COMPASS
INSTITUTE OF PLASMA PHYSICS ASCR

Design of COMPASS-U support structure cooling

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Week of Doctoral Students 2021
Poster session on **Wednesday** from 16:00 to 17:30

INTRODUCTION

COMPASS-U will be tokamak characterized by high toroidal field (5 T) and hot wall (~ 500 °C). It will be situated in place of current tokamak COMPASS at IPP, Prague.

COMPASS-U is designed to be relevant to future devices like ITER and DEMO.

Basic parameters:

Major radius	R = 0.894 m
Minor radius	a = 0.27 m
Tor. field intensity	$B_T = 5$ T
Plasma current	$I_p = 2$ MA
Flat-top length	$t_{flat\text{-}top} \sim 2$ s
Triangularity	Δ = 0.5
Elongation	K = 1.8
Plasma volume	$V_{plasma} \sim 2$ m3
First wall temp.	$T_{wall} \leq 500$ °C

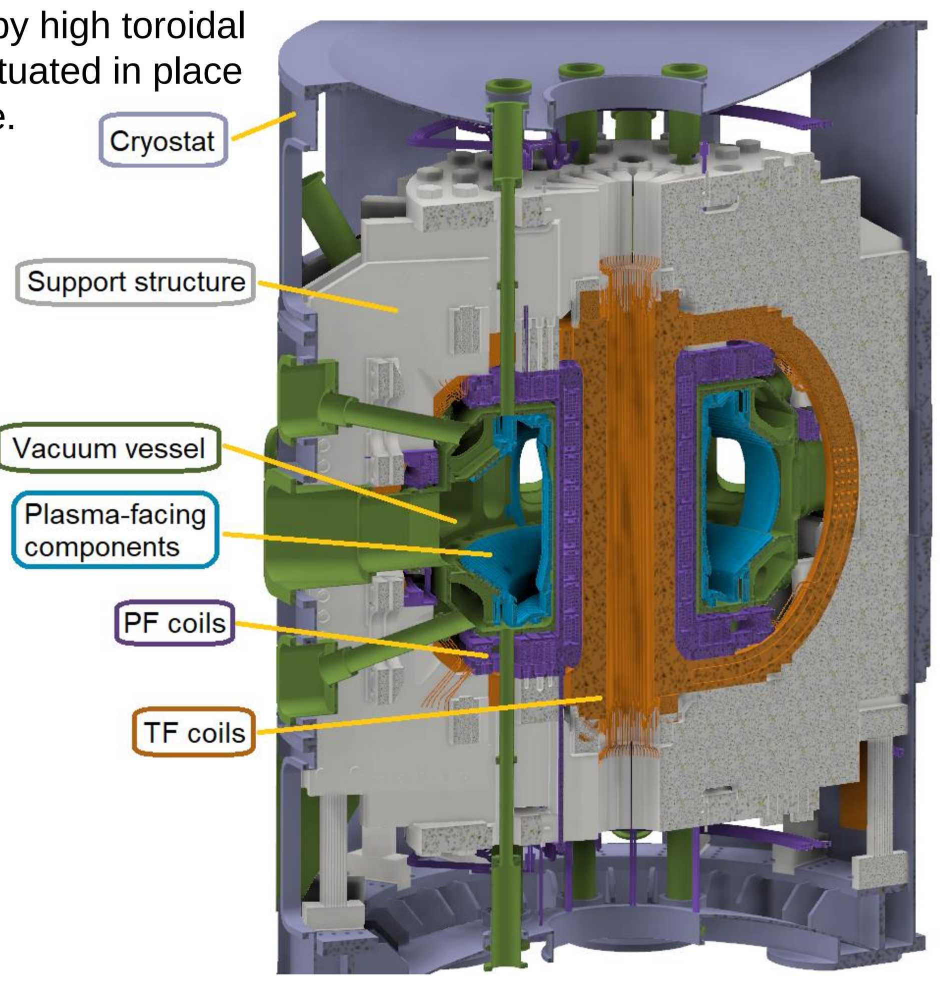

Fig. 1.: Illustrative COMPASS-U cross-section.

