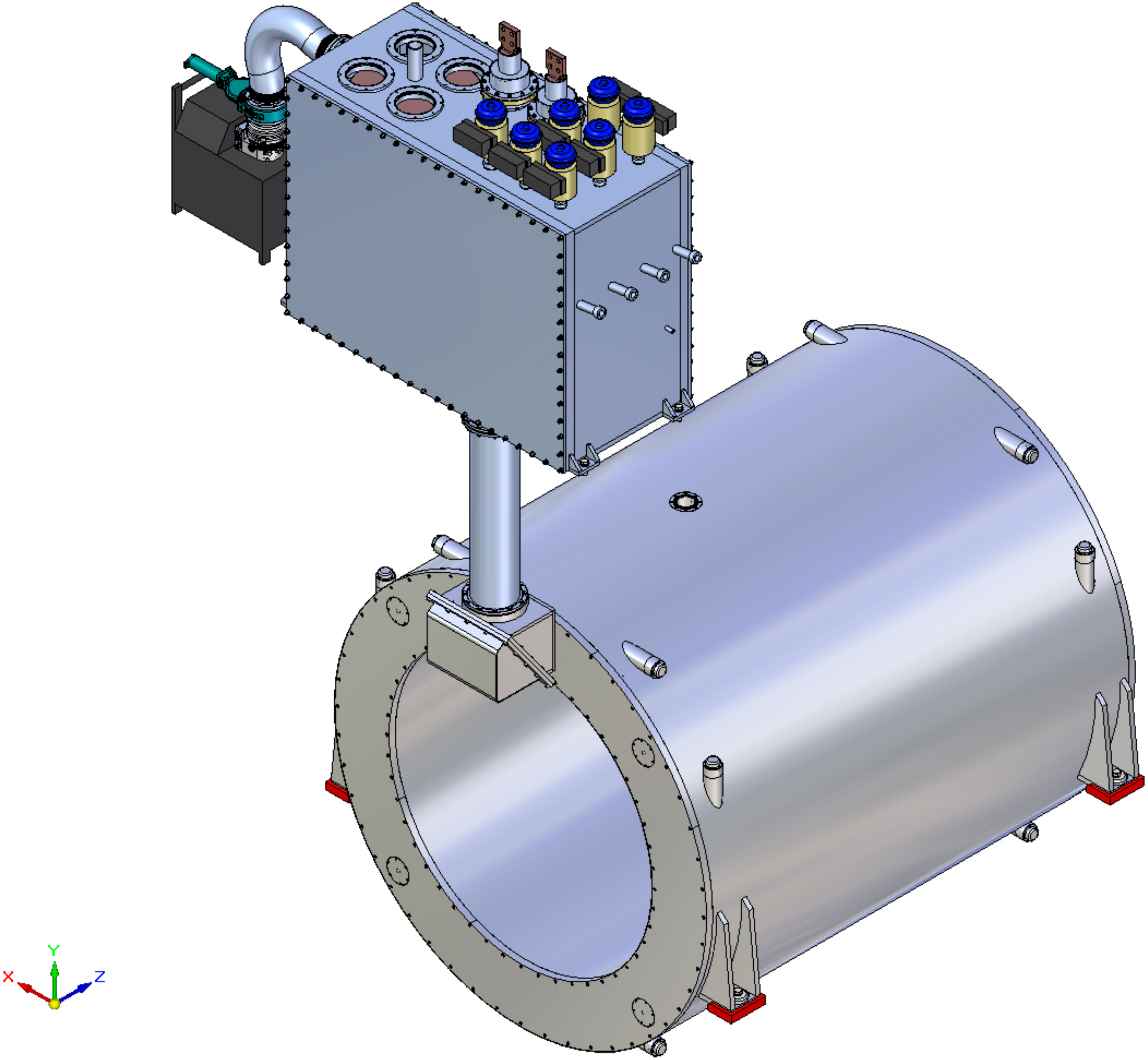
Pre-bending of the rods of the radial suspension in the XZ and YZ planes

