Joint Institute
for Nuclear Research

Mechanical and temperature calculations of the reactivity modulator construction of the research pulsed reactor NEPTUN

Ivan Kushnir,
engineer of SNSCM, FLNP JINR

Goals

1. Evaluate the strength of the reactivity modulator (RM) construction during its rotation;
2. Check the RM construction for the overheating of titanium hydride in the «window» area.

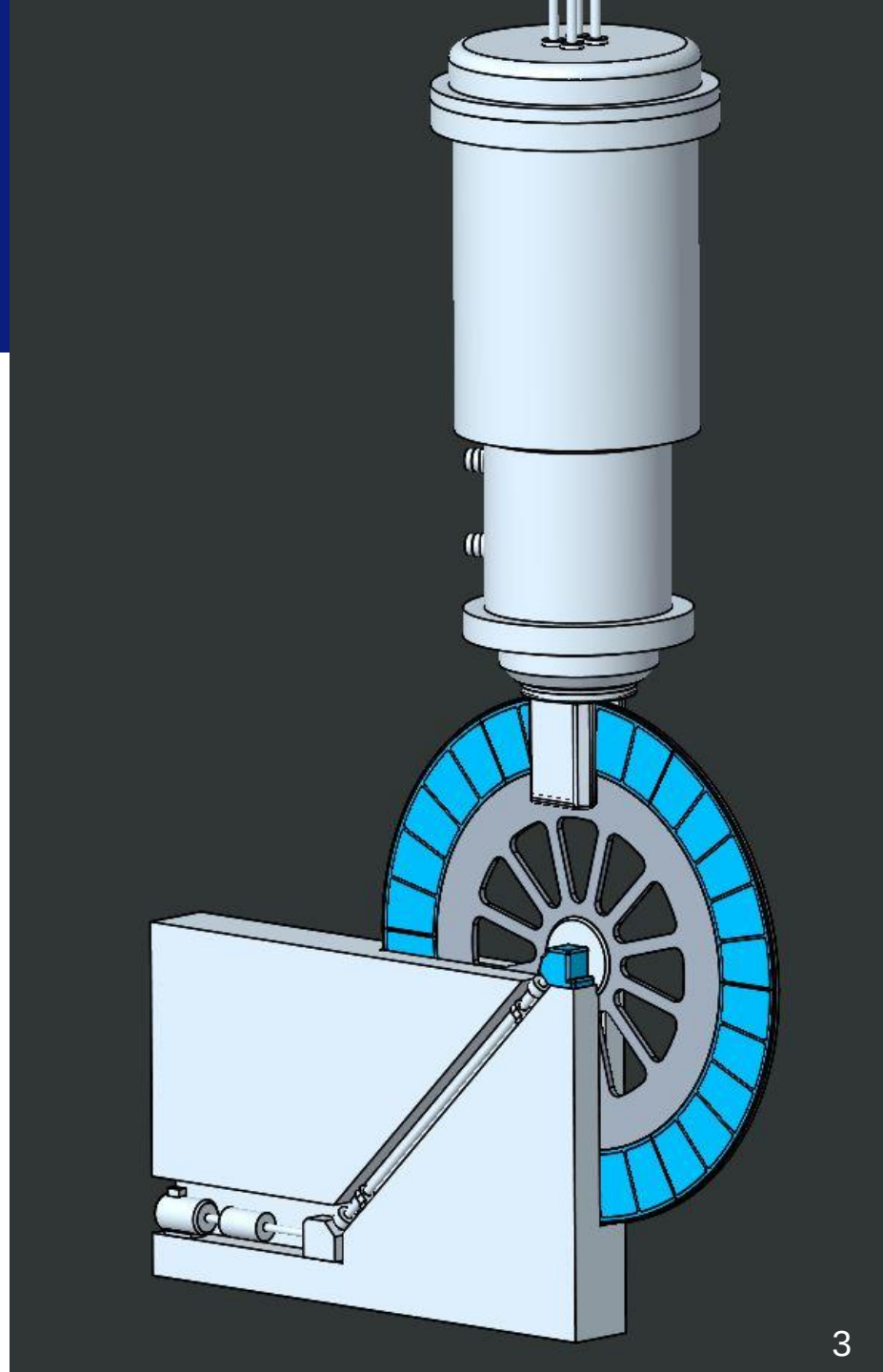
Tasks

1. Determine the natural frequencies and oscillation shapes of the reactivity modulator construction;
2. Determine the distribution of stresses, strains and displacements in the RM construction during its rotation, estimate the safety factor;
3. Determine the temperature field of the RM construction elements.

NEPTUN reactor

Main parameters

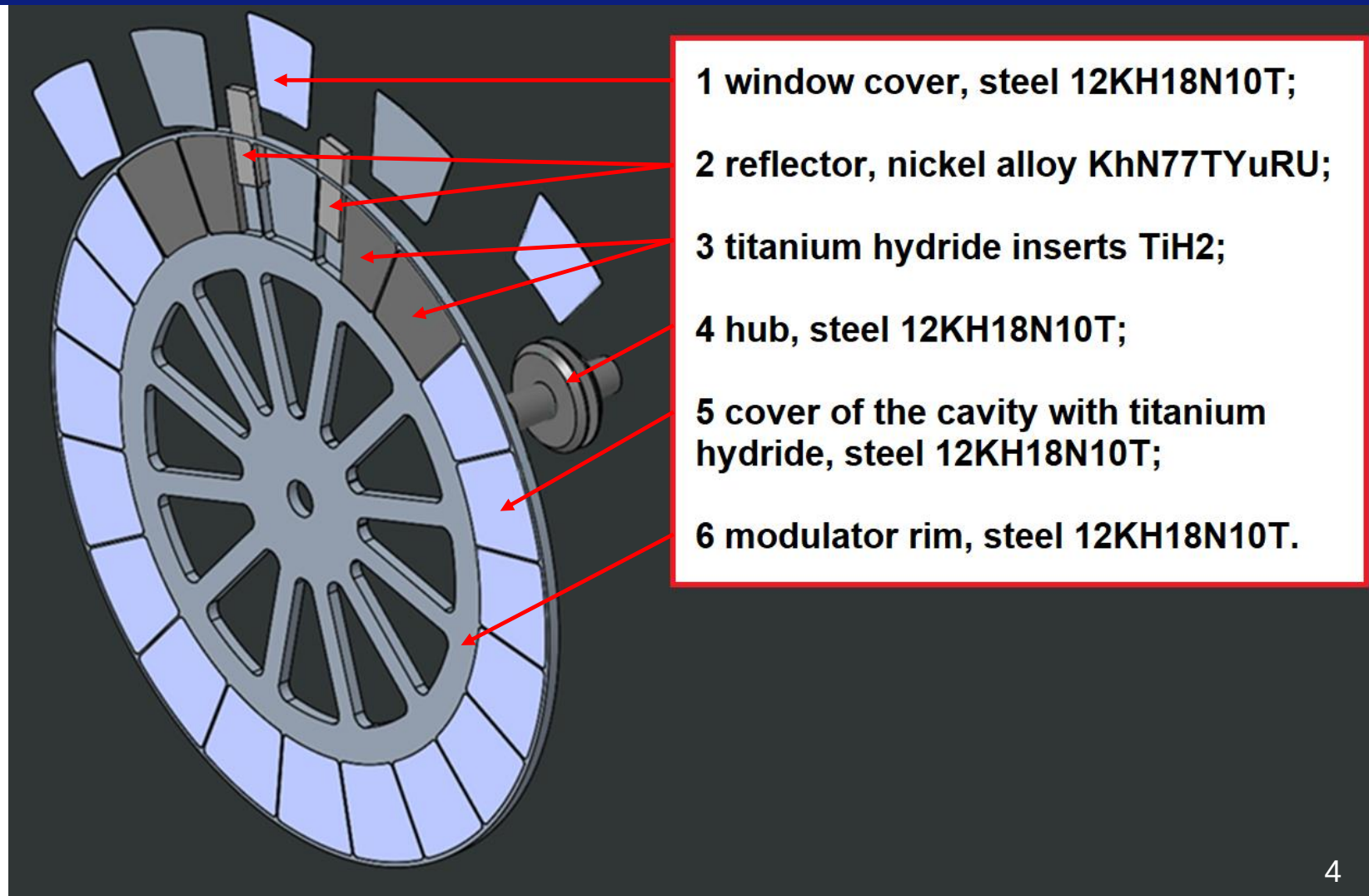
- Average thermal power — **10-15 MW**
- Pulse repetition rate — **10 Hz**
- Pulse half-width — **200 μs**
- Time-average thermal neutron flux density **$\sim 10^{14}$ cm^{-2}·s^{-1}**



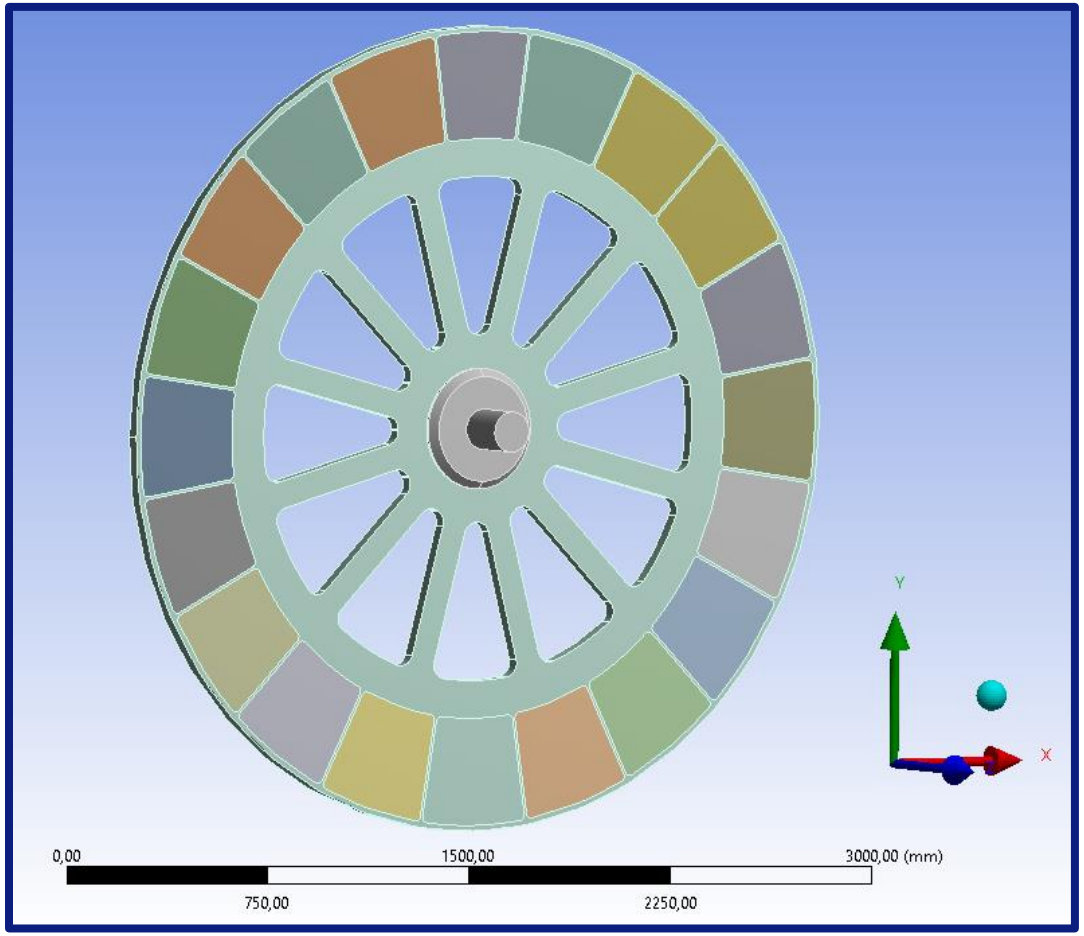
Reactivity modulator

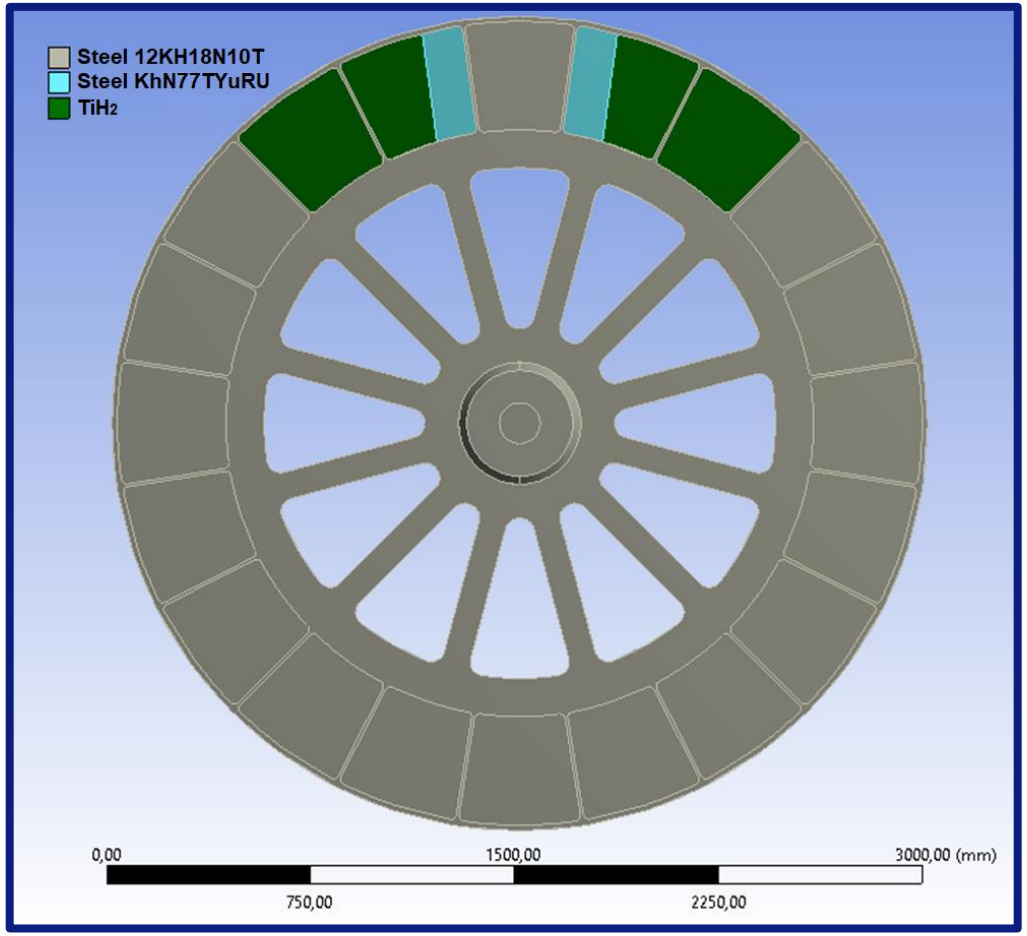
Main parameters

- Disk diameter — **3000 mm**
- Thickness — **50 mm**
- Rotation rate — **10 Hz**



