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.

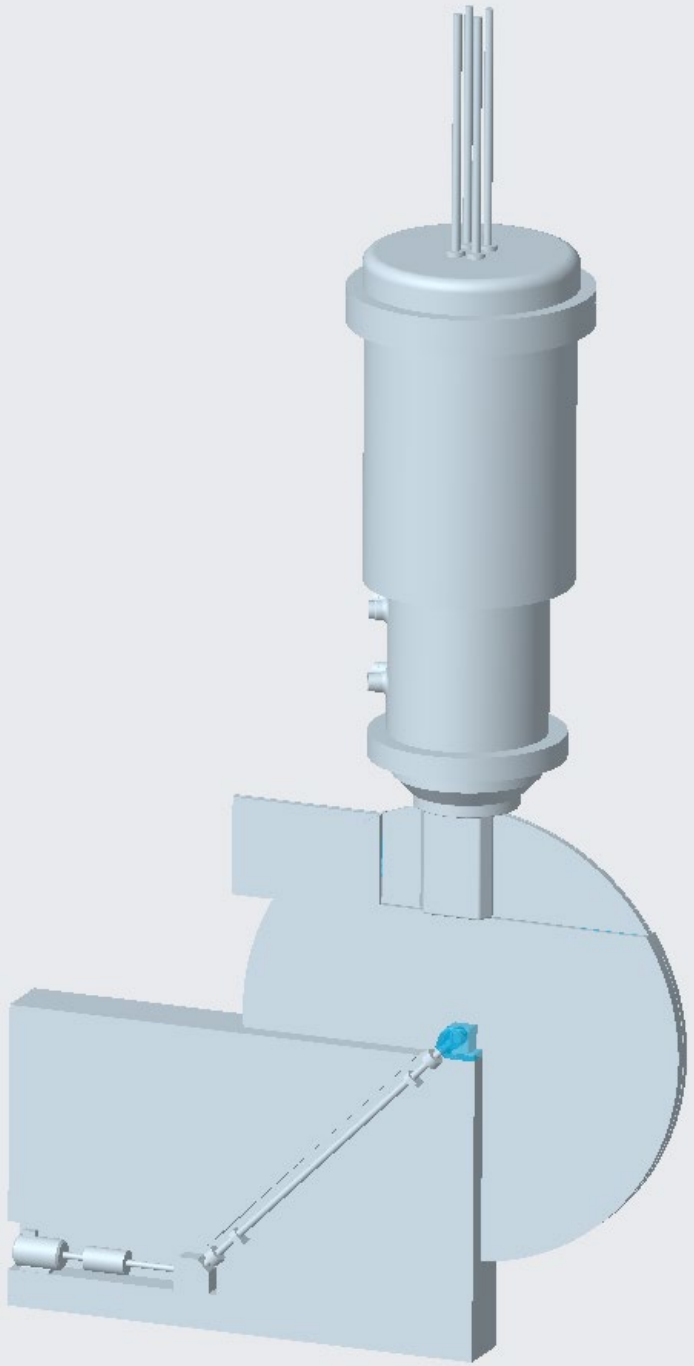
Tasks

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

NEPTUN reactor

Main parameters

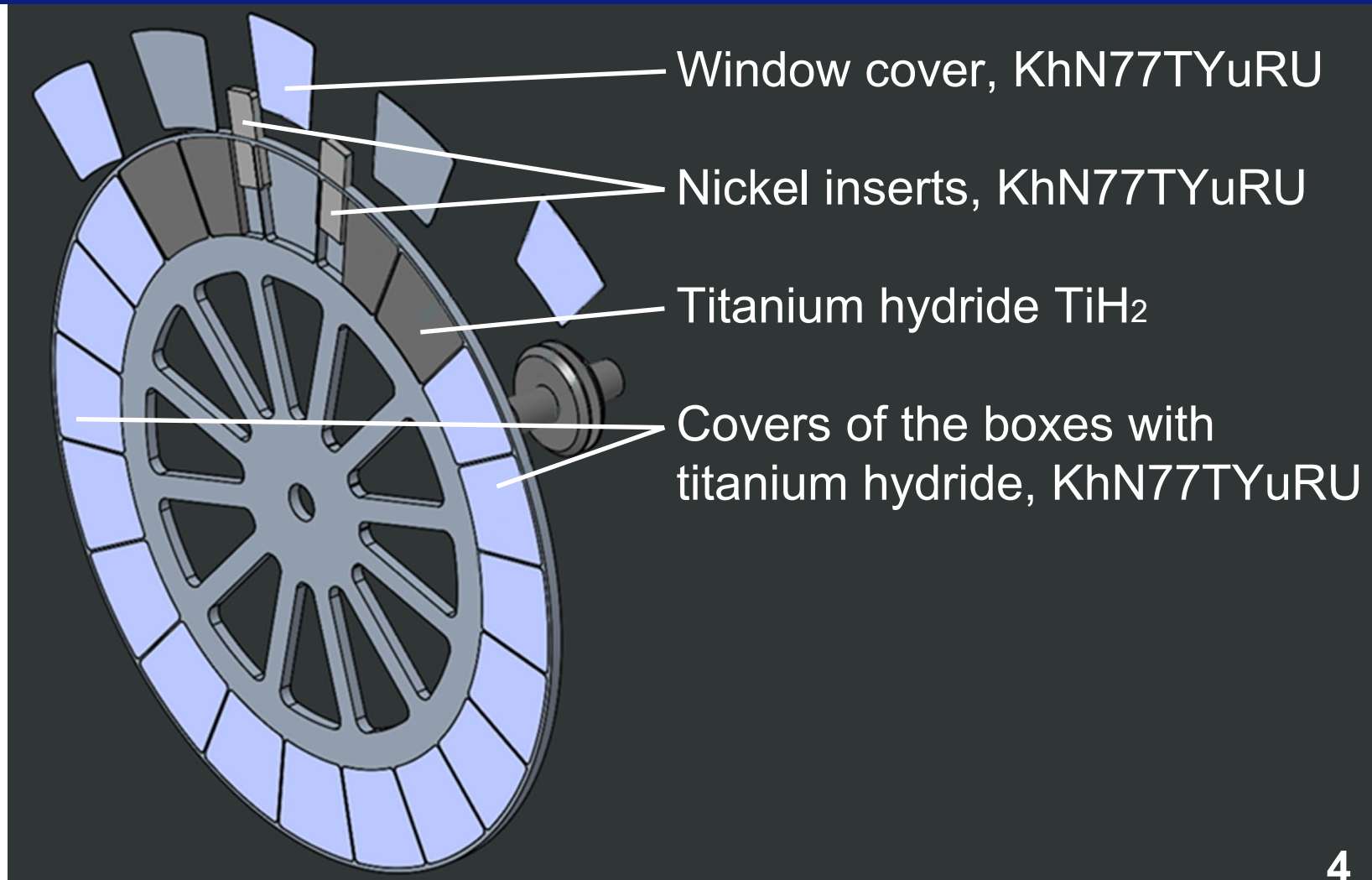
- Average thermal power — **10-15 MW**
- Pulse repetition rate — **10 Hz**
- Pulse half-width — **200 μs**
- Time-average thermal neutron flux density **$\sim 10^{14}$ $cm^{-2} \cdot s^{-1}$**