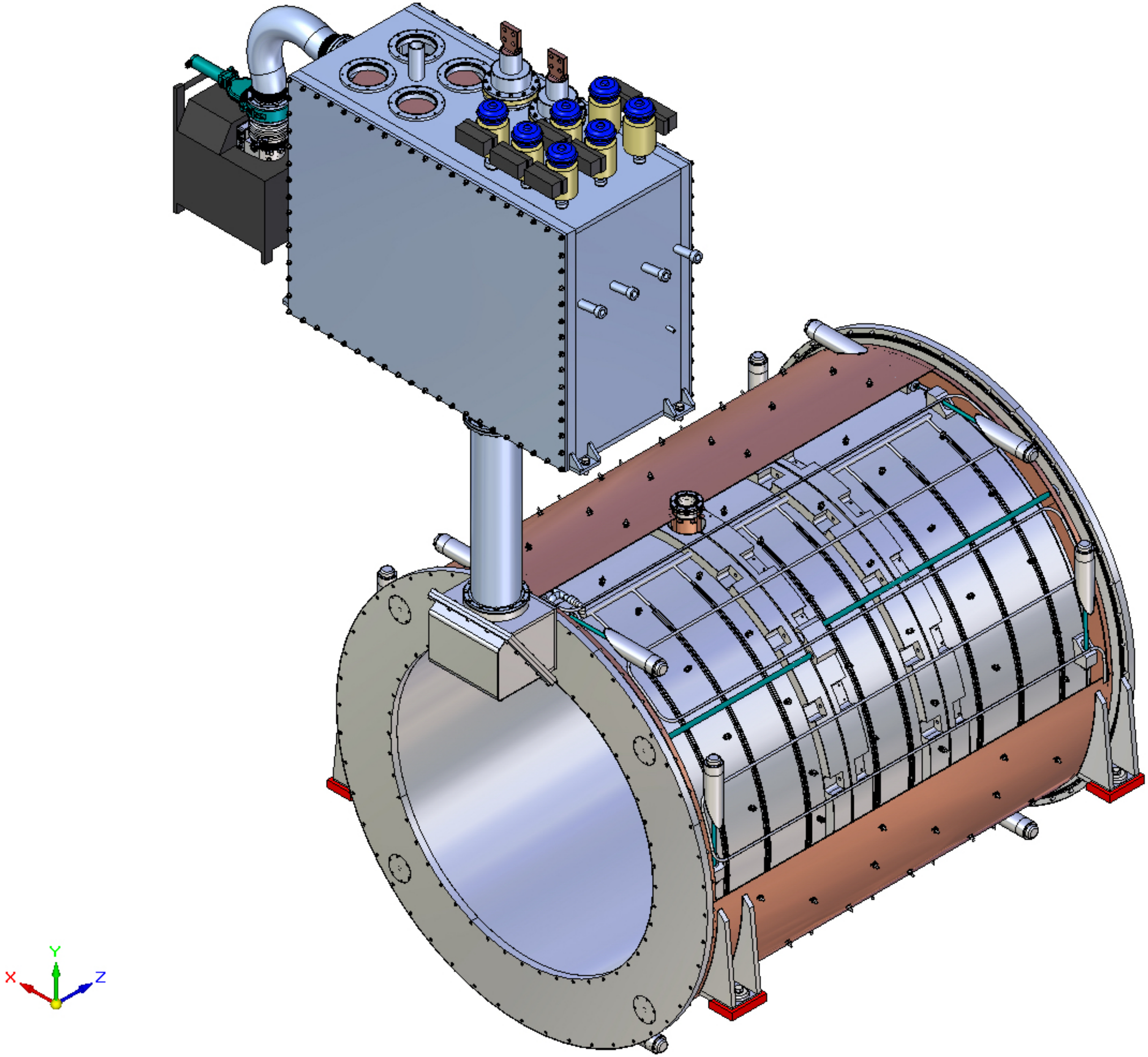


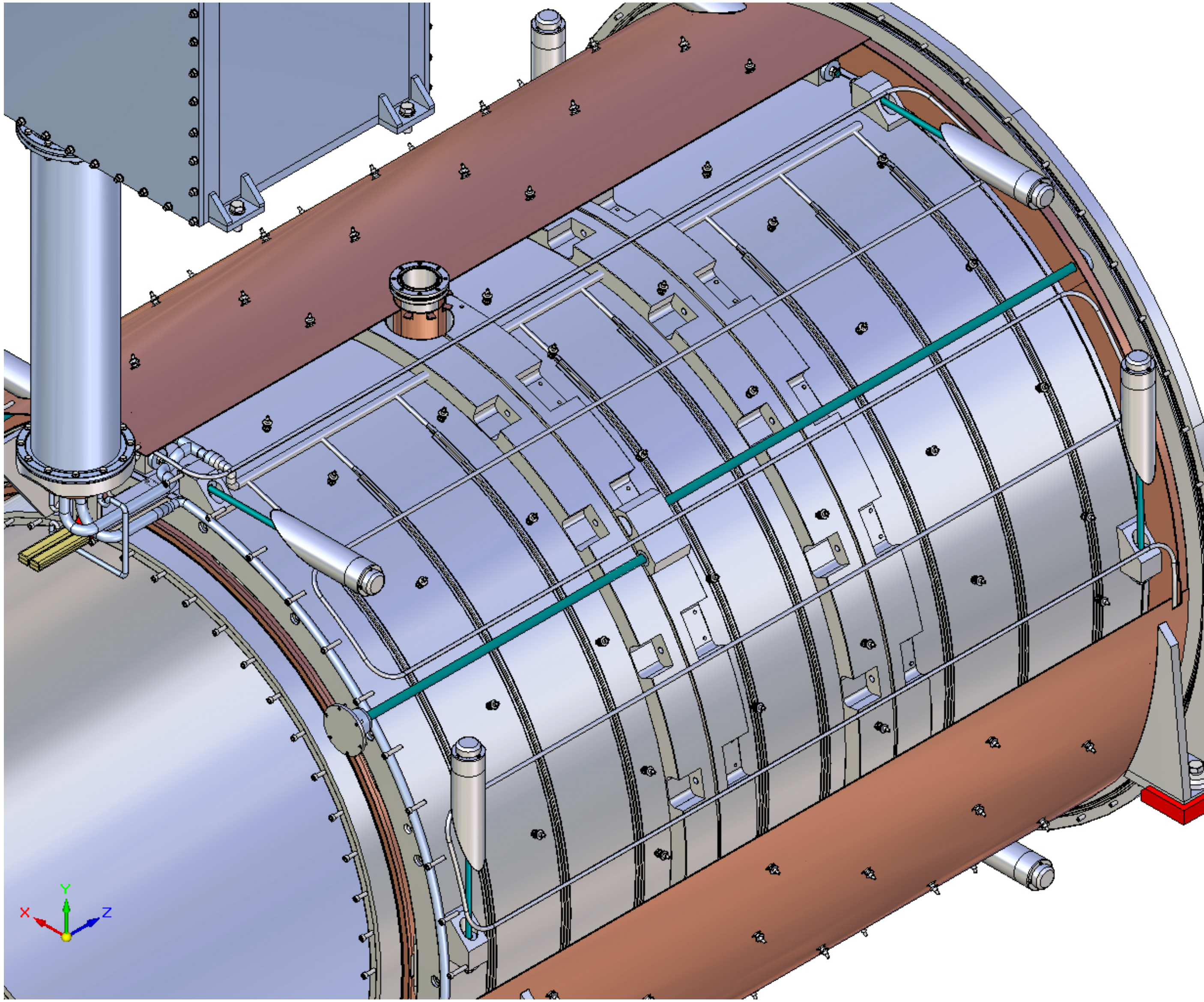
Pre-bending of the axial rods

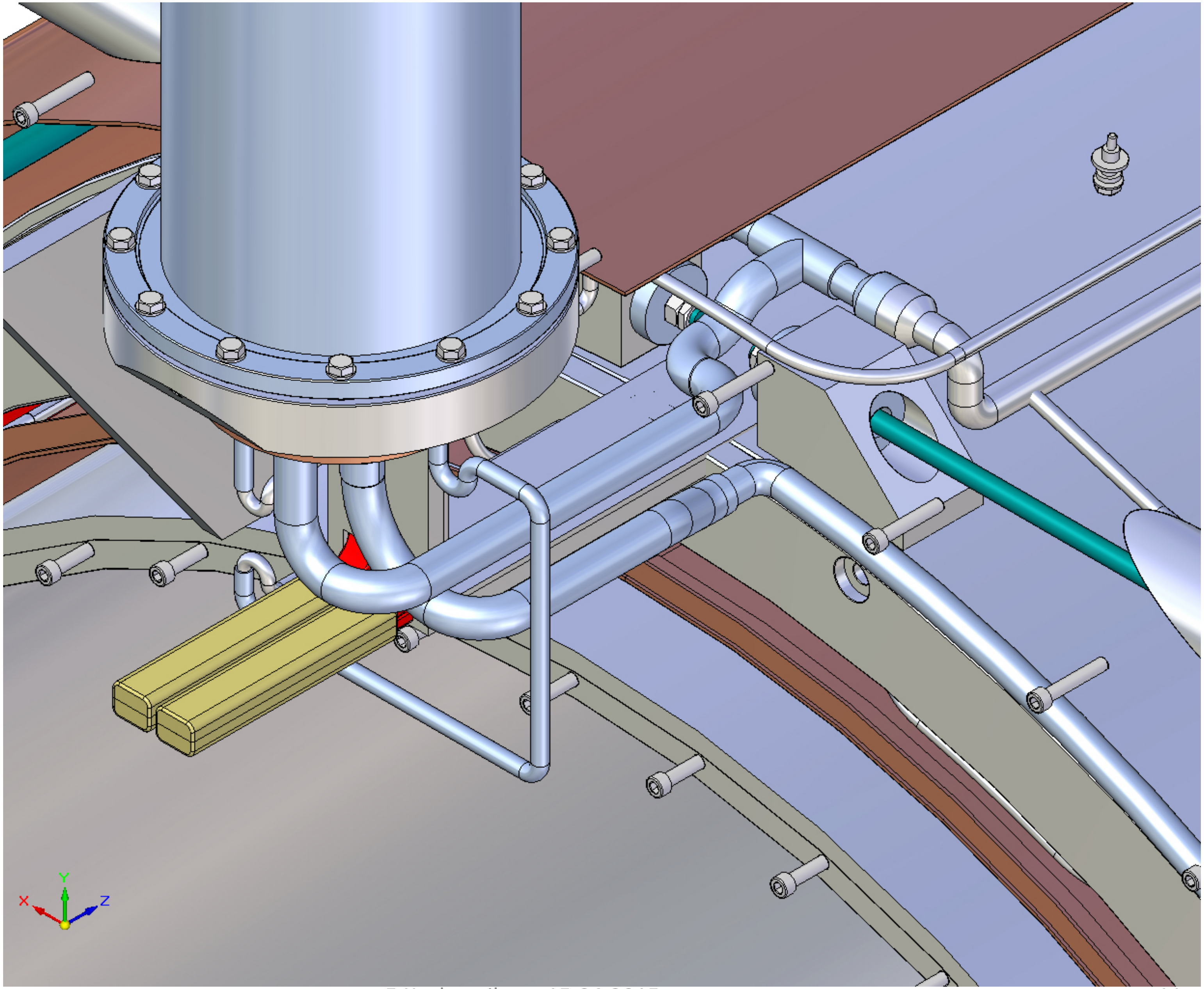


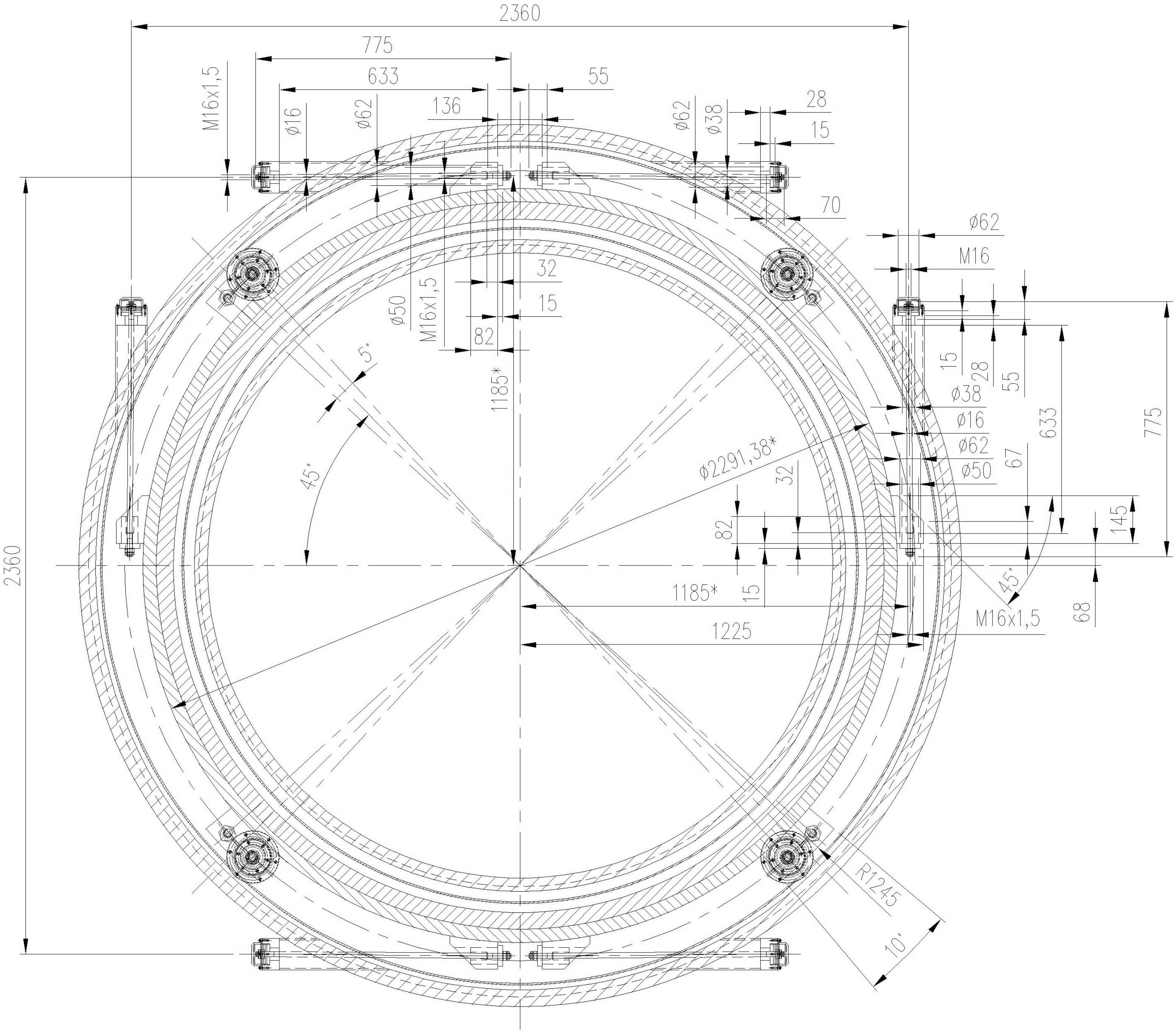
Pre-bending of the axial ties decreases the bending stress but at the same time it could complicates the assembly procedure of the cryostat.

