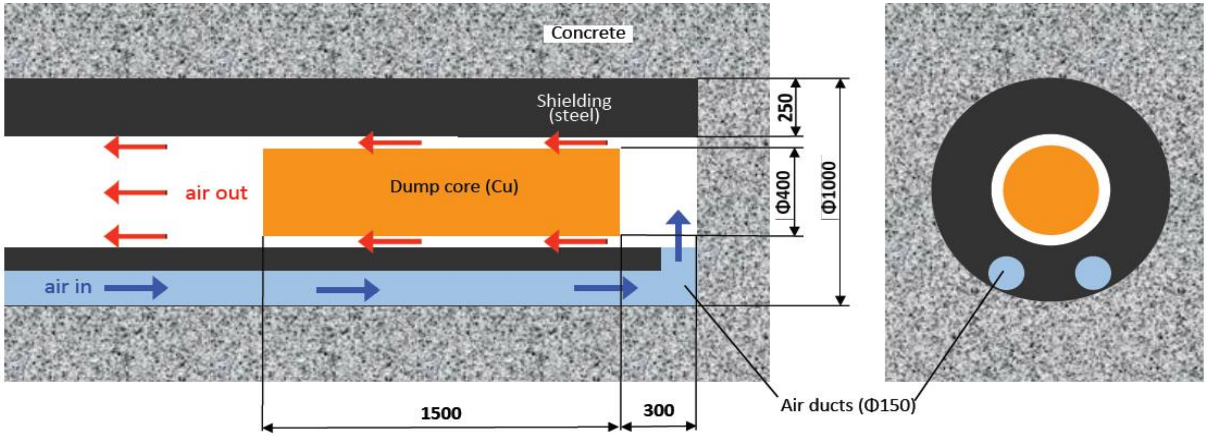
PSB Dump air cooling

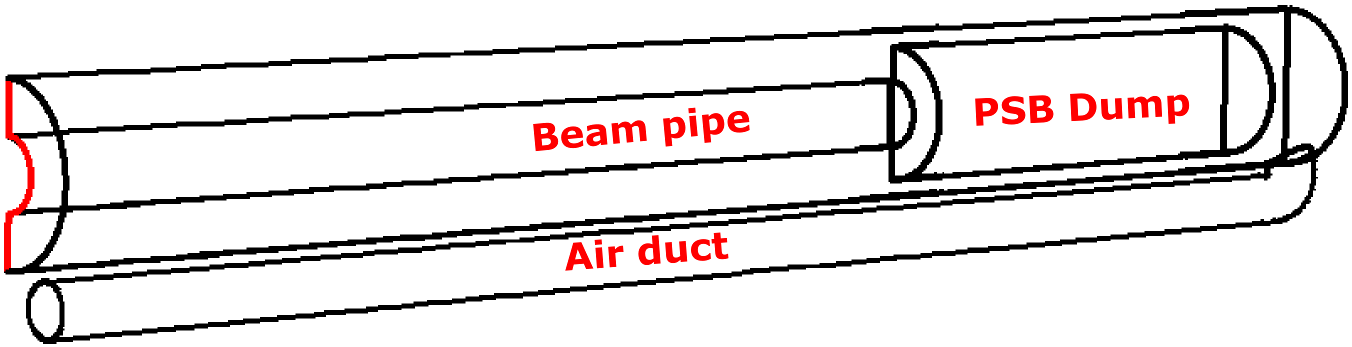
Results with:
-) Flat dump without fins
-) Fins '5 mm – 10 mm – 10 mm'
-) Fins '5 mm – 10 mm – 20 mm'
-) Fins '5 mm – 25 mm – 20 mm'
-) Fins '5 mm – 25 mm – 50 mm'
-) Fins '5 mm – 10 mm – 40 mm'
-) Final design ver.1
-) Final design ver.2 (cut)
-) Structural analysis

CFD model setup & boundary conditions

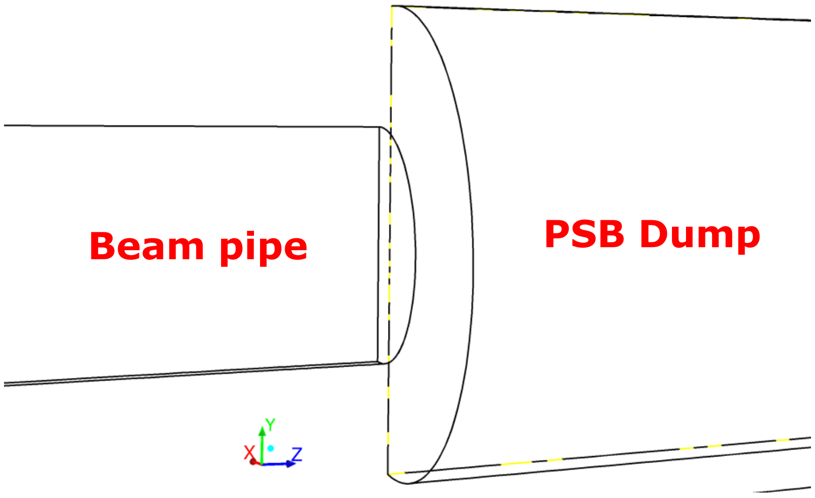
- Air flow and heat transfer in the fluid and solid solved all together in a single simulation.
- Steady-state simulation.
- Turbulence model : Standard *k-ε* + standard wall functions.
- Gravity and buoyancy are take into account.
- Dependence of air density, conductivity, viscosity and constant heat on temperature taken into account.
- Thermal conductivity of copper C18150: 320 W m^{-1} K^{-1} (temperature independent).
- Inlet flow rate: **1800 m^3 h^{-1}** (→ 15 K air temperature rise, 12.5 m/s air velocity in the ducts).
- Air injected from the ducts.
- Air temperature at inlet: **20 °C.**
- Energy deposition inside the dump: **imported from FLUKA** file (~9500 W).



CFD model: geometry



Full geometry: symmetry applied in the model

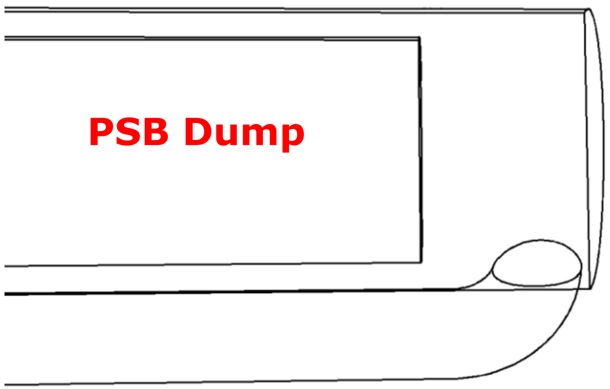


Beam pipe separated 1 cm from dump.

Duct connection geometry

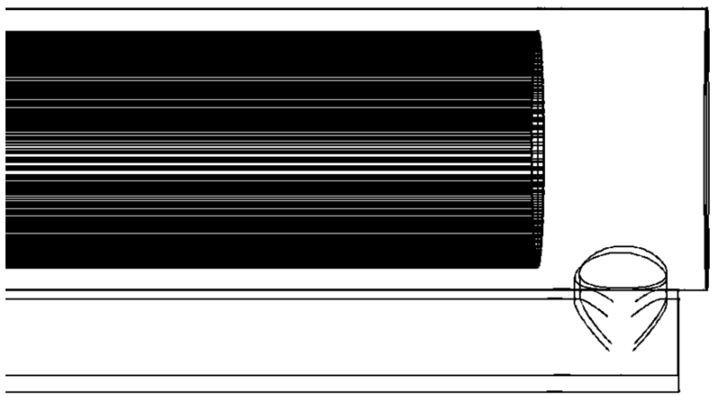
2 geometries considered in the CFD simulations:

A. "smooth connection"



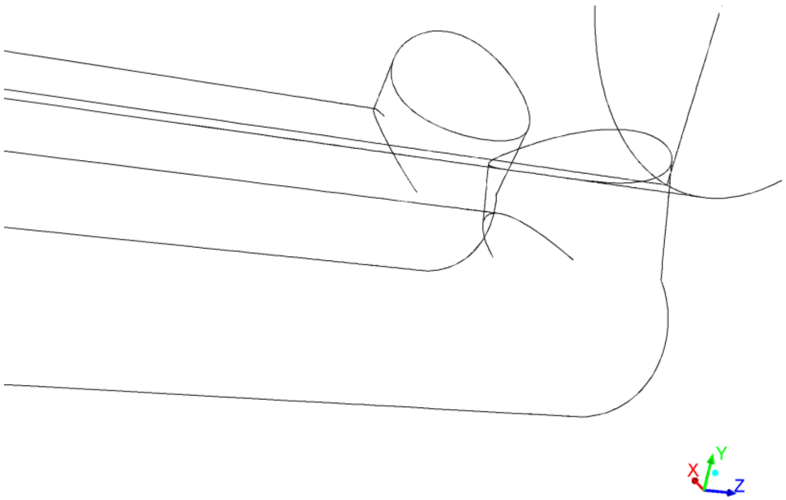
- 150 mm internal diameter
- 150 mm bending radius

