Updated design and integration of the ancillary circuits for the European Test Blanket Systems

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The validation of the key technologies relevant for a DEMO Breeding Blanket is one of the main objectives of the design and operation of the Test Blanket Systems (TBS) in ITER. In compliance with the main features and technical requirements of the parent breeding blanket concepts, the European TBM Project is developing the HCLL (Helium Cooled Lithium Lead) and HCPB (Helium Cooled Pebble Bed)-TBS, focusing in this phase on the design life cycle and on R&D activities in support of the design. The TBS ancillary systems are mainly circuits devoted to the removal of thermal power and to the extraction and recovery of the tritium generated in the Test Blanket Modules. They are:

- The Helium Cooling System (HCS);
- The Coolant Purification System (CPS);
- The Tritium Extraction System (HCLL-TRS, HCPB-TES);
- The Lead Lithium Loop.

Their conceptual design was deeply analyzed during the ITER Conceptual Design Review (CDR) in 2015. The assessment of the CDR was overall positive and recommendations for improvements were made. The present design takes into account the main CDR recommendations as well as the implementation of the requirements related to ITER operation, safety principles application and physical space constrains.

1. Introduction

The preparation of the HCLL and HCPB TBS preliminary design requires specialized and detailed engineering activities. Particularly, detailed technical interfaces with all relevant ITER Systems have to be consolidated and iterative design activities are needed to comply with design requirements/specifications requested by IO, e.g. component integration in buildings. In addition, the design of the two TBS has to be consolidated with respect to Codes & Standards in view of their future licensing.

The conceptual design of TBM auxiliaries was presented in [1]. With respect to the previous configuration, several improvements have been implemented, partially according to the configurations and parameters presented in [2]. The integration of the AEU (Auxiliary Equipment Unit) was carried out considering the needs of the maintenance and the necessity of radiation shield of the PbLi loop. The integration of HCS and CPS in the level 4 of the TCWS (Tokamak Cooling Water System) vault was already carried out considering the needs of the maintenance tasks and the areas already selected to host the cranes and interfaces locations with other PBS. The CAD model in the Tritium Process Room included the glove boxes for TRS and TES equipment as well as the TAS station and all interfaces. The Fig. 1 presents the adopted breakdown [3].

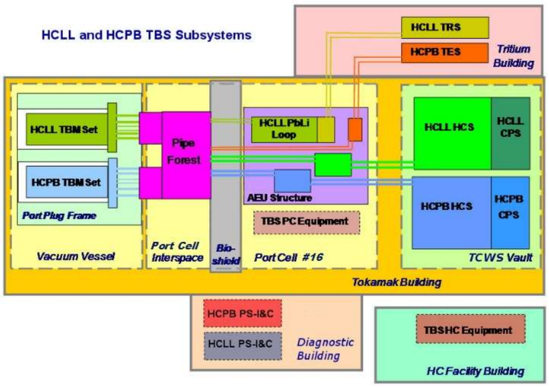

Fig. 1: schematic view of HCLL and HCPB TBS

2. Sub-systems design and integration

The seven TBM ancillary systems are placed mainly in three different locations:

- The TCWS vault area – Room 11-L4-04;
- The PC#16 - Room 11-L1-C16;
- The Tritium Building - Room 14-L2-24.

In Figure 2 are shown the three different locations in which ancillary systems are arranged.

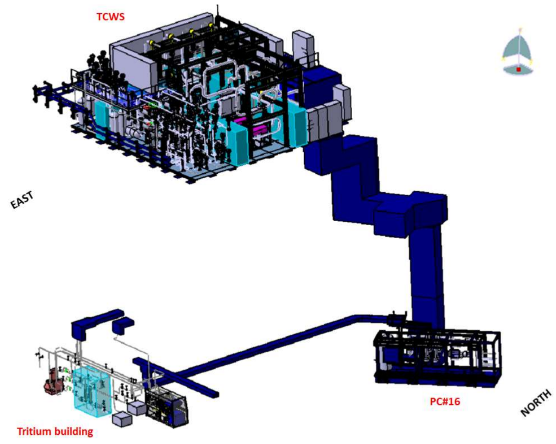

Fig. 2: Location of ancillary systems

The following principles have been taken into account for the components arrangement:

1. Components are arranged below the space reserved for crane;
2. The space dedicated to the pillar and corridor is not available for components allocation
3. Access to the components for maintenance is ensured regarding [4]:
    a. Maintenance requirements
    b. Installation requirements
    c. Welding requirements
    d. Machining requirements

2.1. TCWS area

Major HCS and CPS for the two TBSs are planned to be installed in the TCWS area (11-L4-04). These sections of the HCSs are connected to the helium cooling pipes in the AEU area through the corresponding 4 inches connection pipes (two for each HCS) in the vertical shaft. In fig. 3 the volume available for arranging ancillary systems is reported.

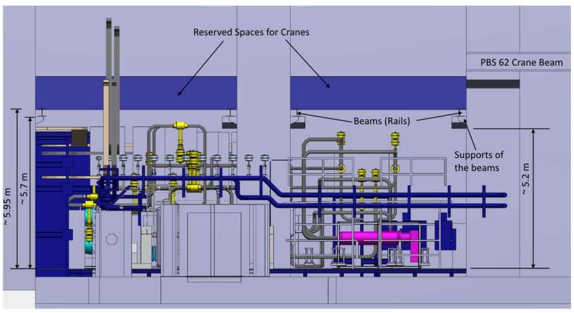

Fig. 3: Available volume in TCWS vault area

The total area is 206 m^2, comparable with the previous one. The general layout of the systems in the room 11-L4-04 is shown in Fig. 4.

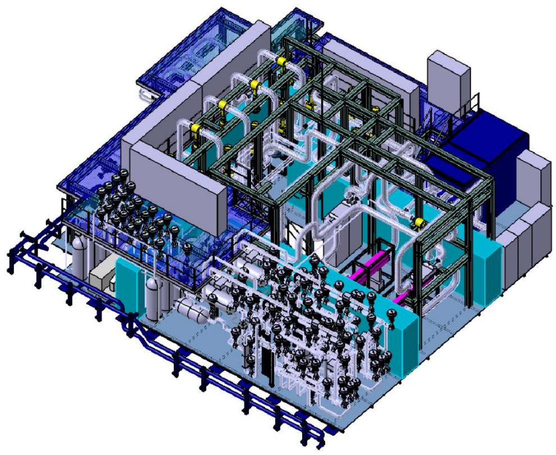

Fig. 4: Integration of HCS and CPS

In the CAD model, an elevated platform has been identified and modified to cover only part of the area in this region so that only some of the cubicles and the valves for the PCSs (Pressure Control Systems) will be arranged on it. The platform is also used as maintenance access to the PCSs valves and part of the CPSs.

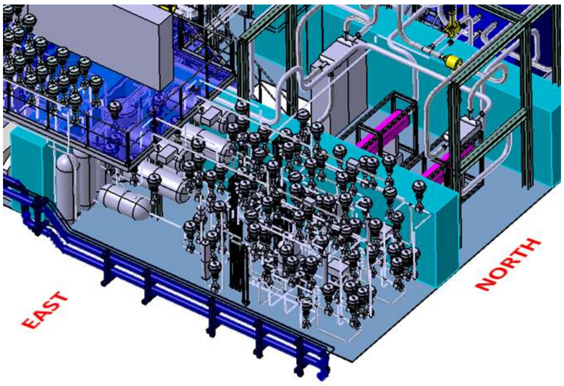

Fig. 5: CPSs updated design and integration

The CPSs have been fully redesigned following the requirements to reduce the tritium partial pressure in the coolant to less than 10^{-2} Pa. The nominal flow rate treated in the system is now 600 Nm^3/h for each HCLL and HCPB concepts.

2.2. PC#16

Concerning the arrangement of ancillary systems in PC#16 the following main changes have been carried out with respect to the past configuration [1]:

- The size of PbLi storage tank have been updated, as those of its gamma shielding. The gamma shielding was updated according to a critical evaluation of the current irradiation scenario presented in [5], resulting in 15 mm of lead around the tank;

- In order to install all components in the reserved space cold trap, valves and piping layout have been changed;
- Following the recess of 860 mm of the AEU the position of connections to interfaces was modified;
- The new designed expansion tanks of HCSs have been placed in the backside of AEU and have been sized in order to withstand a pressure up to 8 bar in accidental conditions.

