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THE DIVERTOR TOKAMAK TEST FACILITY: MACHINE DESIGN, CONSTRUCTION AND COMMISSIONING

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The Divertor Tokamak Test facility (DTT) [1], [2] has been conceived to tackle the power exhaust issues in integrated reactor relevant conditions, close to those of ITER and DEMO. To accomplish its mission, DTT as the flexibility to investigate several magnetic configurations and assess different divertor solutions. DTT (major radius R=2.19 m, minor radius a=0.70 m, magnetic field on plasma axis B_T=5.85 T, plasma current I_p=5.5 MA and pulse length 100 s) will be equipped with, 45 MW of additional heating to the plasma (32MW of Electron cyclotron waves at 170 GHz, 8MW of Ion cyclotron waves at 60-90 MHz and 10MW of Negative Neutral Beam Injector at 510 keV). The neutron production is quite notable ($1.5\cdot10^{17}$ n/s) for a D-D machine. The paper will address the status of the DTT construction and the plan for its assembly and commissioning.

The relatively small dimension and consequently the high-power density implies very accurate engineering design solutions and the use of leading-edge technology. For almost all the subsystems careful design verification, construction specification and commissioning test have been provided as described below.

Magnets: the toroidal field (TF) magnet design took advantage from the recent progress in the Nb3Sn superconductive strand performance with respect the one used in ITER (with an increase from 260 A to 320 A) that has been proven in test campaigns made in the Sultan facility that demonstrated an unchanged the temperature margin after 3000 cycles. The Central Solenoid (CS) is one of the most challenging components having to produce a flux in excess of 16.5 Wb, in a quite narrow space. Several design solutions have been analysed to limit the operational risk, both from the electric breakdown and the mechanical standpoints. Presently, an experimental confirmation test of the insulation system is under way in order to validate the design for the highest stress areas of the CS and the Poloidal Field (PF) coils. The CS strand requires critical current more than the ITER one and very low losses due to the high field derivative during the startup phase and its experimental tests at Sultan facility is foreseen. The PF coils have been designed for a number of different plasma scenarios and will experience very large loads, requiring very tight construction and assembly tolerances. Three sets of internal copper coils will provide ELM’s and error field control, vertical and radial stability, fine tuning of the strike point position and the plasma sweeping. Suitable cryogenic tests of all the Nb_3Sn coils will be performed in a dedicated facility, presently under construction at the Frascati ENEA Center. The TF coils are under construction and the contract for the casing awarded. The PF coil procurement will be awarded in the coming months. The Call for tender for CS will be launched by the end of 2025. The design of the internal coils is almost completed. The axisymmetric in-vessel coils will be manufactured, based on the recent successful experience in ASDEX Upgrade for similar geometry, An extensive qualification campaign, to be performed in a machine mock-up integrating the 30° vacuum vessel sector prototype, is already envisaged in the assembly contract in preparation of the actual assembly.

Plasma facing components: due to its mission, plasma facing components are crucial elements of DTT. The divertor region has been conceived, in close collaboration with Eurofusion, to test a variety of different divertor concepts, including liquid metal one. Particular care has been devoted to reserve the largest possible volume and to guarantee a very efficient pumping speed and the possibility to operate on a reduced number of divertor modules, called “test modules”, at very high pressure (15 MPa) and cooling temperature (250°C) to allow cooling condition similar to DEMO. The optimisation of the geometry of the first tungsten monoblock divertor, shaped to be compatible with single null, XD and Negative triangularity scenarios, has been performed via extensive modelling of the neutral pressure in the private divertor region and of the thermal distribution of temperature and stresses. The design of the inner and outer divertor target is completed based on the ITER-ike monoblock technology (largely developed and qualified at ENEA Frascati labs). Tests on mock-ups are currently ongoing to qualify for one-to-one features of DTT divertor design. Careful evaluation of the tolerances and gaps between adjacent modules, have led to a design that considers toroidal and poloidal bevels and then brought to a large number of different monoblock families. The cassettes hosting the plasma facing units are ready to be procured, as well as the tungsten monoblocks. The first wall has been conceived with a large area having the capability to work as a limiter with 18 out 36 inner FW panels also based on tungsten monoblock. The design is now under assessment by testing suitable mock-ups. The ‘standard’ FW conceived to support about 0.5 MW/m^2 will largely take benefit from additive manufacturing process, in particular in complex geometries in the outboard area in order to ease also the integration in the port plugs.

Vessel: The DTT vacuum vessel (VV) design has to withstand high disruption forces and has to shield the toroidal magnet from neutrons. It is made in AISI 316 LN (with slightly optimised chemistry) and consists of a double wall water cooled welded structure, 15 mm thick, reinforced with a number of poloidal and toroidal ribs. The connection to the cryostat flanges is made by multi-ply bellows. Borated water has been demonstrated necessary for achieving a sufficient shield capacity during the full-power phase of the machine operation. Being the component to which the plasma facing components have to be attached, severe requirements in terms of tolerances are required. The assembly tolerances will be guaranteed by the final adjustment via final machining of the coupling elements on the basis of reverse engineering analysis during the assembly. A large number of ports (82) have been allocated for the 45 MW heating power injection and the diagnostic systems. The thermal shield will be attached to the vacuum vessel which in turn will have a very smooth surface to limit the thermal losses. The VV operates at 60°C and will be baked up to 200°C, by nitrogen gas heating, during the cleaning cycle. The VV thermal shield is made of double wall panels surrounding the wall and the ports, cooled by helium gas at 80 K and is designed to get an almost isostatic structure and to avoid electric loops. The VV procurement contract is under awarding phase. The procurement of the thermal shield will be launched soon.

Cryostat: the cryostat consists of a modular steel structure. Modules are joined through a bolting system and sealed by leap joint welding, using a well-proven design, e.g. that successfully used in JT-60SA. The cryostat module has been organized in order to facilitate as much as possible the maintenance procedure. For example, the upper part is easily demountable leaving space for operating the upper part of the machine allowing access to the central solenoid zone.

Power Supply: TF magnet modules grouped in three parts, each made of 6 coils, are fed by the 3 kV/45 kA power supply system equipped for protection with a Fast Discharge Unit. The original solution using ITER or JT-60SA-like pyro-breakers was substituted by an innovative system. The energy storage to mitigate the power request is based on supercapacitors. The power supply of the TF coils and one fast discharge unit, out of the three required, has been already delivered and dedicated to feed the coils to be tested in the coil cold test facility. The procurement of the power supply systems for the 32 internal coils is ongoing and the delivery is expected by 2025. The call for tender for procurement of the power supply of the poloidal coils will be launched soon. To make available the required 300 MVA, the extension of the electric line has been necessary. TERNA, the Italian utility for the electric network is taking care of the 16 km extension.

Assembly. The optimization of the assembly of the machine and the auxiliary system has been performed to maintain the schedule of the construction and commissioning of DTT. Sequence, tooling, equipment and the optimization of the different phases have been done taking particular care of the planning needs. Detail technical specification fixing the sequence, tooling, pre-assembly and assembly procedure is almost complete. Particular care has been put also in the preassembly phase when crucial process, like port welding and the instrumentation of vacuum vessel, have to be fully qualified. The call for tender for the assembly and commissioning will be launched by the end of the 2025.

References

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