B. "sharp connection"



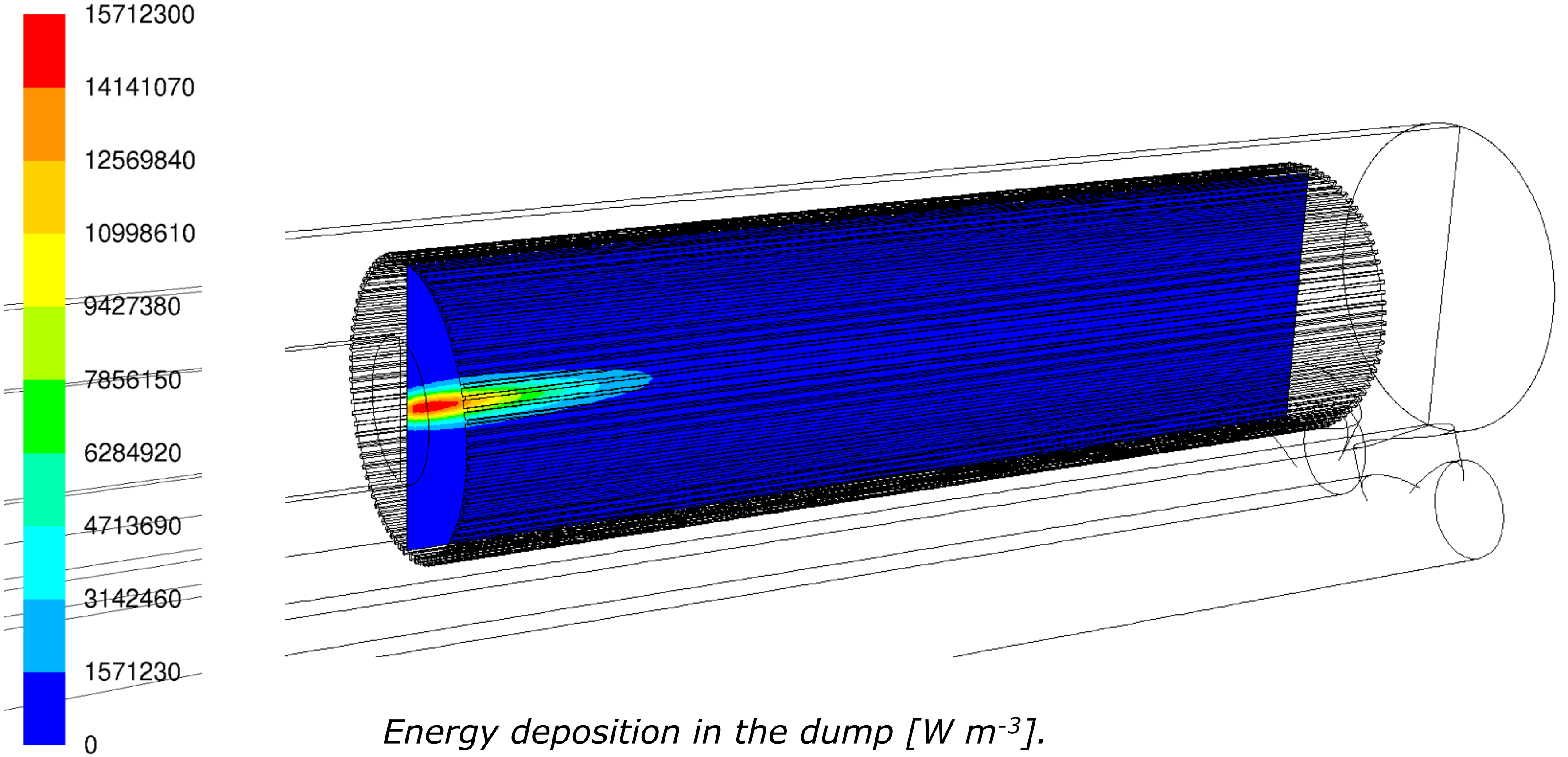
- 159 mm i.d. for both duct & connection

C. Final elbow design



- 160 mm duct diameter
- 150 mm connection diameter

Energy deposition



Energy deposition in the dump [W m^{-3}].

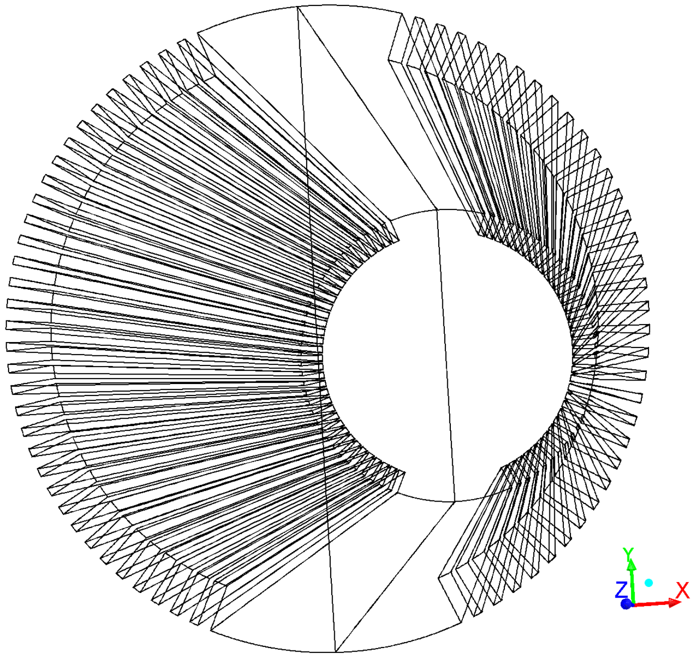
- Heat generation inside the dump **imported from FLUKA** file: ~9450 W total power.

Fins geometry

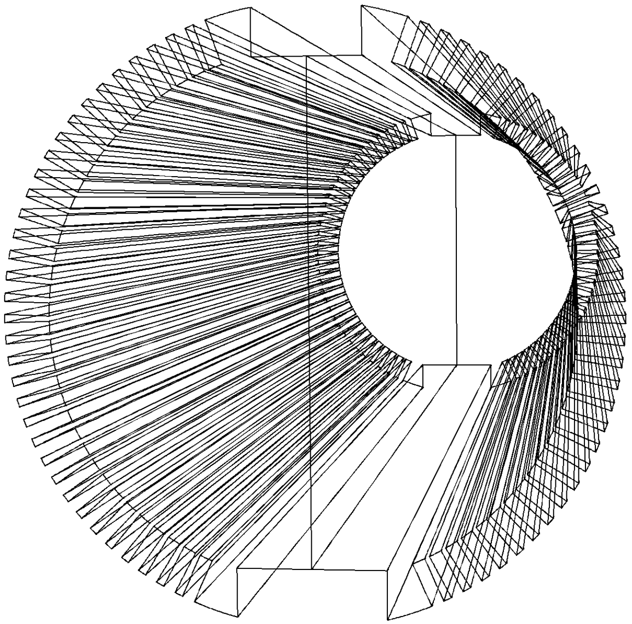
Two version of the final design were simulated:

- Ver.1 considering the space occupied by rollers as part of the dump
- Ver.2 considering the space occupied by rollers as part of the air flow

Version 1

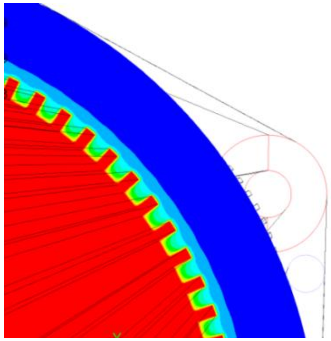


Version 2 ‘cut’

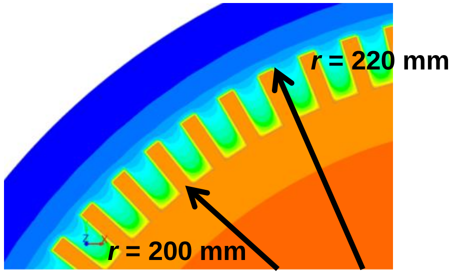


Fins geometry

- Diameter of dump: 400 mm at the foot of the fins.
- 8 different dump surfaces simulated:

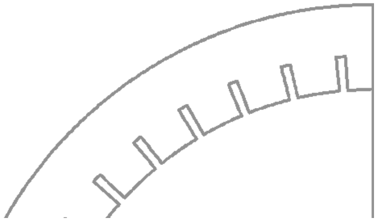


'5-10-10' fins.

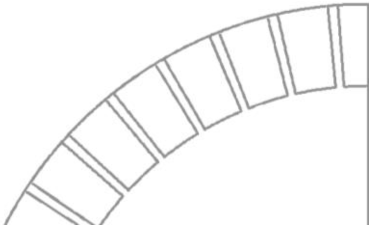


'5-10-20' fins.