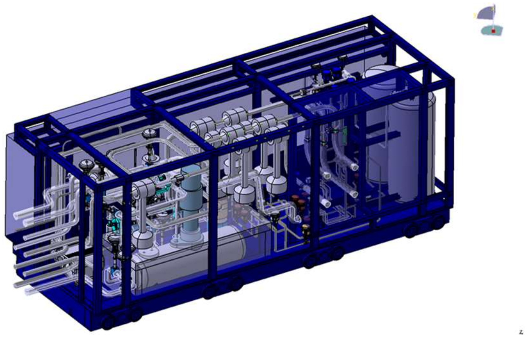

Fig. 6: Isometric view of PC#16 systems arrangement

2.3. Tritium Process Room

The main update in this area with respect to the previous design is the integration of TAS (Tritium Accountancy Station) in the TRS glove box. The new layout is in fig. 7.

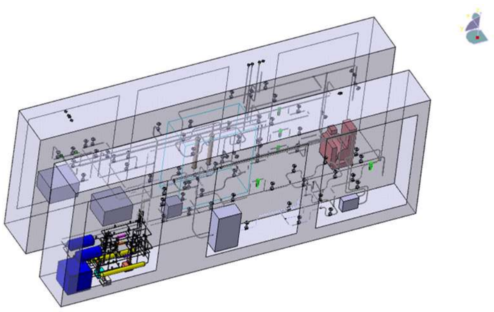

Fig. 7: Isometric view of TRS, in front with TAS on the left, and TES glove boxes

With respect to the original design, the TAS architecture was simplified to follow the new regeneration scheme, in batches, of CPS. Furthermore, a gettering system was added to recover helium used to regeneration and reduce gas consumption, providing tritiated hydrogen highly concentrated to TEP (Tokamak Exhaust Processing) System. The arrangement of TES and TRS getters was modified to simplify maintenance operations.

3. Thermo-hydraulic and thermo-mechanical analysis

The thermo-hydraulic and thermo-mechanical analyses were carried out for the seven HCLL and HCPB TBM ancillary systems, considering the updated operational conditions and the new sizing/dimensions of pipes and components.

3.1. Thermo-hydraulic analyses

For all the seven ancillary systems, the steady state temperatures in the relevant regions have been determined, considering the updated operational conditions (NOS/TOS case conditions) and the new sizing/dimensions.
Algorithms and tools used for such analysis have been adequate to achieve a reliable and accurate temperature field. The pressure drops of the systems have been determined in nominal conditions as well as pressure drop contribution due to the connection pipes has been taken into account in the global assessment.
Compliance between the results of the pressure drop calculation and the available head provided by the pumping systems have been verified. When the compliance verification has given negative results, suitable design modifications have been implemented to solve the issue.
A RELAP5 model was developed for the HCLL/HCPB HCSs and HCLL lithium-lead loop. In particular, the HCS model presented in [6] was improved, considering the simultaneous operation of two compressors in parallel. Temperature and pressure fields were determined in transient and steady state conditions.
The total pressure drop and operative conditions of the different subsystems are summarized in tab. 2.

Subsystem	Flow rate (kg/s)	Maximum pressure (MPa)	Total pressure drop (bar)
HCLL/HCPB HCS	1.3	8.32	13.40
HCLL/HCPB CPS	0.03	7.38	9.00
HCLL LL loop	0.29	0.78	4.80
HCLL TRS	1.24e-5	0.3	1.10
HCPB TES	0.00149	0.3	1.57

Tab.2: pressure drops in the different subsystems

3.2. Thermo-mechanical analysis

The stress analyses have been carried out considering the Plasma/Normal Operation Scenario (POS/NOS) and the Tritium Outgassing State (TOS) foreseen for the ITER TBM.
The level of maturity of these analyses is adequate to an "advanced" conceptual design stage. From this

preliminary stage, it can be stated that no particular critical points have been detected in any of the areas touched by the analysis studies.

Piping stress analysis have been performed according to ASME III Subsection NC for Class 2 components, with the pipe stress analysis software Rohr 2 rev. 32.1. The following loads have been taken into consideration for the different load cases.