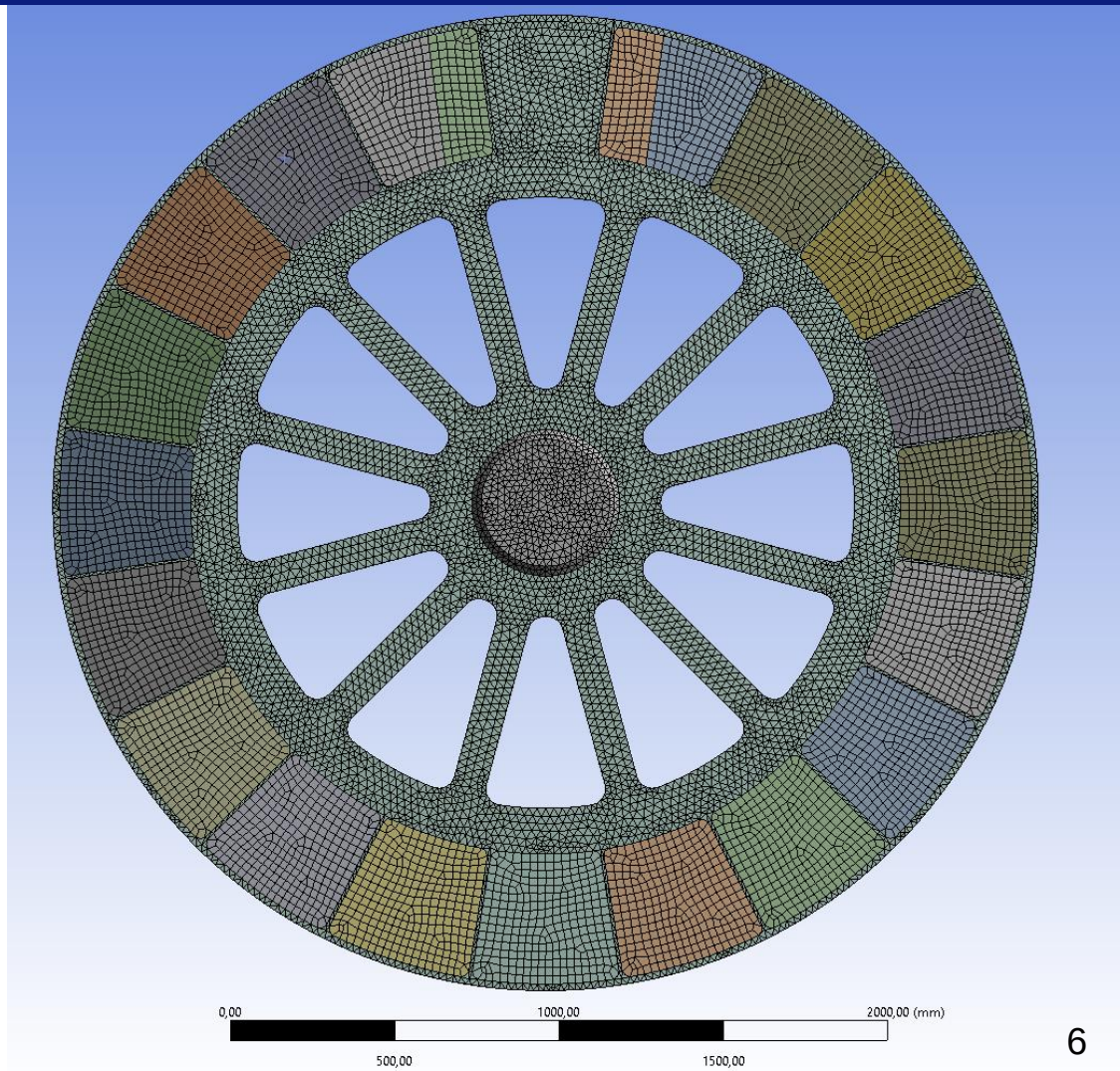
Modal analysis of the RM disk





Mesh model

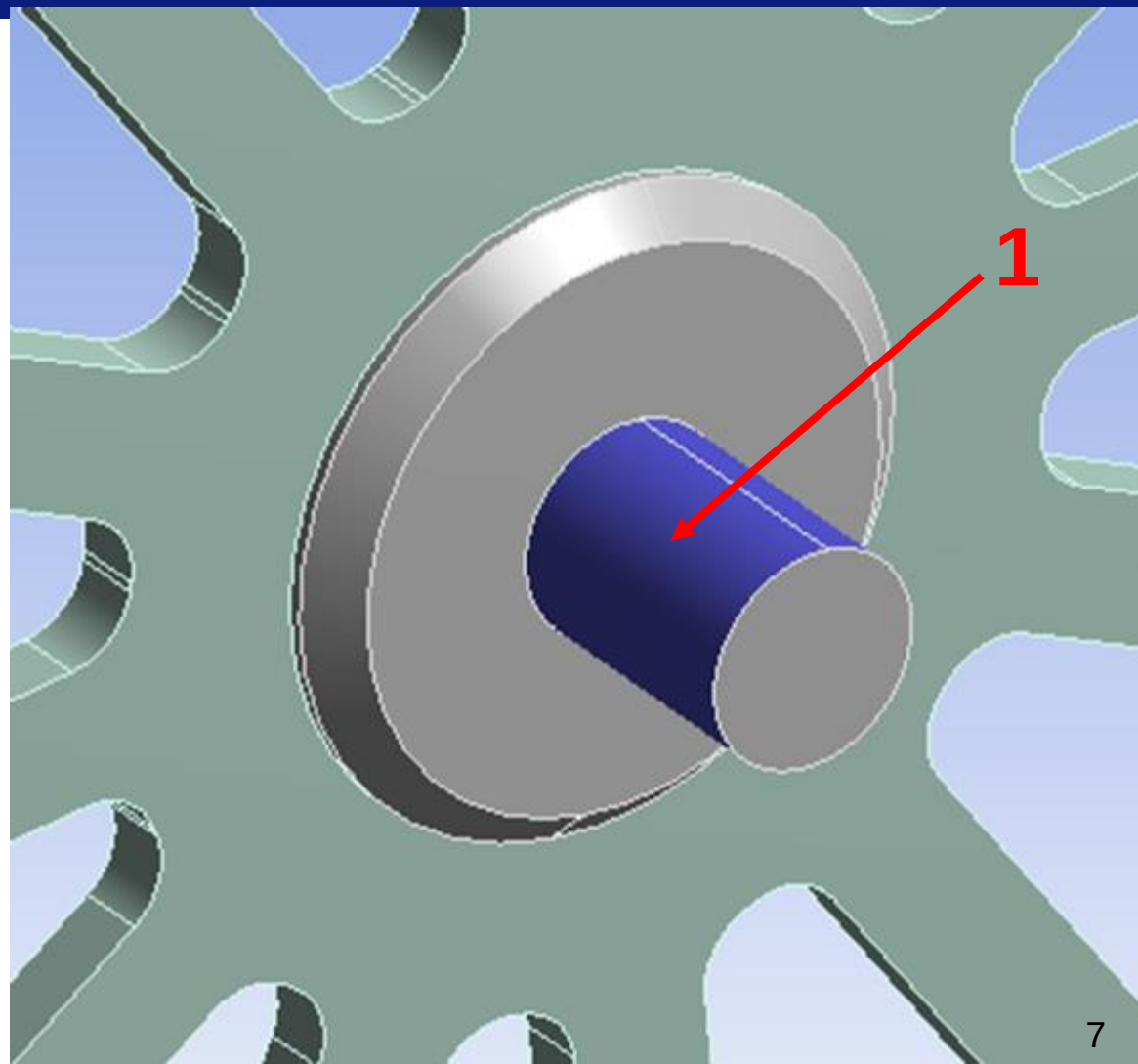
- Constructed mesh has **~396 thousand control elements** (tetrahedral and hexahedral elements are used).
- The amount of model **nodes** is **~137 thousand.**



Boundary conditions

Bearing assembly (1) is modeled using a **Frictional contact** on the wheel hub surface (frictional force is taken into account, the friction coefficient of radial ball bearing is accepted as 0.002).

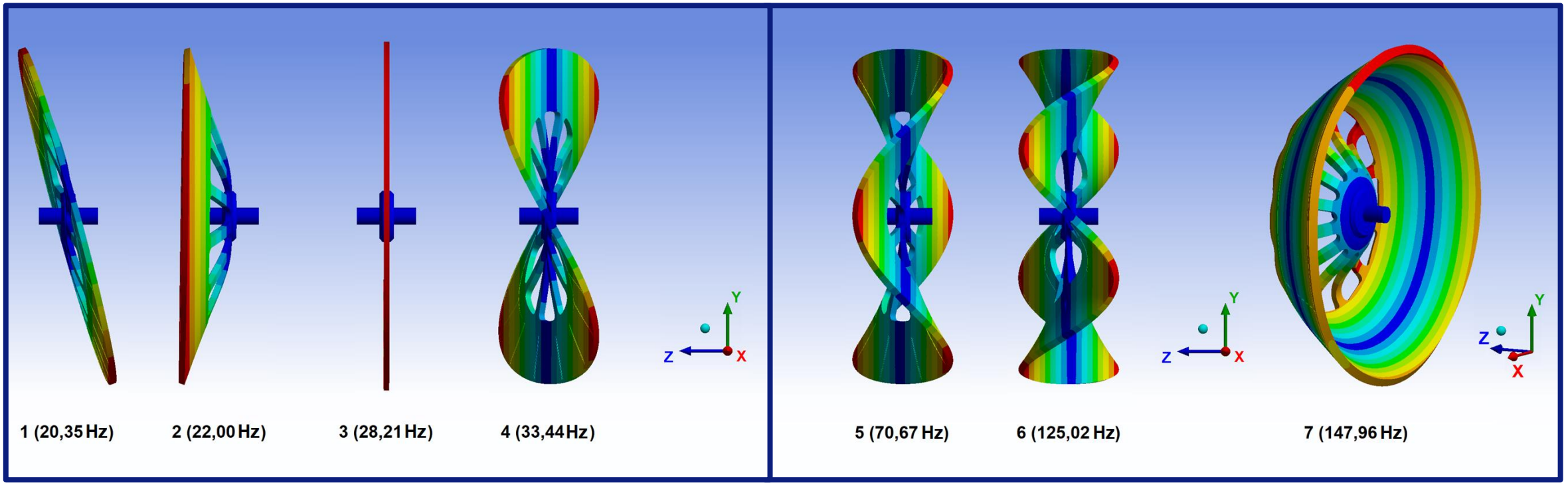
The hub doesn’t move translationally, only rotation is allowed.



Results of the modal analysis

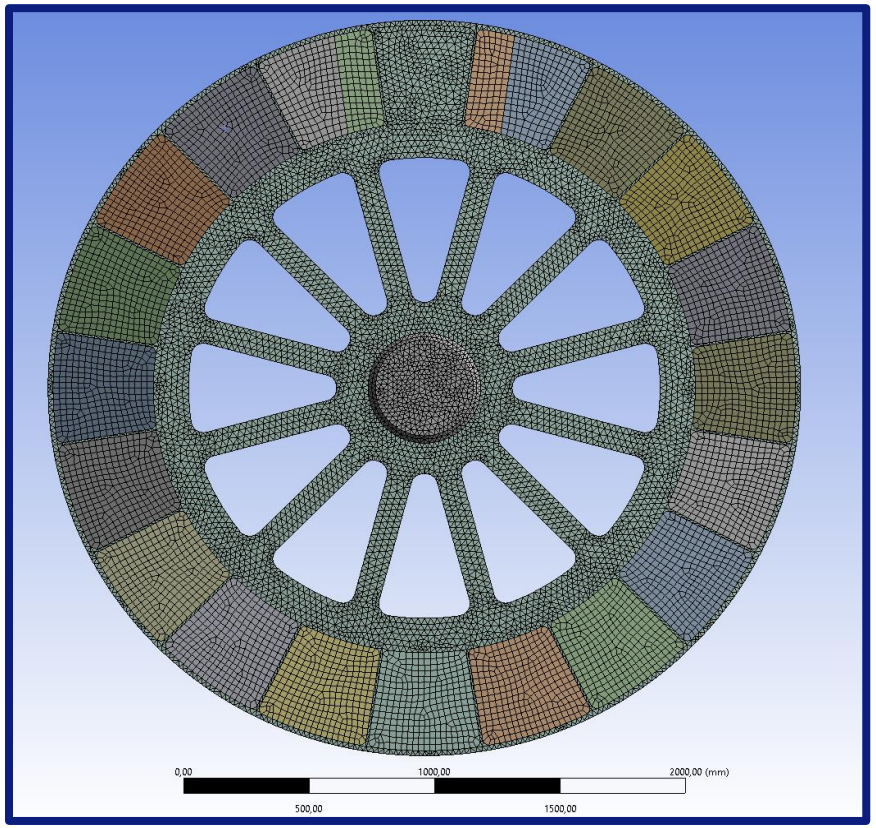
First **7 frequencies** and its **oscillation shapes** have been determined.

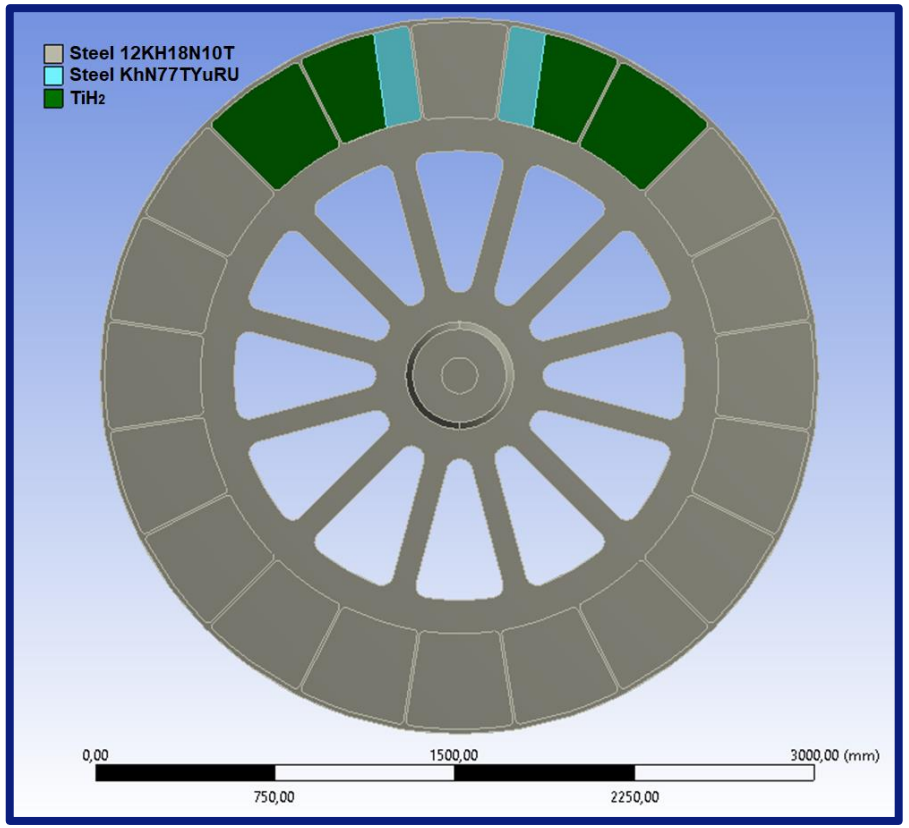
Natural frequencies do not coincide with rotational frequency of RM disk.