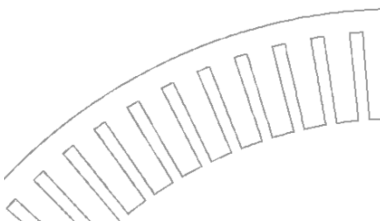
Dump surface	Fin thickness	Gap between 2 fins available for air flow	Fin height
Flat		--	
'5-10-10'	5 mm	10 mm	10 mm
'5-10-20'	5 mm	10 mm	20 mm
'5-25-20'	5 mm	25 mm	20 mm
'5-25-50'	5 mm	25 mm	50 mm
'5-10-40'	5 mm	10 mm	40 mm
Final design 'ver.1.'	4 ÷ 6.5 mm	10 mm	35 mm
Final design 'ver.2'	4 ÷ 6.5 mm	10 mm	35 mm



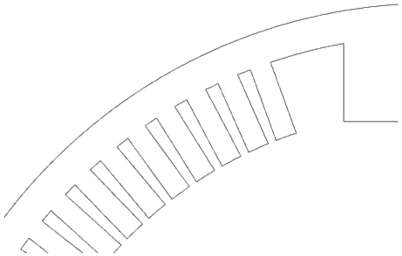
'5-25-20' fins.



'5-25-50' fins.



'5-10-40' fins.



Final design 'ver.2'

Pressure drop results

Geometry	Flow rate	'Static' pressure drop
"Smooth connection" *(no fins)*	2000 $m^3\ h^{-1}$	152 Pa
"Smooth connection" *(no fins)*	1800 $m^3\ h^{-1}$	125 Pa
"Sharp connection" *(5-10-10 fins)*		232 Pa
"Sharp connection" *(5-10-20 fins)*		240 Pa
"Sharp connection" *(5-25-20 fins)*		220 Pa
"Sharp connection" *(5-25-50 fins)*		270 Pa
"Sharp connection" *(5-10-40 fins)*		350 Pa
"Final design" ver.1		**447 Pa**
"Final design" ver.2		**368 Pa**

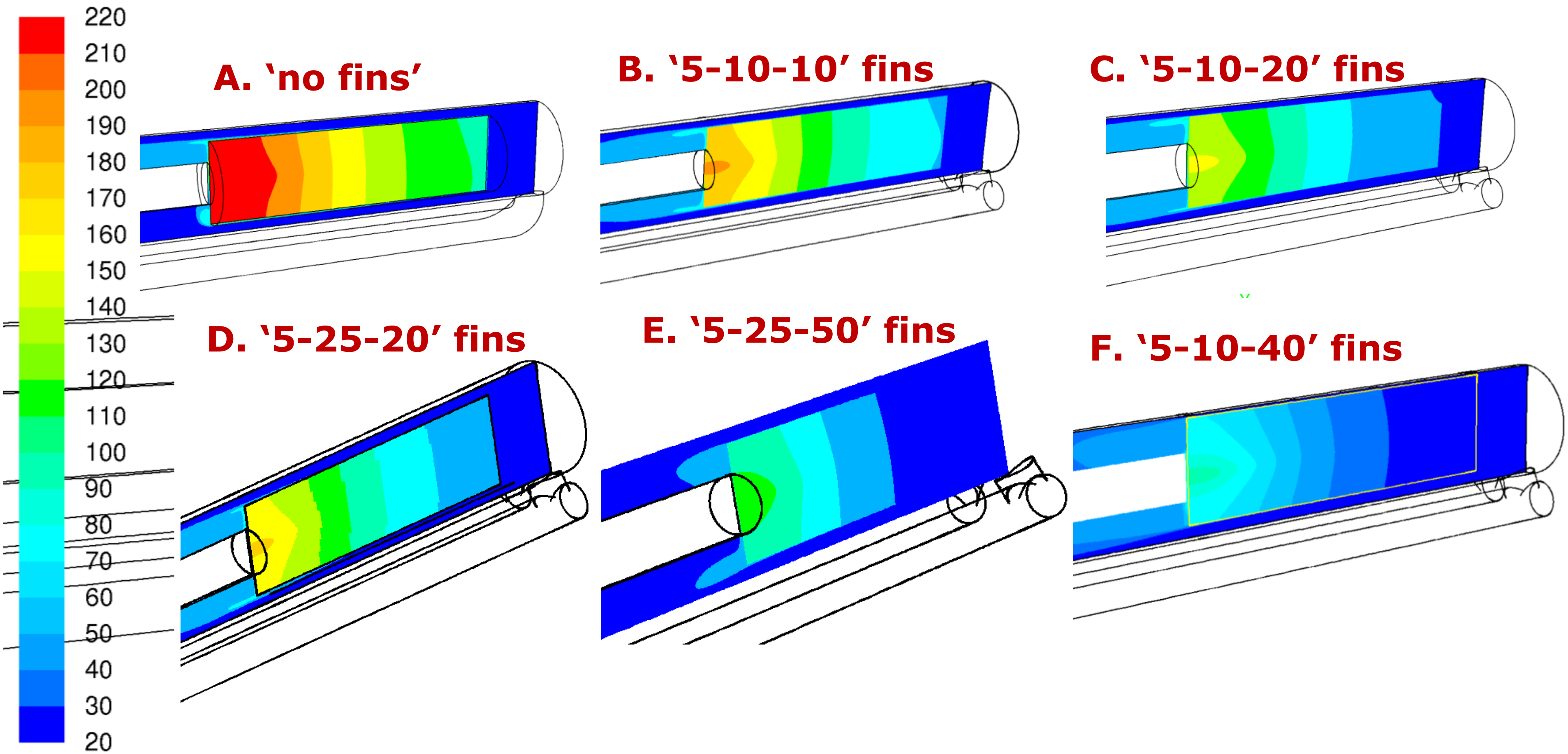
Exhaust air

Tentative selection	
Producer	Huber & Ranner
Unit size	X-Case 01 – Indoor unit
Airflow	1800 $m^3\ h^{-1}$
External pressure *	**560 Pa**
Air velocity	0.65 $m\ s^{-1}$

Despite being only a tentative selection, the above mentioned system is able to overcome the worst pressure drop scenario simulated.

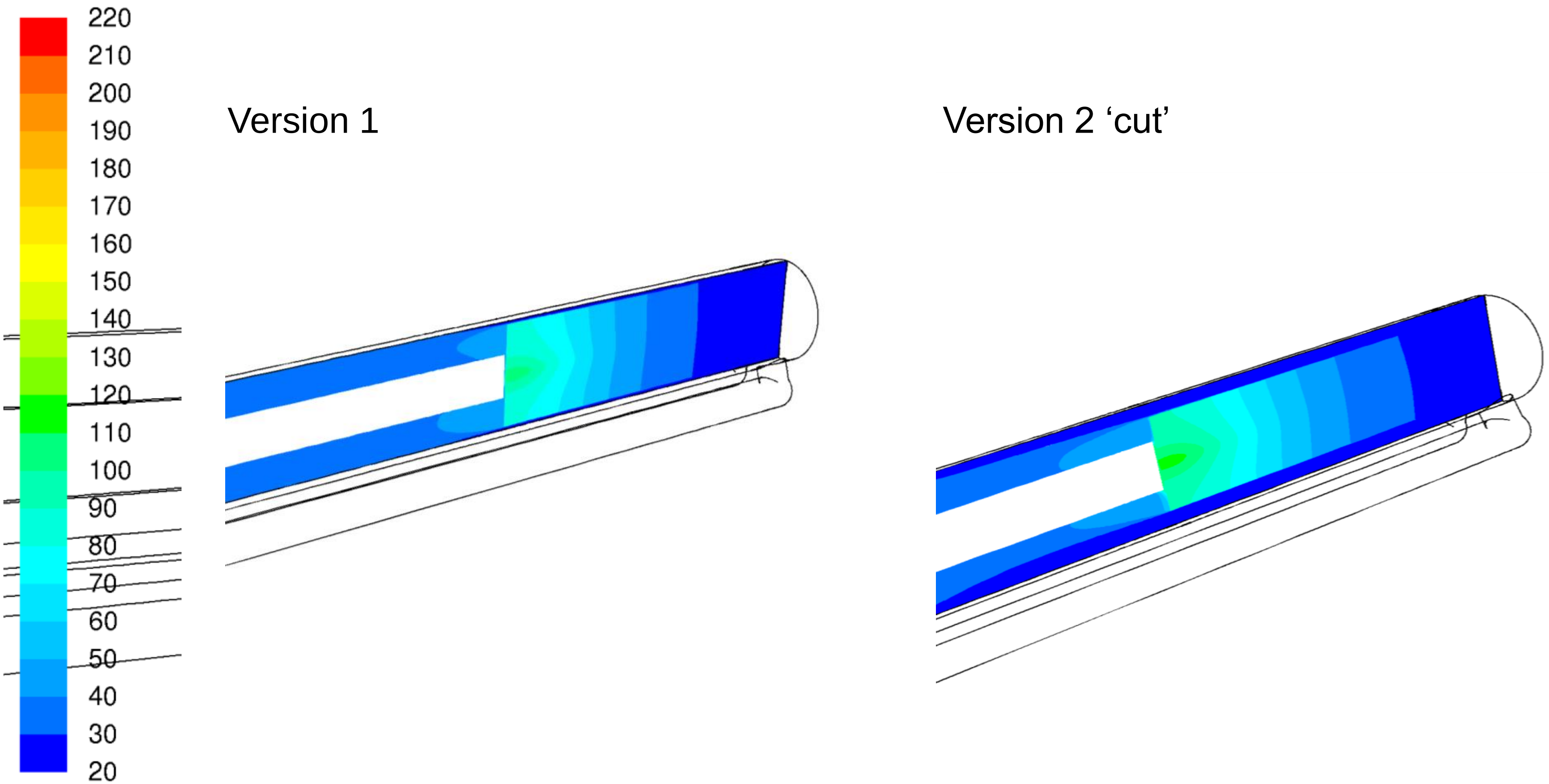
* The fan has to provide an additional pressure of ~100 Pa, corresponding to the dynamic pressure $\frac{1}{2}\rho v^2$, to the reported value.

