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Conceptual design of the Divertor Tokamak Test (DTT) Cryogenic System

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The Divertor Tokamak Test (DTT) facility aims to advance the power exhaust strategies, useful for the first nuclear fusion power plant, by testing the divertor in plasma regimes that are relevant for ITER and DEMO [1]. Central to its design is a tokamak reactor equipped with superconducting magnets, that require to be cooled at low temperatures (4.3 K) for proper operation. The DTT magnet system is supported by an actively cooled structure with thermalized gravity supports and is thermally protected in a cryostat with thermal shields (TS) cooled with pressurized helium at 80 K. The superconducting coils are connected to the power supply by means of High Temperature Superconducting (HTS) current leads, which operate between cryogenic (50 K) and ambient temperatures. Further, DTT employs cryopumps behind the divertor targets, which require 4.3 K helium for the cold panel and helium at 80K for its chevron baffles.
The cryogenic system is a cornerstone of this infrastructure, ensuring stable magnet performance while managing challenging pulsed thermal loads.
The most demanding operational state is the Plasma Operation State (POS), where magnets are subjected to peak heat deposition due to AC Losses (hysteresis and eddy currents during plasma current ramping) and nuclear heating. The Cryogenic System shall be able to handle the variable loads, as well as the static and continuous loads coming from resistivity losses and thermal radiation of the warmer surrounding components.
Another demanding operational state is the baking, where the in-vessel components of the tokamak are warmed-up, leading to an increase of the radiation loads to the vacuum vessel and ports thermal shields, and where the cryopumps need to undergo the regeneration process.
Finally, quench and fast discharge events, which involve the sudden warming of the helium inventory contained in the magnets and leads to an over-pressurization of the system, need to be handled by means of dedicated quench valves, releasing helium through the quench line to the quench tank. Further, a proper Quench Heat eXchanger (QHX) is designed to warm the released helium before its arrival in the quench tank.
The necessary overall cryogenic capacity is currently estimated to be around 10 kW equivalent power at 4.5K. However, the Cryogenic System shall deliver the necessary cooling power at three different operating temperatures: 4.3 K, 50 K, and 80 K.

A preliminary design of the DTT cryogenic system has been developed and its architecture is shown in Figure 1. Nevertheless, the details of the cryogenic process and the final design of the refrigerator will be optimized together with the expertise of the final supplier, with the aim of obtaining the most efficient solution for the needs of DTT.
All the sub-systems span a large area and several buildings of the DTT site, but still must respect the dedicated areas, which are often limited. For instance, a major effort was made by the CRYO-DTT team to develop the layout and the design of the Distribution inside Tokamak Hall within the very limited available space.
Another key feature of the DTT Cryogenic system is the cooling pattern: the cryogenic users are supplied with helium by means of 5 different distribution loops. The first two are closed loops providing helium at 4.3 K

respectively to the TF magnets system (Loop 1), and to PF Coils and CS modules in parallel (Loop 2), by means of two independent cold circulators and dedicated heat exchangers, that allow transferring heat from the two circuits to a common liquid helium bath. Loop 3 provides helium (at about 4.3 K) to the 10 cryopump panels directly from the refrigerator helium flow. Loop 4 supplies the 80 K pressurized helium to the thermal shields, cryopump Chevron Baffles and 80K GSTA. Finally, loop 5 provides 50 K helium to the 30 current leads.

Most important, the cooling strategy is characterized by gathering the cryogenic users in groups cooled in parallel. The main objective of this choice was to reduce the total number of control valves, again due to the constrained space for the CVBs in the Tokamak Hall. For instance, the winding packs of the TF magnets are cooled in 3 group of 6 magnets in parallel, PF and CS are both gathered in two groups with three magnets cooled in parallel, and so on. Each group has one main regulation valve at the inlet and one shut-off valve at the outlet. Moreover, special non-return valves have been appositely chosen to be installed upstream each magnet coil, case and cable to avoid backward flow in case of quench with the aim to protect the other magnets/cables of the same group. Indeed, quench valves are installed one at the outlet of each group and a redundant quench valve is installed at the inlet distribution manifold.

The DTT cryoplant underpins the DTT's mission of solving some of the most critical fusion challenges, by enabling stable operation of the tokamak's magnets. The preliminary conceptual engineering design of this plant has been developed after the main loads and the main requirements were collected. In particular, the cryo-distribution system features strategical choices for helium flow regulation and quench management, that allow minimizing the number of cryogenic valves needed, thus reducing costs and maintenance issues, as well as simplifying the control of the entire cryogenic system during its operation. Since it will be one of the biggest operating Cryoplant in Europe, the lessons learned from the DTT's cryogenic system could become a reference and inspire further innovative solutions for future operating cryoplants.

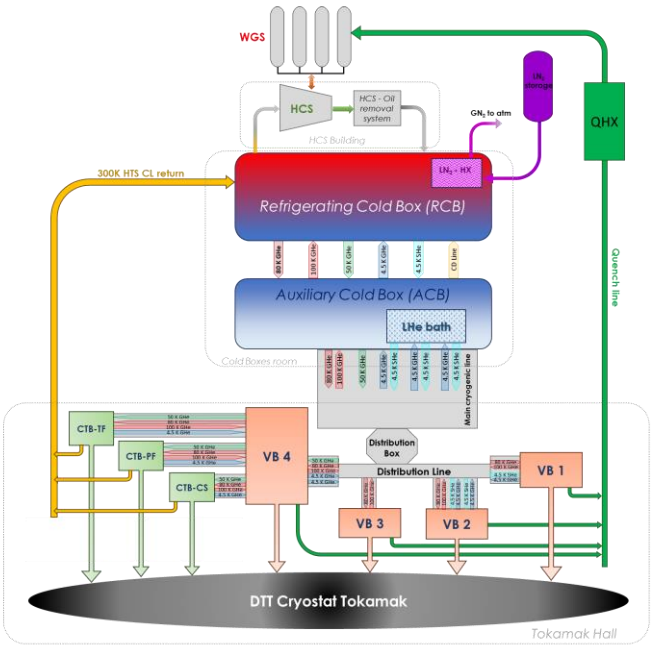

Figure 1: DTT Cryogenic system architecture

[1] Romanelli, F. (2024). Divertor Tokamak Test facility Project: Status of Design and Implementation. *Nuclear Fusion*. 10.1088/1741-4326/ad5740

[2] Lisanti F., et al., Cryogenics, (2023) 136, art. no. 103757.