SUPPORT STRUCTURE

- Copper coils will be cooled down to 80 K to get significantly lower resistivity and thus ability to reach requested magnetic field and plasma current.
- All the **coils will be held in place by so called „support structure“**, allowing them to withstand resulting magnetic forces.
- Support structure consists mainly of 16 C-frames, 2 compression discs and 2 wedgeplates. Each C-frame consists of 7 big parts, this means whole structure consists of ~120 big parts!
- All components will be made from **stainless steel** (~ AISI 316LN)
- To compensate for and to follow thermal shrinkage of copper coils (up to ~10 mm!), whole **support structure will be** also **cooled to 80 K** in sync with coils.
- This means no easy task, because of size of the structure and huge possible thermal input.

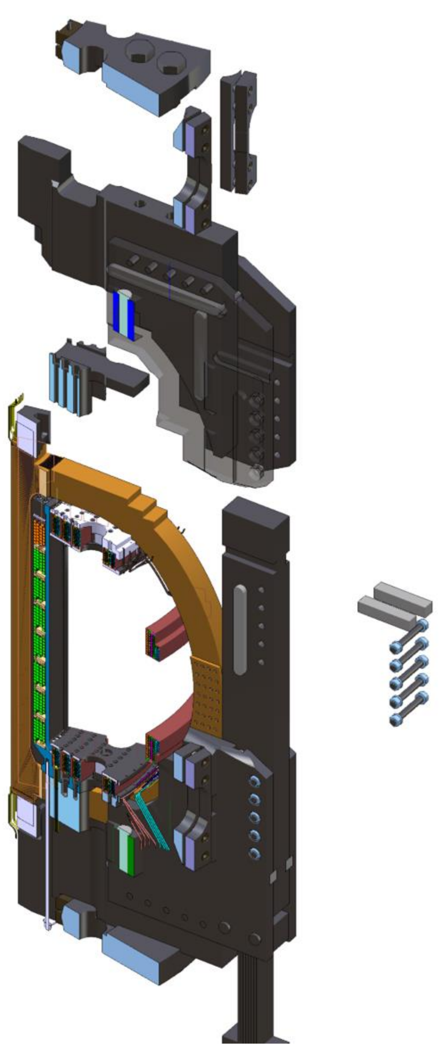
Fig. 2.: Exploded view of 1/16 of support structure

GLOBAL THERMAL MODEL

To help with design and analysis, **2D global thermal** model was created in **cooperation between IPP and PPPL** (mainly by H. Zhang). This enables us to approximate heat fluxes between all components, including support structure.

It includes 3D heat radiation by implementation of radiation loops.

Resulting cryogenic heat loads for full power operation (vessel@770 K):

Central solenoid	PF coils	TF coils	Support structure
550 W	850 W	650 W	4450 W

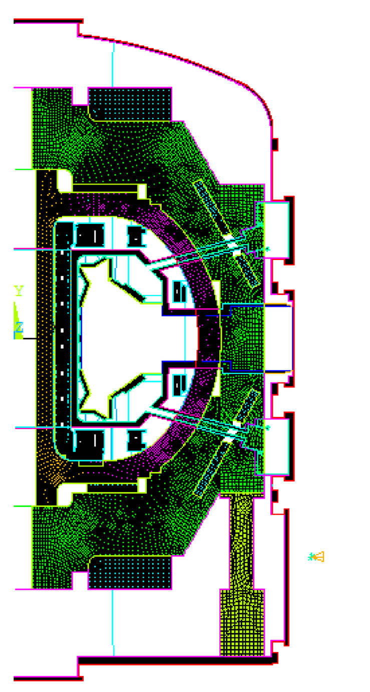
Fig. 3.: Mesh of 2D global thermal model

BASIC CONSTRAINTS

Support structure will be **cooled by gaseous helium**, same way as other tokamak components. Because it will have short channels with small pressure drop, it will be **„attached“ to TF coils cooling loop.** This means available

Base pressure: **20 bars** and maximal pressure drop: **~10 kPa.**

Required cooling power

Support structure will be **cooled down within one week** (to limit required cooling power and to help with thermal-induced deformations). Assuming its weight (180 tons) and material (stainless steel), we get

- Required energy to extract: **20 GJ** and therefore
- Required cooling power: 30 kW + 5 kW = **~40 kW.**

COOLANT CHANNELS

As whole structure will be **situated in evacuated cryostat** (required pressure <10-3 Pa), channels and connections must be **helium-leak tight**. Because fixing pipes on surface of huge structure pieces proved difficult, we decided to go with **deep drilled channels!**

- Expected channels diameter: 20 mm

Because stainless steel is bad thermal conductor, coolant channels are needed in almost every part of structure – so there will be **~150 channels**!