Mechanical calculation of the RM disk for stresses and deformations

The calculation uses the same model as was used in modal analysis



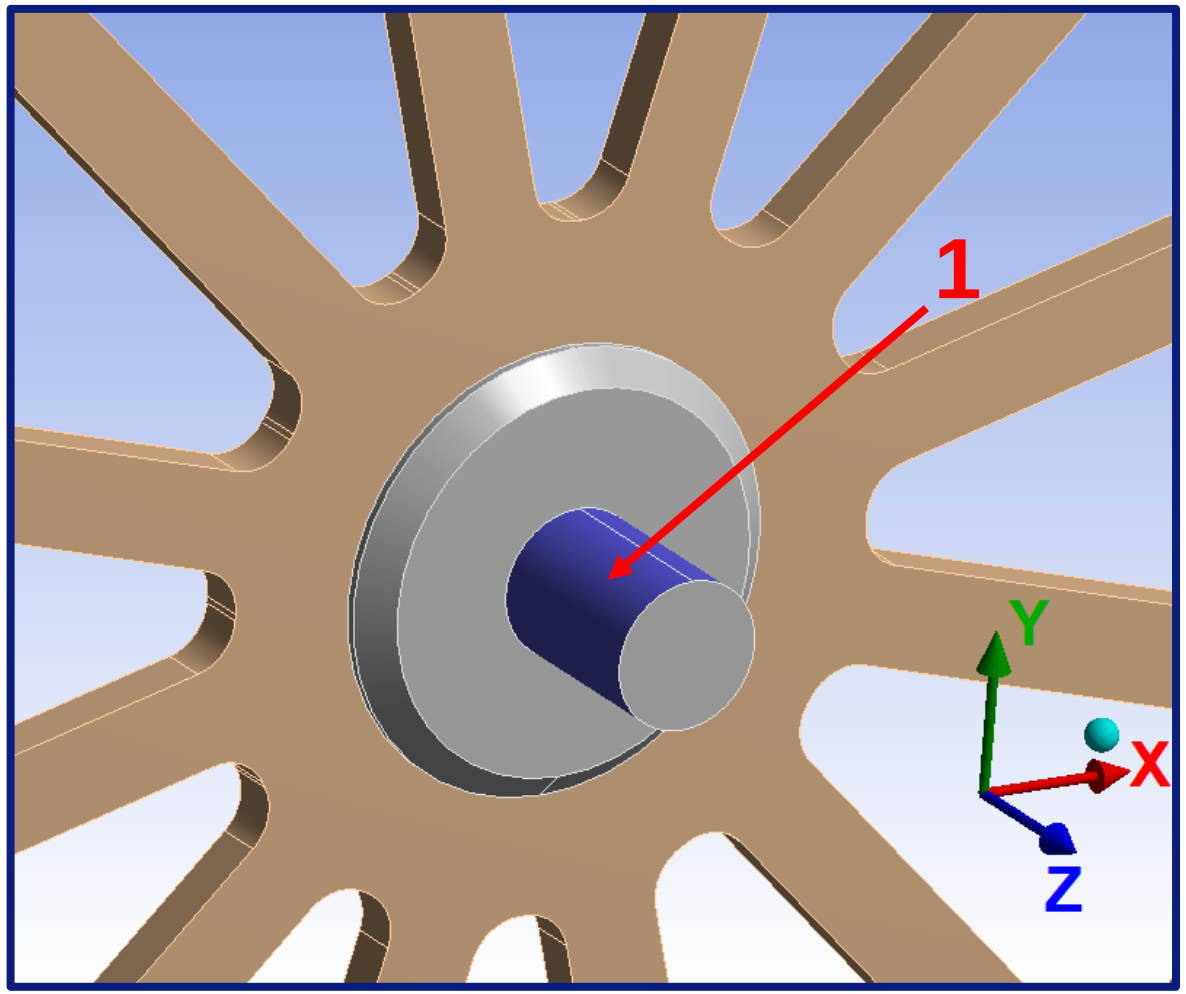


Boundary conditions

Bearing assembly (1) is modeled using **Frictional contact** on the wheel hub surface (frictional force is taken into account, the friction coefficient of radial ball bearing is accepted as 0.002).

Rotation rate of the RM disk is **10 Hz.** The calculation took into account the gravity force acting in the negative direction of the Y axis.

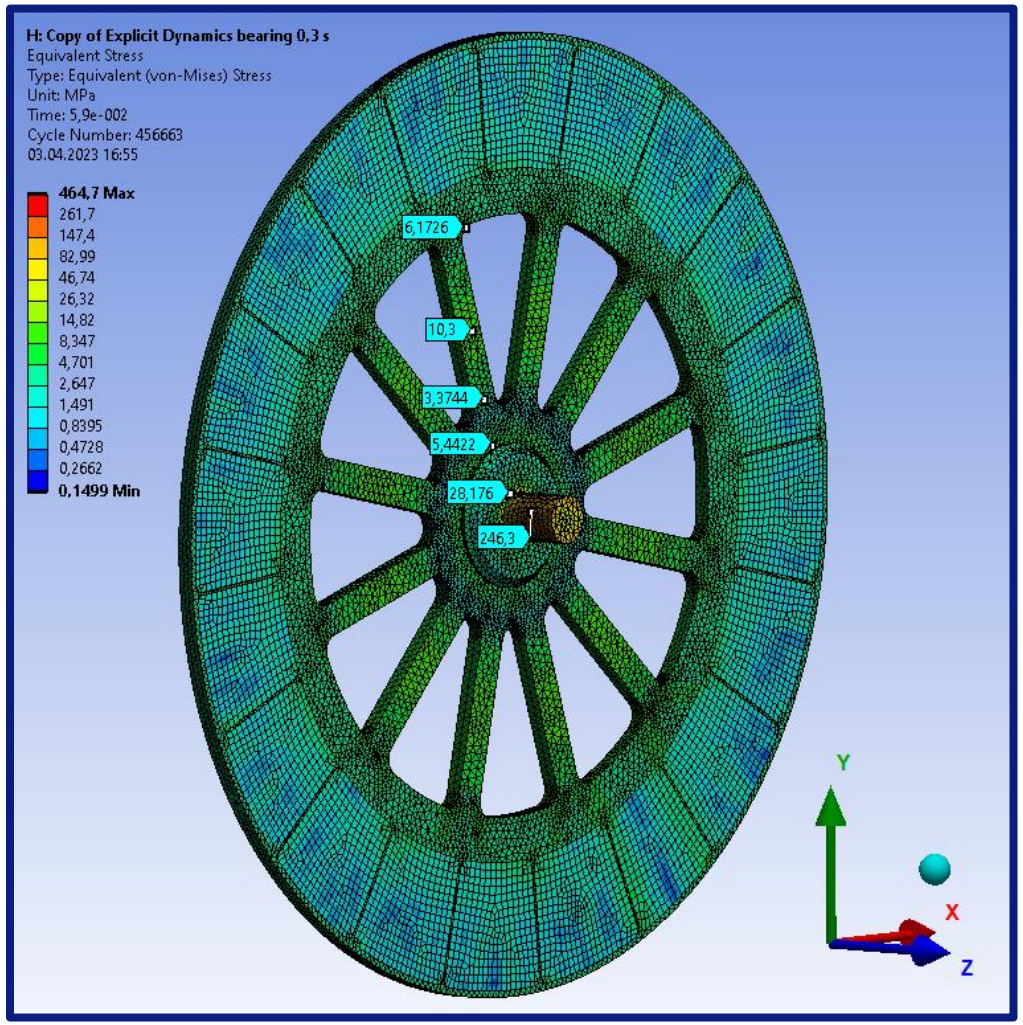
The calculation was carried out for a duration of 0.3 s (which corresponds to 3 full revolutions of the RM disk). The initial timestep is 0.01 s, the minimum timestep used for solution convergence is 10^{-7} s.



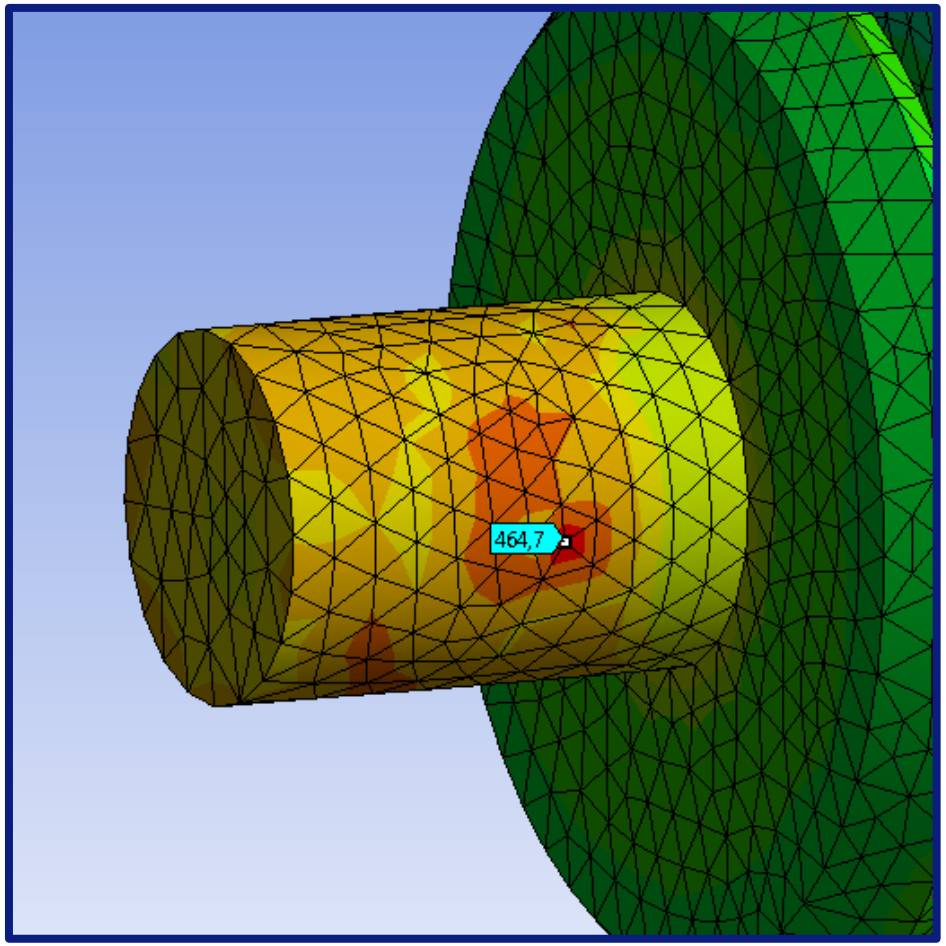
Results of the mechanical calculation

σ_{max} = 464.7 MPa
σ_{min} = 0.15 MPa

Yield strength:
σ_{ys} = 207 MPa

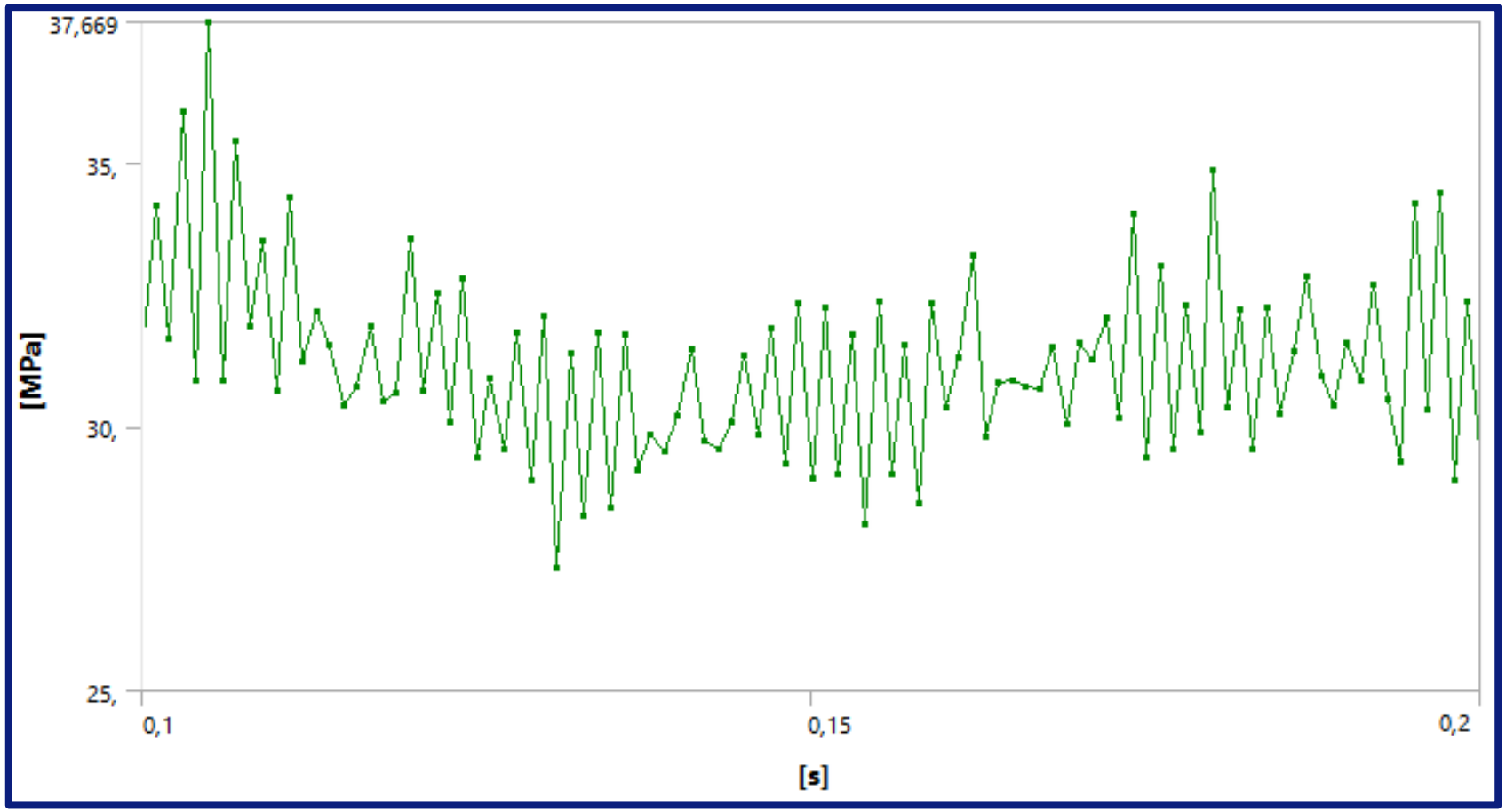


Distribution of stresses in the RM disk at time $5.9 \cdot 10^{-2}$ s (the moment of maximum stresses)

