"Study of the hydraulic Properties of the Components in Plasma Vessel of the Wendelstein 7-X and of its Cooling System"

By Guillermo Orozco

INTRODUCTION

Wendelstein 7-X is an experimental Fusion reactor of the Stellarator concept for magnetic confinement approach. It uses 70 superconducting non-planar modular coils, optimized to create a special magnetic configuration (fig. 1). They must be cooled at 3.4 K, while the plasma reach up to 140 mill K. A heat shield must protect all the components in the machine from the plasma and the heat must be removed during the long pulse operation (up to 30 min).

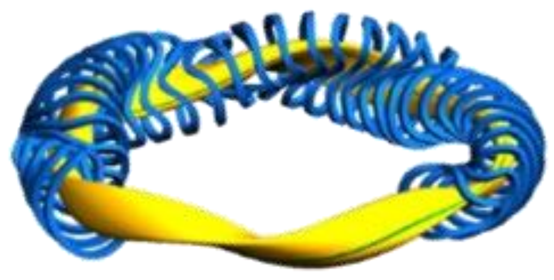


Figure 1: W-7X coil configuration and plasma geometry (yellow)

MOTIVATIONS

- For the complex active water-cooled system of the Plasma Facing Components of the W7-X, a model is needed before everything is assembled.
- The previous analysis of the Cooling Loops can lead to their optimization with orifices and a first estimation of the working parameters can be obtained.
- In order to perform "in situ" flow measurements after the assembly, a favorable method must be found and its agreement with the simulation must be tested.

PLASMA FACING COMPONENTS (PFC)

- **Protect** the plasma vessel
- **Control** plasma/wall **interaction**
- **Heat removal**
- **Fusion ash exhaust**

According to 3D Position in respect to the plasma (*fig 3*) the Heat-load is determined and a different PFC technologies are used.

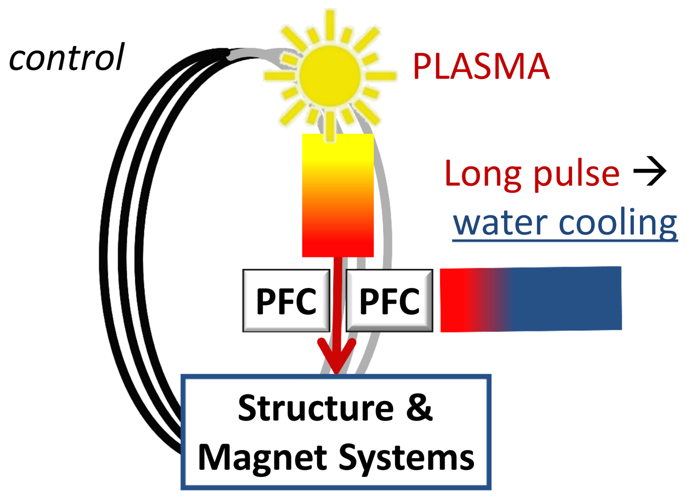


Figure 2: Plasma-System coupling

	Max heat-flow (Mw/m²)	Surface covered %	Technology used (water cooled)
Divertor	10	13	CFC tiles brazed to CuCrZr heat sink
Baffle	0.5	19	CFC tiles screwed to SS heat sink
Heat-shield	0.5-0.2	28	CFC tiles screwed to SS heat sink
Panel	0.2	40	Stainless steel plates

*Blue : Pipe-work

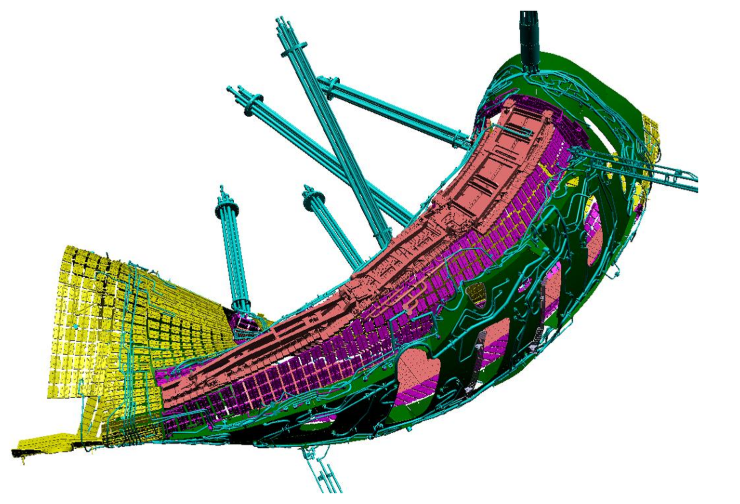


Figure 3: 1 out of 5 "symmetric" modules of the W7-X

COOLING LOOP MODELING AND ANALYSIS

1D Simulation : electric -resistance model with aid of Flowmaster ® (Fm)