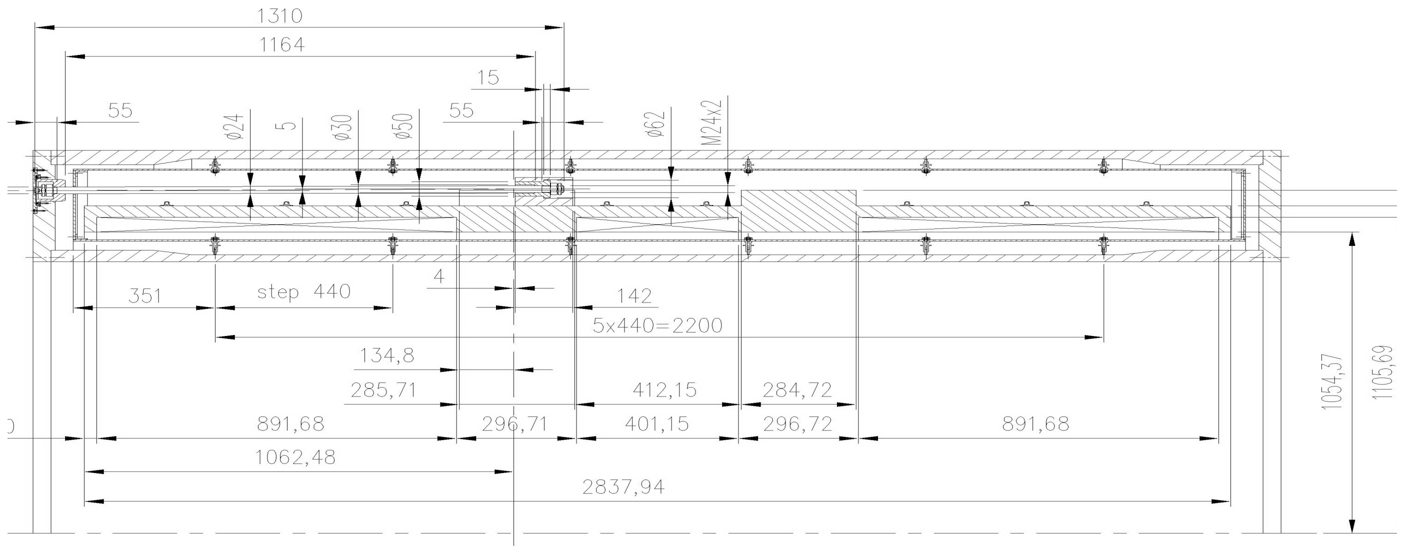

Y
X
Z

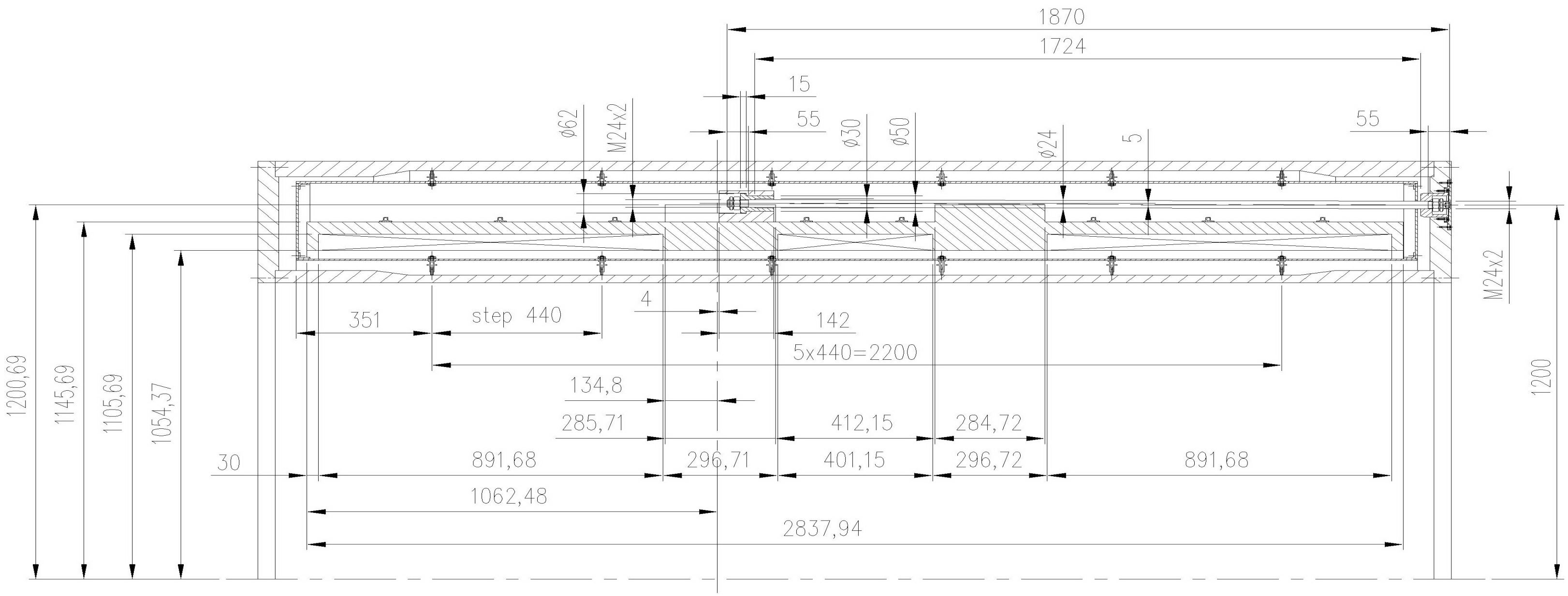

Y
X
Z


Y
X
Z


X
Y
Z

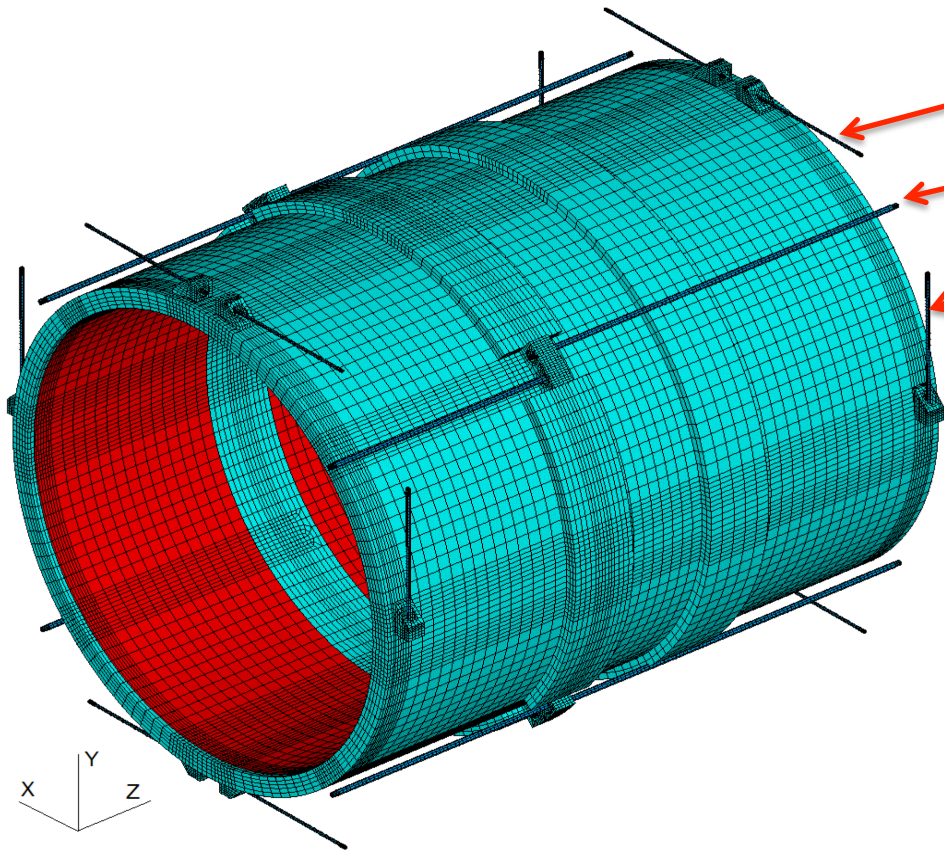

2360
775
633
55
136
M16x1,5
⌀16
⌀62
⌀62
⌀38
28
15
70
⌀62
M16
32
15
⌀50
M16x1,5
82
1185*
5°
45°
15
28
55
⌀38
⌀16
⌀62
⌀50
633
775
67
⌀2291,38*
32
82
145
15
1185*
1225
45°
M16x1,5
68
2360
R1245
10°


1310
1164
15
55
55
⌀24
5
⌀30
⌀50
⌀62
M24x2
351
step 440
4
142
5x440=2200
134,8
285,71
412,15
284,72
891,68
296,71
401,15
296,72
891,68
1062,48
2837,94
1054,37
1105,69


1870
1724
15
55
55
⌀62
M24x2
⌀30
⌀50
⌀24
5
M24x2
351
step 440
4
142
5x440=2200
134,8
285,71
412,15
284,72
30
891,68
296,71
401,15
296,72
891,68
1062,48
2837,94
1200,69
1145,69
1105,69
1054,37
1200