CFD results: temperature



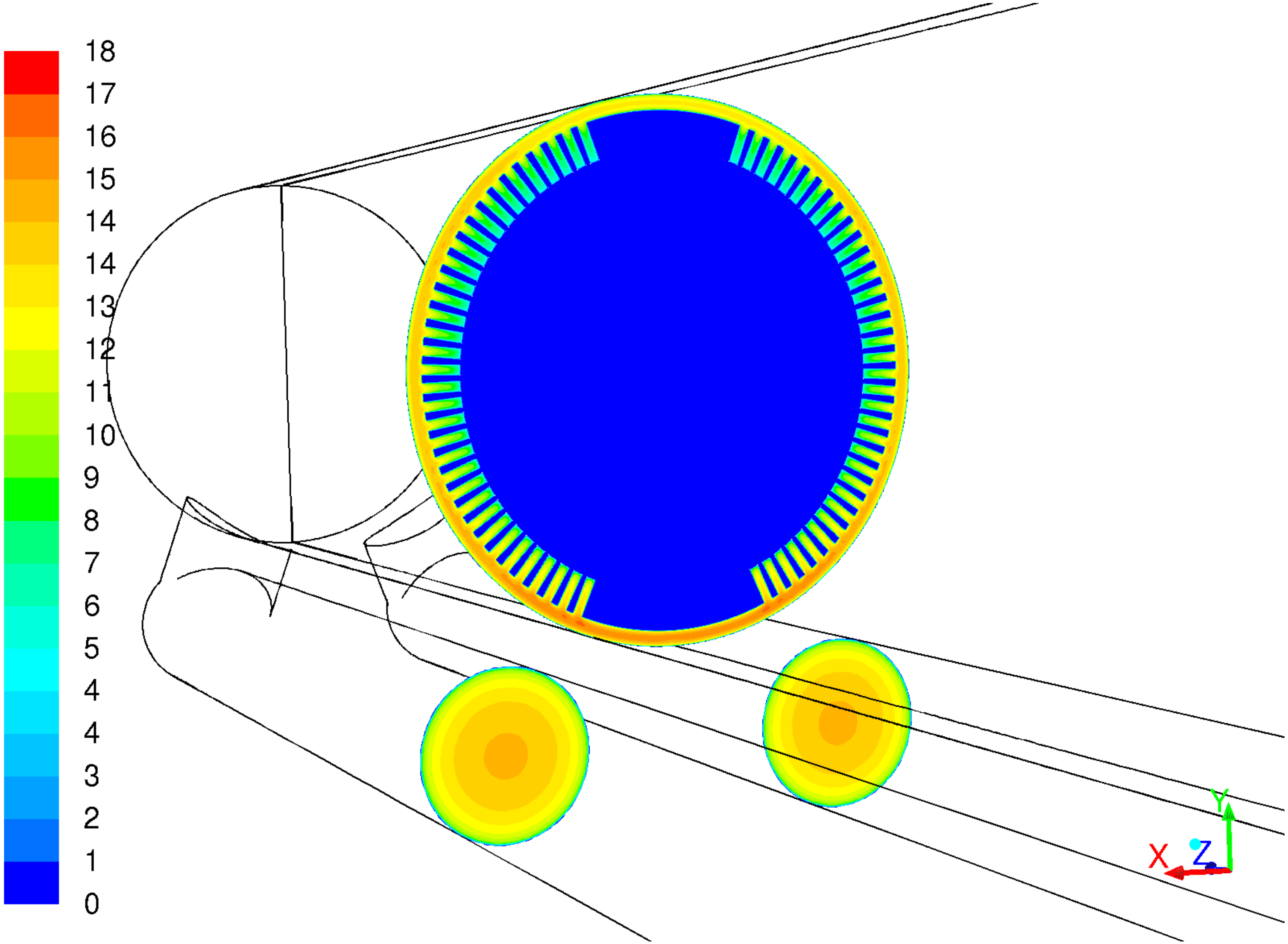
Temperature at the symmetry plane [°C].

CFD results: temperature



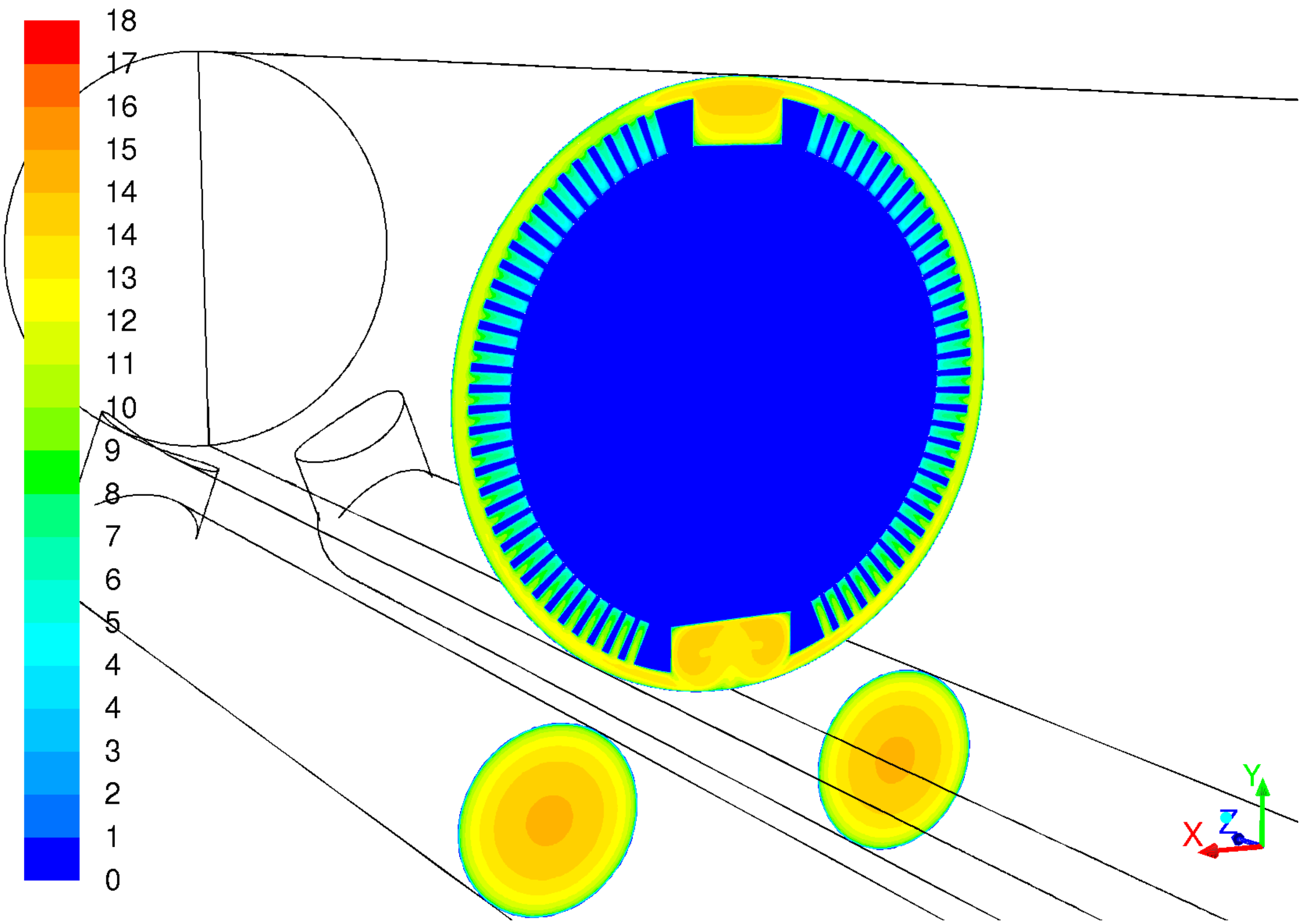
Temperature at the symmetry plane [°C].

Velocity field for 'ver.1'



Contours of velocity magnitude (m/s)

Velocity field for 'ver.2'



Contours of velocity magnitude (m/s)

Results Summary

Fins Geometry	Maximum *T* in the dump [°C]	Heat Transfer Surface [m²]	'Static' pressure Drop [Pa]
Flat	236	1.1	125 *
'5-10-10'	188	2.3	232
'5-25-20'	168	2.3	219
'5-10-20'	150	3.6	240
'5-25-50'	119	4.1	271
'5-10-40'	98	6.1	348
Final design 'ver.1.'	**107**	**4.9**	**447**
Final design 'ver.2'	**115**	**5.0**	**368**

* Simulation run with "smooth connection", pressure drop is underpredicted.

Structural analisys

In order to provide a complete analysis of the air cooling system of the PSB dump, a series of structural analysis' have been conducted to value the stress level and the deformation of the dump on the two final design model.