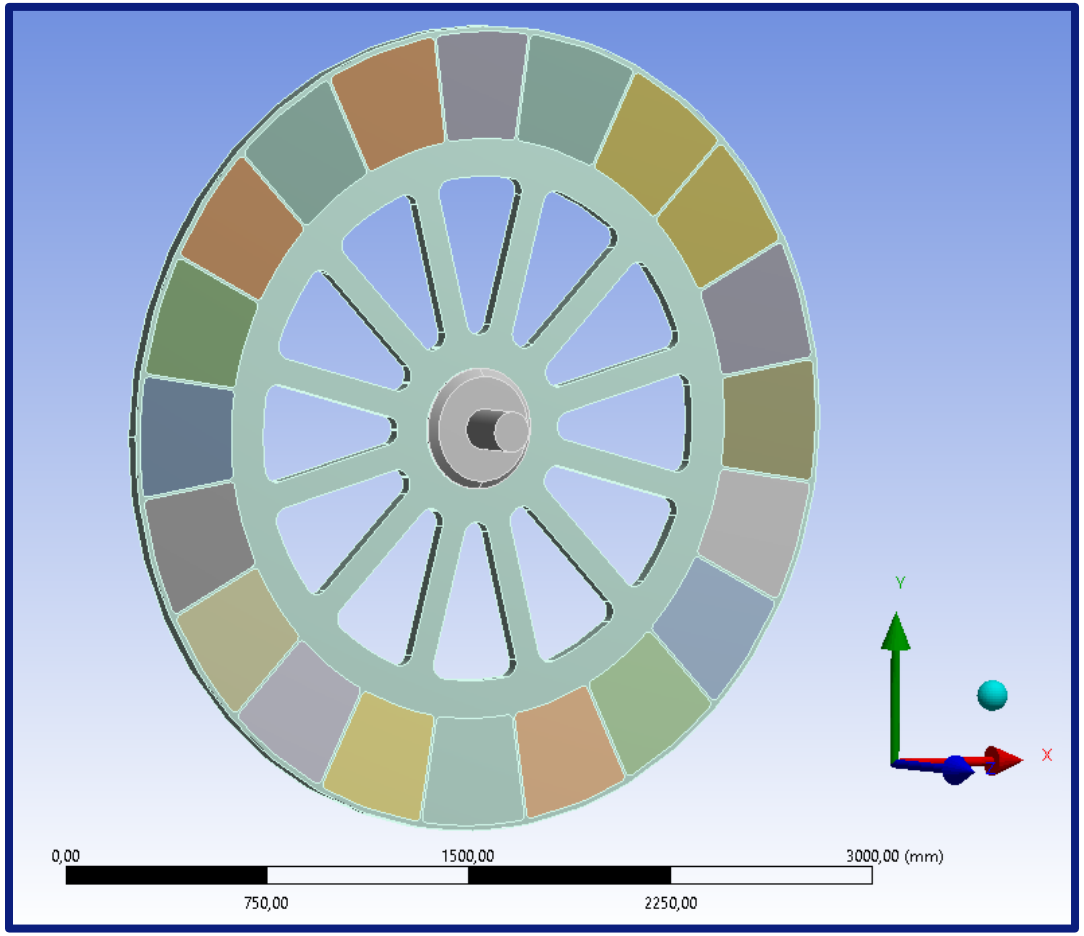
Reactivity modulator

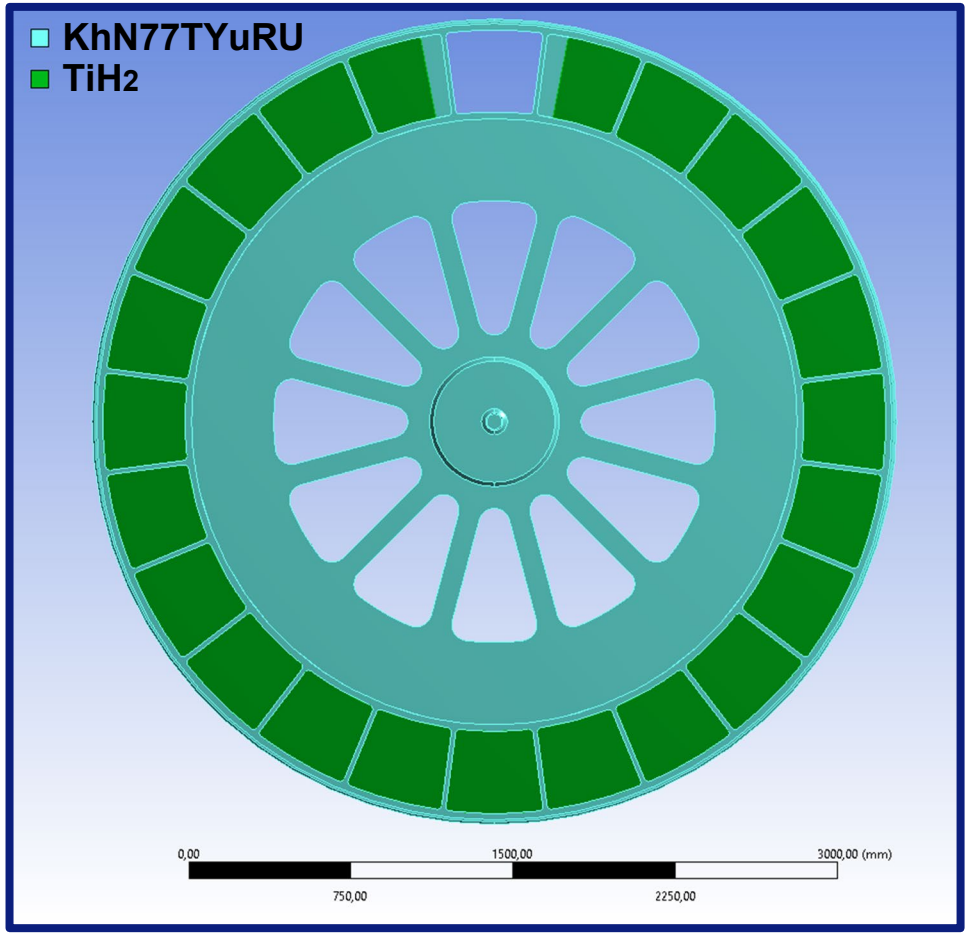
Main parameters

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



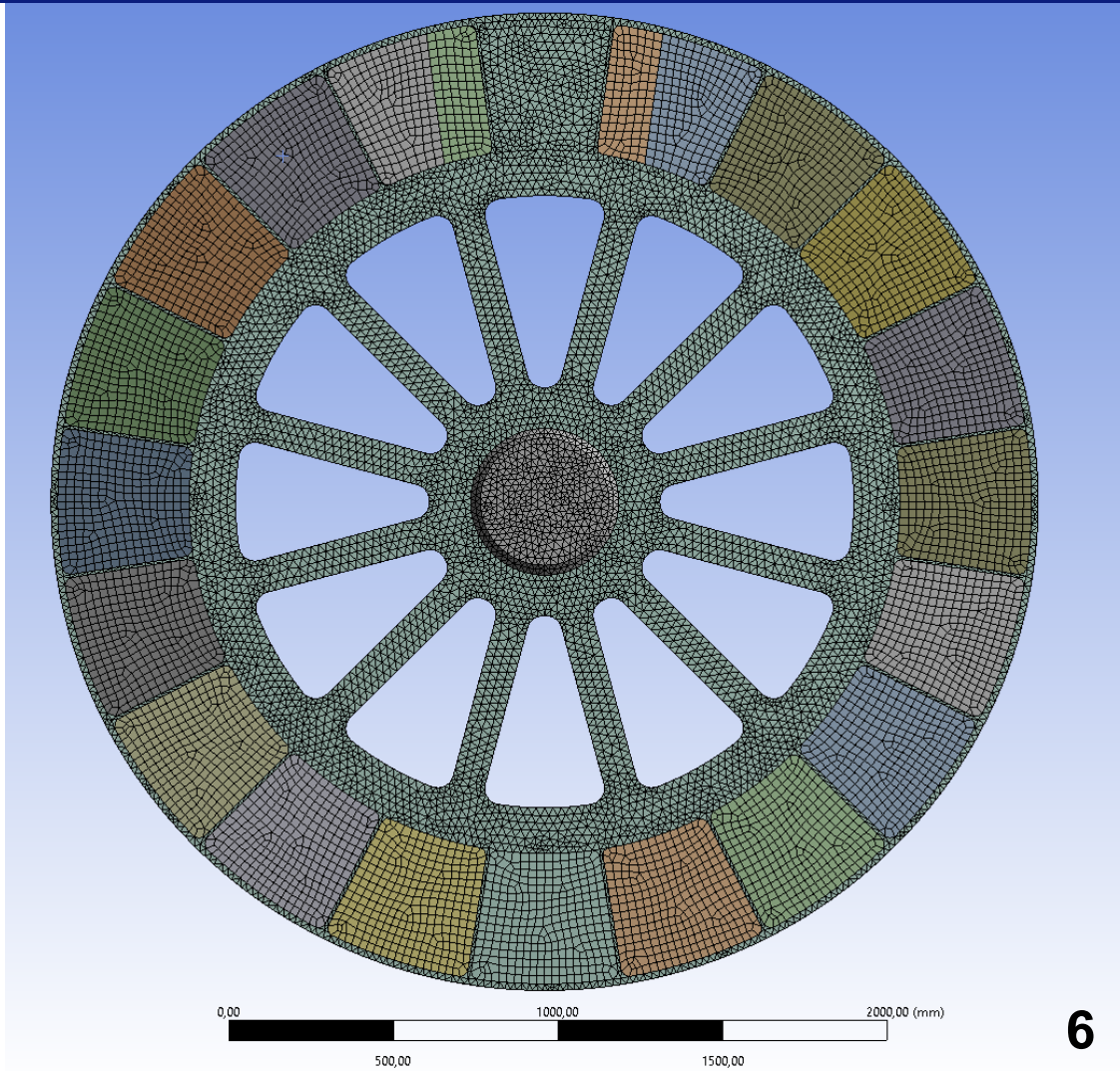
Modal analysis of the RM disc





Mesh model

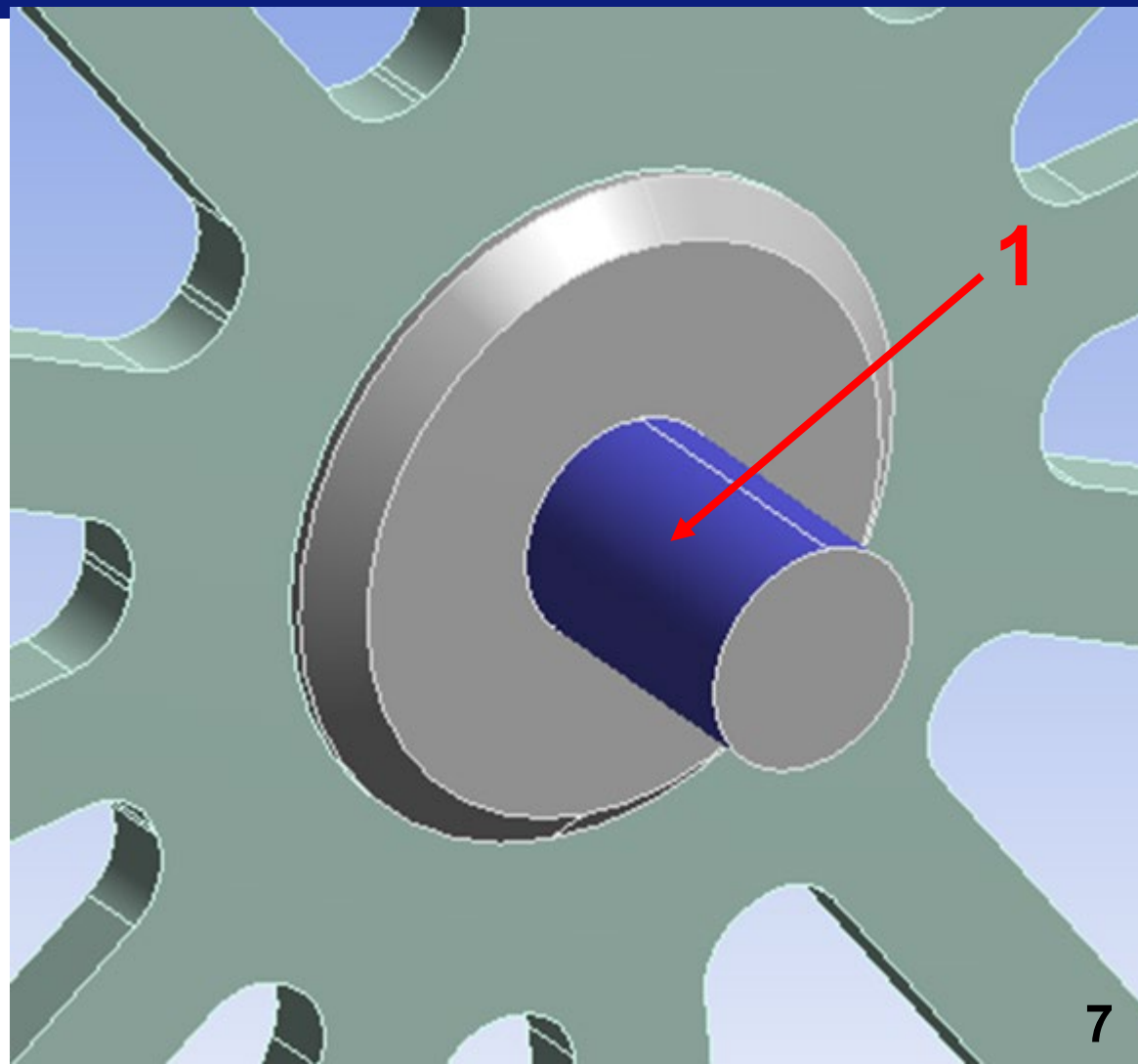
- Constructed mesh has **~396 thousand control elements** (tetrahedral and hexahedral elements are used).
- The amount of model **nodes** is **~137 thousand.**