Resistances → turbulence effects --> *pipe wall roughness, pipe bends…*

Challenges

- Huge Net (650 PFC, +8 Km Pipe work)
- Geometry description only in CAD

Solution

- Automatization → Excel Macros *(fig 4)*
- "*Bottom-Up"* approach *(fig 5)*

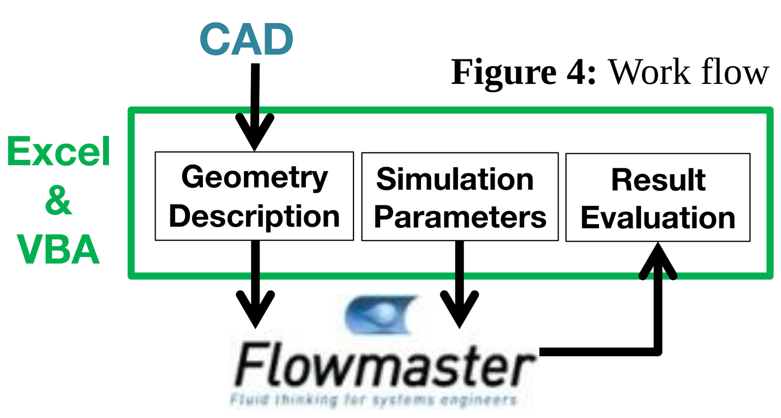


Figure 4: Work flow

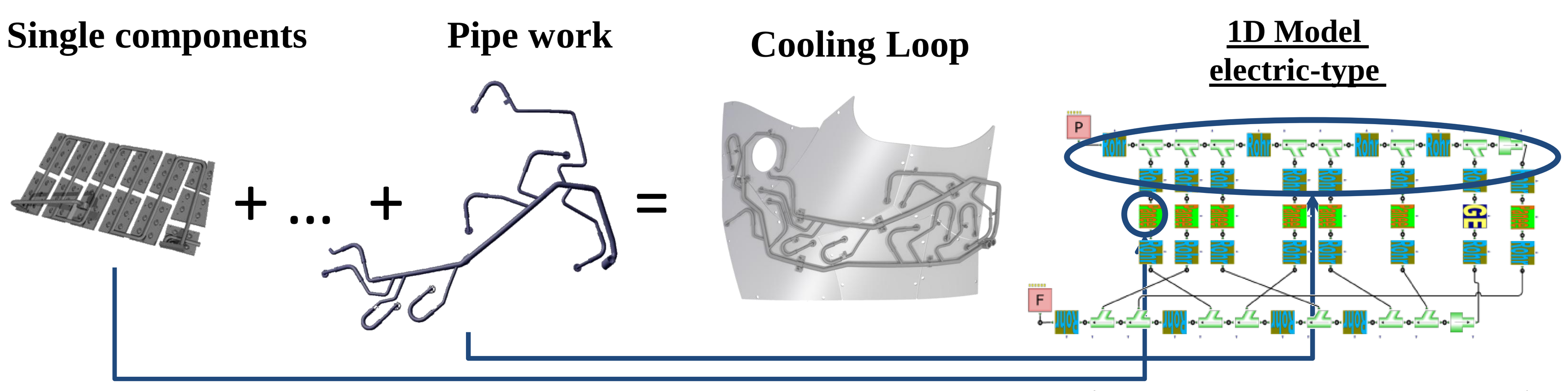
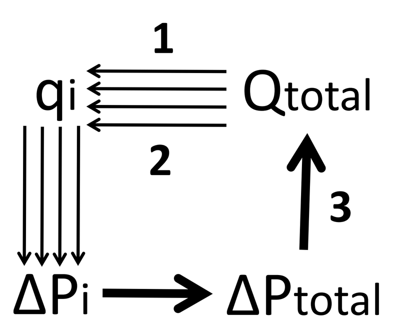


Figure 5: "Bottom-Up" approach

Analysis

- Flow and pressure drop distribution in the cooling loop
- Working conditions: Total flow, pressure drop , pumping power



Requirements

1. **max** branch **flow**→ damage components (flexible pipes)
2. **min** branch **flow** → Thermal performance (heat removal)
3. **max total ΔP**→ damage in components (deformation, cavitation..)