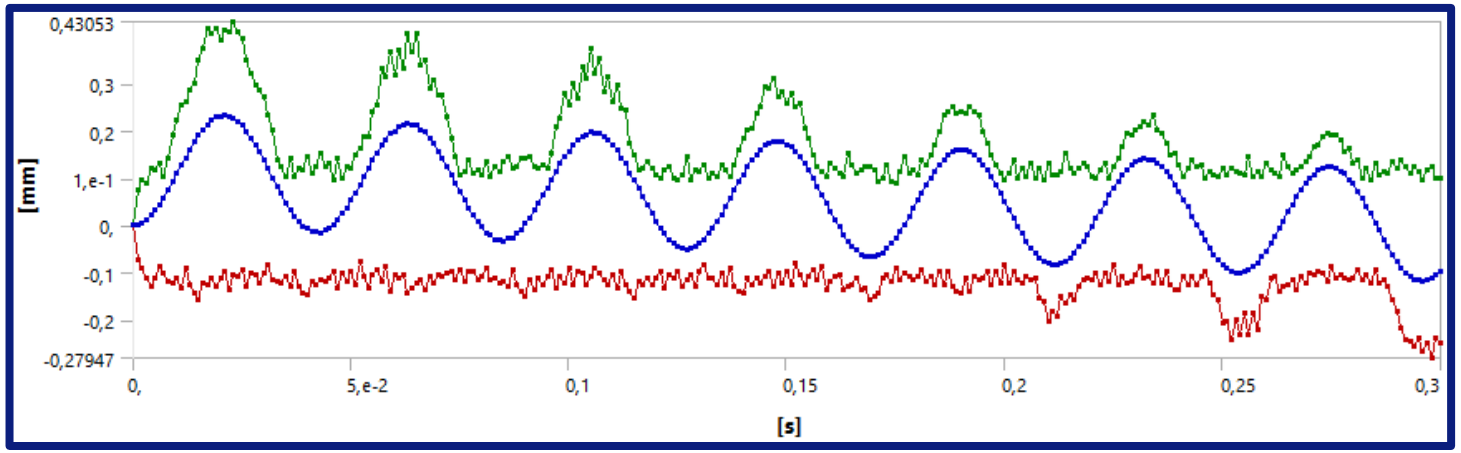


Maximum stress area

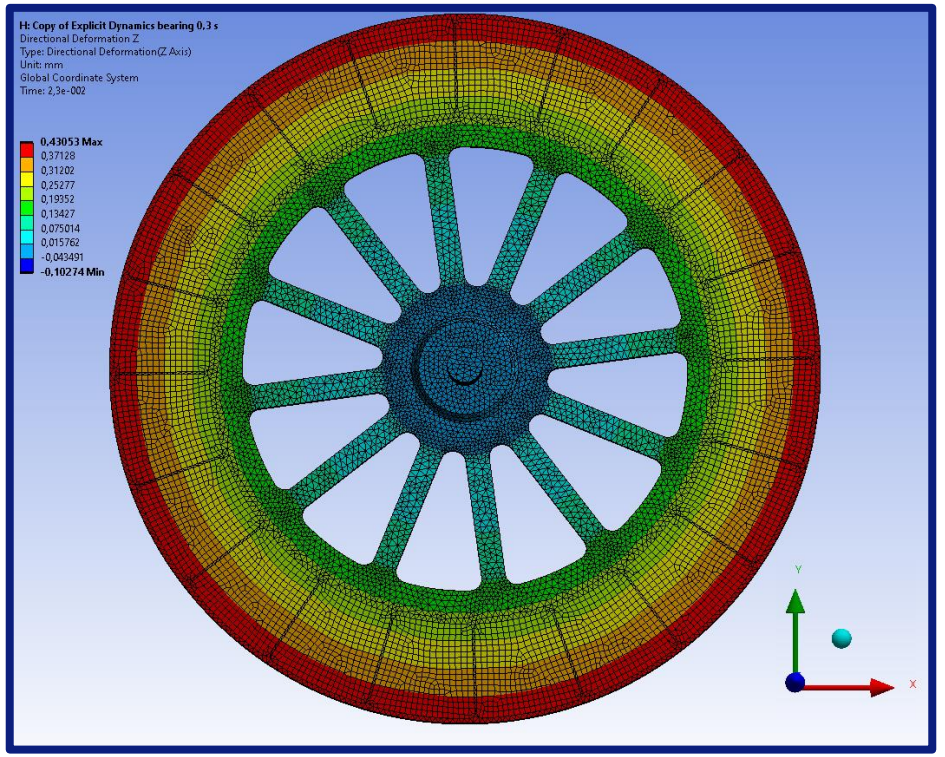
Changes in maximum stresses in the RM disk during one revolution



Deformation of the RM construction



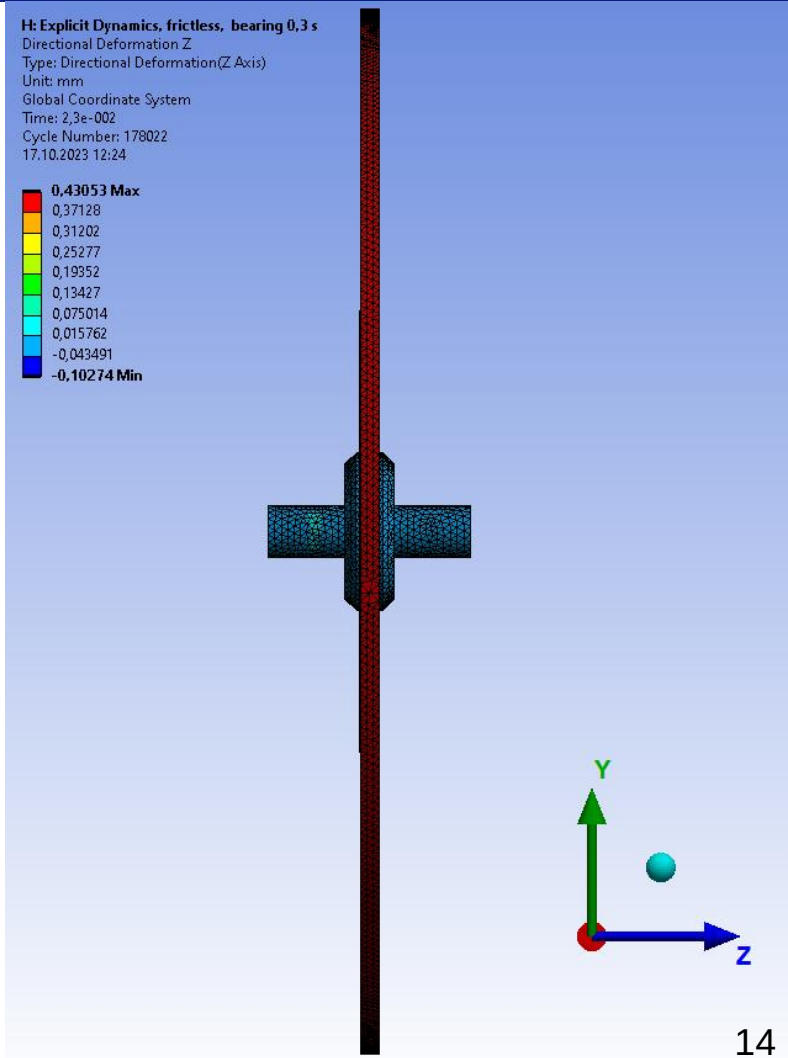
The graph of the dependence of maximum (green color), minimum (red color) and average (blue color) deformations on time



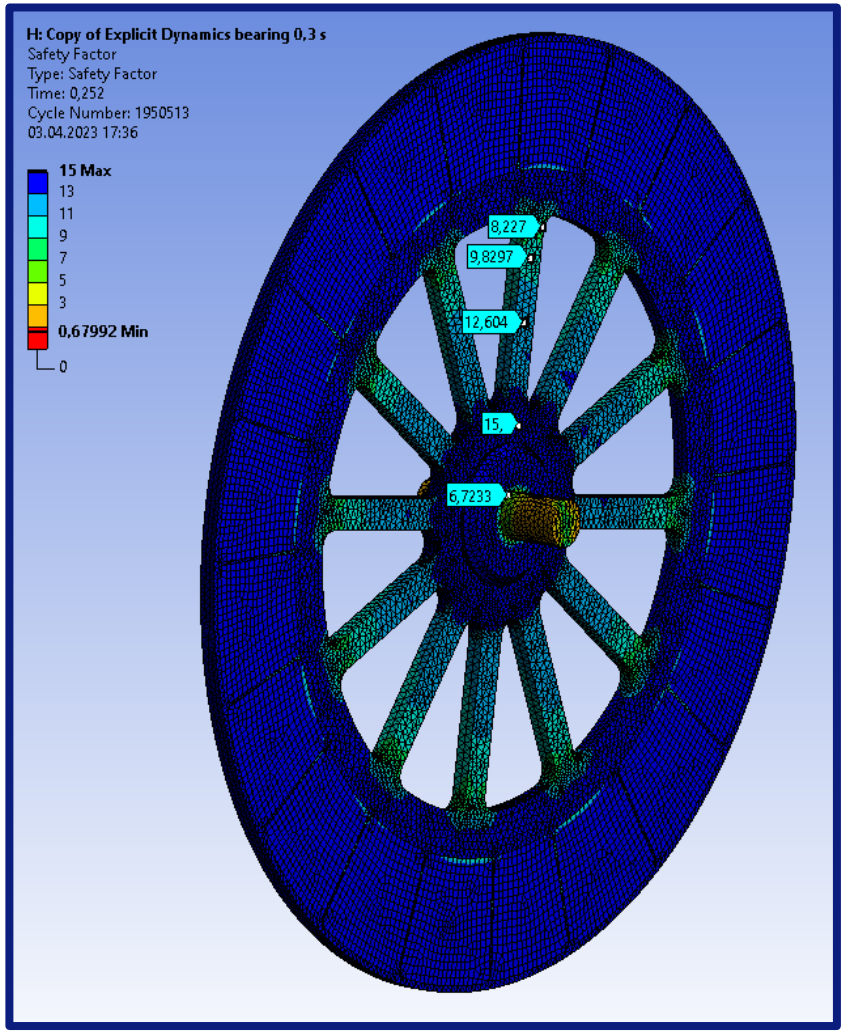
Distribution of deformations at time $2.3 \cdot 10^{-2}$ s (the moment of maximum deformations)

Deformation of the RM construction

Distribution of deformations at time $2.3 \cdot 10^{-2}$ s (the moment of maximum deformations)



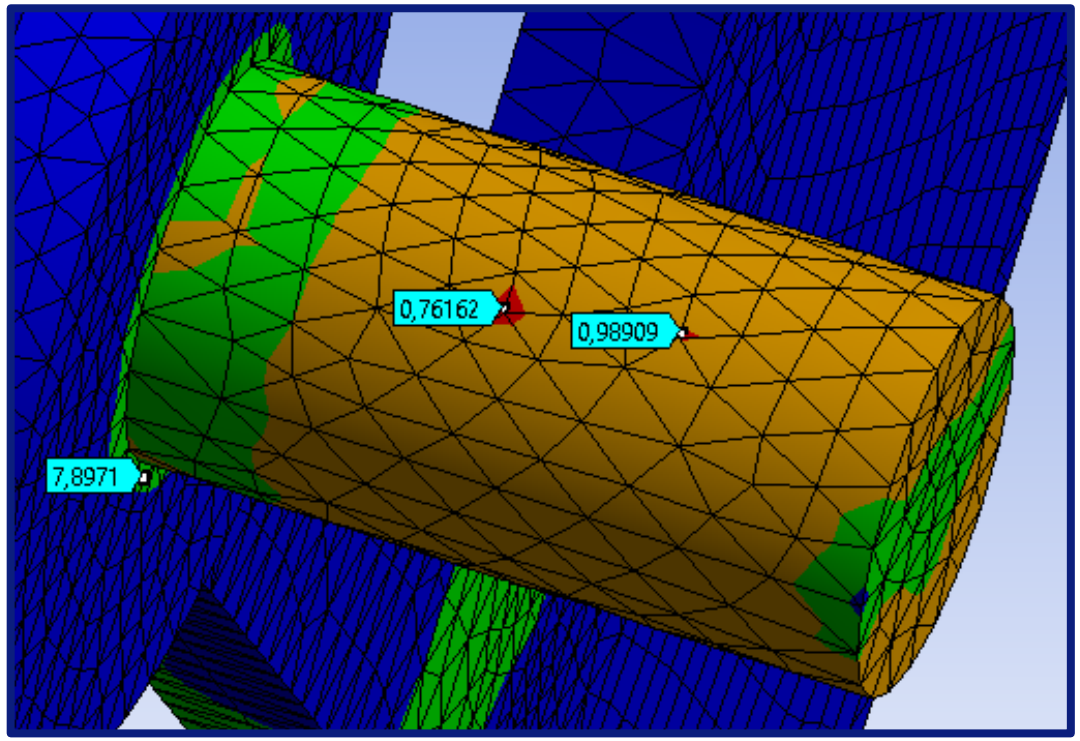
Safety factor



Safety factor

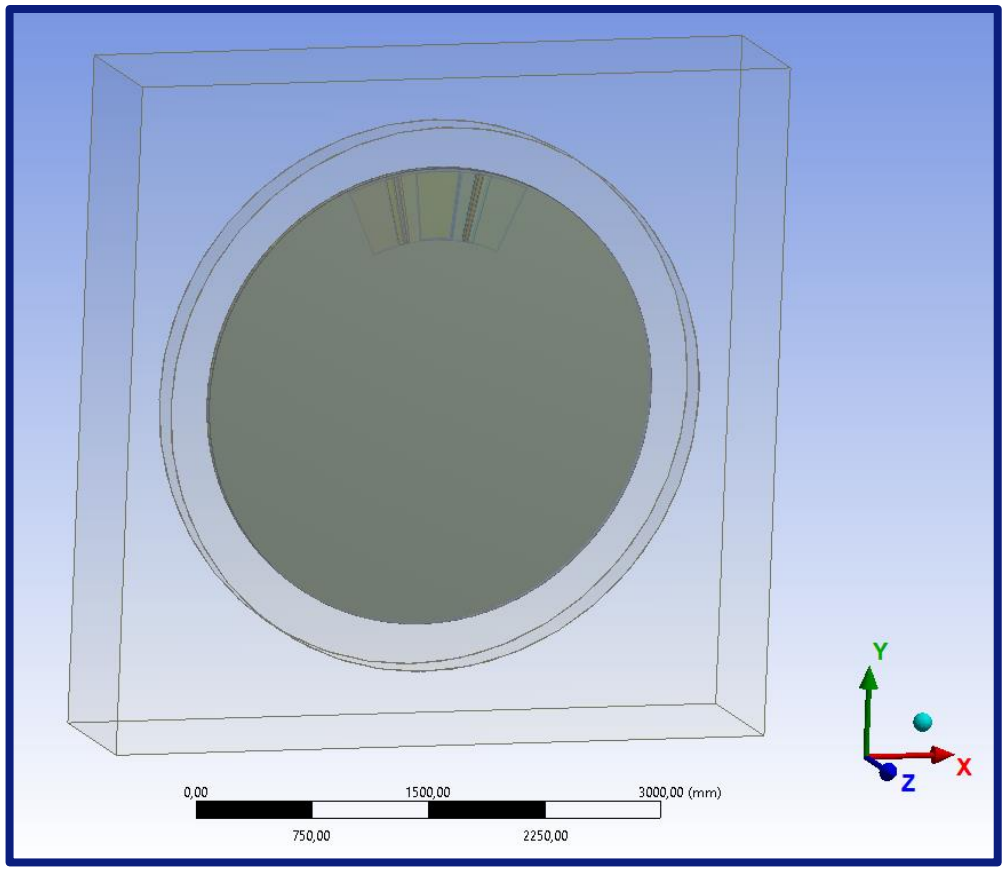
$k = \sigma_{ys} / \sigma_{calculated}$, σ_{ys} = 207 MPa

