Design and qualification activity of the first divertor of the DIVERTOR TOKAMAK TEST FACILITY

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The Divertor Tokamak Test facility (DTT) [1] is a fusion device under construction in Italy, with the support of the EUROfusion consortium, dedicated to testing alternative divertor concepts under integrated physics and technological conditions relevant to DEMO. Several divertors which may differ in design or/and technologies or/and poloidal profile will be tested during the life of the machine. In the first phase of exploitation of the facility different magnetic configurations and scenarios will be study with the aim to identify the most promising. The first divertor will therefore have to be robust and flexible, able to withstand high thermal loads for long pulses and to accommodate strike points located at various positions according to the different equilibria. For this reason, almost the entire divertor plasma-facing surface is in Tungsten (W) monoblocks and the monoblocks are joined to CuCrZr pipes (plasma-facing units, PFUs) using the design and technology developed for the ITER divertor targets which, at the state of the art, is the most reliable. Furthermore, building on the design and technology developed for ITER allowed to take advantage of previous experience, limiting the necessary research and development acitvities.

The design activities started from the definition of the interfaces and of the overall constraints, which are the same ones that future divertors (the position of the rails for the fixation to the VV, the maximum size to allow insertion into the machine through the equatorial port, the maximum weight compatible with the remote handing system,....)..The poloidal profile of the first divertor followed the choice of the 3 reference magnetic equilibria (Single Null, X-Divertor and Negative Triangolarity) with which it must be compatible and the geometric (Figure 1) and technological constraints related to the design and the production process.

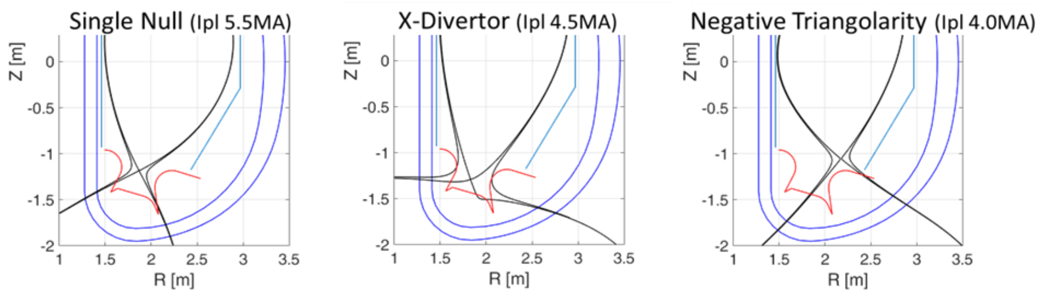

Figure 1 compatibility with the reference equilibria

The divertor consists of 3 Plasma Facing Components: Inner Target (IT), Outer Target (OT) and Central Target (CT). In each PFC there are straight parts (targets) and curved parts (baffles). In the IT and CT components there are one baffle and one target, named, respectively, Inner Vertical Target (IVT) and Central Horizontal Target (CHT), whilst in the OT there are one baffle and two targets; the Outer Vertical Target (OVT) and Outer Horizontal Target (OHT).

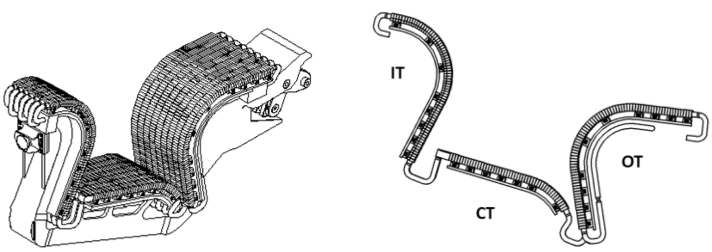

Figure 2 Diverotor module and polodal profile

For each divertor module IT and CT consist of 7 PFUs, while OT of 9. The 7 central PFU of the three components are connected in series by curved tubes hidden from direct plasma radiation, but not covered with monoblocks to leave free slots between the target allowing adequate pumping close to the strike point (Figure 2).

With the purpose to increase the flexibility in operational scenarios by maximizing the allowable thermal load, the monoblocks have a reduced plasma side thickness to respect of the ITER ones. The monoblock thickness of 3 mm was fixed compatible both with the erosion estimates in the DTT divertor area and with the manufacturing constraints. In the development of the toroidal profile, to avoid local damage of protruding leading edges due to the gaps between PFU and to assembly and manufacturing tolerances, a toroidal monoblock bevel has been implemented. The resulting admissible load on the monoblock has been evaluated and compared with those predicted by SOLEDGE2D-EIRENE code simulation: even partially detached scenarios can be sustained by the targets in steady state for the three reference magnetic configurations. This ensures an adequate safety margin for divertor operations even in case of loss of detachment.

Although, based mainly on the well proven ITER technology, the implemented specific design solutions requested high heat flux (HHF) experimental campaigns to be validate: both HHF thermal fatigue and critical heat flux (CHF) test campaigns were conducted.

Fatigue tests [2] have proven that the monoblock with reduced thickness can withstand 1000 cycles at 20 MW/m^2 without any plastic deformation and without the onset of cracks up to toroidal widths of 25 mm (maximum width for the vertical targets). Subsequently, a mock-up representative of the central target with 30 mm toroidal width was subjected to 1000 cycles at 16 MW/m^2 (which is the design load for this target) in the HHF test GLADIS facility at IPP in Garching. Results comparable to those of the previous campaign were found: no plastic deformation and no cracks on the surface.

The Critical Heat Flux tests were conducted in the HADES e-beam facility in the CEA center in Cadarache. The purpose of these tests was evaluating the possibility of not equipping the CT with a twisted tape in favor of design and manufacturing simplification. Considering the short plasma footprint on the CT in the NT scenarios, it was possible that the actual CHF was greater than the estimated by the semi-empirical relations. The tests were conducted on four medium scale mock-ups and two small scale ones at different water temperatures. The dependence of the CHF from the loaded area was observed, however at 60°C water temperature (reference hydraulic condition for the DTT divertor) despite the reduced loaded length, the CHF increase was marginal, highlighting the need to maintain the turbulator to ensure an adequate safety margin.

During the CHF testing (30 mm of monoblock toroidal width), deep crack formation along the tube axis was observed following complete surface recrystallization. While operational loads remain significantly below CHF levels (with a minimum safety margin of 1.4), the gradual decrease of recrystallization temperature with prolonged high-temperature exposure [3] could cause the formation of deep cracks even at lower loads. This suggested further testing to verify the survival capability of the component with a monoblock of only 3 mm of thickness even when deep cracks are presented. A mockup representative of the horizontal targets was deliberately recrystallized and loaded until cracks formed in HADES. After that, the mockup was subjected to 1000 cycles at 16 MW/m^2. No significant crack propagation or surface temperature variations were observed during this fatigue testing.

Finally, a small portion of the central horizontal target of the DTT divertor must be covered with flat W tiles instead of monoblocks. These flat-tiles are joined by solid state diffusion process to an OFE-Cu interlayer and subsequently joined to the CuCrZr cooling tube together with the monoblocks with the Hot Radial Pressing process. The process parameters were varied to allow the simultaneous joining of flat-tiles and monoblocks. To verify the resistance to thermal load of the developed flat-tile solution, small ad hoc mock-ups were produced and tested under thermal fatigue in the GLADIS facility.

In conclusion, the qualification activities of these years have allowed to validate most of the design choices, allowing us to reach the full-scale prototyping phase for the PFCs and the technical specifications for the cassette body and monoblocks procurement ready for the tender launching. The 1:1 scale prototype of the fixation system to the VV has already been built and is being tested and verified for compatibility with the RH system.

References

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