MODEL CHECK

1. Pressure Drop Measurement

More than 100 single components (*Baffle and Heatshield*) measured →good accordance between measured and calculated values (*fig 7).*

A hydraulic pipe system is modeled with the Darcy-Weissbach equation

$$\Delta p = \textbf{K-Value} \cdot V^2 + \Delta p_0$$

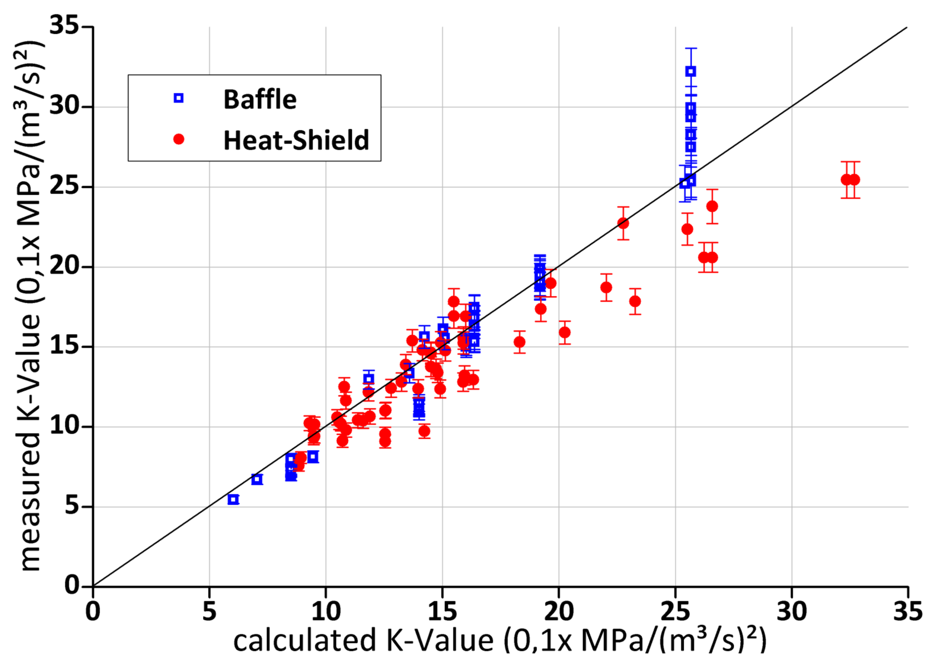


Figure 7: Measured vs Modeled K-Value

2. Flow Distribution

in an assembled "cooling loop", a Divertor Unit. Composed of **Target Elements (TE)** as heat sinks (*copper colored fig 8*) connected with pipe work and inlet/outlet manifolds).

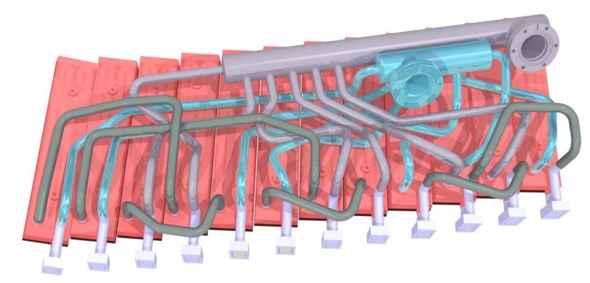


Figure 8: 12TE in 2x6 Branches

Each TE is hydraulically unique due to its manufacturing process, different gap geometries have been observed, connecting the intern meanders.

1D Simulation

1D – 3D CFD coupled simulation →

manifold influence check.

1D-modell coupled with a 3D -CFD code for the manifold description (*fig 9*)

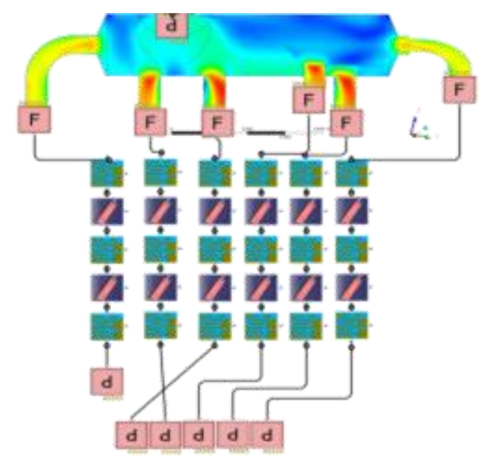


Figure 9: Coupled CFD + FM

Measurements – Two methods selected

a) **Thermography→** Too low time and spatial resolution for accurate results.

b) **Ultrasonic flow meter →** A whole study has been performed to check the goodness of its results.