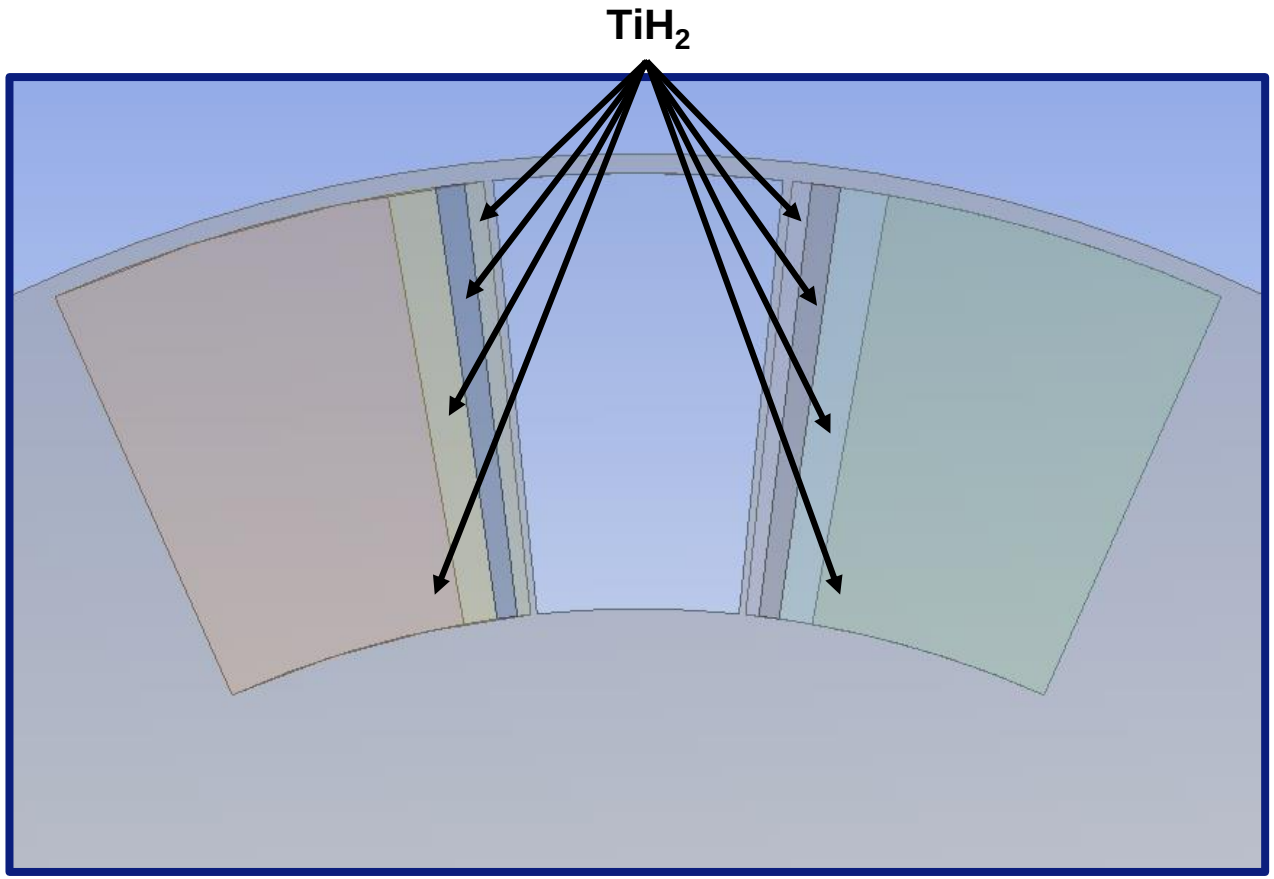
Strength condition: k > 1



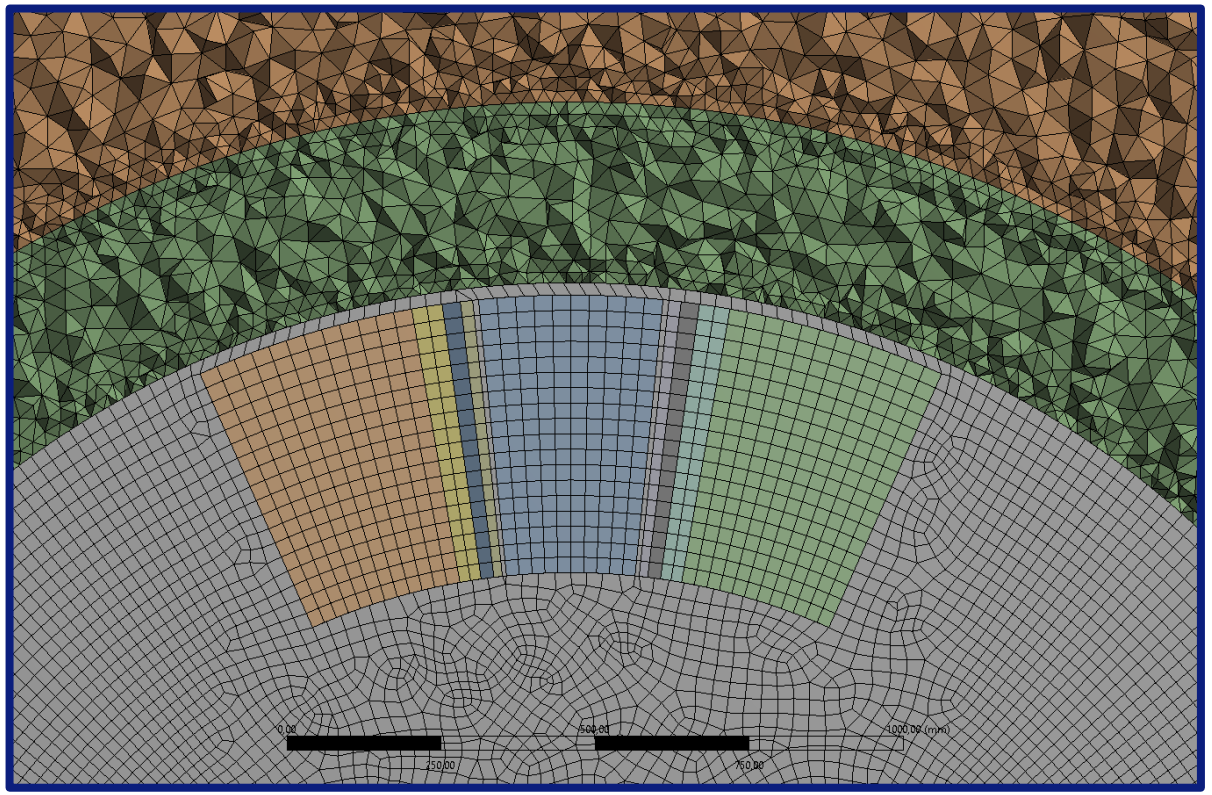
Temperature calculation of the RM taking into account the energy release corresponding to the nominal capacity mode of the reactor

Geometry of the RM without nickel inserts

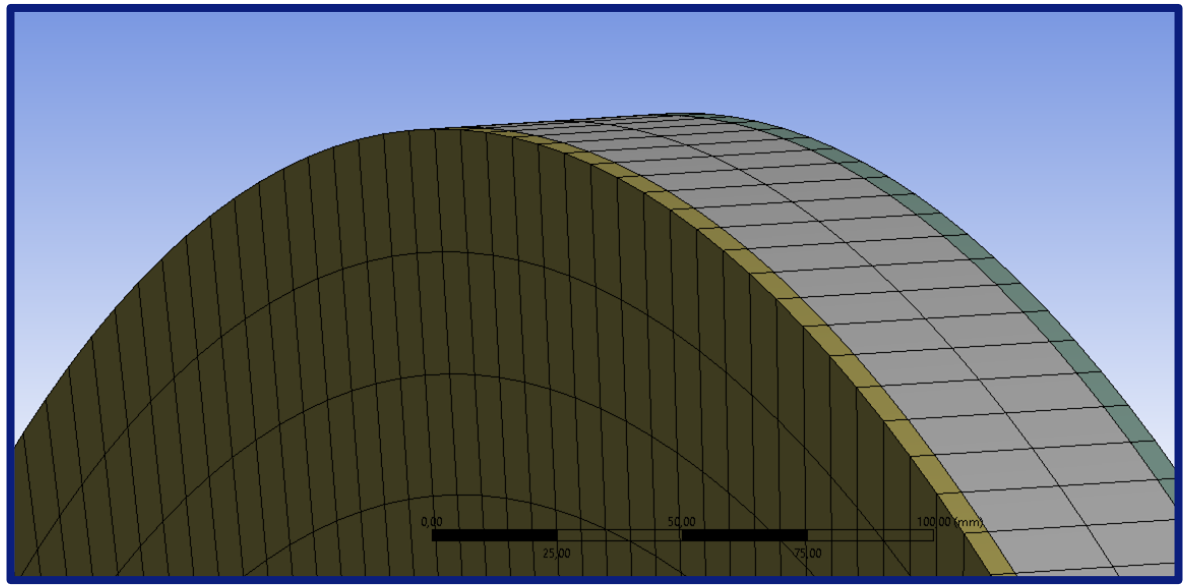




Mesh model

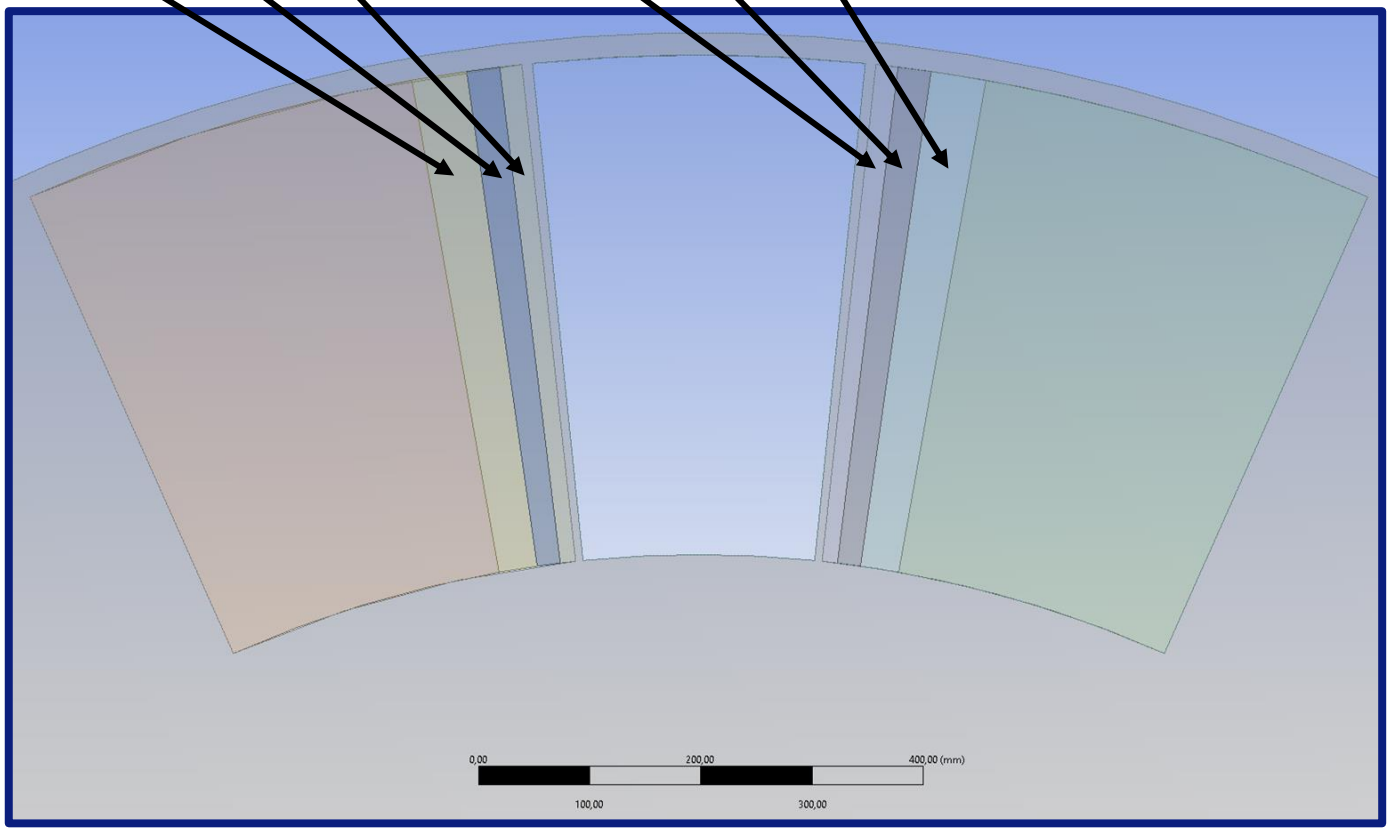


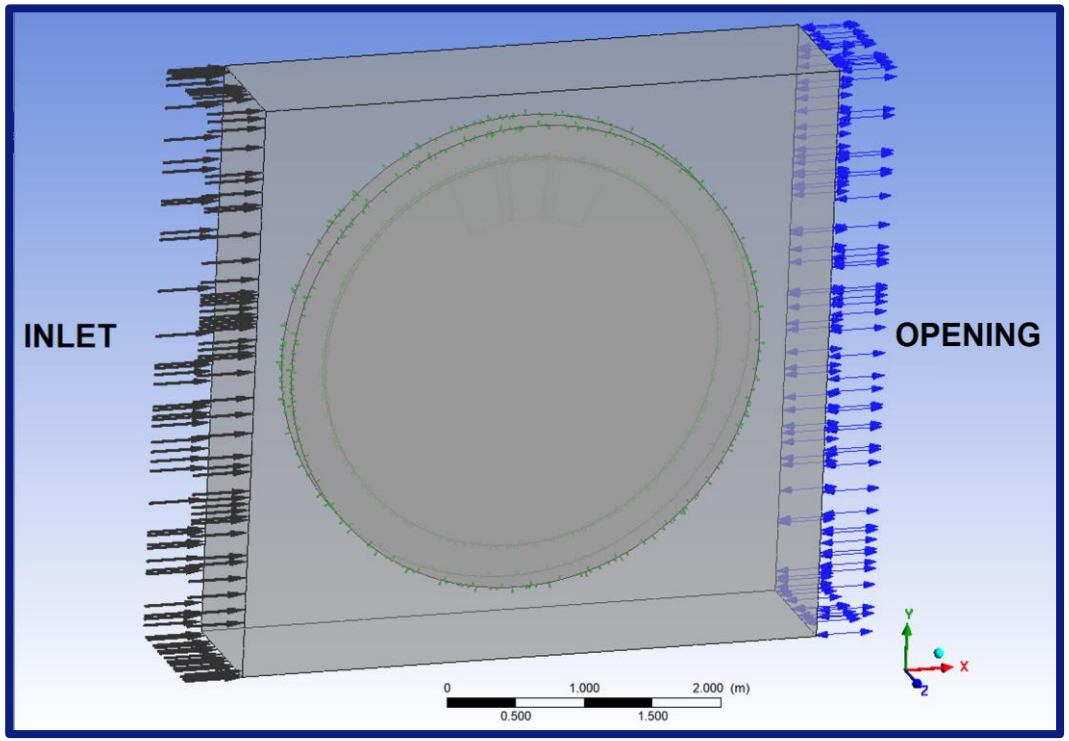
- The amount of model **control elements** is **~4.3 million.**
- The amount of model **nodes** is **~916 thousand.**