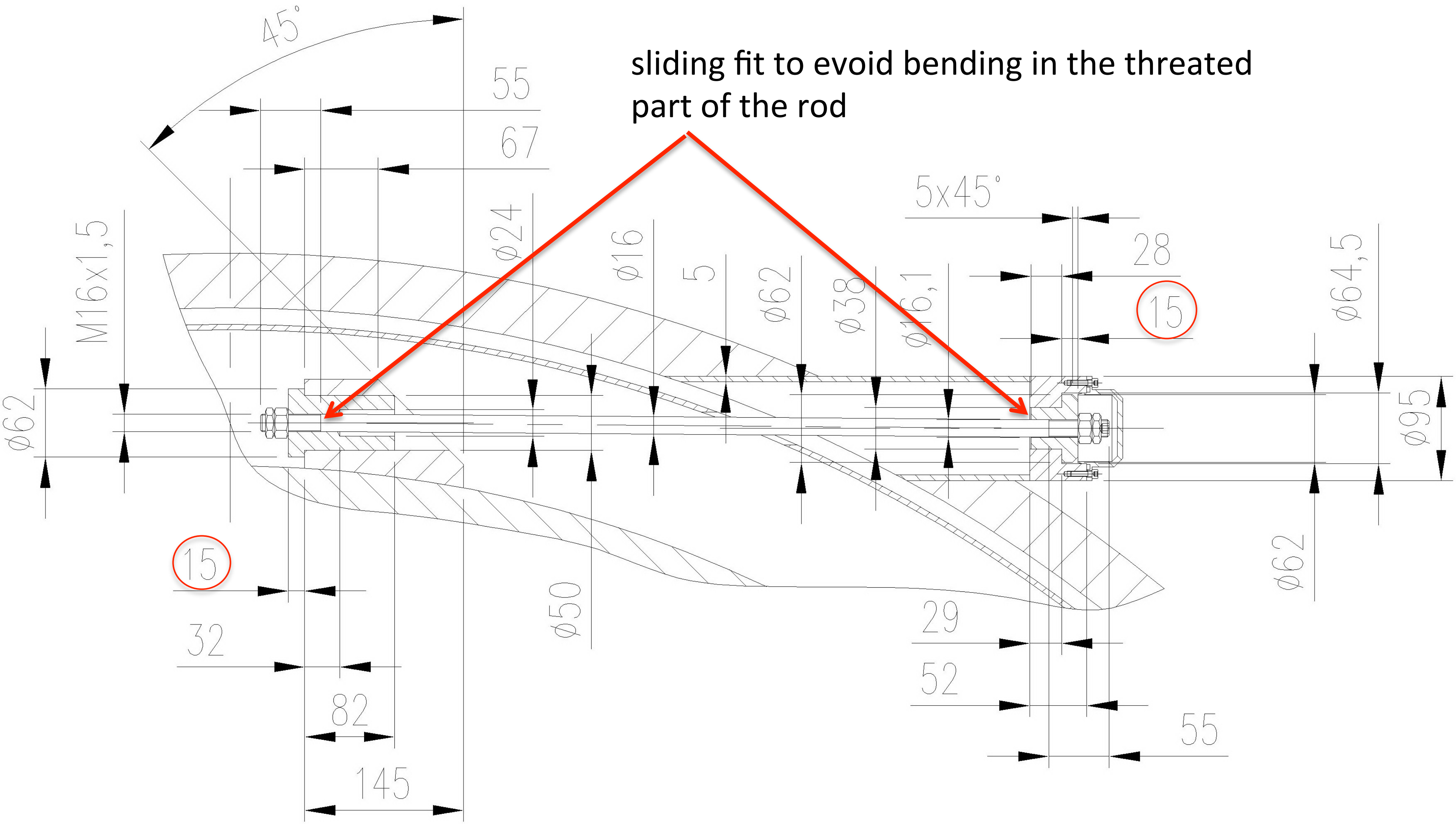
Maximal forces in the thickened ties

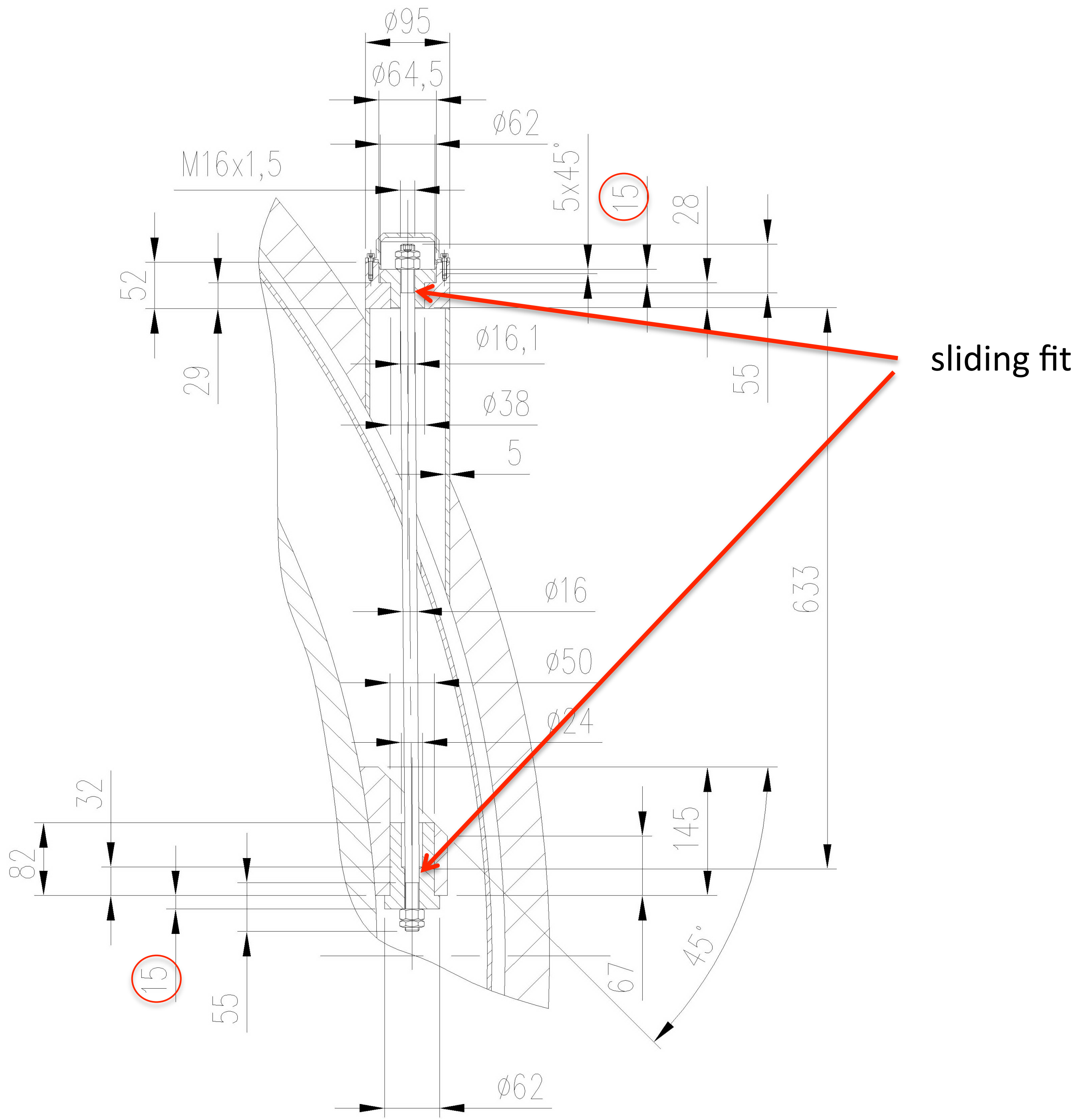
Large forces lead to the high stresses in the head and foot units of the suspension rods



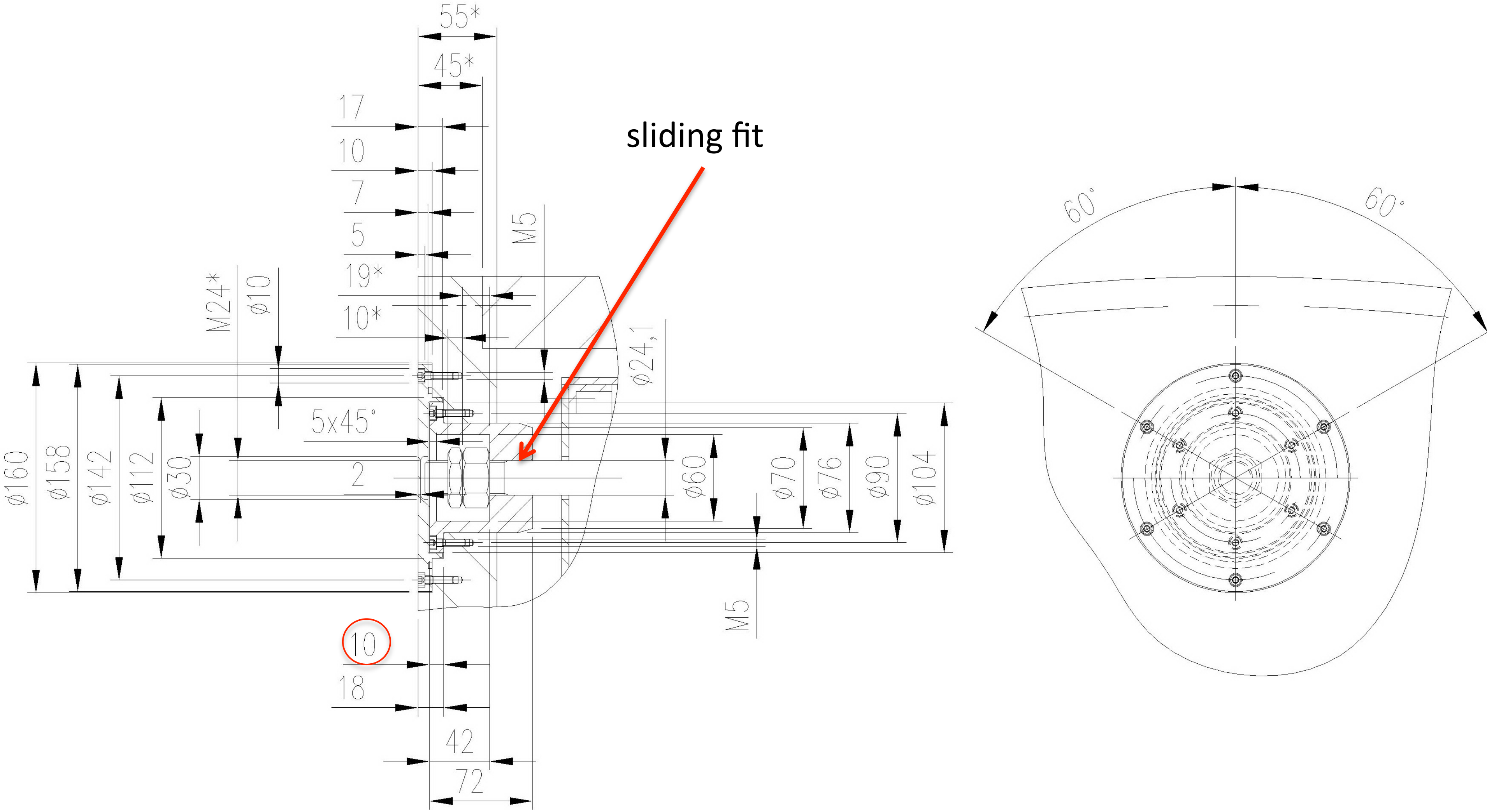
$F_{x\,max} = 79$ kN
$F_{z\,max} = 158$ kN
$F_{y\,max} = 30$ kN

sliding fit to evoid bending in the threated part of the rod




Ø95
Ø64,5
Ø62
M16x1,5
5x45°
15
28
52
29
Ø16,1
55
Ø38
5
633
Ø16
Ø50
Ø24
32
145
82
67
45°
15
55
Ø62
sliding fit