3. Results

- Both models agree with the measurements
- The difference between the two models does not justify the use of the more complex "coupled model".
- The Ultrasonic flow meter is the only method available to measure flow in the cooling loops with precautions

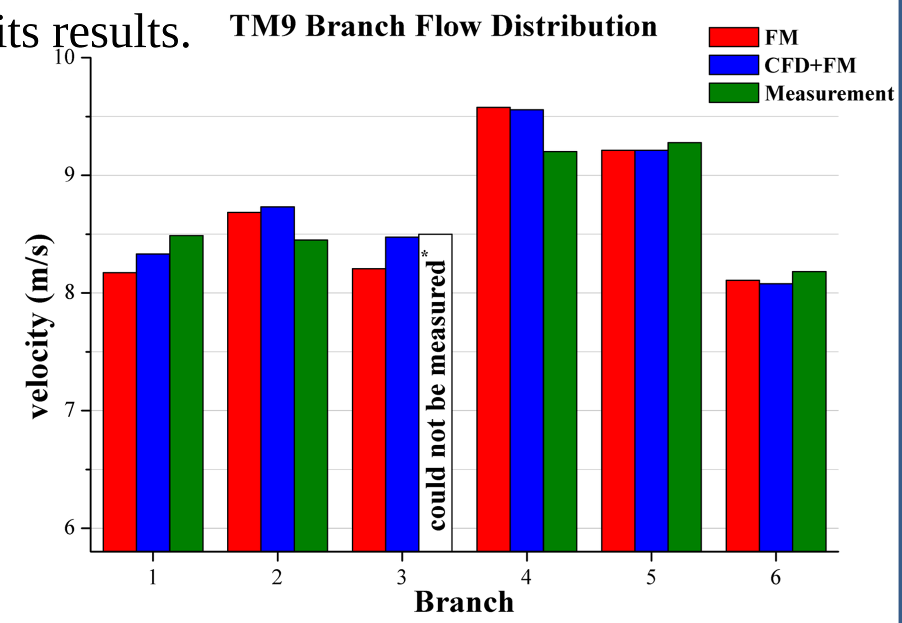


Figure 10: Flow distribution for 3.3 l/s inlet flow

* In Branch 3 there is no measuring position

COOLING LOOP OPTIMIZATION

By implementing strategically "constrictions" (orifices) in some branches of a cooling loop the flow distribution is optimized to a better balance among branches.

Advantages

- lower total flow needed (up to 30%)
- lower pumping power (up to 30%)
- Lower flow velocity in branches
- Not greater total pressure drop

Disadvantages

- Laborious integration

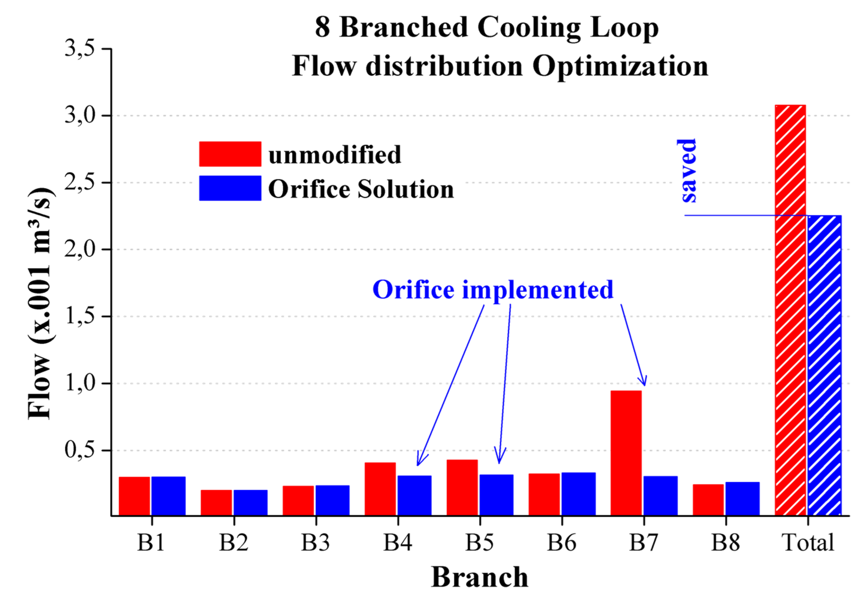


Figure 11: Orifice Optimization of the flow distribution of the circuit in *fig 5*

CONCLUSIONS

The 1D simulation of the cooling system with the method used is efficient and accurate

• **Modeled and analyzed** :10 Half Modules x 17 Cooling Loops Types = **170** with around 650 Plasma Facing Components and 8Km pipe work

• **Optimized** 10 HM x 3 CL = 30 showing up to 30% saved total flow and pumping power

The ultrasonic flow meter is the suitable as a **measuring technique** for further studies in the cooling loops

Contact person: Guillermo Orozco (g.orozco@mytum.de)