All the channels will be connected together via **distribution busses**.

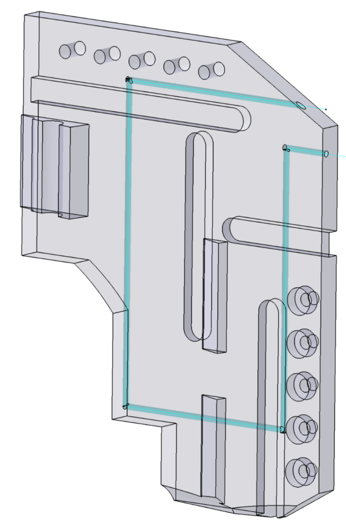
Fig. 4.: Illustration of drilled channel in one part of SS

COOLDOWN SIMULATION

As heat is coming to support structure by three different processes, simple „0-D“ analysis is not really accurate. Therefore to asses channel distribution, we have built **3-D thermal model of 1/8 of whole tokamak assembly**, including dummy models of toroidal vessel, coils and cryostat. Heat transfer by radiation was included by raytracing.

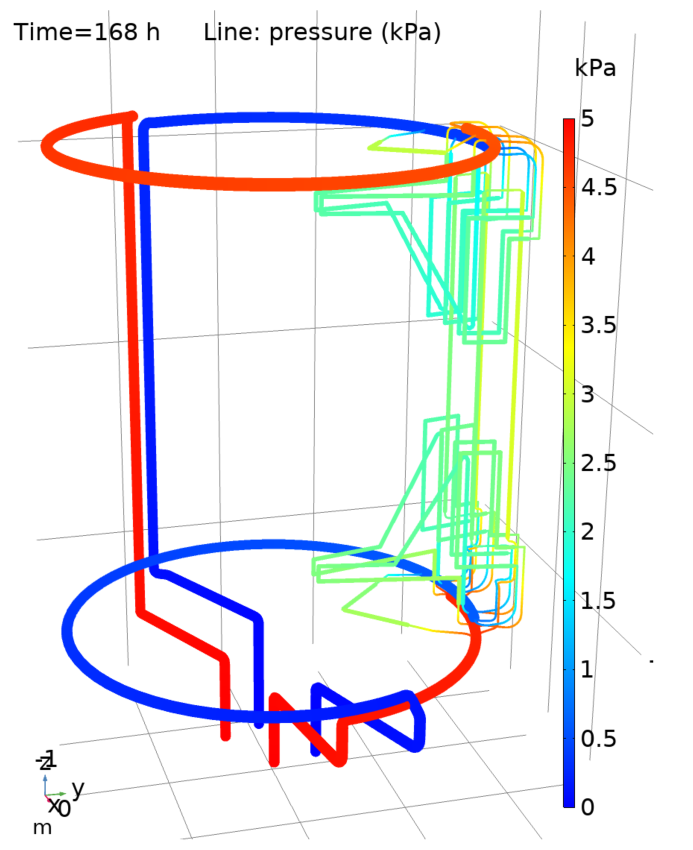