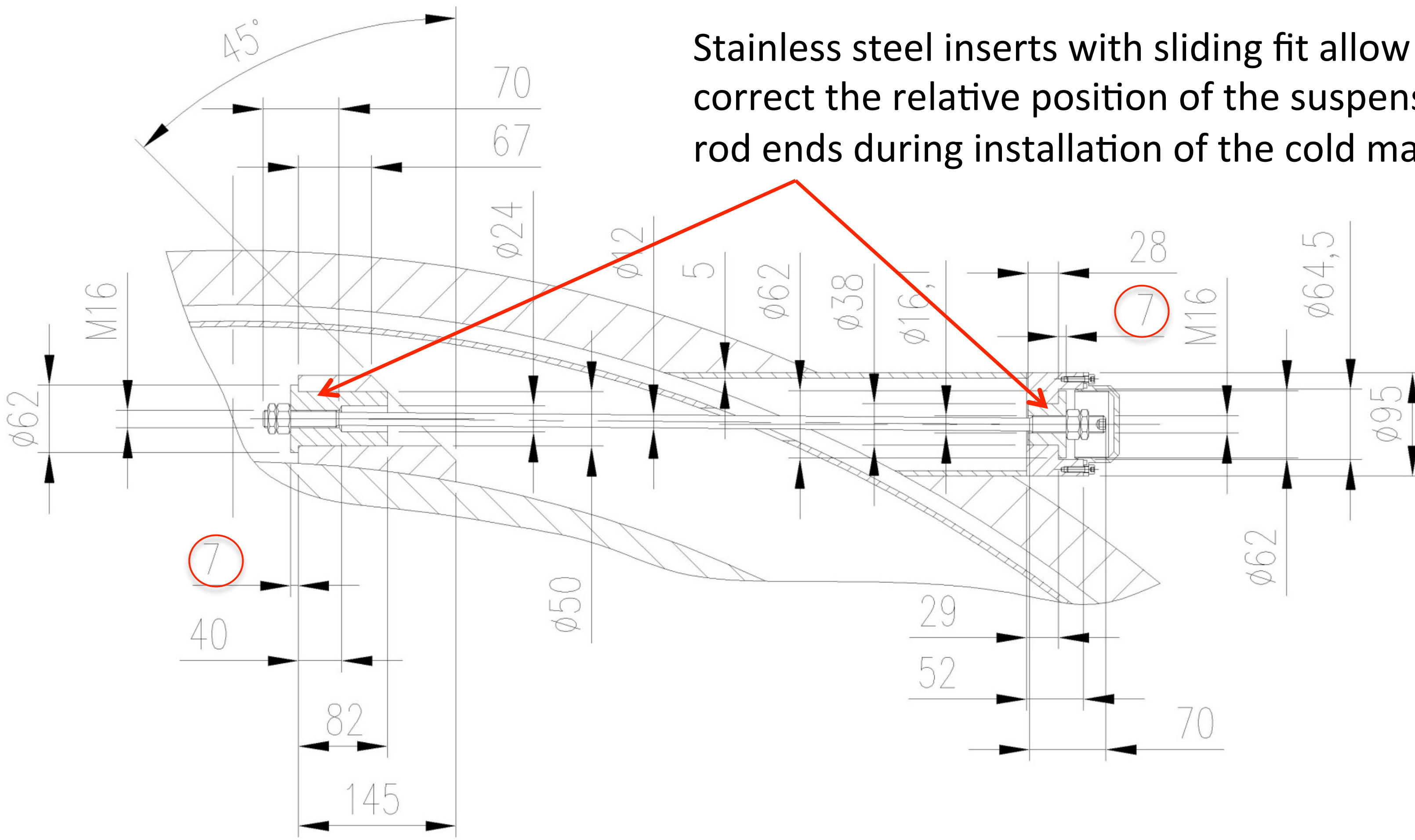
sliding fit



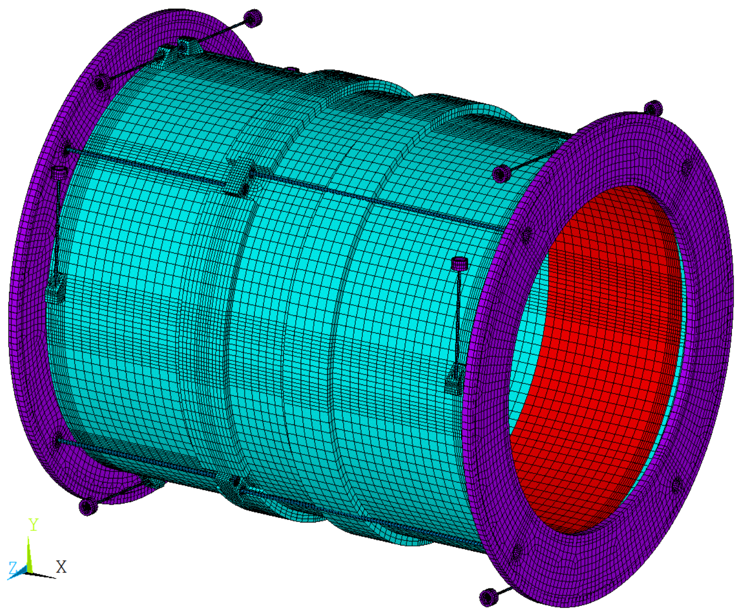
55*
45*
17
10
7
5
19*
10*
M5
M24*
ϕ10
ϕ24,1
5x45°
2
ϕ160
ϕ158
ϕ142
ϕ112
ϕ30
ϕ60
ϕ70
ϕ76
ϕ90
ϕ104
M5
10
18
42
72
60°
60°

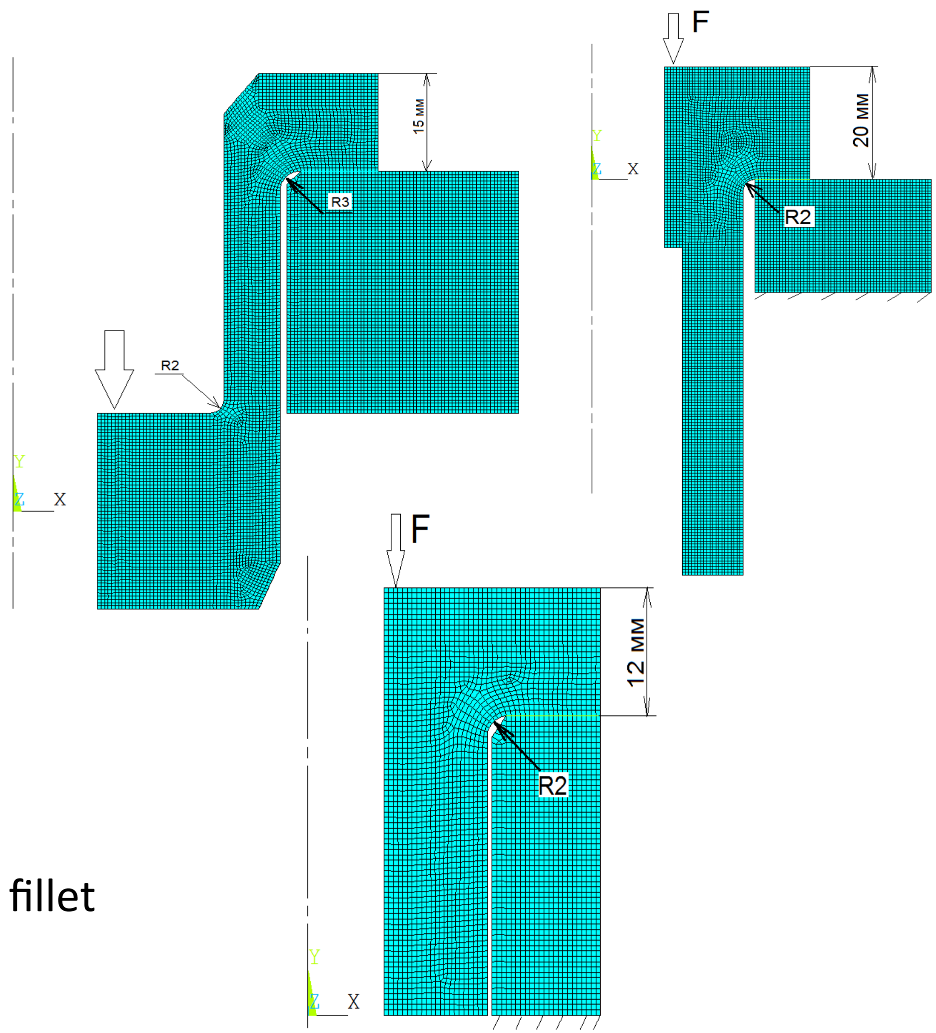
Details of a horizontal unit of the radial suspension

Stainless steel inserts with sliding fit allow to correct the relative position of the suspension rod ends during installation of the cold mass.



FE mesh for mechanical computations

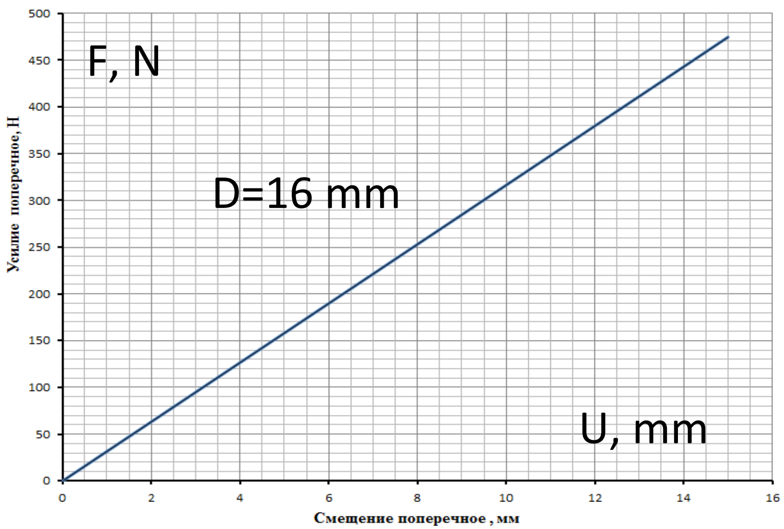




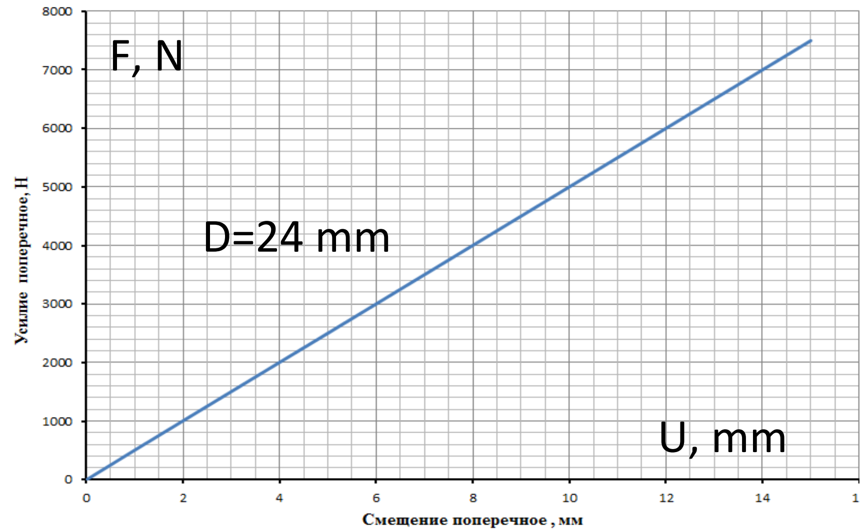
Recommendations resulting from calculations:

thickness of the flanges and the fillet radius should be increased

Lateral force required to displace the end of one rod when installing the cold mass



U,мм	F, H
0	0
1	31.63
2	63.27
3	94.9
4	126.5
5	158.2
6	189.8
7	221.5
8	253.1
9	284.7
10	316.4
11	348.1
12	379.7
13	411.4
14	443.1
15	474.7

