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THERMAL-HYDRAULIC CALCULATIONS OF PLASMA-FACING COMPONENTS (BLANKET AND DIVERTOR) OF FUSION REACTORS (ITER AND DEMO)

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1. INTRODUCTION

Plasma-facing components in Fusion Reactors are designed to work in extremely severe conditions, being characterized by rigorous thermal and mechanical stress. They provide a physical boundary for the plasma transients and participate in the thermal and nuclear shielding of the reactor external components.

As a consequence, it is fundamental to assess the thermal-hydraulic behaviour of the cooling circuit of those components, in order to verify that an adequate cooling is always ensured while complying with the required pressure drop limits, recommending specific changes in the configuration when optimization may be required.

In particular, the cooling systems of plasma-facing components under investigation belong to the Blanket of ITER reactor and to the Divertor of DEMO reactor.

A theoretical-computational approach based on the Finite Volume Method is followed, adopting a suitable release of the ANSYS-CFX Computational Fluid-Dynamic (CFD) code.

The modelling strategies as well as the analysis methodologies adopted for the thermal-hydraulic investigations are herewith presented.

2. ITER BLANKET COOLING SYSTEM

ITER Blanket system is composed of 440 modules, covering a plasma-facing surface of ~650 m^2 and distributed in 18 toroidal sectors as well as in 18 poloidal positions (Fig. 1). Each of them consists of a plasma-facing First Wall (FW) panel and a Shield Block (SB), actively cooled by a proper mass flow rate of pressurized water coolant fed by a system of manifolds.

These components are arranged in 363 different cooling systems, connected in parallel and composed of a couple of inlet/outlet manifolds, a coaxial connector (that connects the manifolds with the FW and the SB) and one or two Blanket modules (Fig. 2).

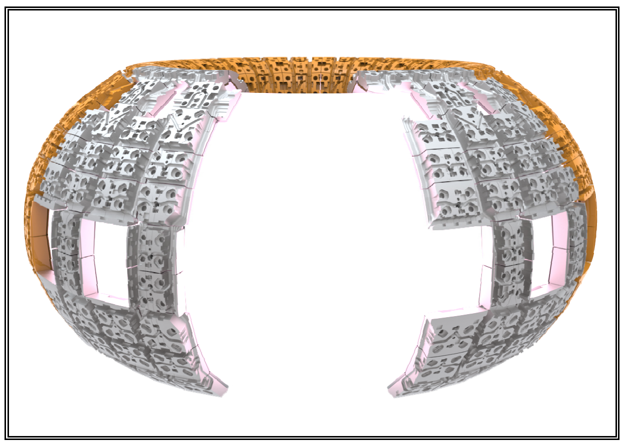

Fig. 1. Overview of ITER Blanket modules.

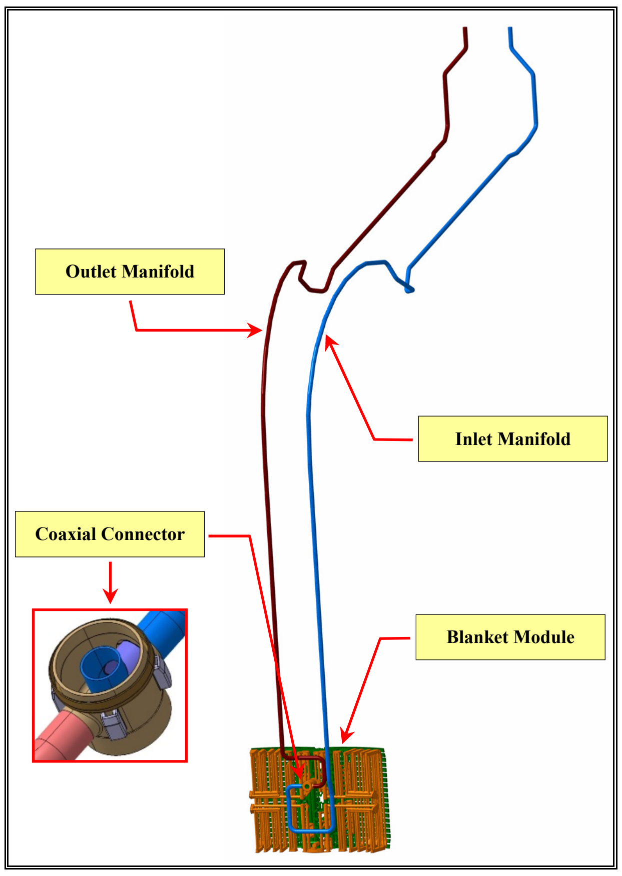

Fig. 2. Typical design of a ITER Blanket cooling system.