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).

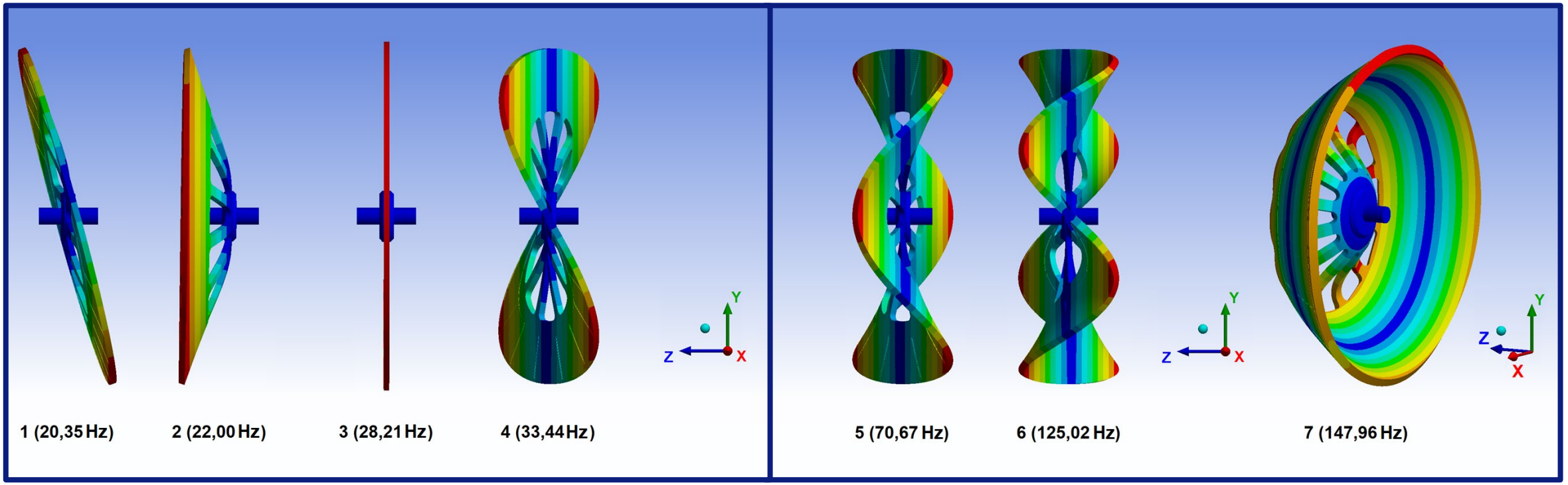
The hub doesn’t move translationally, only rotation is allowed.



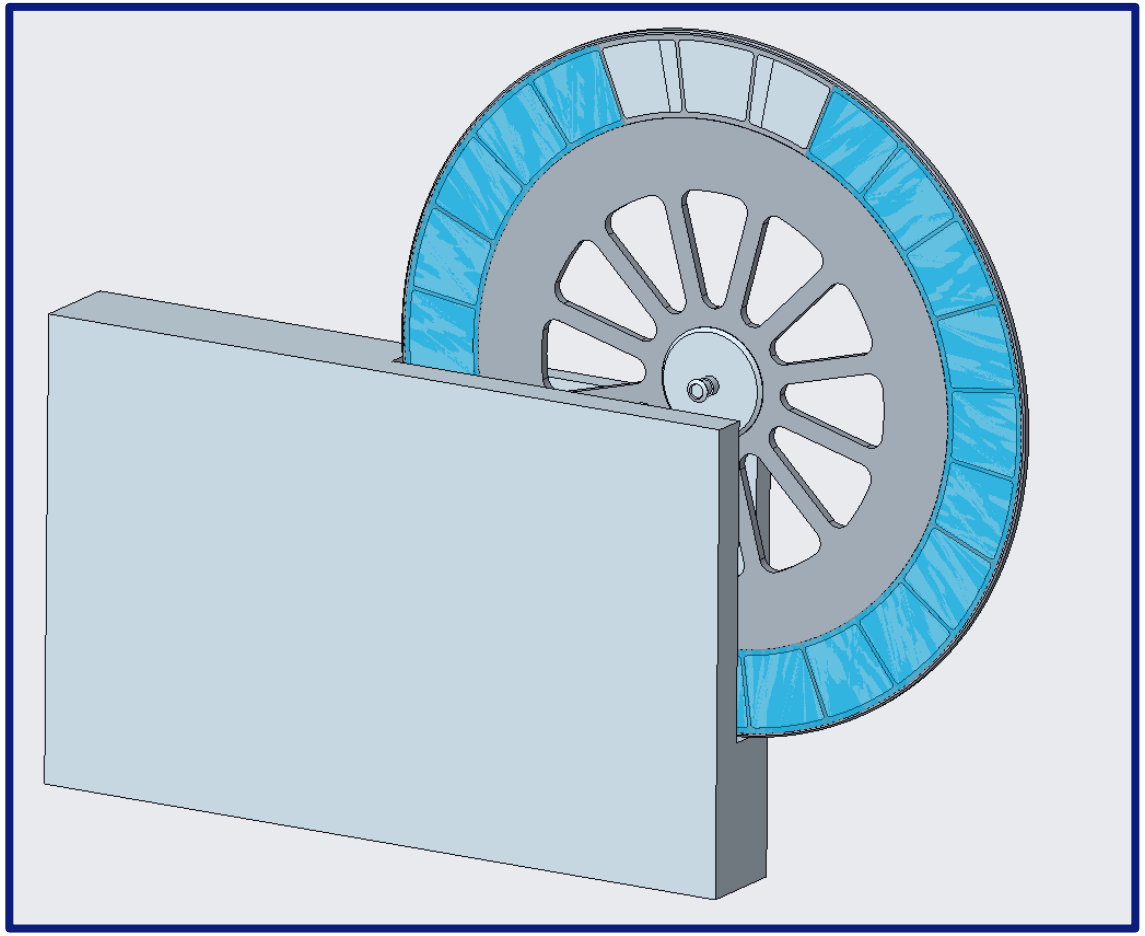
Results of the modal analysis

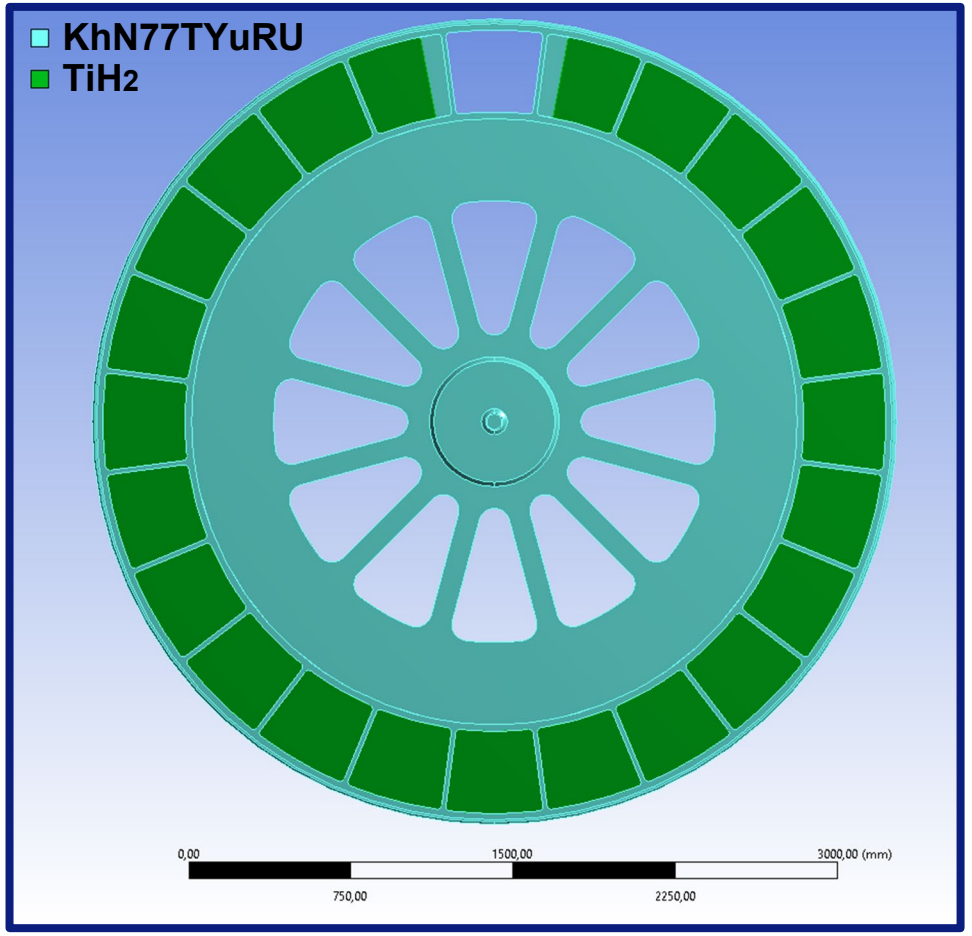
First **7 frequencies** and its **oscillation shapes** have been determined.