Three different configurations have been considered:

A. Final uncut with T profile imported by Fluent results
B. Final uncut with heat generation profile imported from Fluka results and CFD results from Fluent
C. Final cut with T profile imported by Fluent results

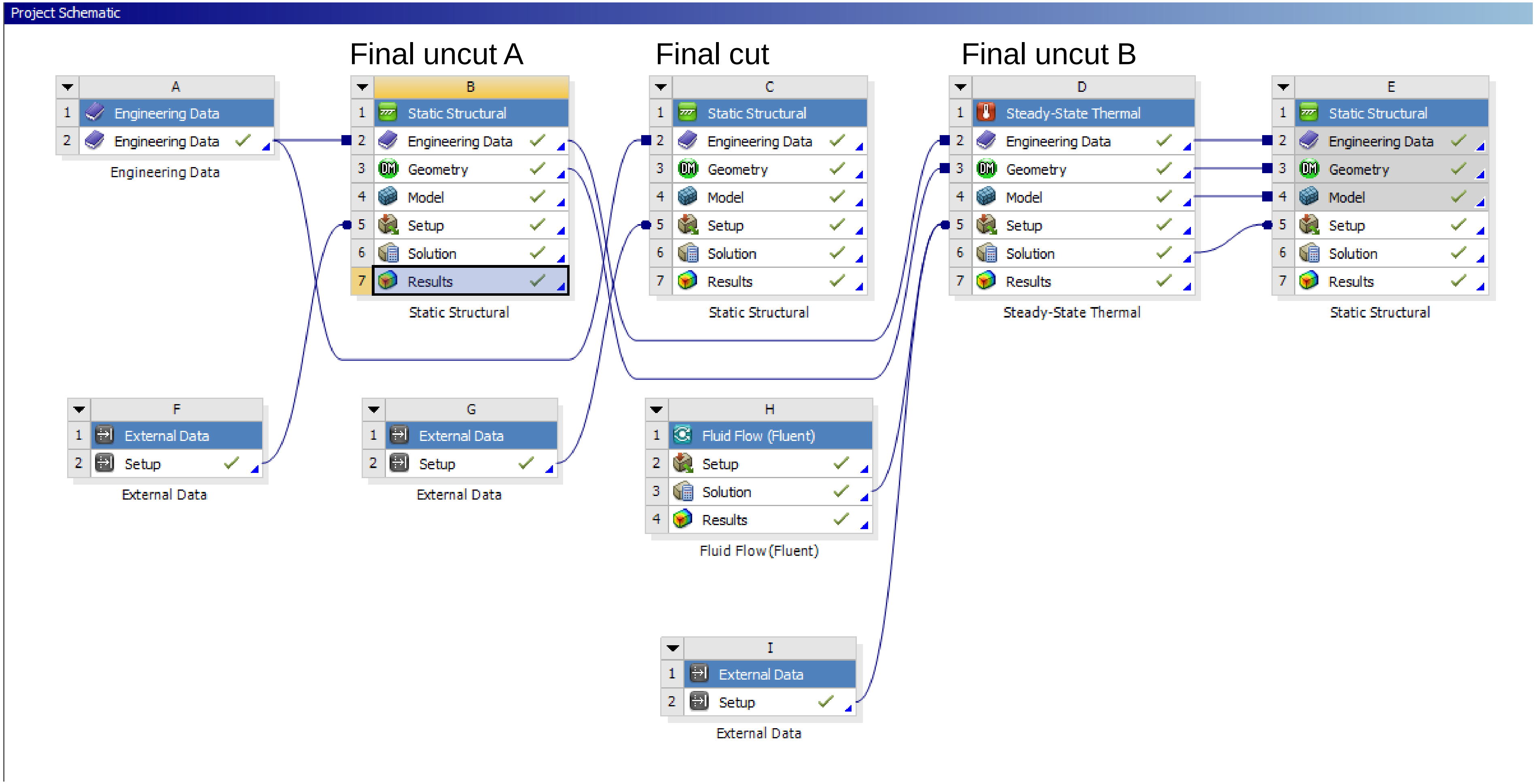
Results

Model	Max T [°C]	Yield strength [Mpa]	Equivalent stress [MPa]	Max Deformation [mm]
Final uncut A	107	270	26.8	0.4
Final uncut B	107	270	26.7	0.4
Final cut	115	270	26.8	0.5

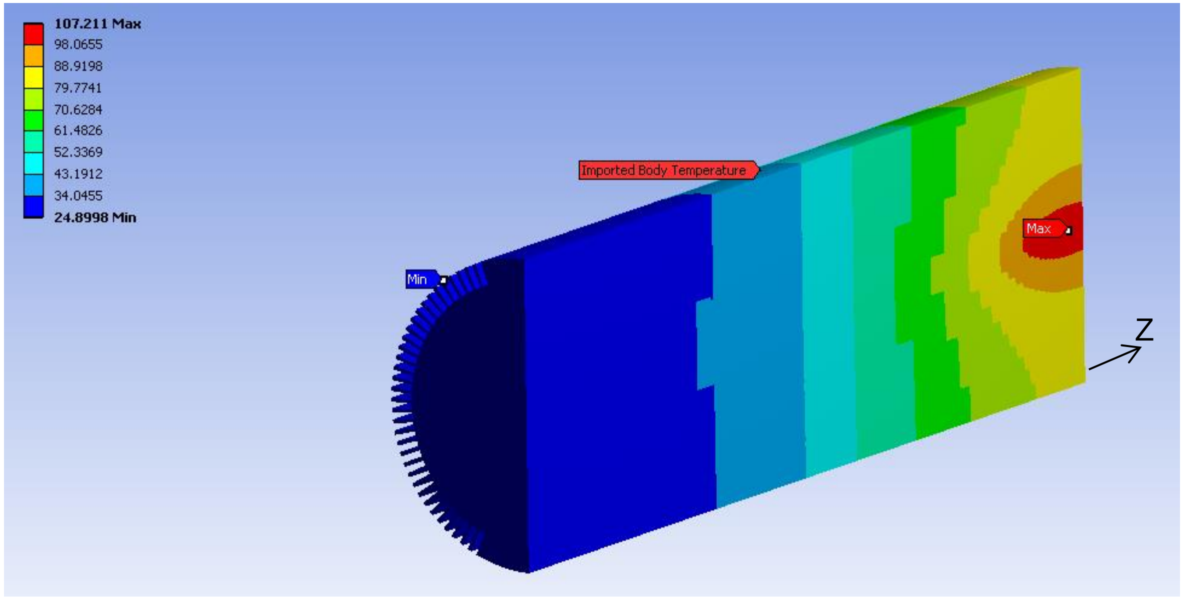
The table shows how the two different approach brought up the same results.

In all the three considered cases, the results are consistent for the loads considered for both the stress level and the max deformation. Thus said the results might change remarkably in a transient analysis.
A further fatigue analysis might be considered to establish an approximate value of the number of cycles available.

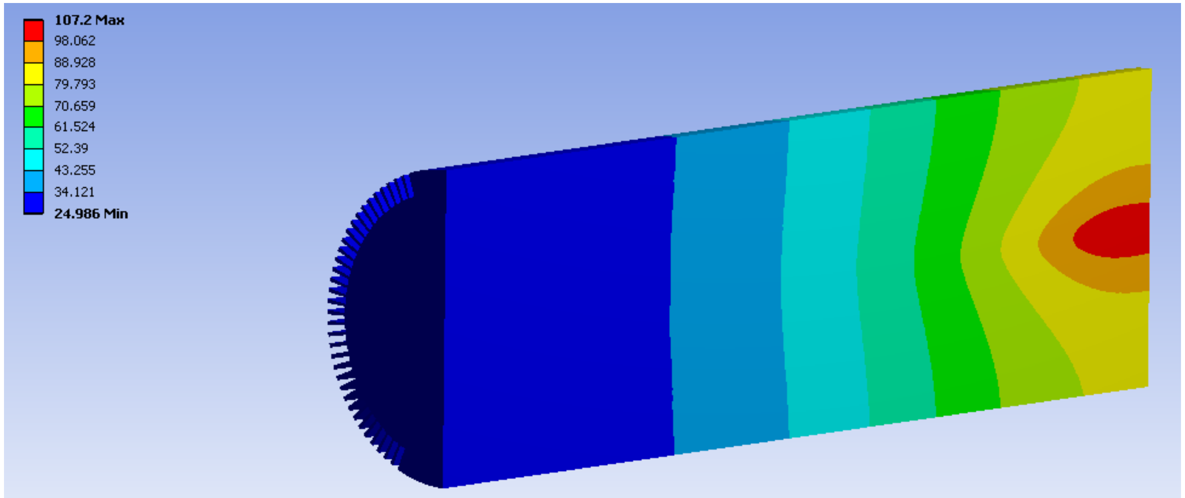
Workbench schematic



Temperature profiles



Imported temperature profile of Final uncut A case



Temperature profile from steady-state thermal analysis of Final uncut B case

Despite both profiles shapes' are very similar, the imported temperature from the Fluent file in the Final uncut A case shows irregular iso-T profiles.
This is mainly due from the high differences between the used meshes.