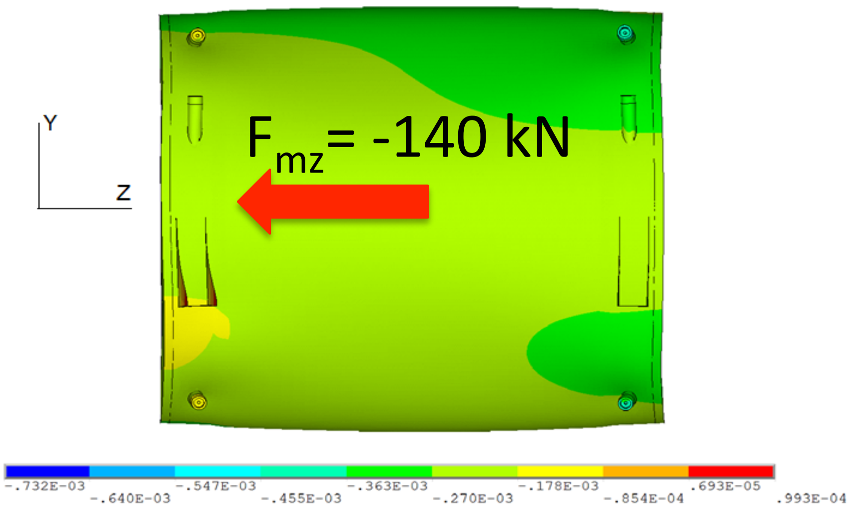


U,мм	F, H
0	0
1	505.4
2	1005
3	1504
4	2004
5	2503
6	3003
7	3503
8	4002
9	4502
10	5001
11	5501
12	6000
13	6500
14	6999
15	7499

For example, to displace the cold mass in the axial direction in the process of its installation into the vacuum shell at a distance of 11 mm for mounting the rods of radial suspension it is required to apply the total force of 2100 N.

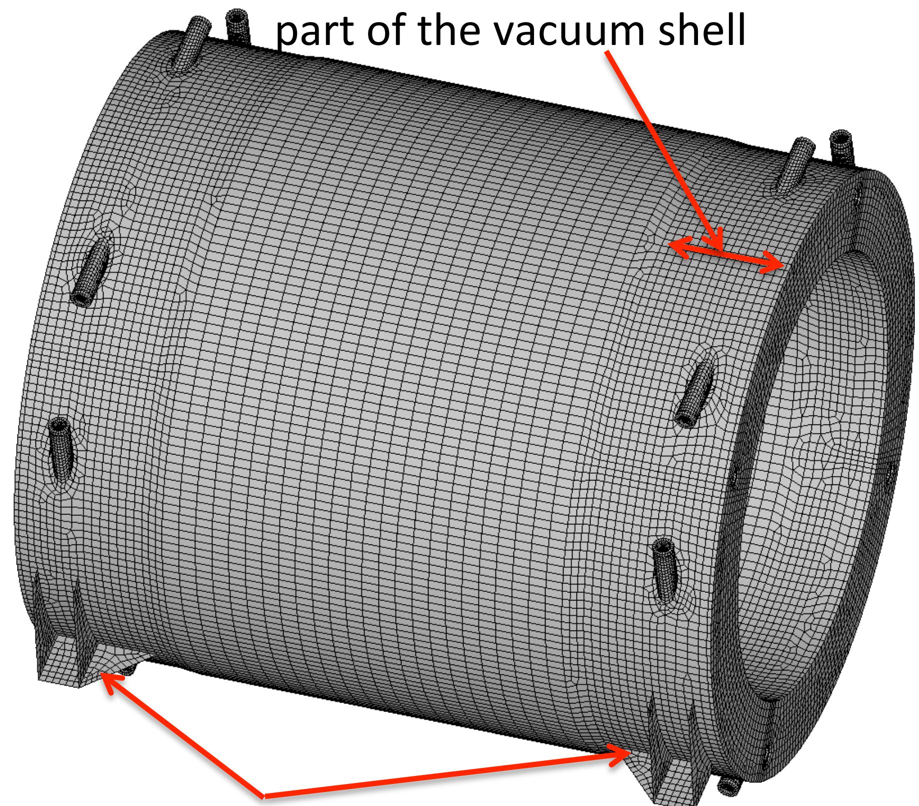
Possible strengthening of the cryostat supports

Cryostat fixation units have excessive flexibility in axial direction.



Axial displacement of the outer shell of the cryostat

Widening of the the thickened part of the vacuum shell



Reinforcement of the supports

Strengthening reduces displacement by 0.06 mm

Shift of the cold mass under action of the magnetic forces

Maximal allowable shift of the cold mass center in any direction because of magnetic forces	0.5 mm
Maximal axial deviation of the cold mass position	-20 mm (F_{mz} = -140 kN)
Maximal radial deviation of the cold mass position	15 mm (F_{mr} = 45 kN)

	Thin suspension rods		Thickened suspension rods		Thickened suspension rods + reinforced cryostat supports	
Magnetic loads	U_z, mm	U_x, mm	U_z, mm	U_x, mm	U_z, mm	U_x, mm
F_z = -40 kN	0.23	0	0,164	0	0,166	0
F_z = -140 kN, F_x = 45 kN	0.79	0.6	0,59	0,243	0,531	0,241

Contribution to the axial movement of the cold mass 0.59 mm:

- elasticity of the axial rods — 0.27 mm (46%)
- deformation of the cryostat supports — 0.173 mm (29%)
- deformation of the flanges of the cryostat shell together with support flanges of the axial ties and deformation of the support bosses on the cold mass — 0.147 mm (25%)

Interface of the cryostat and cold mass in nominal position

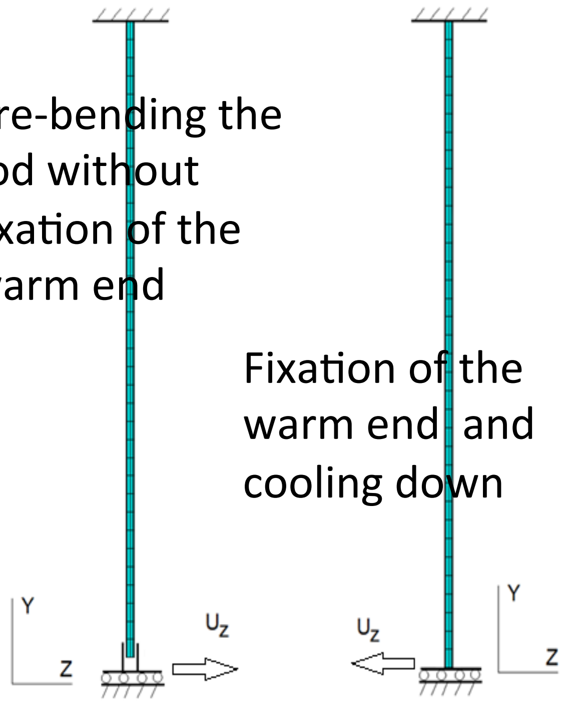
- Although we have some space for axial and radial corrections of the cold mass position inside the cryostat, practically it can't be implemented due to the limitations imposed by stresses in radial suspension rods.
- Correction of the sc coil position relative the yoke aperture can be provided by means of fitting spacers in the cryostat support legs. This type of adjustment can be limited by the positions of the detectors

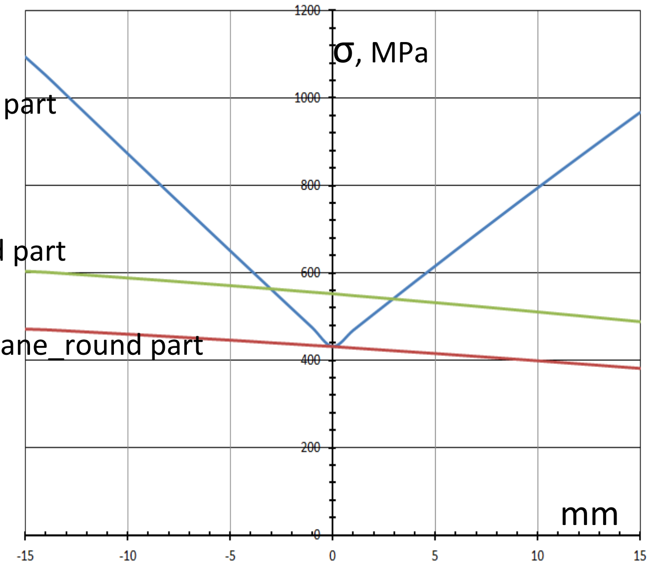
Conclusion: We have to ensure precise location of the cold mass inside the cryostat maximally

Evaluating permissible devation of foot/head mutual positions of a horizontal rod in the process of cold mass installation

Pre-bending the rod without fixation of the warm end

Fixation of the warm end and cooling down





Maximal membrane stress in the horizontal rods (no bend after cooling down):

round part	391 MPa
threaded part	500 MPa < $(\sigma)_3$=689MPa

Permissible additives in membrane and bending stresses due to incorrect installation of a suspension rod in the warm state

$\Delta\sigma_{membr}$ = 689 – 500 = 189 MPa

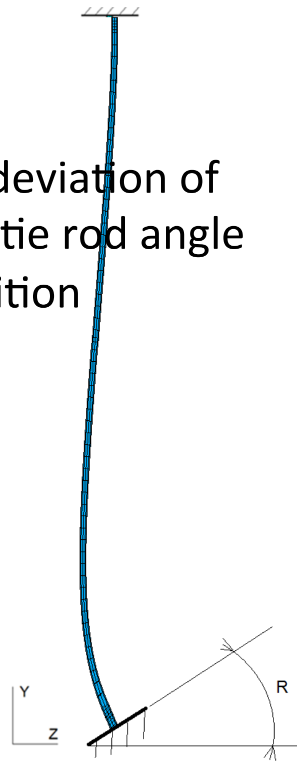
For the increase of bending stress of $\Delta\sigma_{membr}$= 2.8 Mpa/mm it would correspond to 67 mm of permissible shift

$\Delta\sigma_{bend}$ = $(\sigma)_4$– 391 = 510 MPa - it corresponds to the maximal permissible shift of the head part of a rod of about **12 mm**