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

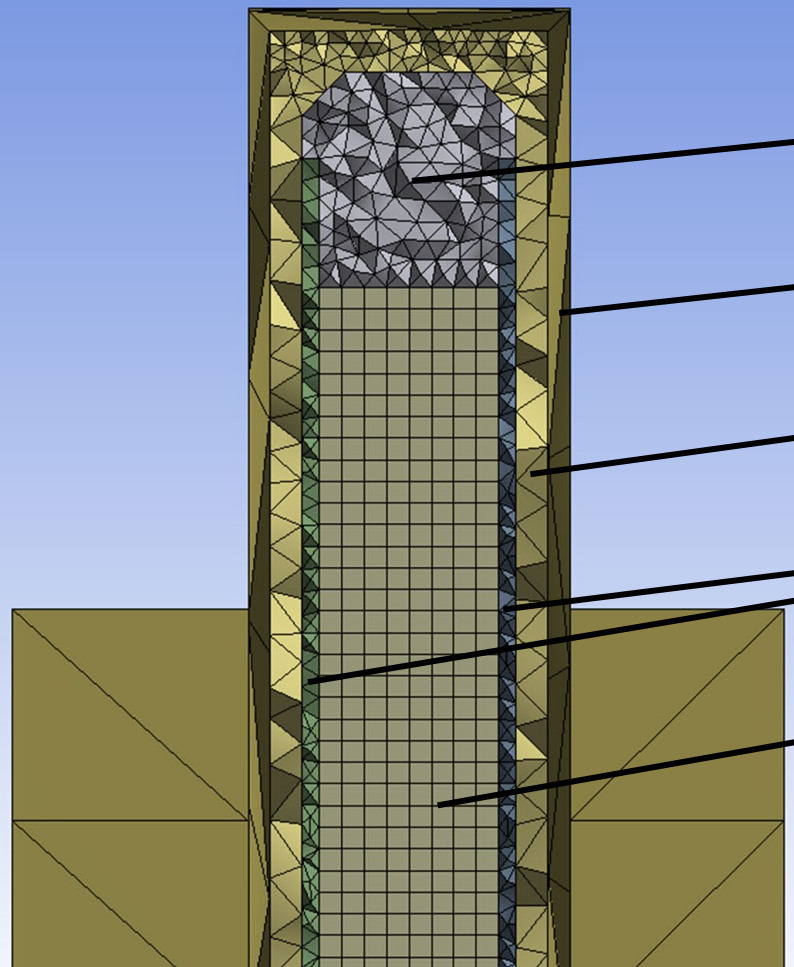


Temperature calculation of the RM





Mesh model



Upper part of the RM rim

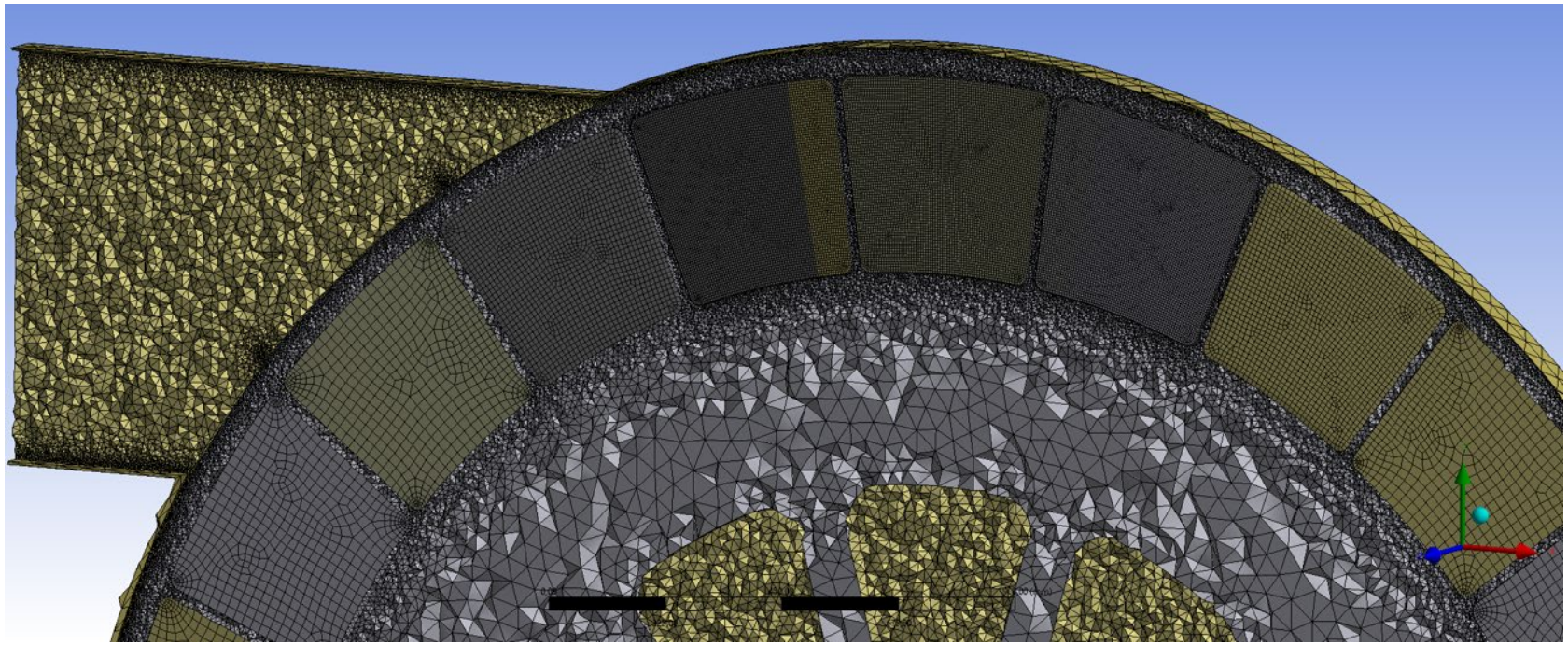
Cooling jacket

Helium

Window covers

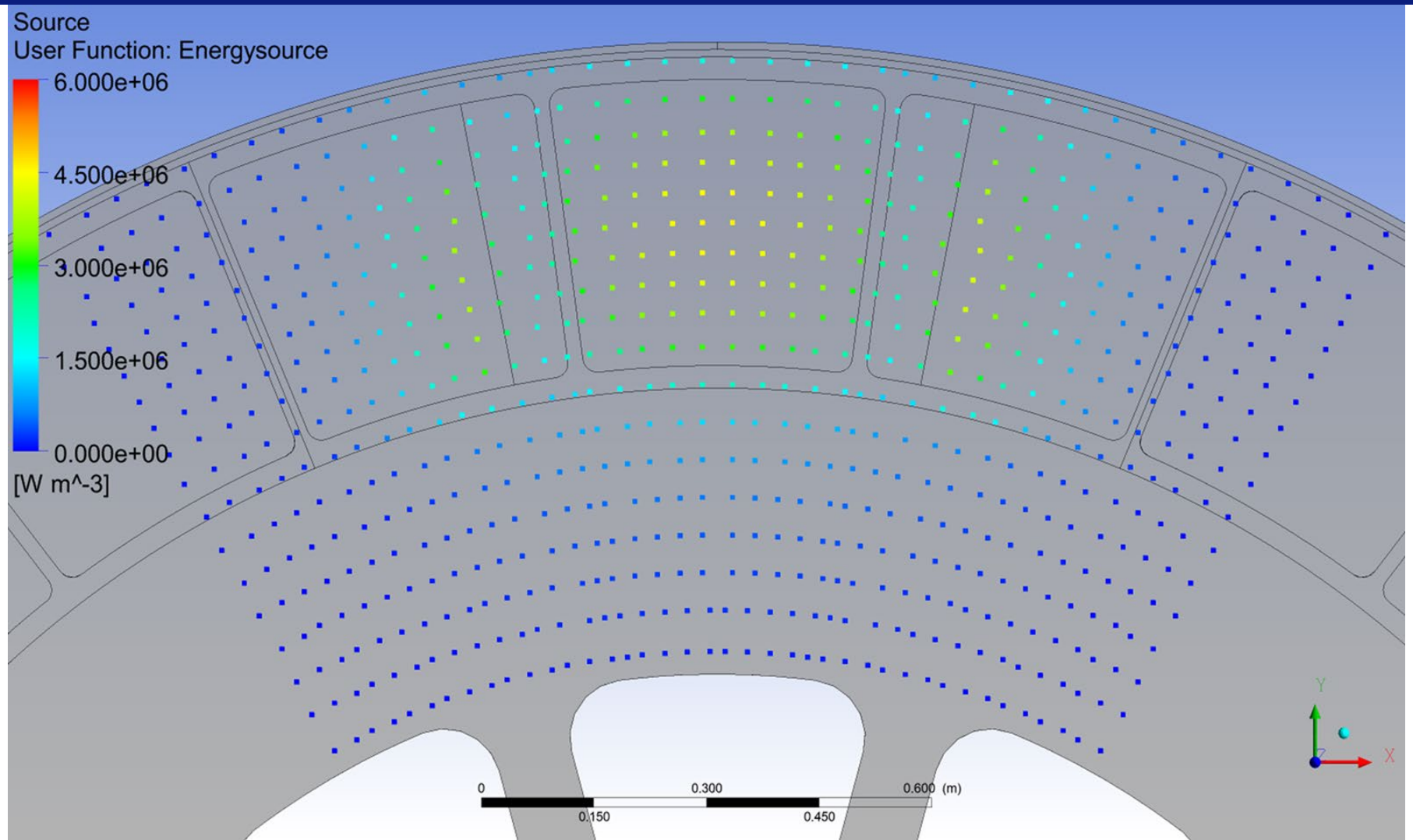
Helium in «window»