Fig. 5.: Schema of distribution busses and coolant channels

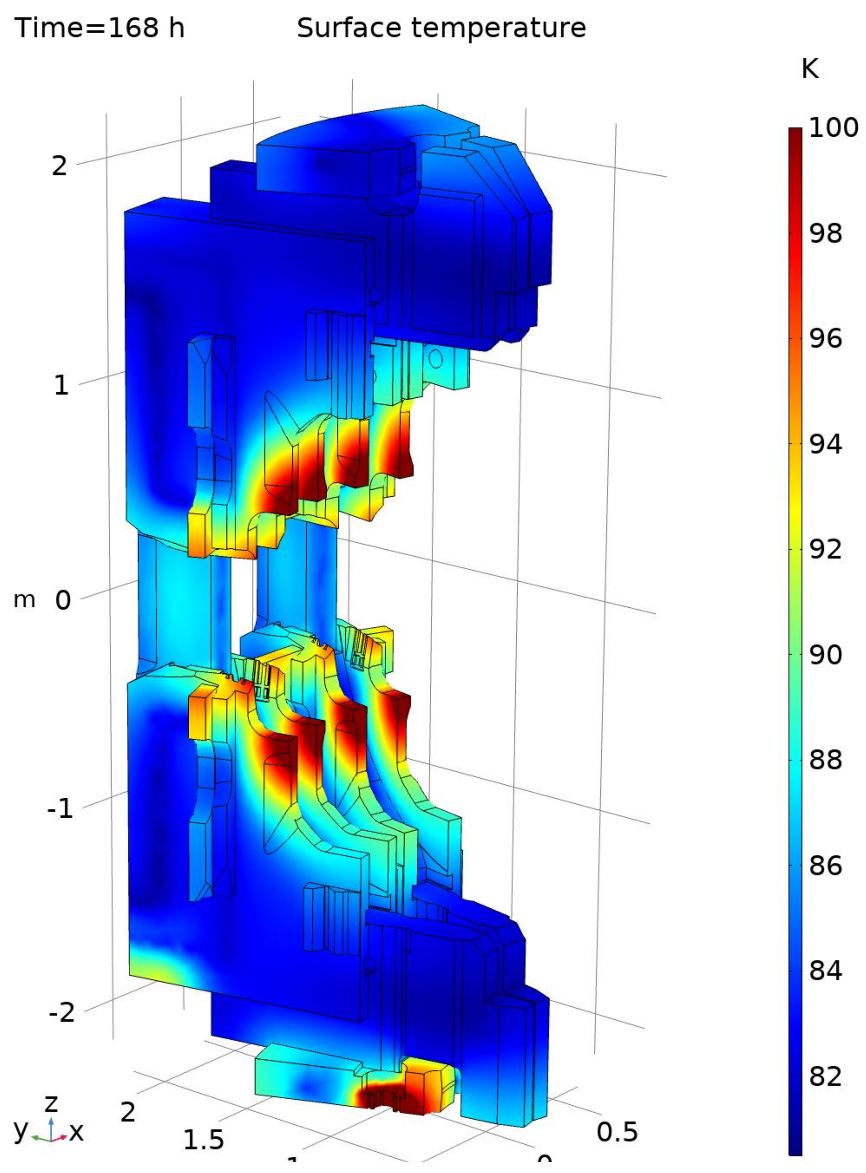

Fig. 6.: Resulting temperature distribution in 1/8 of support structure

Simulation outcome

As can be seen in figure 6, resulting temperature distribution is **acceptable** – higher temperature (> 90 K) is present only in localized places like hot vessel legs or corners near ports.

Resulting required cooling power is ~40 kW. Steady state heat load is ~10 kW.

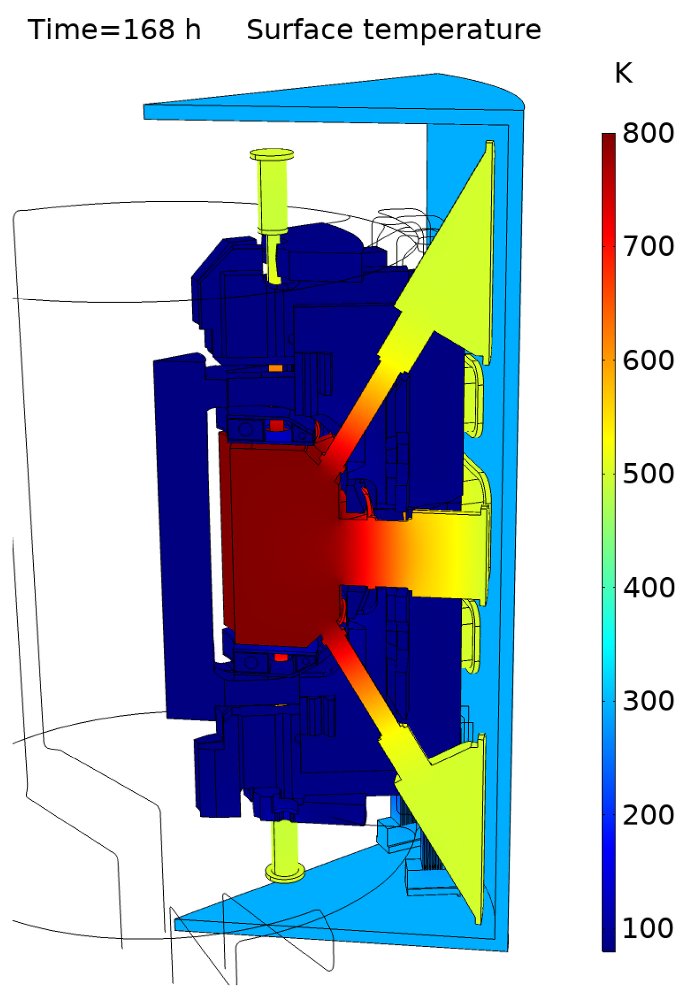

Fig. 7.: Boundary conditions (rest of tokamak structure)