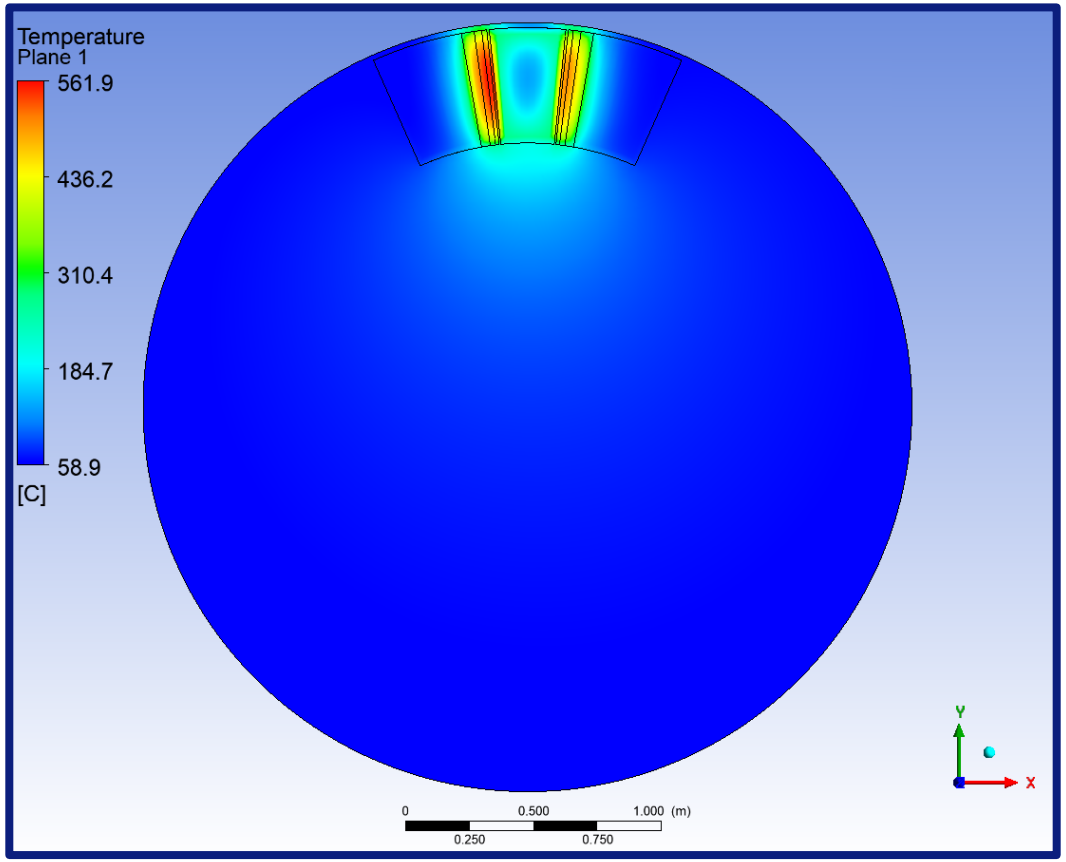
Boundary and initial conditions (for the calculation without nickel inserts)

4.80 6.52 8.15 7.49 5.80 4.14 – energy release in W/cm^3 in TiH_2 from neutrons and gamma radiation

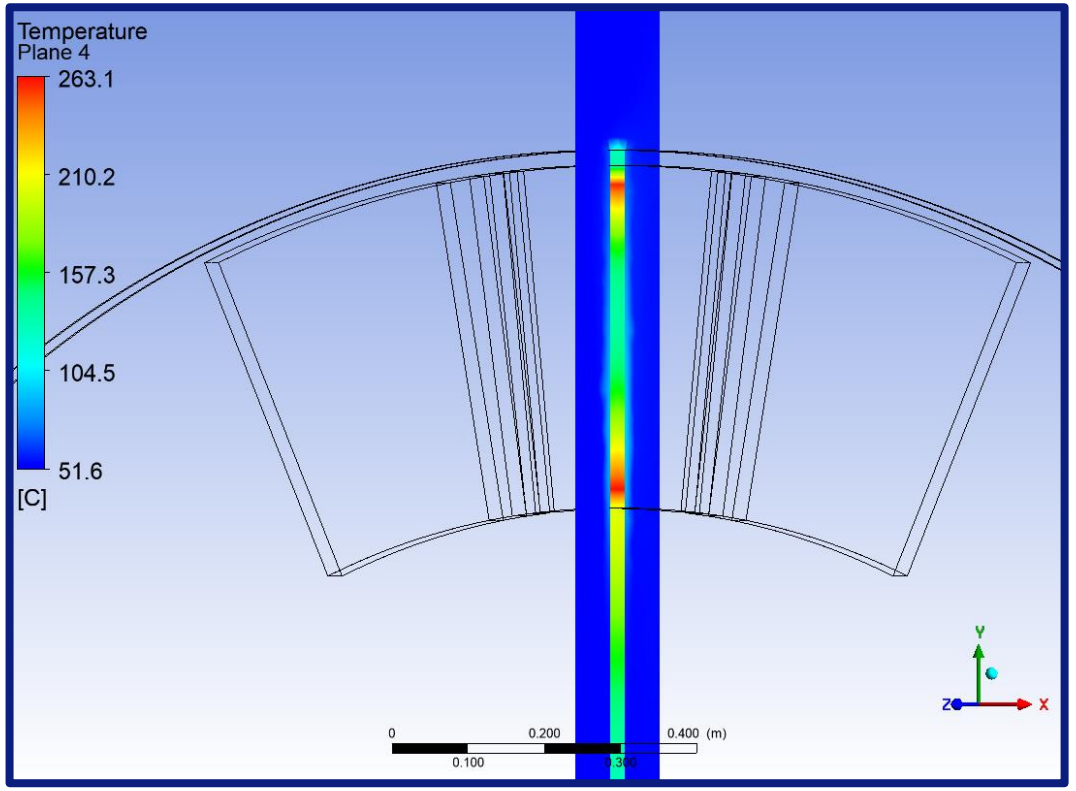




Results of the temperature calculation



Distribution of the temperature in the RM disk
(central cross-section in the XY plane)



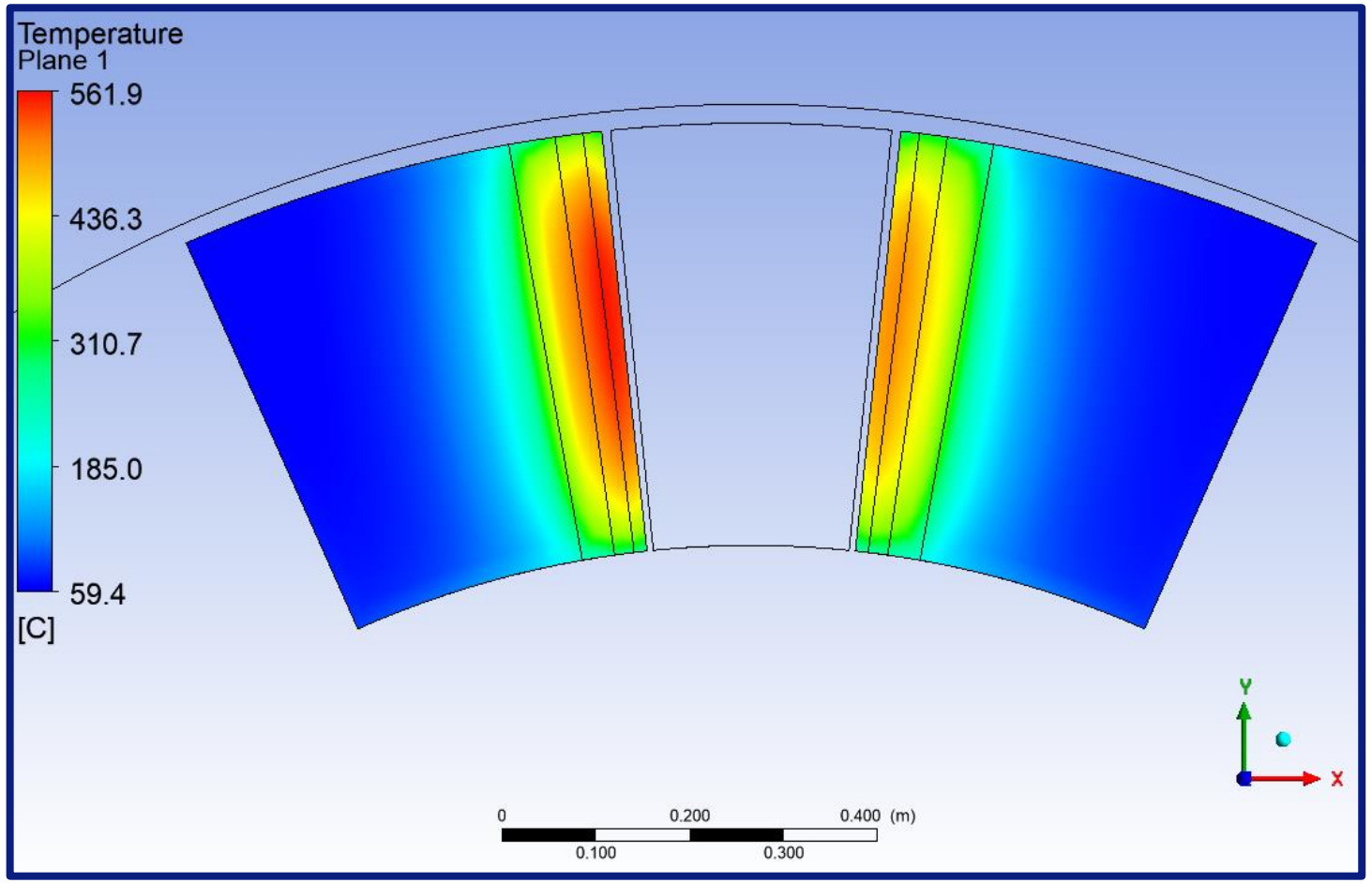
Distribution of the temperature in the RM disk
(cross-section in the YZ plane)

Distribution of the temperature in titanium hydride

Tmax = 561.9℃

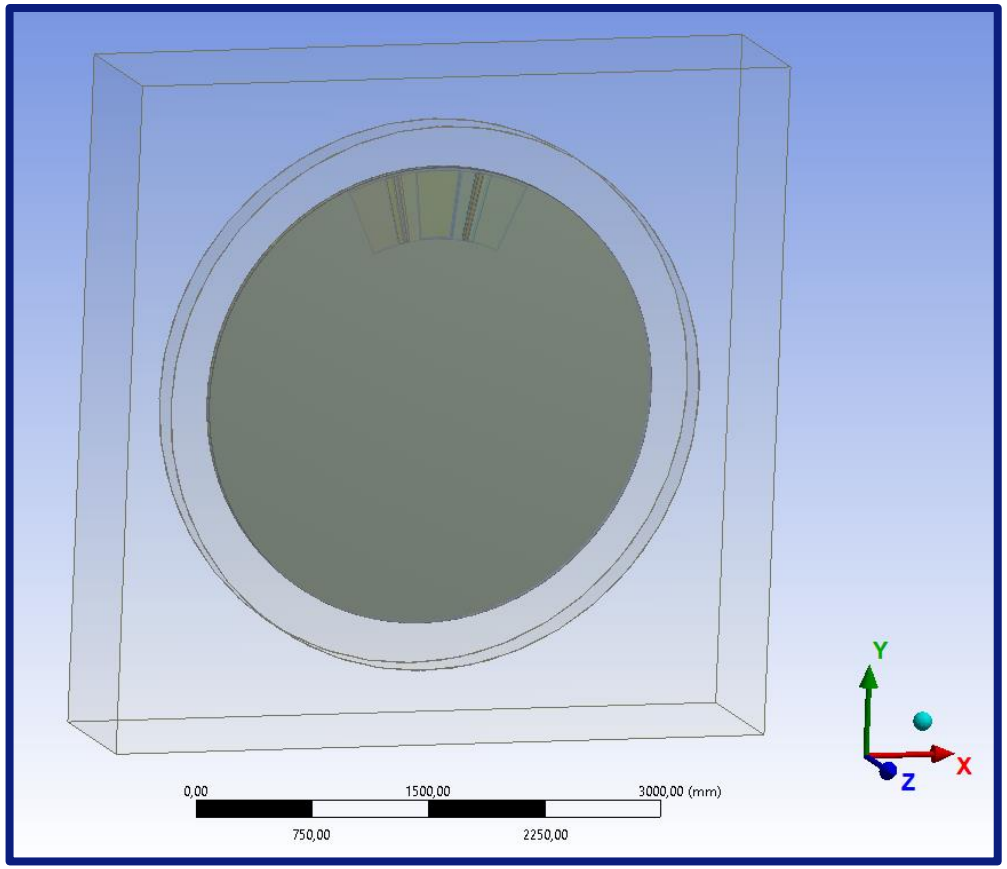
Tmin = 59.4℃

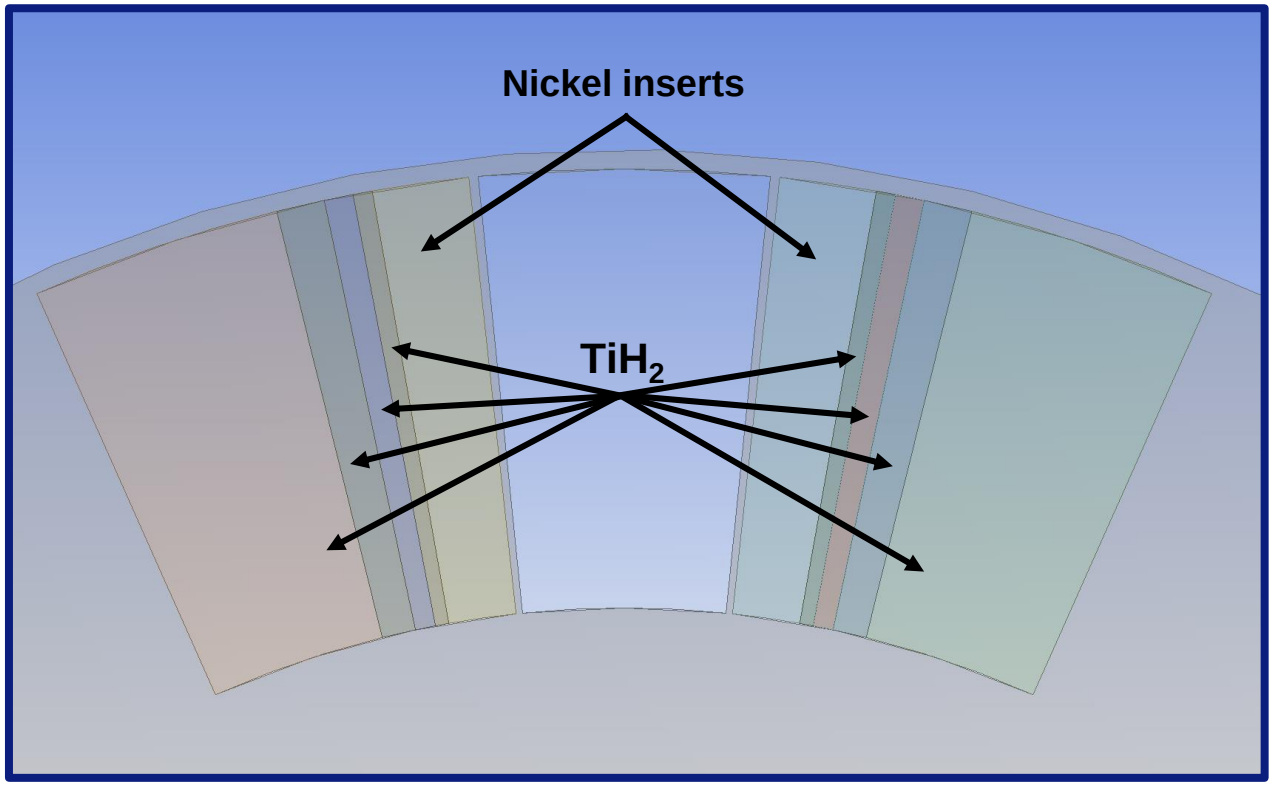
Tav = 180.4℃.