Mesh model

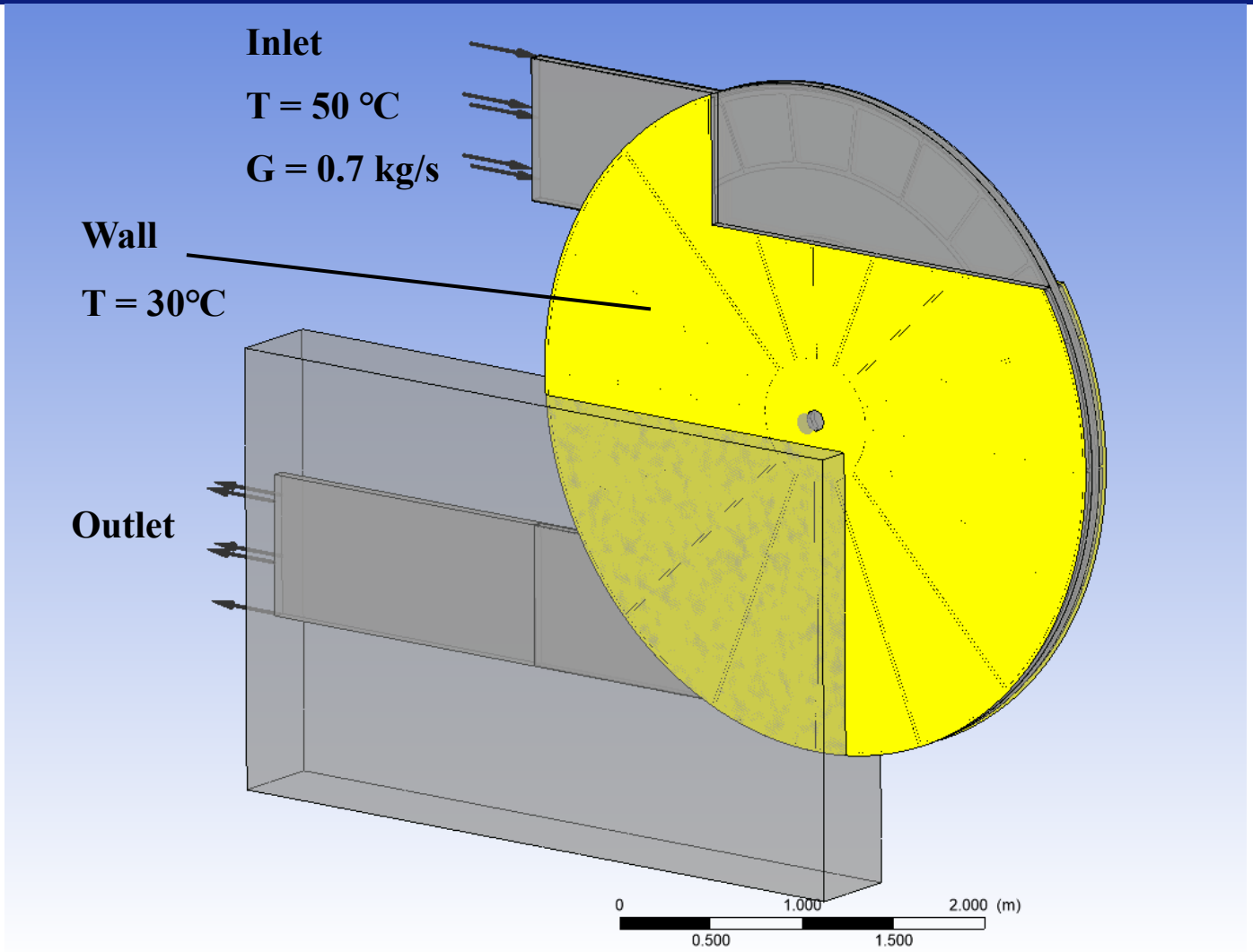


- Mesh has **~22.7 million control elements** (tetrahedral and hexahedral elements are used).
- The amount of model **nodes** is **~5.6 million.**