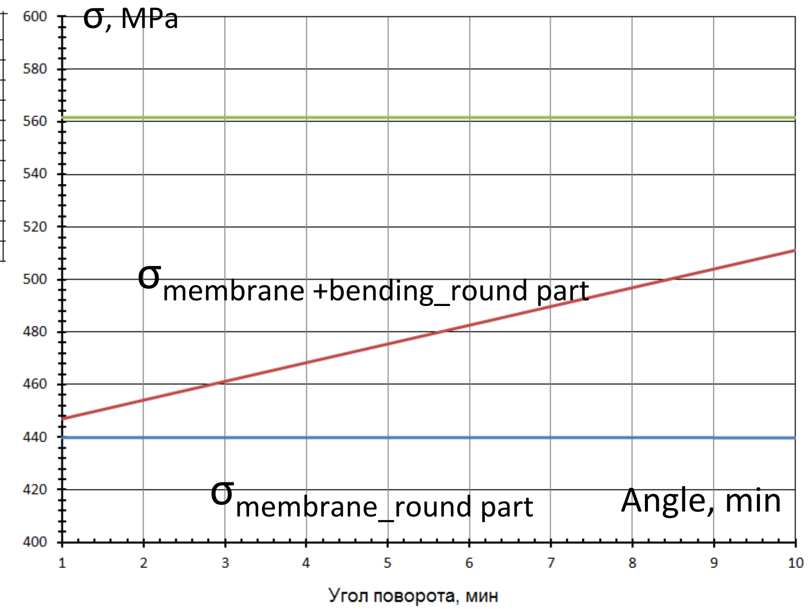
$(\sigma)_4$=901 Mpa

Evaluating permissible deviation of a horizontal rod end angle position in the process of cold mass installation

R - deviation of the tie rod angle position



R	Sm1	Sm	Sb	Smb
мин	МПа			
1	561.7	439.8	7.1	447.0
2	561.7	439.8	14.3	454.1
3	561.7	439.8	21.4	461.2
4	561.7	439.8	28.5	468.4
5	561.7	439.8	35.7	475.5
6	561.6	439.8	42.8	482.6
7	561.6	439.8	49.9	489.8
8	561.6	439.8	57.1	496.9
9	561.6	439.8	64.2	504.0
10	561.6	439.8	71.4	511.1



$\Delta\sigma_{bend} = (\sigma)_4 - 391 = 510$ MPa - corresponds to the maximal permissible incorrect angle of a suspension rod end of about **1°**

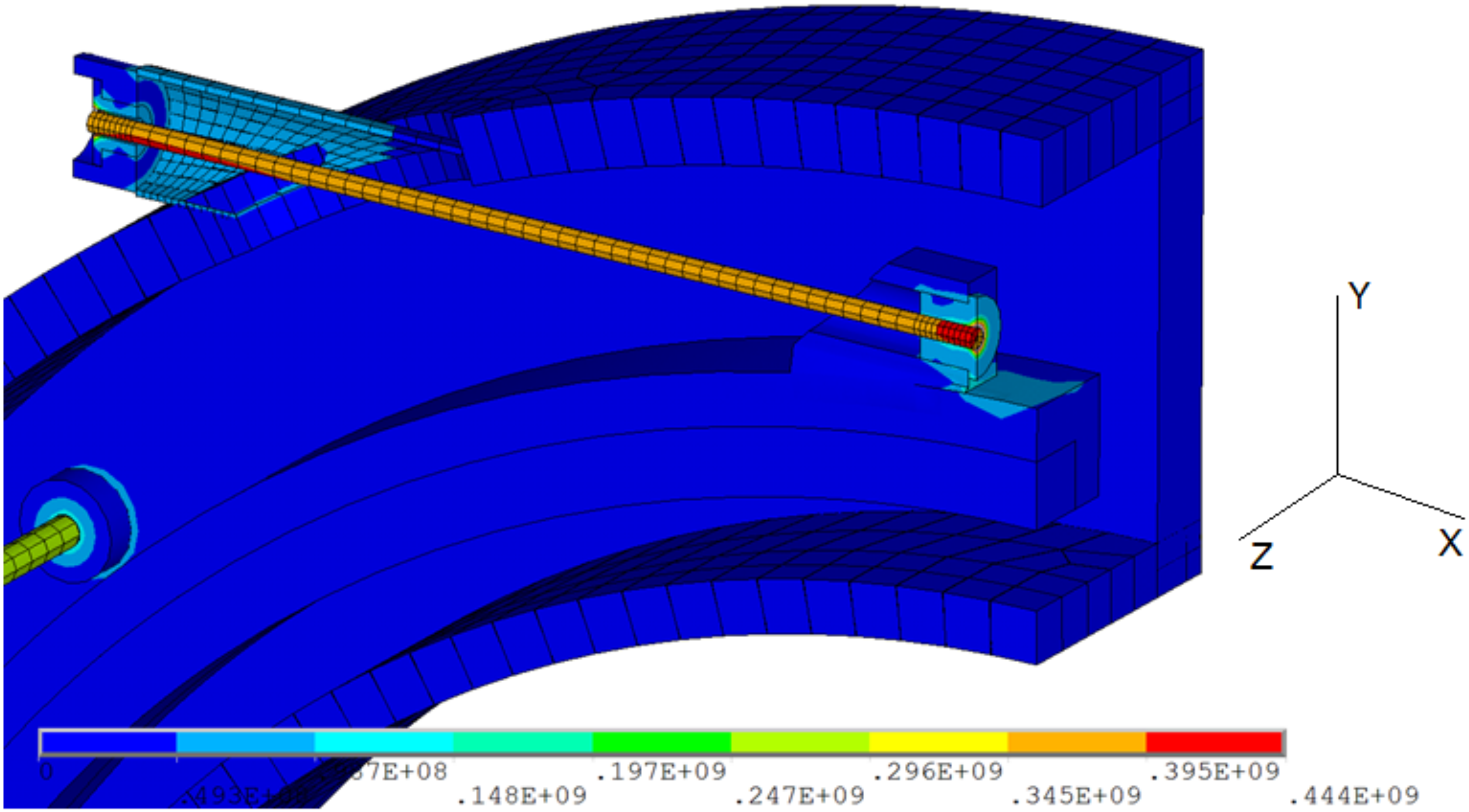
$(\sigma)_4 = 901$ Mpa

Heat gain to the cold mass

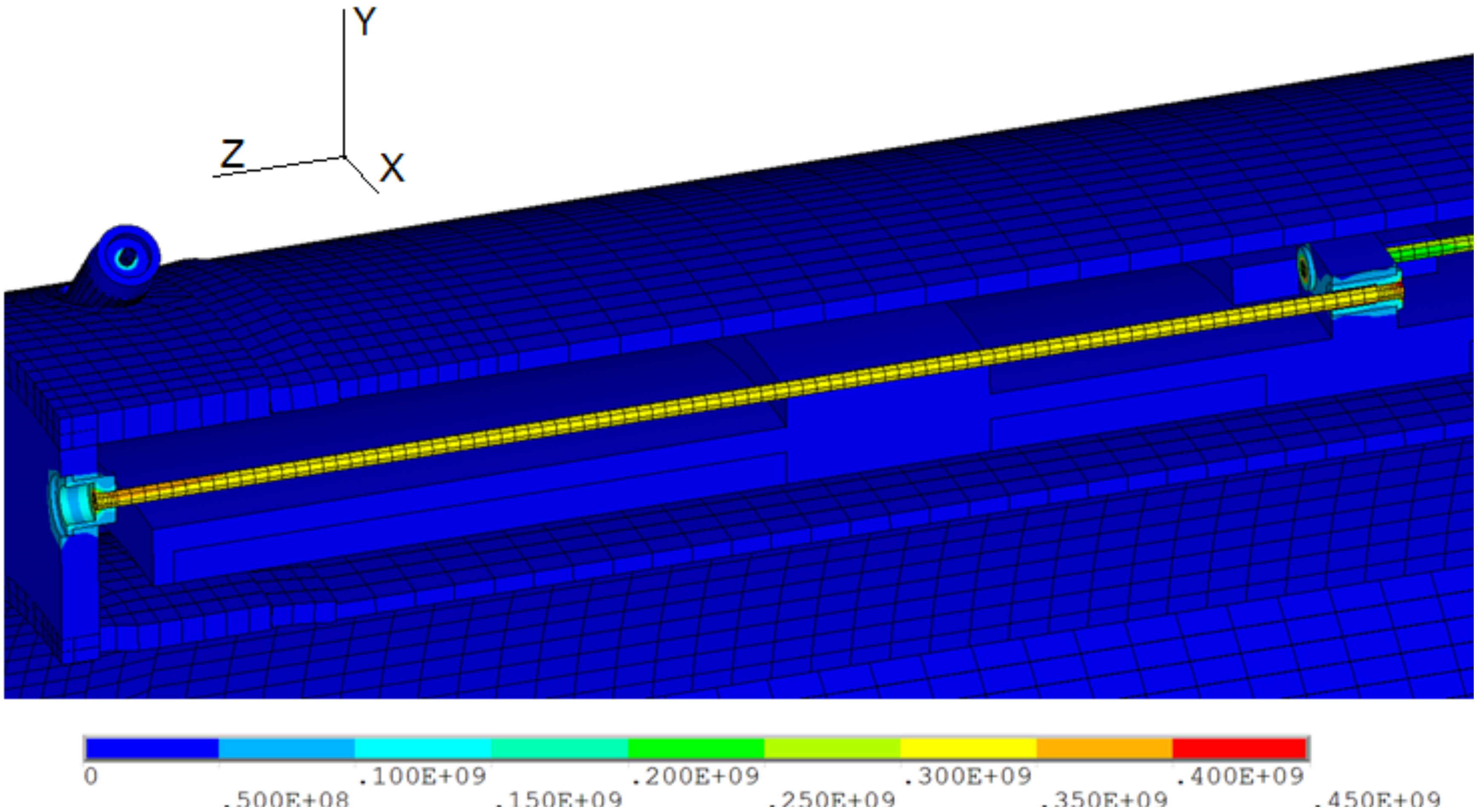
	Suspension system with optimized strength and heat gain to the cold mass	Suspension system with optimized elasticity
$Q_{sum4.2}$, W	2.1	2.88
Q_{sum77} , W	24.8	34.5

Increasing the diameter of the rods leads to growth of the heat leakage of ~40% only.