Fluent mesh:

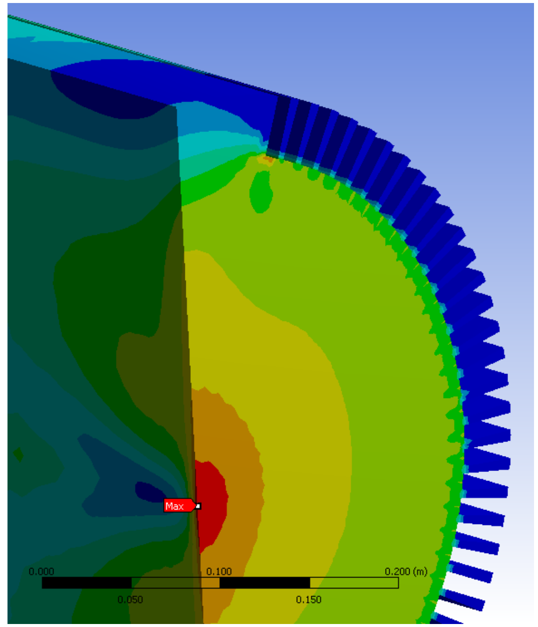
- double sided successive ratio on the z axe applied
- 2.5 million nodes

Mechanical mesh:

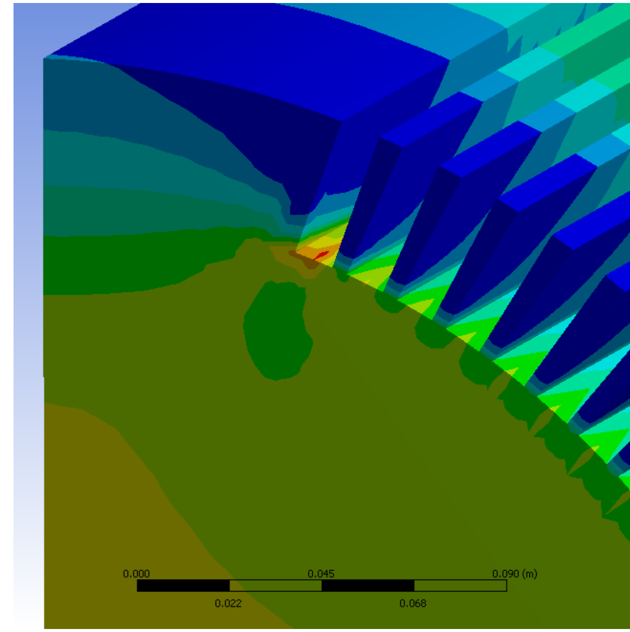
- Uniform brick dimensions on the z axe
- 1 million nodes

On the other hand, the temperature profile in Final uncut B case is extremely sharp.

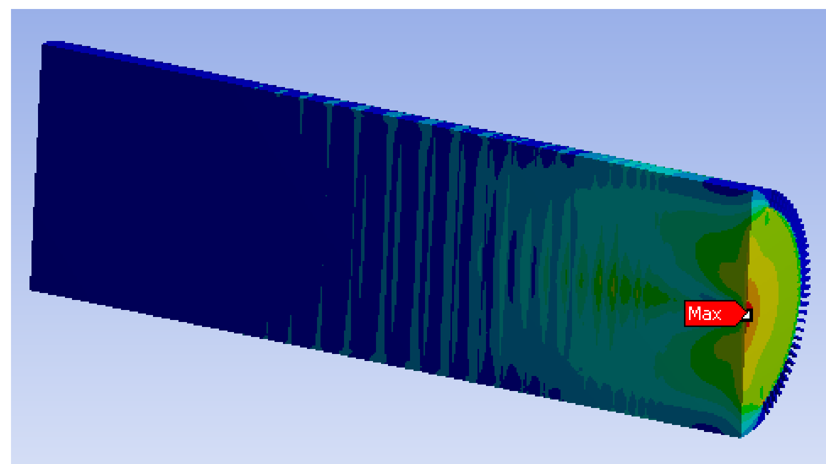
Final uncut A



Detail 1



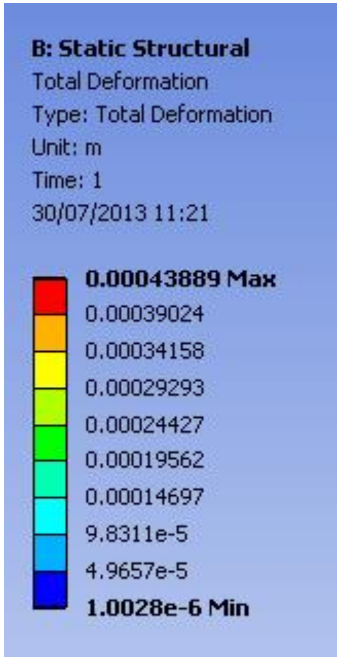
Detail 2

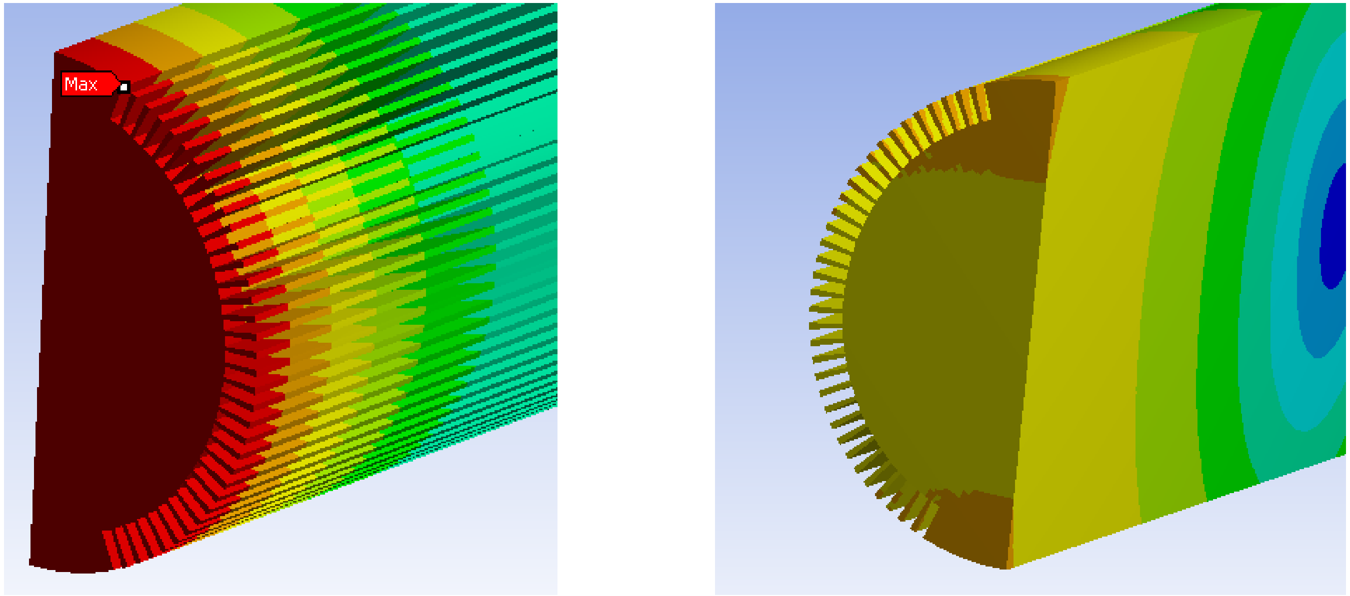


Stress distribution

The stress shape is highly influenced by the interpolation process from the mesh used for the CFD analysis to the one used in the structural

Final uncut A





Front

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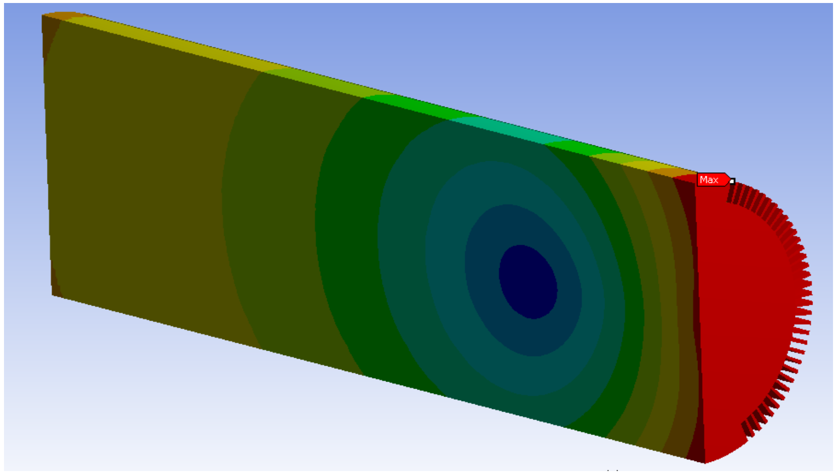
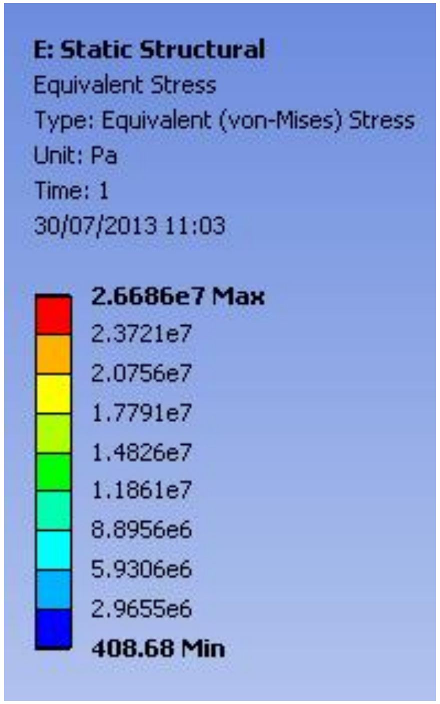
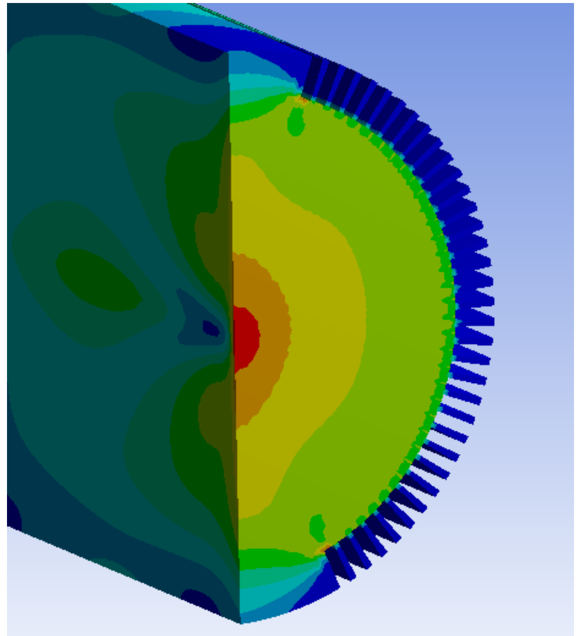