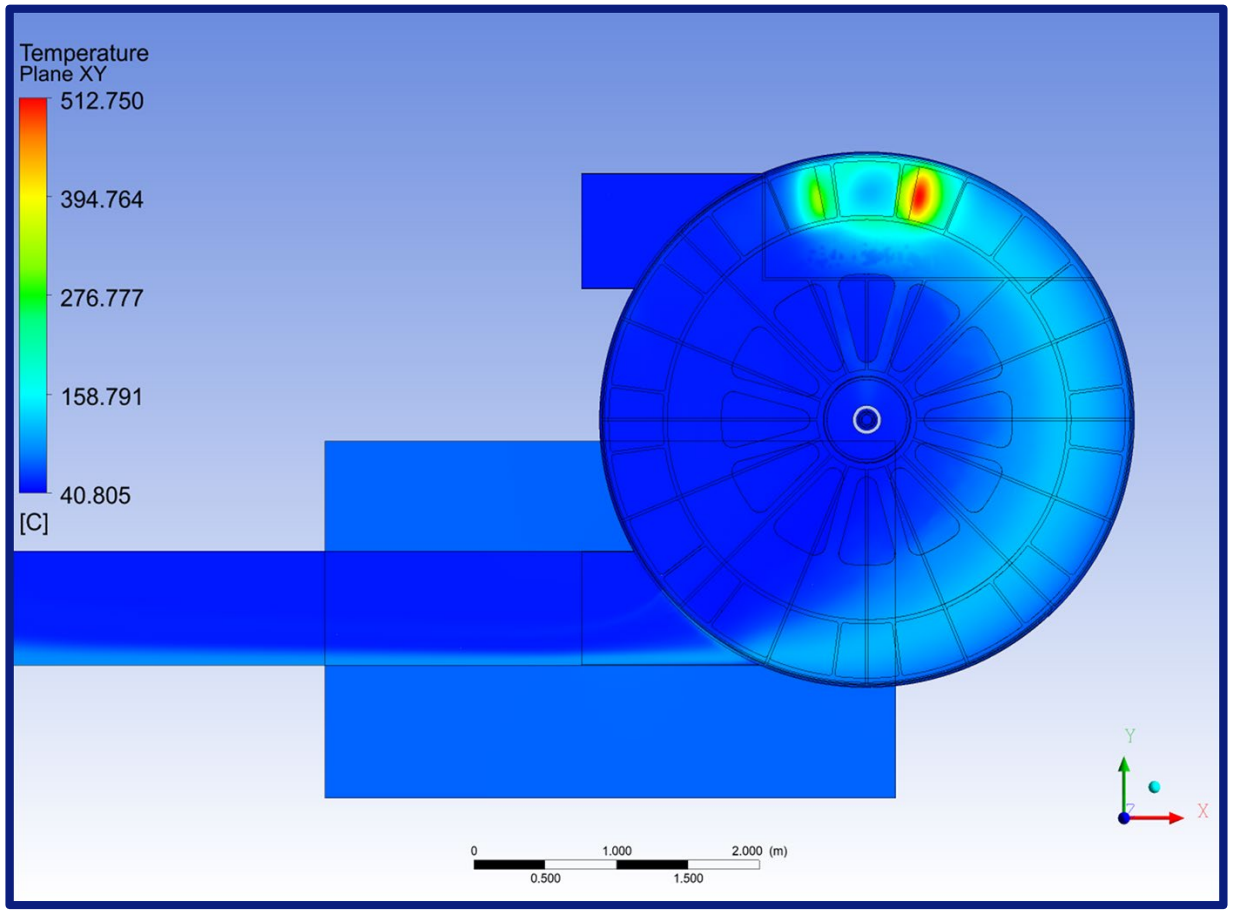
Boundary and initial conditions



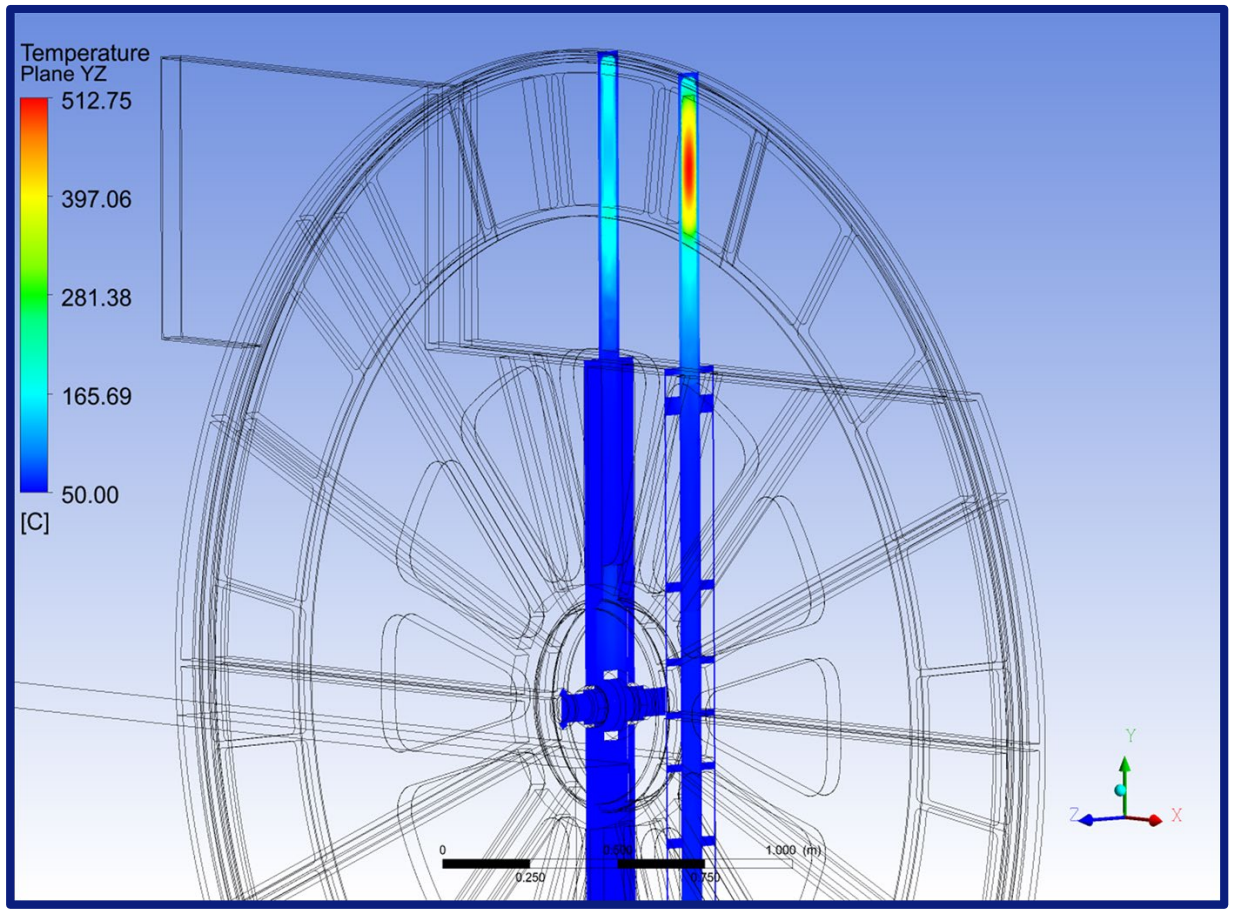
Boundary and initial conditions



Results of the temperature calculation



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



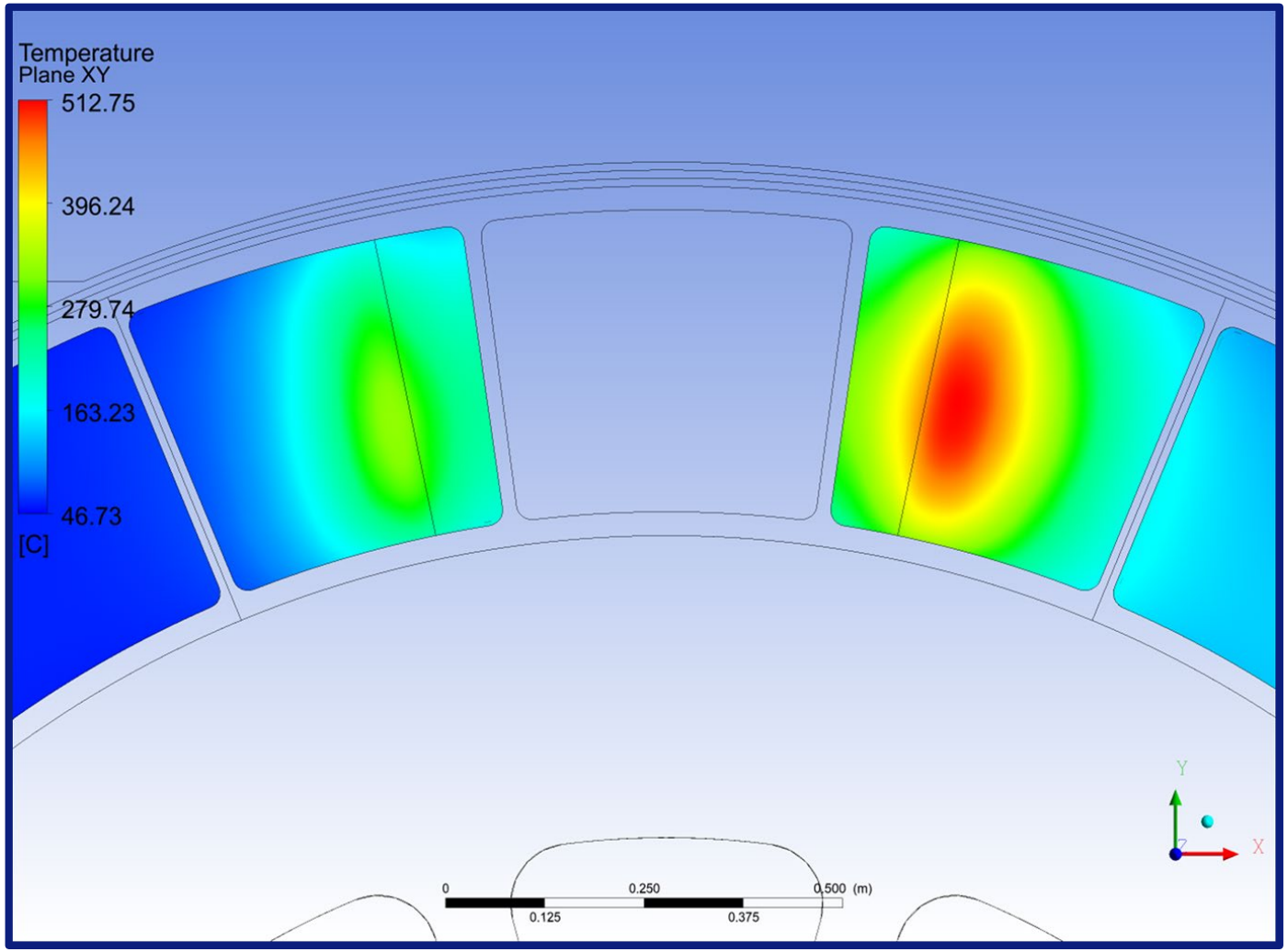
Distribution of the temperature in the RM disc (cross-sections in the YZ plane)

Distribution of the temperature in titanium hydride

Tmax = 512.75℃

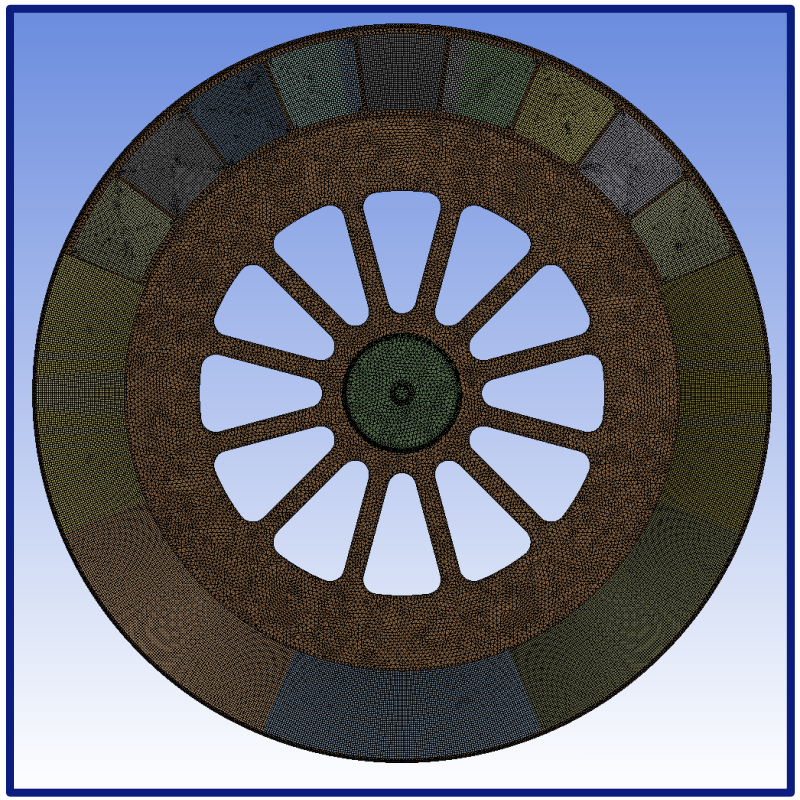
Tmin = 46.73℃

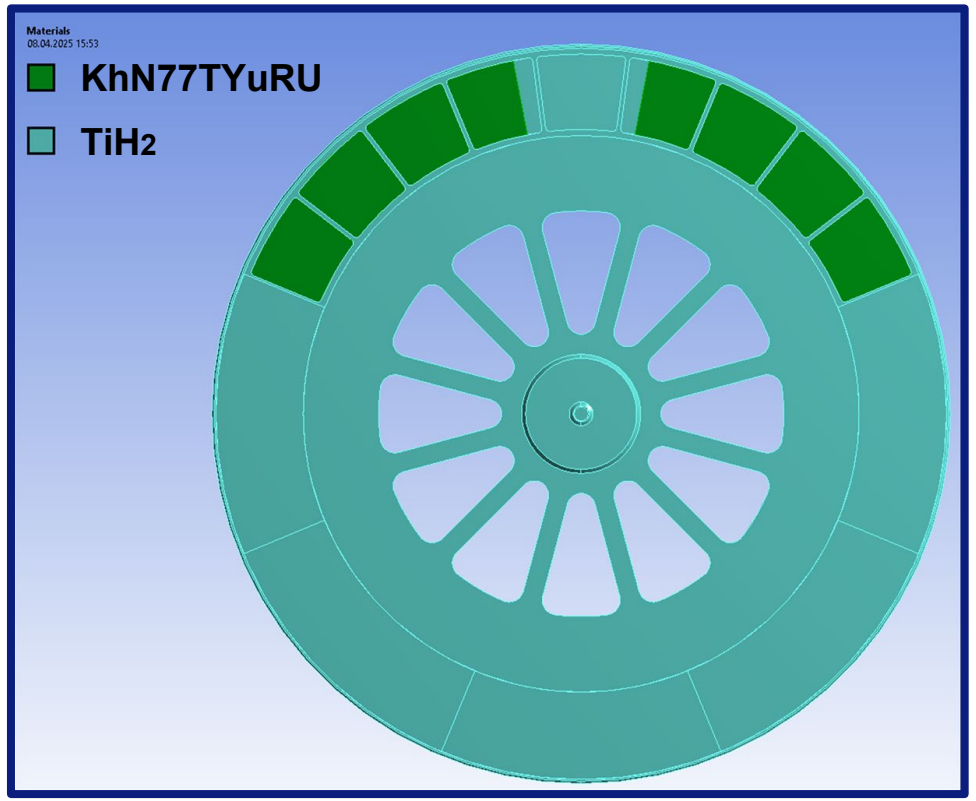
Tav TiH_2 = 233.7℃.