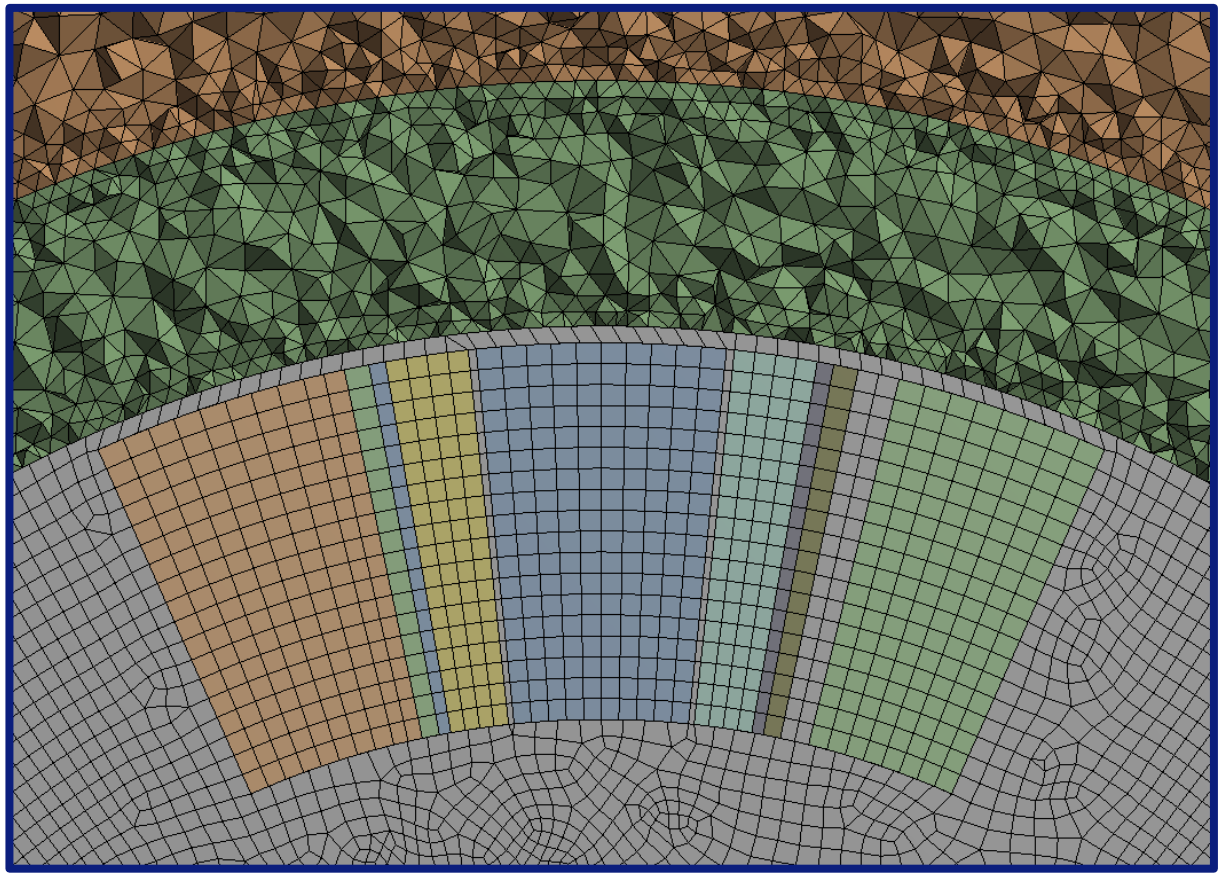
Temperature calculation of the RM taking into account the energy release corresponding to the nominal capacity mode of the reactor

Geometry of the RM with nickel inserts





Mesh model



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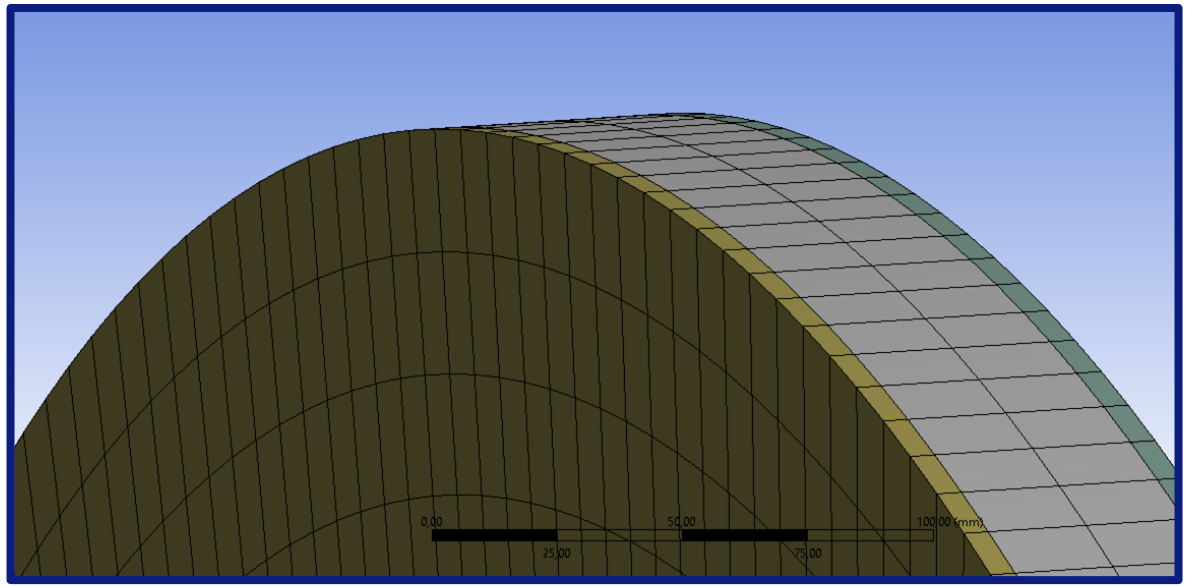
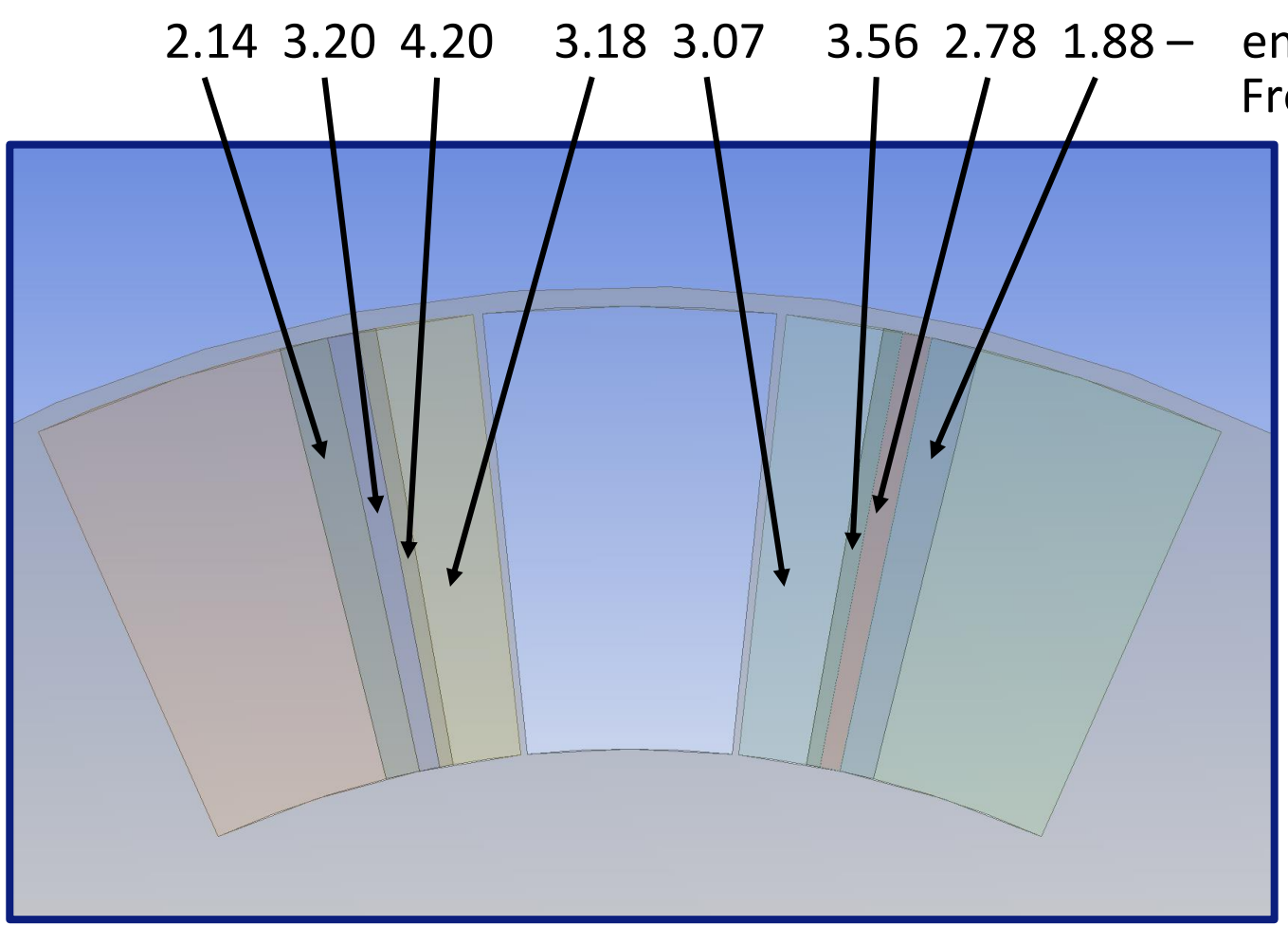
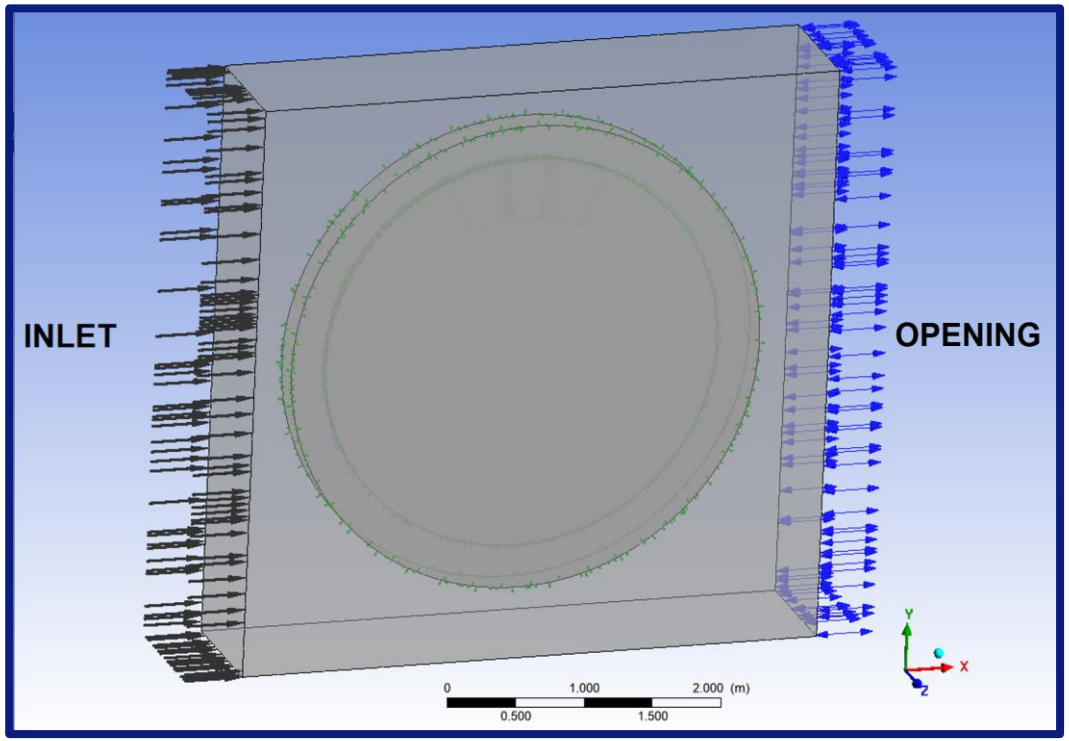


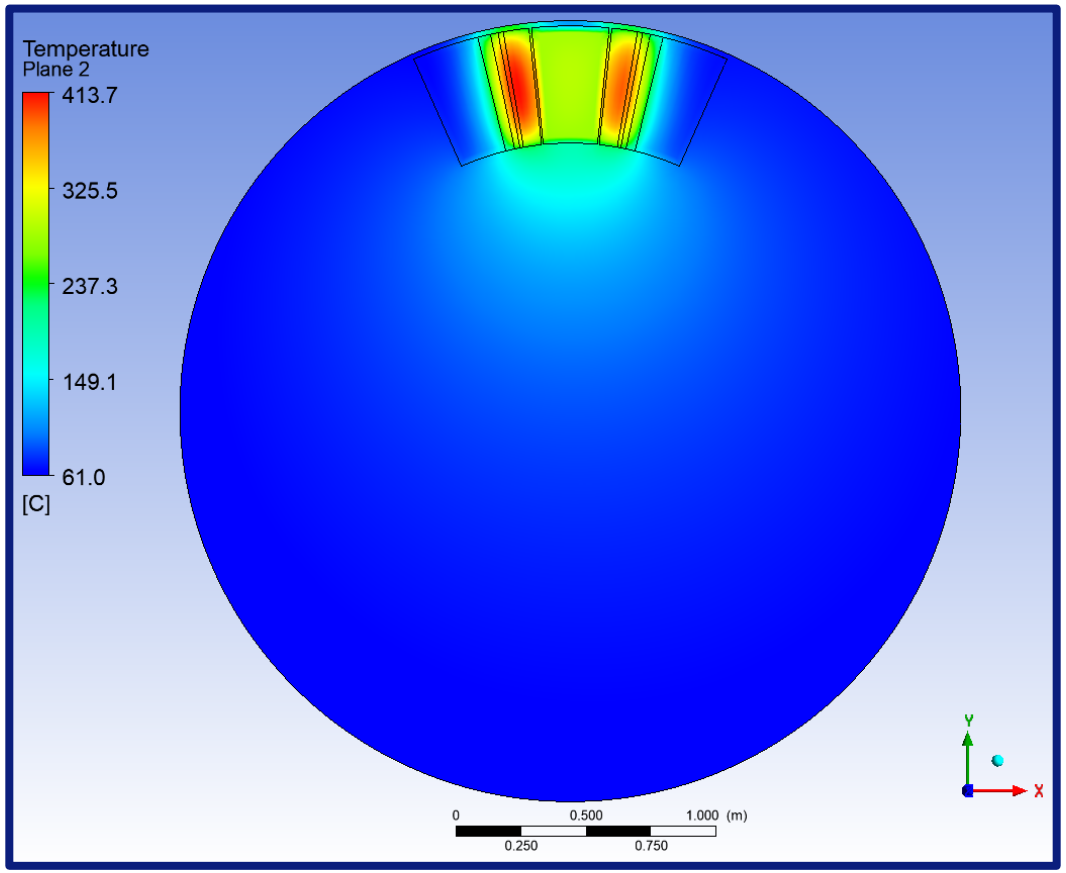
Boundary and initial conditions (for the calculation with nickel inserts)