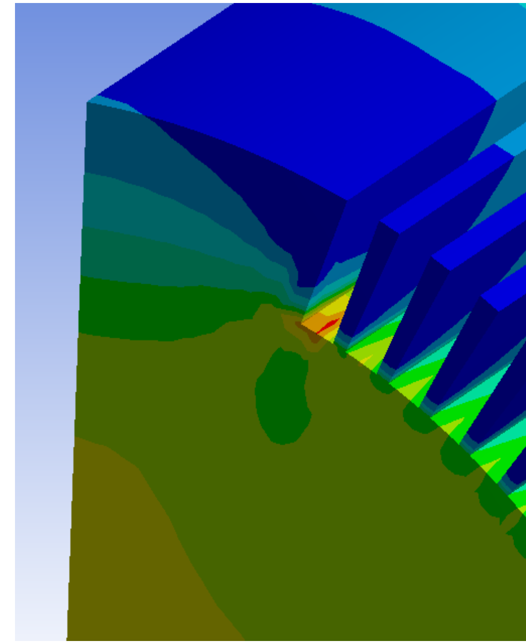
Total deformation distribution

Final uncut B

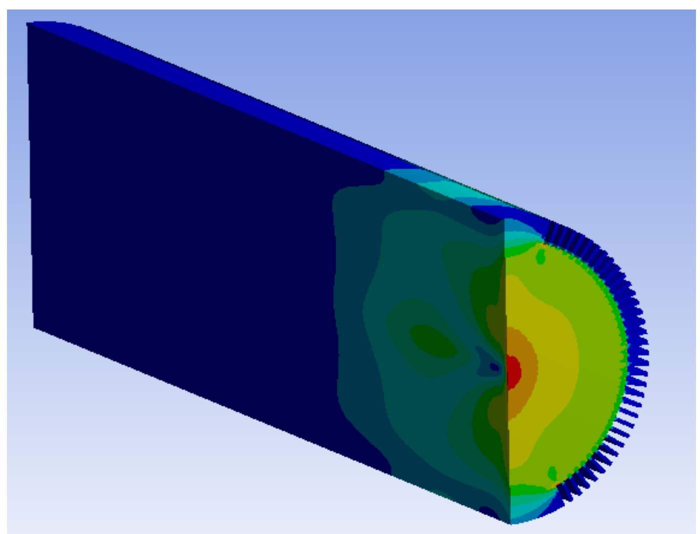




Detail 1



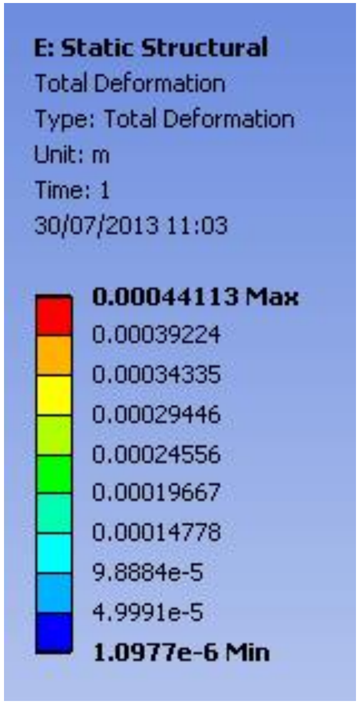
Detail 2

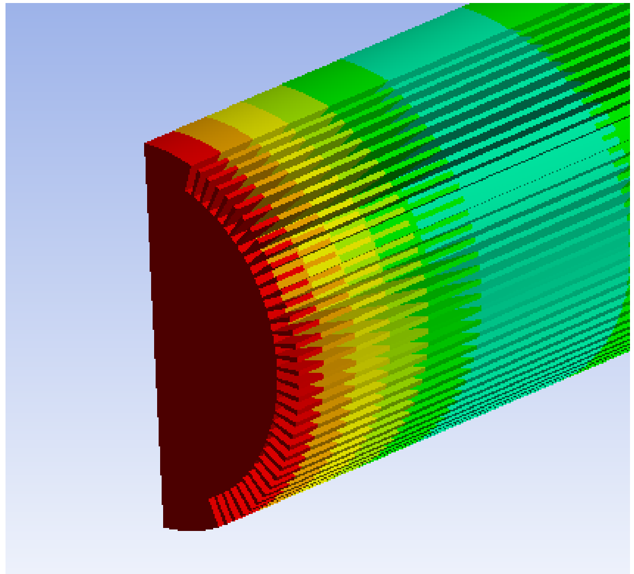


Stress distribution

In this case the results are less influenced by the interpolation process. The result is a sharper stress shape.

Final uncut B





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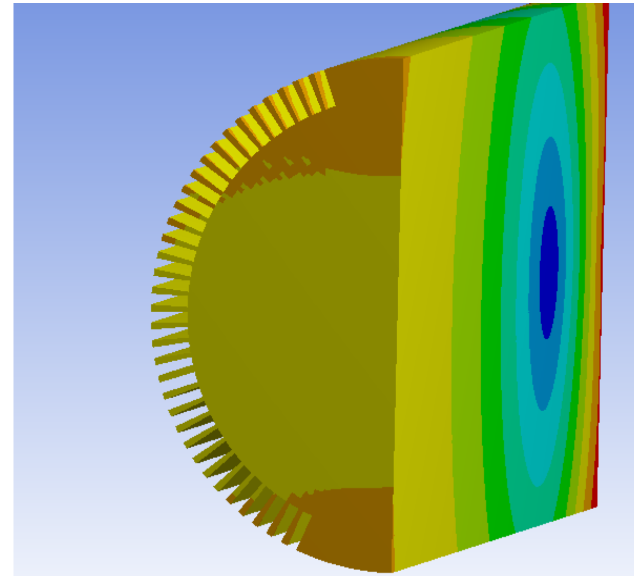

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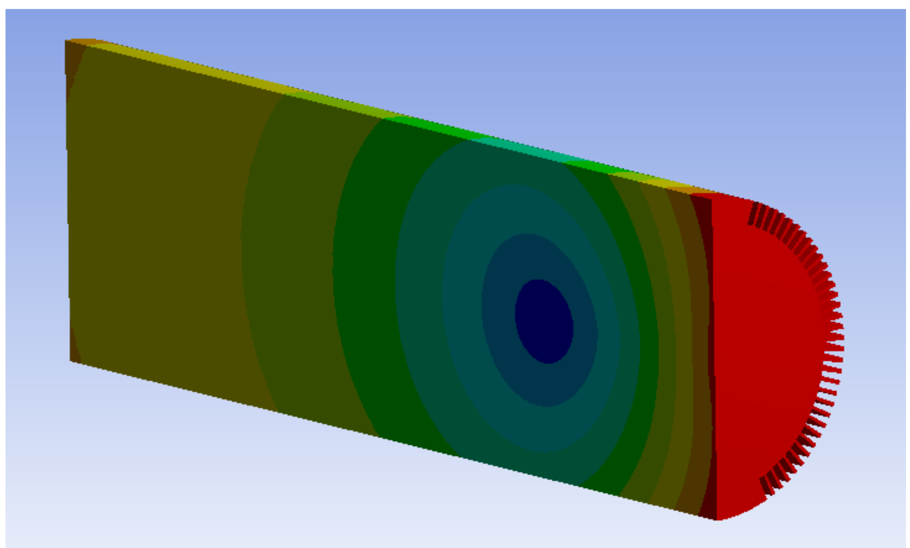
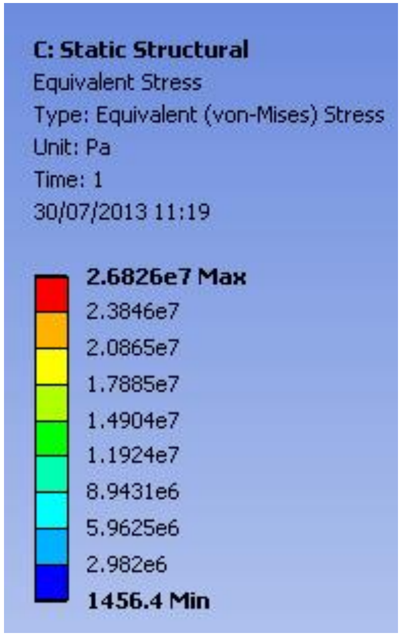
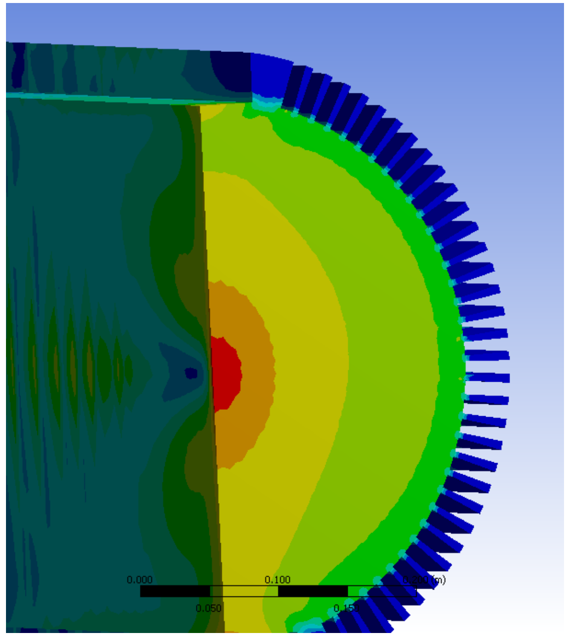