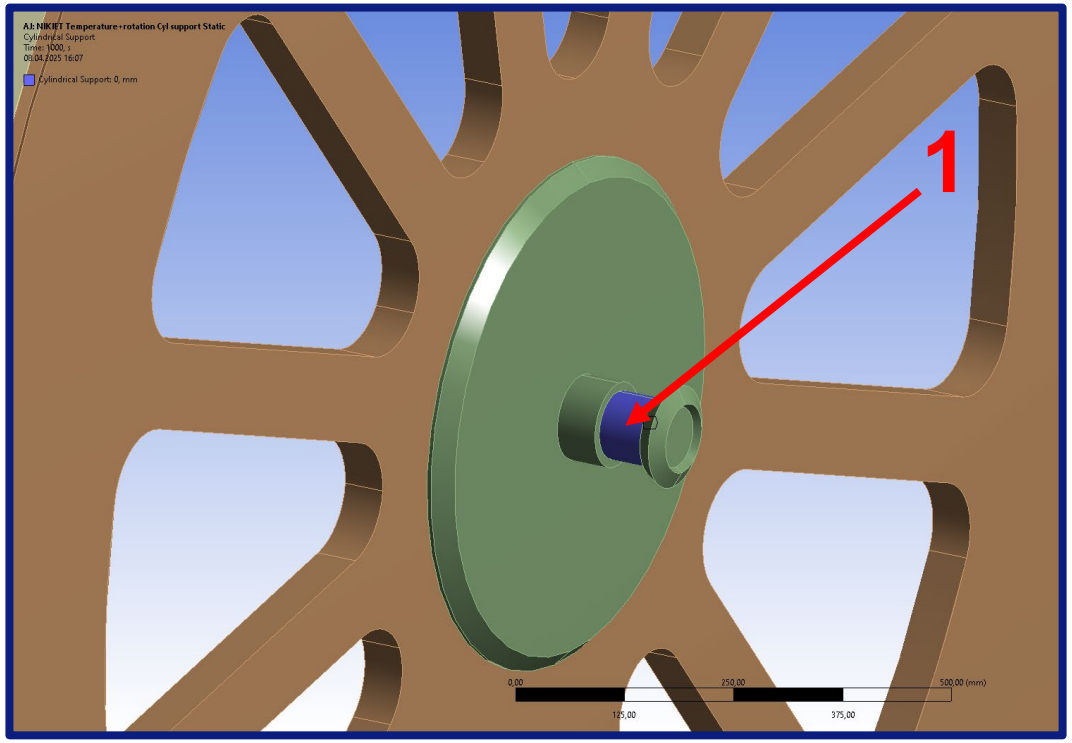
Mechanical calculation of the RM disc for stresses and deformations

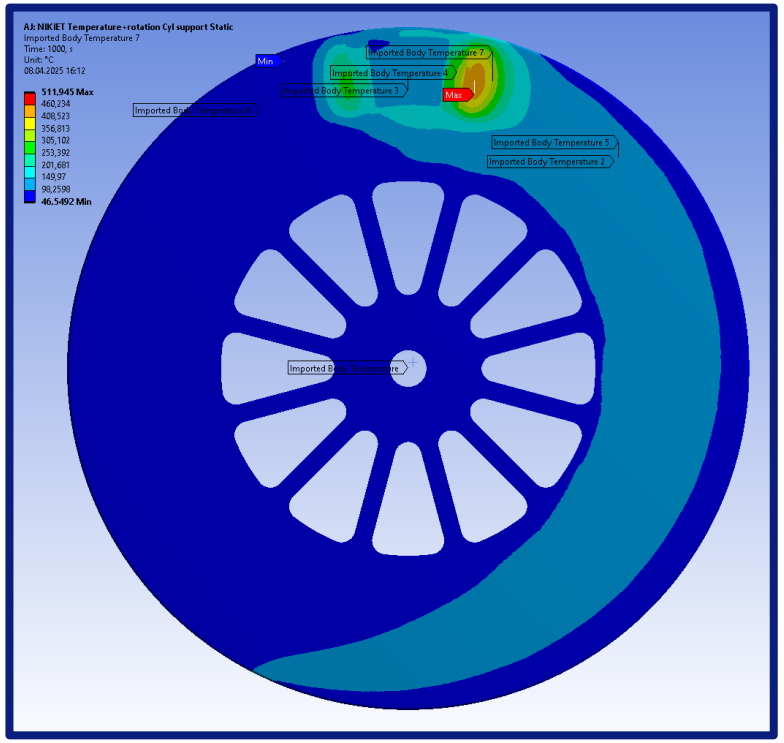
The calculation uses the same model as was used in modal and thermal analysis





