ACTIVELY COOLED PLASMA FACING COMPONENTS DESIGN FOR W7X AND JT-60SA IN SUPPORT OF THE ITER DIVERTOR

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In ITER, plasma scenarios will be developed to achieve durations up to 3000 s [1]. To achieve such durations plasma facing components (PFCs), which handle the exhaust from the plasma, need to be adapted. To face heat loads in the divertor region (10 MW/m² as nominal peak stationary power load) and operation duration constraints, water is circulating in the cooling channels of each PFC. Taking into account plasma wall interaction and sustainability under high heat load constraints, tungsten (W) is considered as the best option as an armor material. Up to now, a lot of efforts have been undertaken to understand plasma interaction on W PFCs, mainly in laboratory, but the principal difficulty lies in performing assessments under realistic tokamak plasma operating conditions, meaning simultaneous impact of high fluence, stationary and transient heat fluxes. Until this is achieved, no lifetime assessment is possible for ITER. This statement is also true for future fusion power plant. As a consequence, to foster a successful operation of ITER and define what is the most appropriate PFC technology, several fusion devices (such as WEST, EAST, KSTAR) are testing W actively cooled PFCs (ITER-grade actively cooled divertor with W monoblock PFC concept)) [2]. Further, this research on W PFCs should be also carried on the recent large long pulse devices such as JT-60SA and W7-X. A program within EUROfusion has been launched in 2021 to develop W actively cooled prototypes for W7-X and JT-60SA. Since then, new materials and W PFCs optimised designs have been proposed and successfully tested.

W7-X (Greifswald,Germany) is the largest superconducting modular stellarator of the world. It started plasma experiments with a carbon-based water-cooled plasma-facing wall in 2022, allowing long pulse operation. The objective of W7-X is to demonstrate the feasibility of the stellarator concept for a future fusion power plant. One crucial step to reach this goal is the demonstration of high performance plasmas with a tritium compatible (i.e. carbon free) wall. Based on the lessons learnt, a key objective of the new W-PFC design is simplification of the manufacturing process, the inspection steps, the testing steps and the installation [3]. More specifically, the goal is to minimize the number of welds resulting in a target module made of a single CuCrZr heat sink part (figure 1) in which the manifold is integrated and only one inlet and one outlet water connection are required. The heat sink made of CuCrZr is planned to be manufactured using laser powder bed fusion (LPBF) [3]. This manufacturing technology has indeed the advantage to build geometries which may difficult to manufacture with conventional process. The plasma facing side of the heat sink is protected against the plasma by a W or W95NiFe based cover (spraying or HIP diffusion bonding). To reduce thermal stresses at the interface between the W-based plasma facing material and the CuCrZr heat sink

material, a copper interlayer of ~1 mm thickness is mandatory. Finite element modeling suggests that the design proposed meets the 10 MW/m² requirement of heat load capacity over the entire plasma facing surface, while design constraints of the existing water infrastructure, available space, weight limitations per module are fulfilled. We will show in this paper that the qualification of the required technologies is successful (hot leak tightness of additive manufactured CuCrZr was demonstrated without any density strengthened post-processing). Small scale heat sinks according to the new design were indeed successfully manufactured and tested hydraulically and under high heat loads (10 MW/m²).

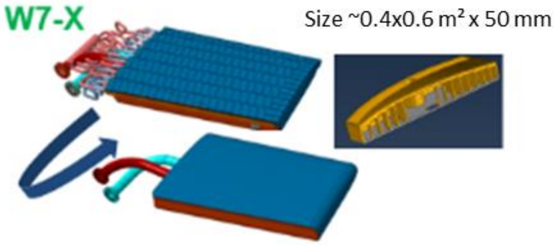

Figure 1 : Simplification of the W7X target module in the view of the tungsten PFC operation

On its side, the tokamak JT-60SA has been constructed and will be operated in the framework of the broader approach with strong European support. A transition to a metallic device is foreseen after 2029 for the so called "Integrated Research Phase II". For the divertor region, the W monoblock PFC concept has been chosen as the reference. It is currently developed by Fusion for Energy in the frame of a contract with the industry. In addition, some advanced W actively cooled PFCs are currently developed to propose alternative designs, enabling cost saving on the series manufacturing phase and / or sustain heat loads higher than 15 MW/m². One way to reduce cost is a concept with flat interface surfaces (W to copper, copper to CuCrZr), instead of cylindrical one for the reference concept. To sustain heat loads higher than 15 MW/m², one option is to propose cooling design able to increase the heat transfer coefficient between the cooling channel and the coolant. To manufacture such heat sink, additive manufacturing is considered as an option (Figure 2) [4]. However, it turned out that the use of this manufacturing technic also drives some constrains in the PFC geometry definition (heat sink wall thickness for example). The definition of cooling channel geometries was studied by computational fluid dynamics and provides the conclusion that such concept could be able to sustain heat loads higher than 15 MW/m². In this paper the latest results on performance assessment of the reference and alternative W-PFC designs, developed for their potential integration in JT-60SA, will be presented. All these developments in PFC should eventually contribute to the optimization of the divertor armor in next step metallic devices.

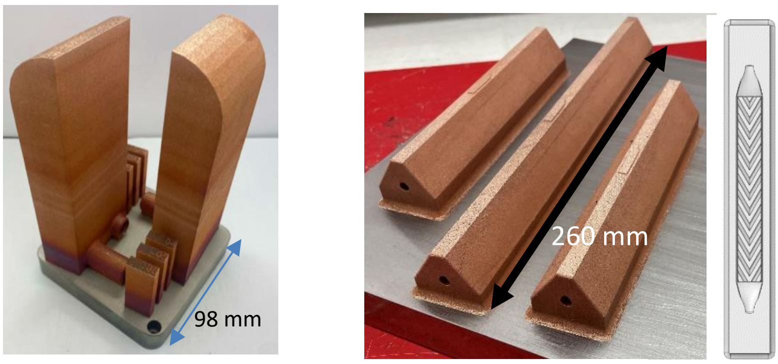

Figure 2: Mock-ups manufactured with additive manufacturing : W7-X (courtesy Fraunhofer IGCV) (left), JT-60SA (Right)

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