Given the modular structure that characterises Blanket cooling systems, it is reasonable to divide their numerical calculation into four separate analyses of their components in a stand-alone configuration. This approach still allows to assess the nominal steady state thermal-hydraulic performance of a whole circuit while operating on much simpler Finite Volume Models, implying the need for sensibly lower calculation time and resources.

A Finite Volume Model of the hydraulic circuit under consideration is developed performing the discretization of the flow domain and the definition of constitutive model, loads and boundary conditions as well as turbulence model. The steady state fully-3D CFD analysis is carried out at the relevant mass flow rates and assuming an isothermal flow of water coolant at 371 K.

The calculations are mainly focussed on the assessment of both pressure drop and velocity spatial distributions through the circuits. Those evaluations also allow to determine the overall pressure drop as well as to detect the most critical areas, which may undergo revision process.

Fig. 3 and Fig. 4 show the configuration of typical FW and SB cooling circuits, along with the contour of representative calculated quantities.

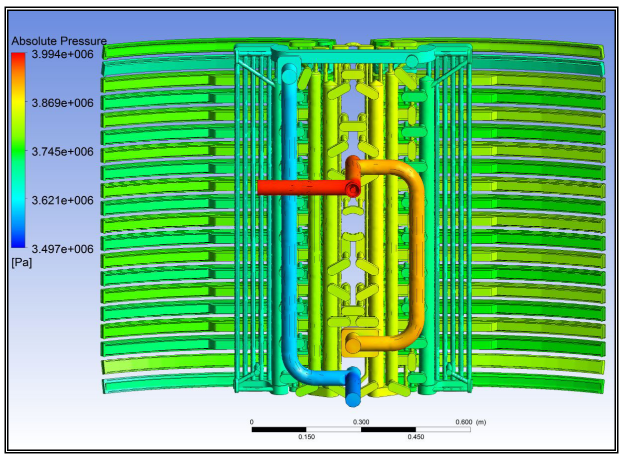

Fig. 3. Typical lay-out and pressure contour of a FW cooling circuit.

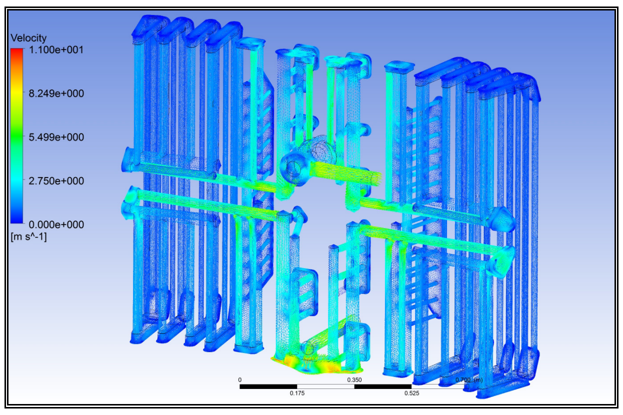

Fig. 4. Typical lay-out and velocity contour of a SB cooling circuit.

3. DEMO DIVERTOR COOLING SYSTEM

The primary function of the Divertor in a Fusion Reactor is to exhaust the main part of the alpha particles and impurities power, together with a portion of the heat load that comes from the plasma.

The Divertor belonging to DEMO reactor (Fig. 5) should be divided into 48 Cassette assemblies, each of them composed by a Cassette body and two Plasma-Facing Components (PFCs), namely the Inner and Outer Vertical Target (Fig. 6).

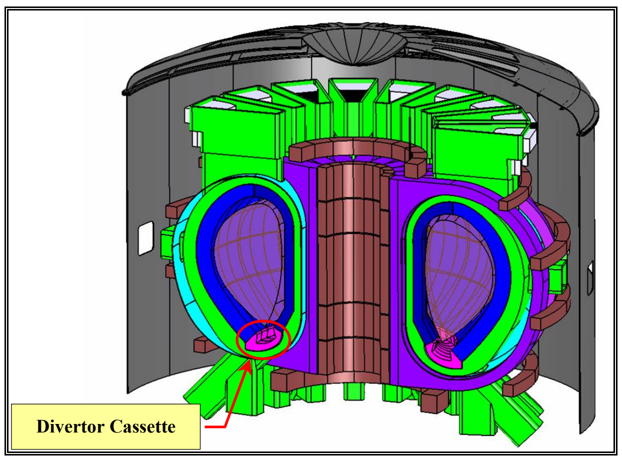

Fig. 5. Overview of DEMO tokamak complex.