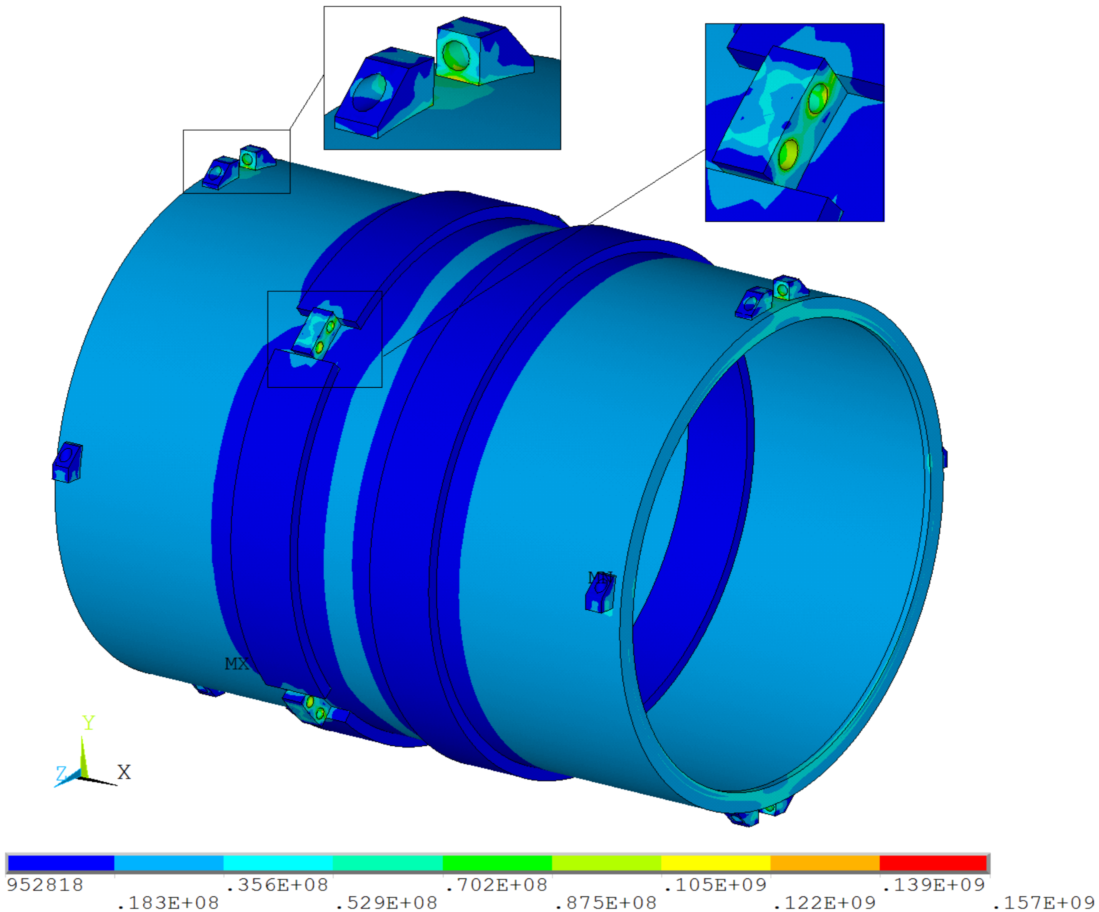
Reduced stress in a top horizontal tie for maximal lateral magnetic decentering force F= 45 kN



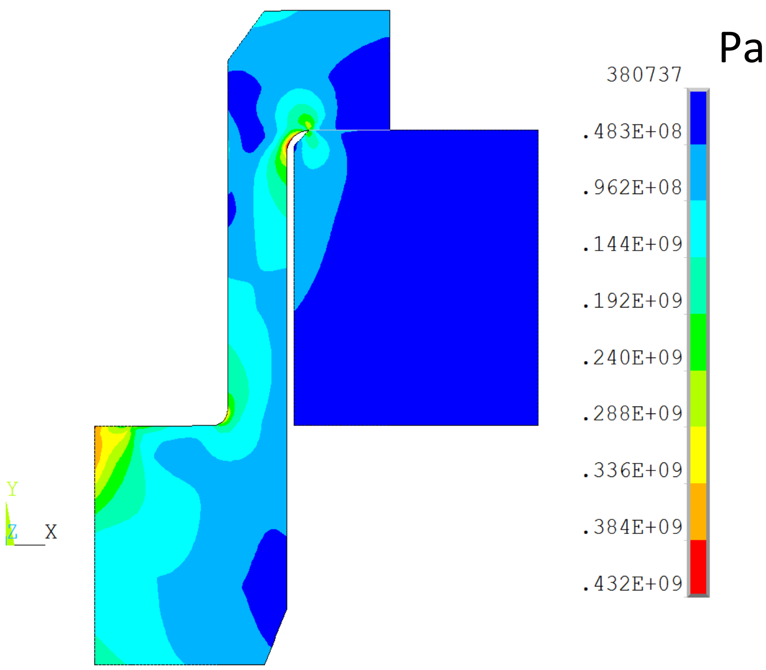
Reduced stress in an axial tie for maximal axal magnetic decentering force F= -140 kN



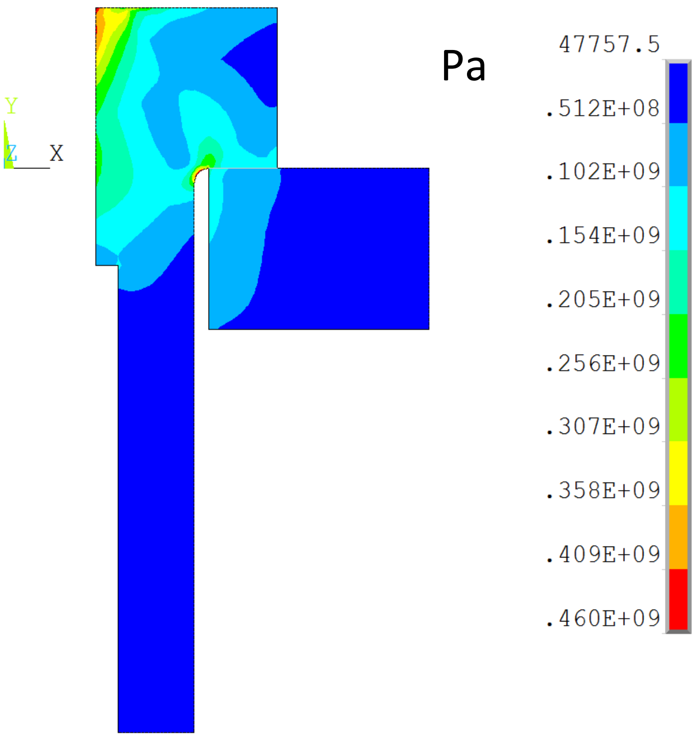
Reduced stress in bosses on the cold mass



Reduced stress in the units of an axial tie for the maximal force (F = 158 kN)



Flange of the head part of an axial tie



Sleeve of the cold mass axial support

Static strength of all cryostat units is provided

1. Maximal average tensile stress $(\sigma)_1$ in section of the suspension rods against mechanical loads (initial tightening, weight) is 178 MPa (less than the allowable stress at Normal Operating Conditions(NOC) equal to 530 MPa) and occurs in the vertical rods.
2. Maximal shear stress in thread from mechanical loads (weight) in vertical rods is 88 MPa (less than the allowable stress equal to 265 MPa)
3. Maximal average tensile stress $(\sigma)_{3w}$ in section of the rods from mechanical loads (initial tightening, weight, magnetic force and seismic load) and temperature effects is 500 MPa and occurs in horizontal radial rods (it is less than the allowable stress at Normal Operating Conditions equal to 689 MPa).
4. Maximal shear stress in thread from mechanical loads and temperature effects is 246 MPa (less than allowable stress at Normal Operating Conditions equal to 339 MPa) and occurs in radial horizontal rods
5. Maximal stress $(\sigma)_4$ in suspension rods determined by the sum of the components of the average tensile and bending stresses from the overall mechanical loads (initial tightening, weight, magnetic force) and thermal effects is 451 MPa and occurs in smooth part of the horizontal radial rods and is 500 MPa in the threaded part (it is less than the allowable stress at Normal Operating Conditions equal to 901 MPa);
6. Maximal stress $(\sigma_s)_{4w}$ in suspension rods for combined loads NOC + planned earthquake is occurs in radial horizontal rods is 451 MPa in the smooth part and 499.7 MPa in the threaded rod parts, and does not exceed the allowable value 1219 MPa;
7. Maximal reduced stress in the cold mass support units (bosses) for the stress group $(\sigma)_2$ (overall and local membrane and overall bending) do not exceed the allowable value of - 124 MPa. Static strength of these structural elements of the cryostat is provided. Peak reduced stresses of 159 MPa are located in the area of connection of the bosses and the support cylinder. Due to the low-cycle loading nature of the cryostat (<200 cycles) the contribution of these peak stresses in the fatigue damage is irrelevant.
8. Maximal reduced stress in support flanges of the heads of the radial ties for the stress group $(\sigma)_2$ (overall and local membrane and overall bending) is 83 MPa (less than the allowable stress equal to 124 MPa)
9. Maximal reduced stress in the connecting pipes of the heads of the radial suspension ties is 57 MPa (less than the allowable stress equal to 124 MPa). This is the compressive stress. To enhance the stability margin and to increase the compressive stiffness of the unit it is recommended to increase the wall thickness of the tube up to 8 mm.
10. Bearing stress in the sleeves fixated in the cold mass bosses and flanges of the tie heads, in the areas of their contact with the nuts of axial and radial horizontal ties exceed the allowable value for stainless steel 294 MPa. It is recommended to use in these units washers made of a material with a tensile strength of at least 300 MPa.

Work performed in the first quarter of 2015

Cryostat

- Preparation of 3D model of the cryostat with the cold mass developed at CERN. The model is placed at EDMS service:
  https://edms.cern.ch/file/1458626/1/Solenoid12d_3D100_Cryostat_Full_Update-1_stp.zip
- Design changes implemented in accordance with recommendations based on the results of the mechanical analysis;
- Stress analysis of the new design of the suspension system;
- Evaluation of the safety factors for suspension units taking into account the technological deviations in the processes of manufacturing and installation of the seats of the suspension rods.

THANK YOU
FOR YOUR ATTENTION!

Contribution to the axial movement of the cold mass

- elasticity of the axial suspension rods 0.27 mm (46%)
- deformation of the cryostat structure in the area of the supports 0.173 mm (29%)
- deformation of the flanges of the cryostat shell together with support flanges of the axial ties and deformation of the support bosses on the cold mass 0.147 mm (25%)

Contribution to the axial movement of the cold mass

- elasticity of the radial suspension rods 0.27 mm (46%)
- deformation of the cryostat shell and support units on the cryostat in the area of the supports 0.173 mm (29%)
- deformation of the flanges of the cryostat shell together with support flanges of the axial ties and deformation of the support bosses on the cold mass 0.147 mm (25%)