Load Case	Axial thermal expansion	Axial expansion due to oper. Press.	Acceleration due to gravity	Friction	Forces due to internal pressure
Dead load			x		x
POS NOS	x	x	x	x	x
TOS	x	x	x	x	x

Tab 3: Load cases for the stress analysis

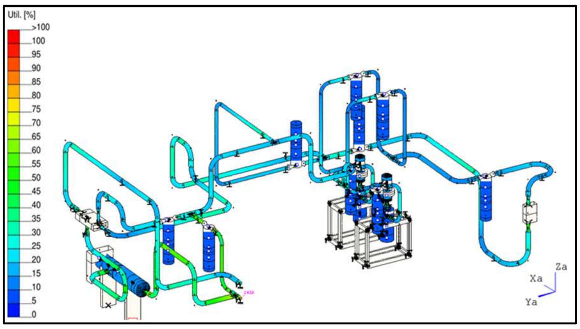

Fig. 8: HCPB HCS utilization factor (TOS) – TCWS area

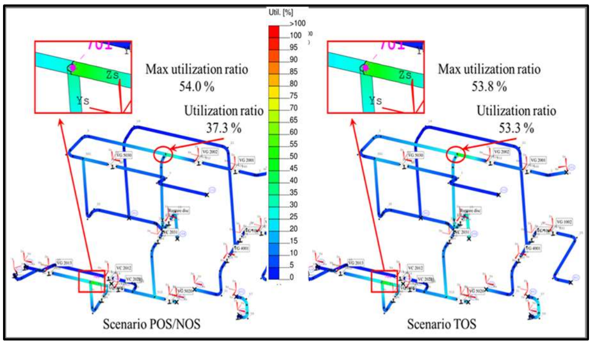

Fig. 9: lead lithium loop utilization factor

In figs 8 and 9 the utilization factors for HCPB HCS in TCWS area and lead lithium loop in PC#16 are depicted. Values are well below the limits.

Similar results have been obtained for the other subsystems. The lead lithium loop storage tank, critical component from the point of view of safety demonstration, was analyzed using Ansys package ver.15.0 for the operational pressure of 0.75 MPa and considering the operational temperature of 300 °C. In figure 10 are shown the equivalent Von Mises stresses and the total deformation, values increasing passing from blue color to red one. Also in this case there is coherence with standards.

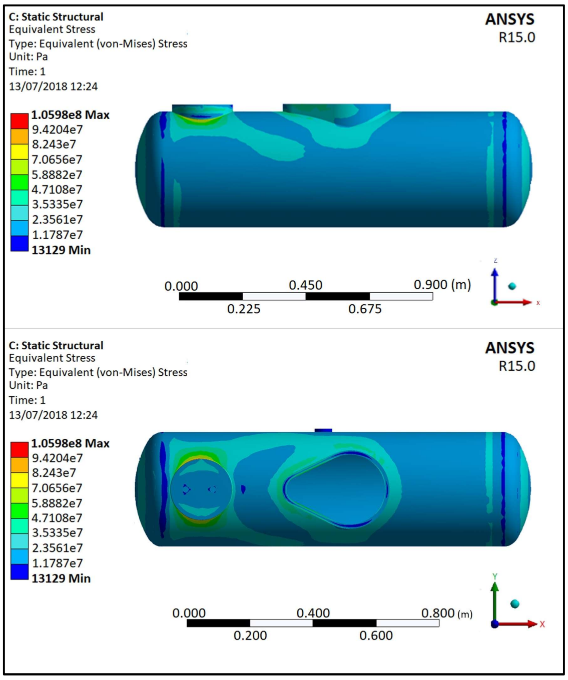

Figure 10: Lead lithium storage tank analysis. Up: side view; down: top view.

4. Conclusion

The conceptual design of the HCLL and HCPB-TBS ancillary systems was updated taking in consideration outcomes and requirements from the ITER CDR. Both CPSs were redesigned to fulfill tritium concentration requirements, while the integration of subsystems in the different areas was updated to improve maintainability and accessibility of critical components. The TAS design was simplified and the integration in Tritium Process Room completed. Some open issues are still present but they will be solved consolidating the design through the further step of preliminary design.

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5. References

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