Boundary conditions

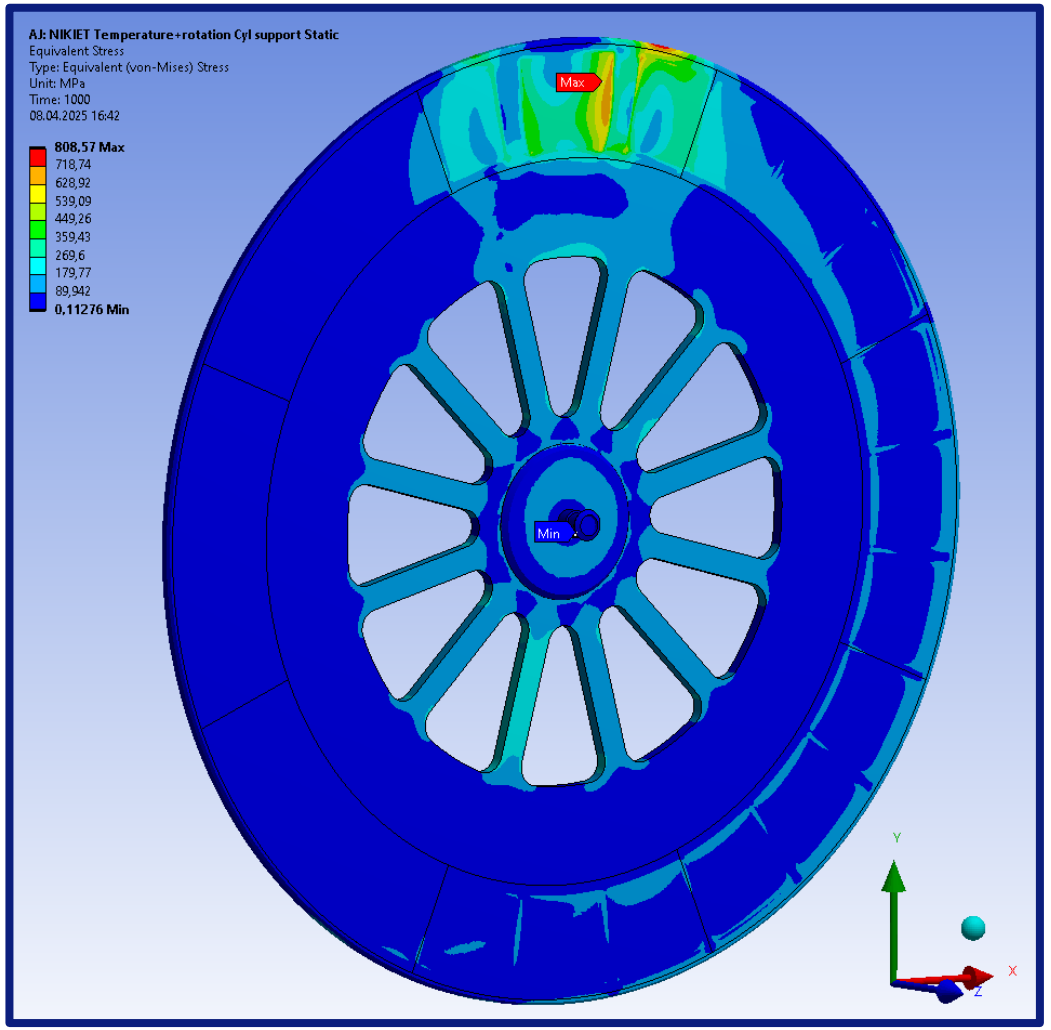




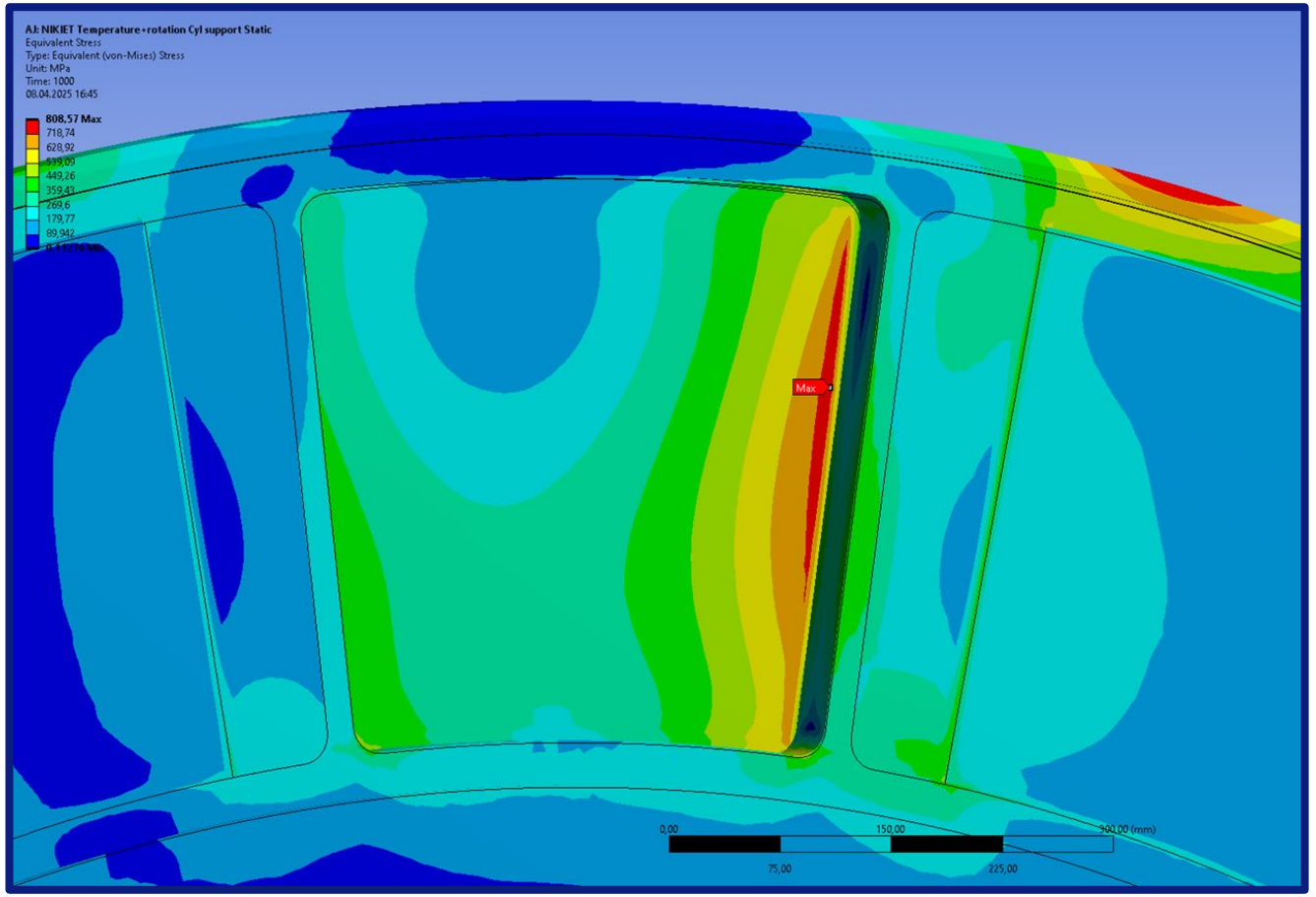
Bearing assembly (1) is modeled using **Cylindrical Support** on the wheel hub surface (tangentional movement only).

Rotation rate of the RM disc is **10 Hz.**

Results of the mechanical calculation

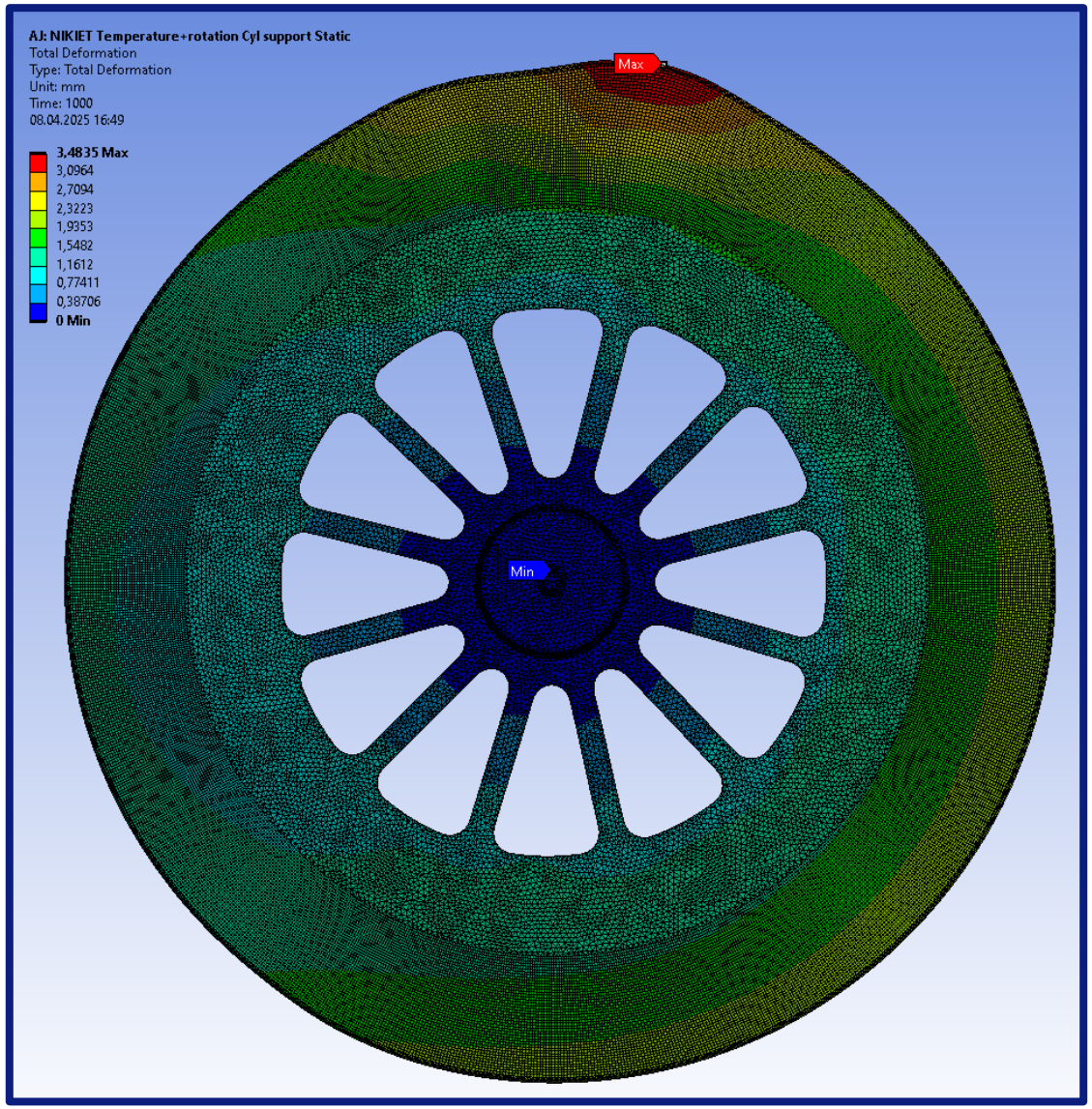


Distribution of stresses in the RM disc



Maximum stress area (σ_{max} = 808.6 MPa)

Results of the mechanical calculation



Maximum deformations:

Total 3.48 mm (in the maximum temperatures area of the rim)

Axial 0.2 mm (in the maximum temperatures area of the cover)

Radial 3.45 mm (in the maximum temperatures area of the rim)

Conclusion

1. The natural frequences do not coincide with the RM rotation frequency;

2. Overheating of titanium hydride is observed, with a maximum temperature of 512.75℃.

3. The maximum displacements are observed in the area of peak temperatures. The maximum axial displacements reached 0.2 mm, which is less than the clearance between the RM disc and the cooling jacket. The maximum radial displacements reached 3.45 mm, which also does not lead to contact between the RM disc and the jacket.

Further work

1. Carrying out calculations using power density computed in Serpent with varying reactor power levels (12 and 15 MW);

2. Carrying out the corresponding mechanical calculations;

3. Calculation of the RM cooling jacket and reactor vessel deformations.

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Thank you for your attention!

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engineer of SNSCM, FLNP JINR

Основные характеристики реактора НЕПТУН

Параметр	Значение
Средняя тепловая мощность, МВт	15
Режим работы	Импульсный
Частота импульсов, Гц	10
Полуширина импульса, мкс	200
Топливо	NpN
Материал оболочки твэла	Сталь ЧС-68-ИД
Теплоноситель	Na
Отражатель	Никелевый сплав + бериллий
Замедлители	Вода, углеводороды, бериллий
Температура теплоносителя на входе в активную зону, °С	290
Температура теплоносителя на выходе из активной зоны, °С	390
Расход теплоносителя через половину активной зоны, кг/с	58
Флюенс быстрых нейтронов на корпусе реактора в течение 10000 эфф. ч, $см^{-2}$: E > 0,1 МэВ; E > 0,5 МэВ	 $1,72 \cdot 10^{22}$ $9,6 \cdot 10^{21}$
Средняя ППТН с поверхности водяного замедлителя при мощности 15 МВт, 10^{14} $см^{-2} \cdot с^{-1}$	1,10
Максимальная ППТН, 10^{14} $см^{-2} \cdot с^{-1}$: E > 0,4 МэВ; интегральная	 4,0 7,2