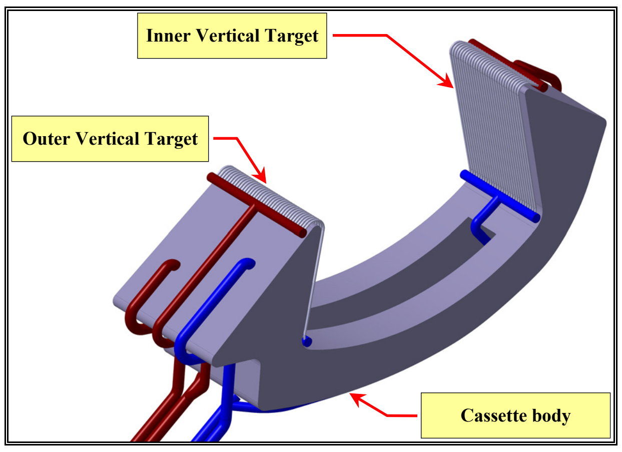

Fig. 6. Typical design of a DEMO Divertor configuration.

The purpose of the Cassette body is primarily to provide neutron shielding and to support some plasma-facing components and diagnostics. On the other hand, the PFCs are designed to intercept the magnetic field lines in their lower part and to baffle neutral particles in the upper part.

At present, several different Divertor configurations are under investigation, differing mainly for the cooling circuit structure.

For each Divertor configuration, a Finite Volume Model of the hydraulic circuit is set-up, realistically reproducing its flow domain and specifying constitutive model, loads, boundary conditions and turbulence model. The nominal mass flow rate is imposed and an isothermal flow of water coolant at 423 K is considered.

Focussing mainly on the assessment of pressure drop and velocity spatial distributions through the circuit, the calculation allows to determine the overall pressure drop as well as to detect the most critical areas, which may be revised for optimizations.

Fig. 7 shows the lay-out of the Finite Volume Model of a Divertor PFCs configuration along with a pressure contour, whilst Fig. 8 shows details of the model mesh (geometrical discretization).

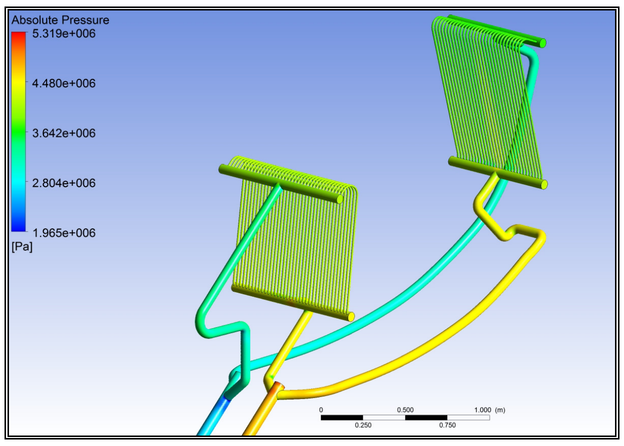

Fig. 7. Lay-out and pressure contour of a Divertor PFCs configuration.

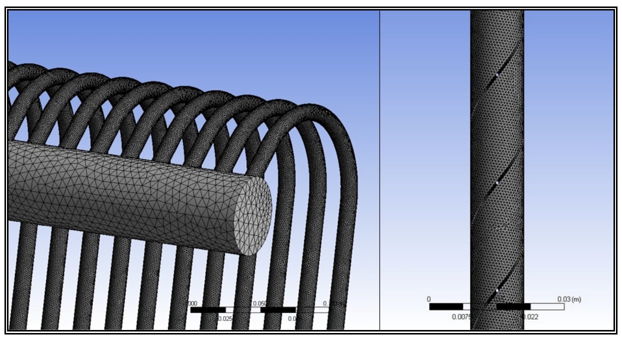

Fig. 8. Details of the Divertor PFCs mesh.

5. CONCLUSIONS

A theoretical-computational research campaign is currently ongoing, aiming to investigate the thermal-hydraulic behaviour of the ITER Blanket cooling system and the DEMO Divertor cooling system.

The main purpose of those calculations is to assess the pressure drop of the analysed components.

Furthermore, it is also requested to confirm the aptitude of those cooling systems to effectively remove the deposited power with acceptable temperature rise and pumping power, suggesting design optimizations when these requirements are not met.

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