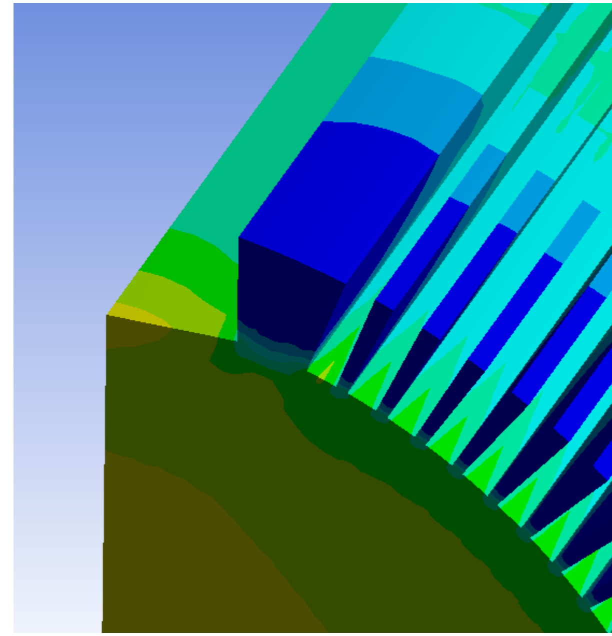
Total deformation distribution

Final cut

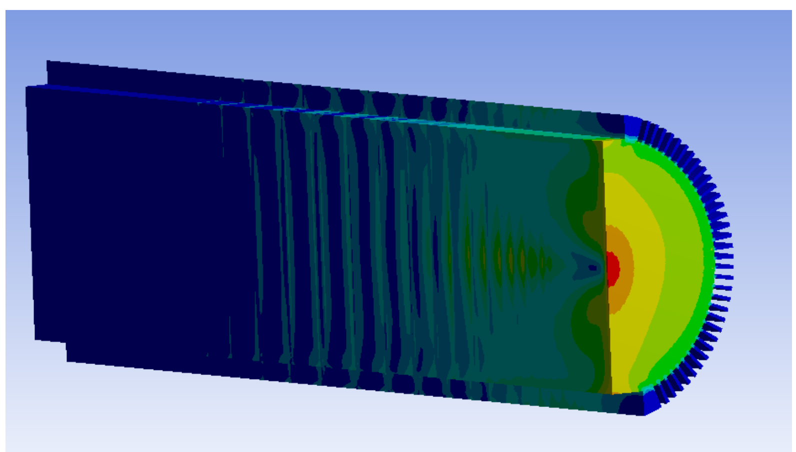




Detail 1



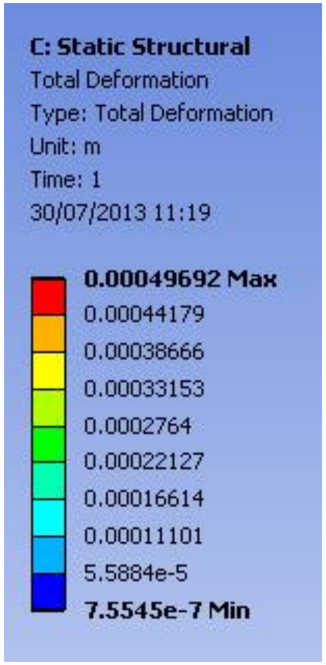
Detail 2

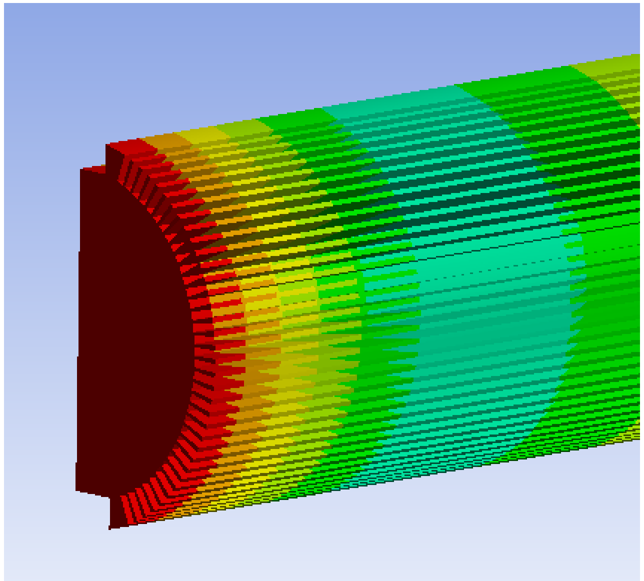


Stress distribution

As for the final uncut A case, the stress distribution results are deeply influenced by the interpolation process

Final cut





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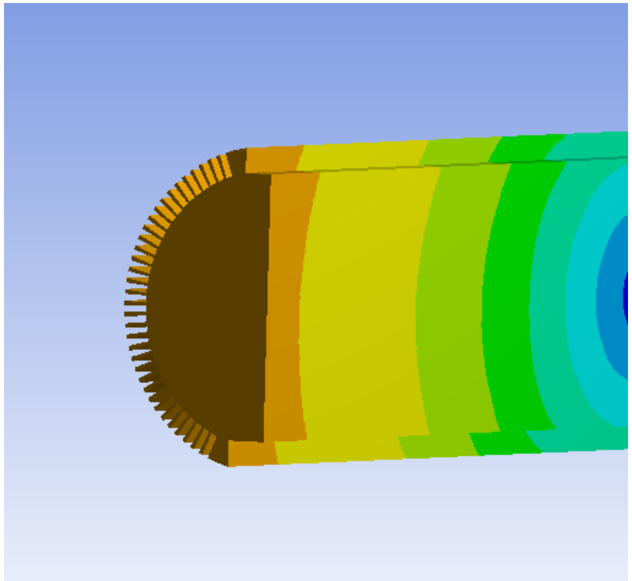

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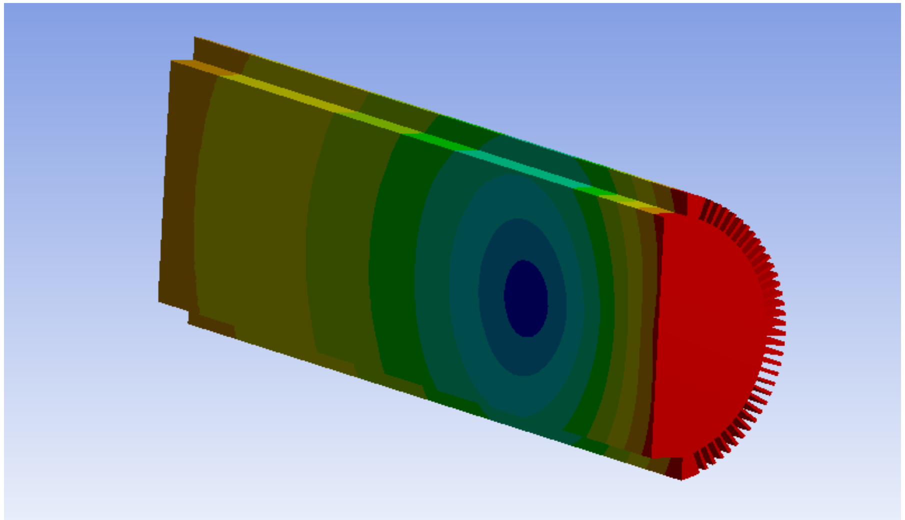

Total deformation distribution

Results Summary

According to the structural analysis results, at steady-state, the local maximum stress due to the temperature gradients is estimated to be 27 kPa.

- This stress value is well below the yield strength of the selected material (C18150) of 270 Mpa;
- The maximum deformation is expected to be around 0.4 mm.