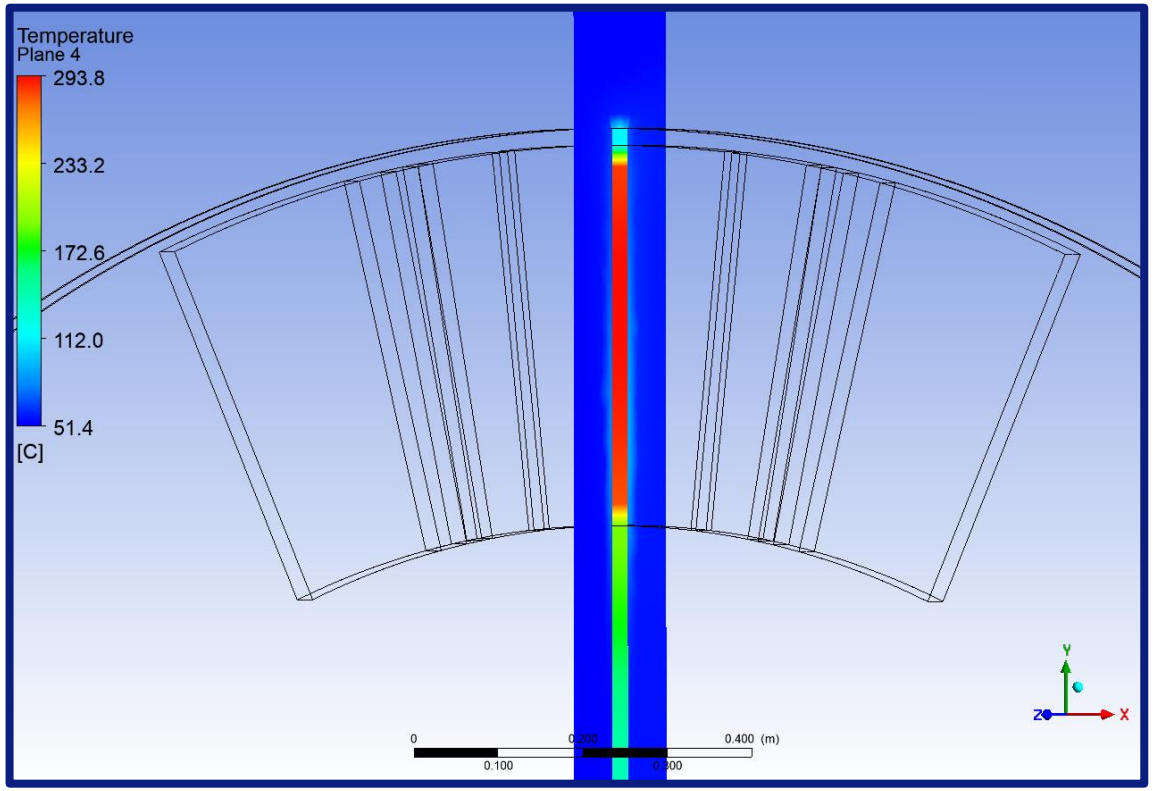
energy release in W/cm^3 in TiH_2 and nickel inserts
From neutrons and gamma radiation



Results of the temperature calculation



Distribution of the temperature in the RM disk
(central cross-section in the XY plane)



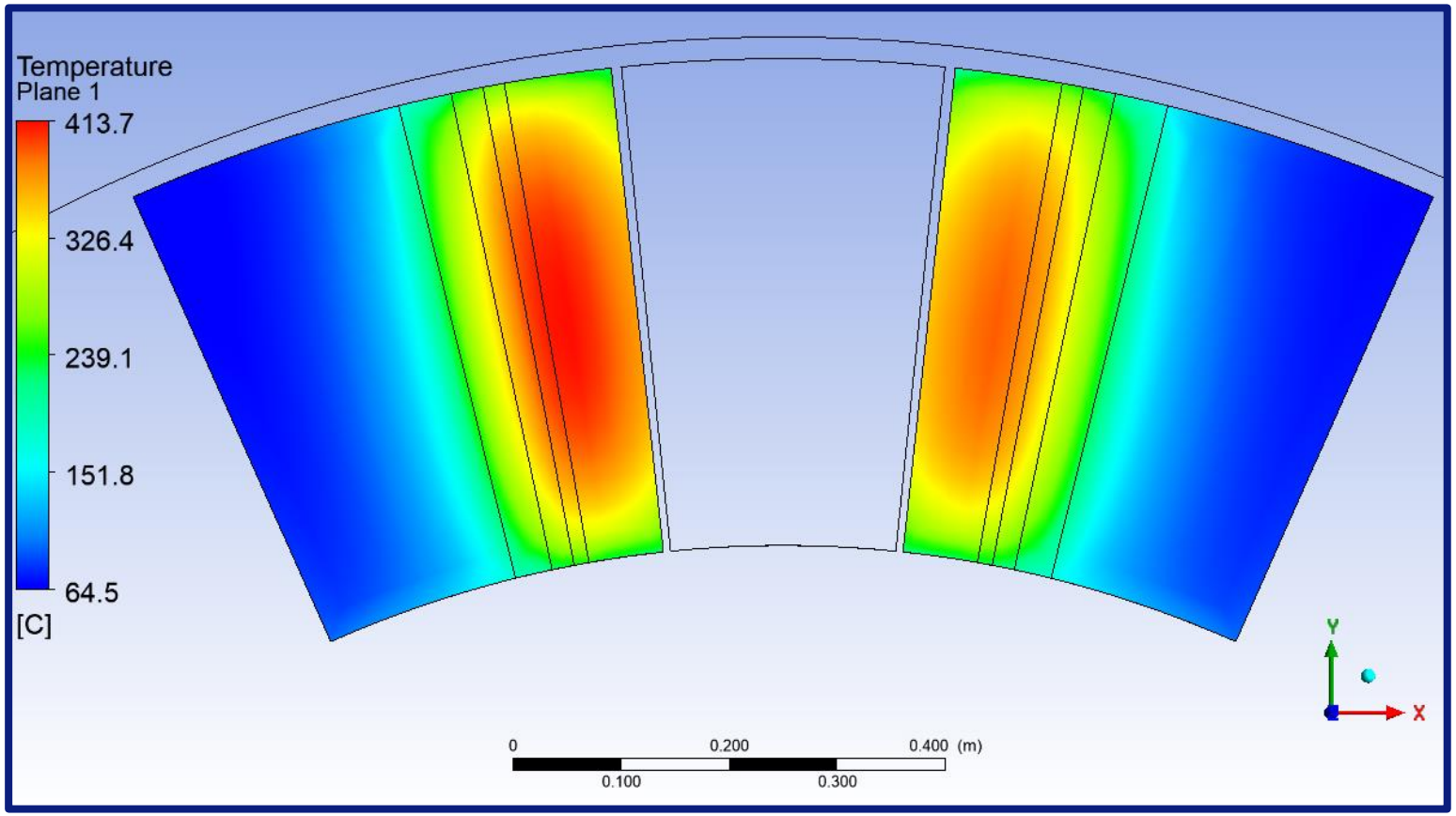
Distribution of the temperature in the RM disk
(cross-section in the YZ plane)

Distribution of the temperature in titanium hydride and nickel inserts

Tmax = 413.7℃

Tmin = 64.5℃

Tav_{TiH_2} = 158.1℃.



Conclusion

1. The natural frequences do not coincide with the RM rotation frequency.
2. The yield strength exceeding during rotation is found only in contact between the hub and the bearing area.
3. In the version of the highest energy release (without nickel inserts) titanium hydride overheats to 561.9℃. In the version with 10 cm wide nickel inserts the maximum temperature is decreased to 413.7 ℃.

Further work

1. Carrying out calculations with a more detailed mesh;
2. Taking into account the reactor vessel in temperature calculations;
3. Specifying a more detailed energy release distribution in the RM elements in temperature calculations;
4. Reactor vessel temperature calculating.

Joint Institute
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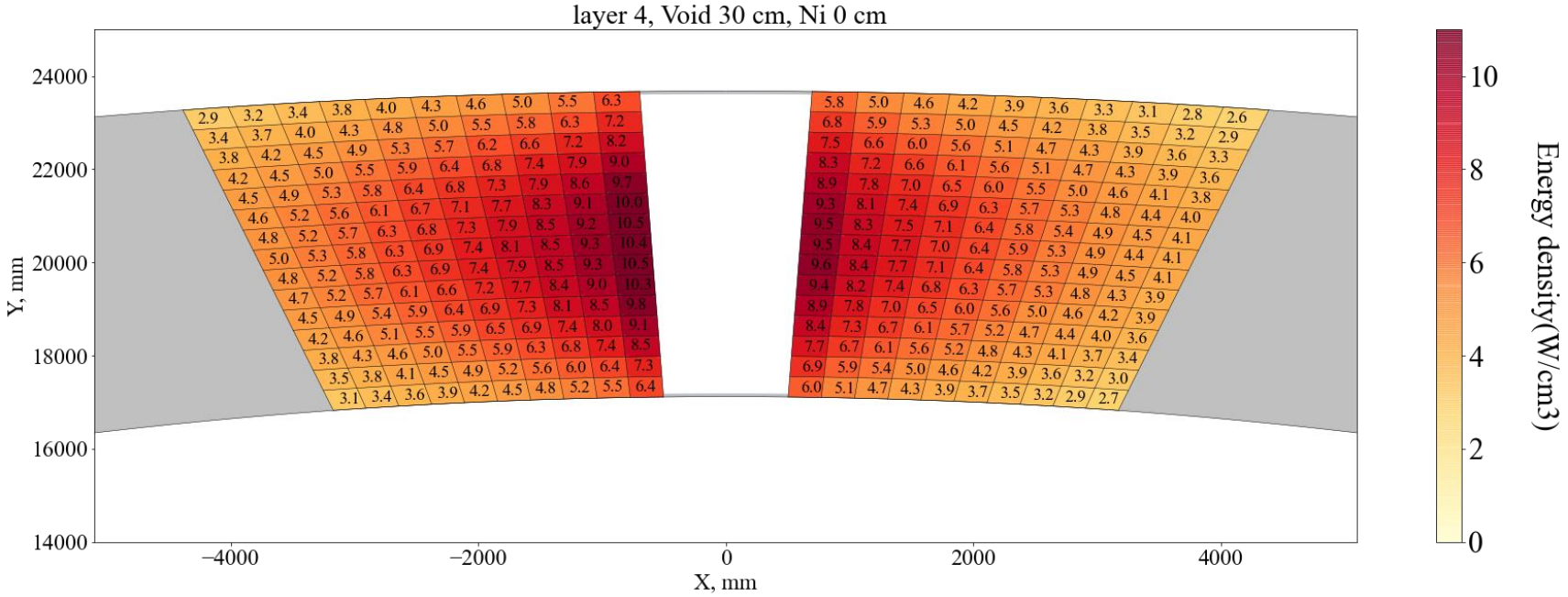
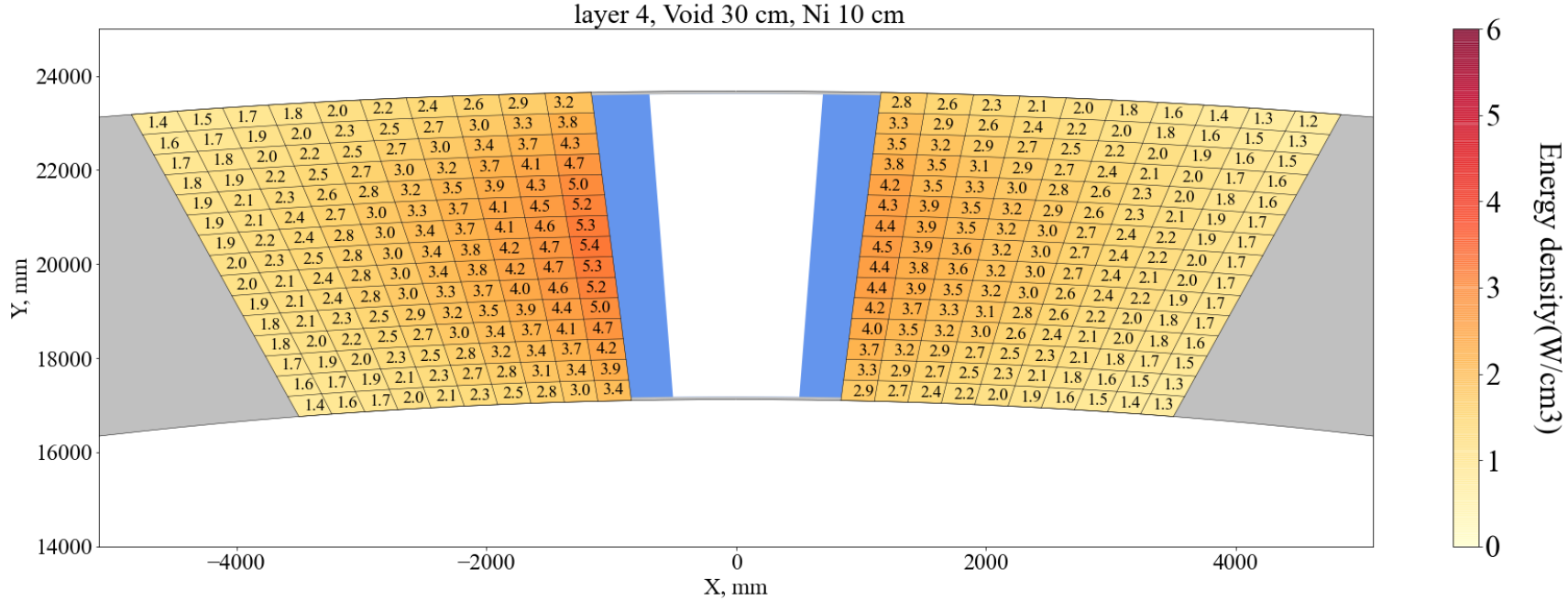
Thank you for your attention!

Ivan Kushnir,
engineer of SNSCM, FLNP JINR

The main parameters of the NEPTUNE reactor

Parameter	Значение
Average thermal power, MW	10-15
Operating mode	Pulsed
Pulse repetition rate, Hz	10
Pulse half-width, μs	200
Fuel	NpN
Material of the fuel rod cladding	Steel ChS-68-ID
Coolant	Na
Reflector	Nickel alloy + beryllium
Moderators	Water, hydrocarbons, beryllium
Coolant temperature at the inlet of the core, °C	290
Coolant temperature at the outlet of the core, °C	390
Coolant flow rate through half the core, kg/s	58
Fast neutron fluence on reactor vessel within 10000 eff. h, cm^{-2}: E > 0,1 MeV; E > 0,5 MeV	 $1,72 \cdot 10^{22}$ $9,6 \cdot 10^{21}$
Thermal neutron flux density from water moderator surface (with a power 15 MW), 10^{14} $cm^{-2} \cdot s^{-1}$	1,10
Maximum thermal neutron flux density, 10^{14} $cm^{-2} \cdot s^{-1}$: E > 0,4 MeV; integral	 4,0 7,2


layer 4, Void 30 cm, Ni 0 cm
Y, mm
X, mm
Energy density(W/cm3)


layer 4, Void 30 cm, Ni 10 cm
Y, mm
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Energy density(W/cm3)