PIPING OPTIMIZATION

To optimize and balance whole cooling system, 1-D piping simulation was run on complete piping geometry.

Input pressure was 5 kPa (minimal dp for SS cooling), coolant temperature 80 K.

Simulation outcome

Resulting **bus diameter** is **60 mm,** connection pipes are with diameter 10 mm.

Flow inhomogeneity is **below 20%**, which is acceptable.

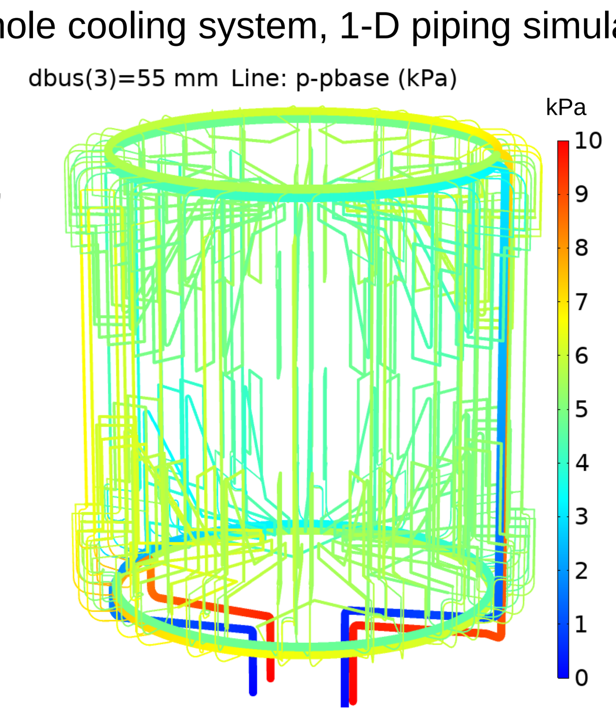

Fig. 8.: Complete piping geometry

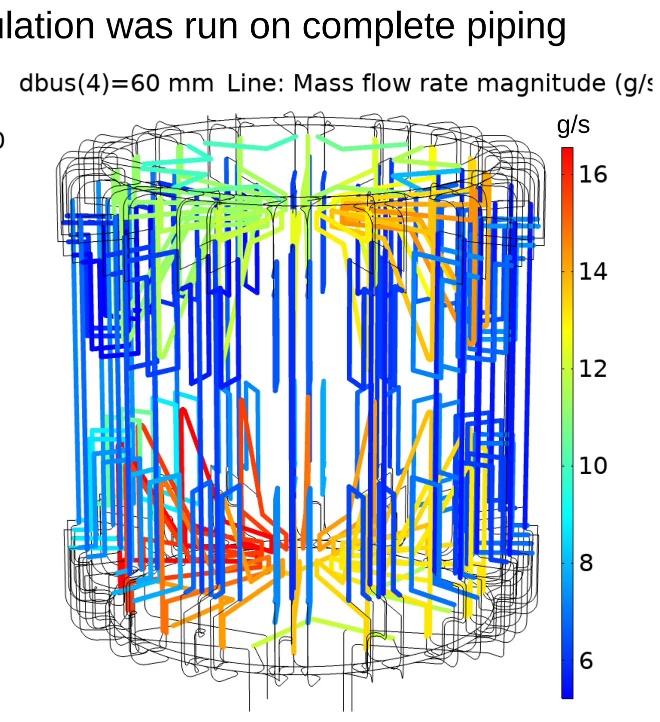

Fig. 9.: Resulting mass flow

CONCLUSION

System of drilled cooling channels with diameter of 20 mm was design and verified by simulation. Distribution busses and connection pipes were optimized to get best performance with reasonable space requirements.

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