Status of the ITER Cryodistribution

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Abstract. Since the conceptual design of the ITER Cryodistribution many modifications have been applied due to both system optimization and improved knowledge of the clients’ requirements. Process optimizations in the Cryoplant resulted in component simplifications whereas increased heat load in some of the superconducting magnet systems required more complicated process configuration but also the removal of a cold box was possible due to component arrangement standardization. Another cold box, planned for redundancy, has been removed due to the Tokamak in-Cryostat piping layout modification. In this proceeding we will summarize the present design status and component configuration of the ITER Cryodistribution with all changes implemented which aim at process optimization and simplification as well as operational reliability, stability and flexibility.

1. Introduction

The Cryodistribution (CD) presently consists of seven cold boxes; namely one Cryoplant Termination Cold Box (CTCB), five Auxiliary Cold Boxes (ACBs) and one Thermal Shield Cold Valve Box (TCVB). They distribute the cooling power generated in the Cryoplant to the clients at proper conditions to sustain the Tokamak plasma experiments. The Cryoplant itself is made up of three identical liquid helium (LHe) plants, two identical 80 K gaseous helium (GHe) loops, one LHe tank and two identical liquid nitrogen (LN2) plants including a huge gas management system as described elsewhere [1].

As shown in figure 1, the CTCB directly collects the cryogens from the LHe plants and 80 K loops to distribute them to the ACBs and TCVB. The LHe tank is used as an intermediate 4.5-K-cooling-power storage to manage the parallel operation of the three LHe plants [2] with respect to the dynamic load variation of the superconducting (SC) magnet system where at some instances the heat generated requires a cooling power higher than the average value of the total LHe plant capacity.

Each ACB is exclusively in charge of a client sub-system. ACB-1/2/3/4 are respectively dedicated to the Central Solenoid coils (CS), the Toroidal Field coils (TF), the magnet Structures (ST) and the
Poloidal Field & Correction Coils (PF&CC), which make up the SC magnet system (including their high-temperature-superconductor current leads) whereas ACB-5 is allocated to the Cryopump (CP) system.

By using the cryogens from the CTCB, in the ACBs, the conditions for forced convection cooling are prepared. A cold circulator (CCL) pressurizes the supercritical helium (SHe) which is then cooled via a heat exchanger (HX) connected to a LHe phase separator (PS). The vapor pressure (and therefore temperature) of the PS is regulated with a cold compressor (CCP) [3]. The distribution of mass flow within each client’s sub-system or the regeneration procedure of the CPs is managed by the Coil Termination Boxes (CTBs) or the Cold Valve Boxes (CVBs). From the viewpoint of the ITER project Plant Breakdown Structure (PBS), such CTBs and CVBs do not belong to the Cryogenic System but are part of each client’s PBS.

The increase of nuclear heat load during the plasma experiments in some of the SC magnet sub-systems required the ACBs to be modified for more flexible and economical operation from the cooling power point of view [4]. Even though it resulted in a more complicated internal arrangement with additional components, the existing Cold Compressor Box (CCB) [3, 5] could be removed which allowed the standardization of the ACB component configuration.

Compared to other CD cold boxes, the TCVB is the only one directly connected to its client; namely the in-Cryostat Thermal Shield (TS). Due to complexity and feasibility of installation of various in-Cryostat components, it was decided on the ITER project level to remove one of the two redundantly operating TS cooling-channel-manifold groups. Such a decision resulted in the single TCVB compared to earlier design configuration [3].

Figure 1. Schematic overview of the ITER Cryogenic System (Cryoplant, Cryolines, Cryodistribution) and its clients (in-Cryostat TS, SC magnet system, CP).

2. Status of the Cryoplant Termination Cold Box
In figure 2 the internal configuration of the CTCB as per the manufacturing design is shown. Most of the valves are for the (dis)connection with interfacing systems (Cryoplant sub-systems, ACBs/TCVB) and are therefore fully open or closed without active control during operation. Such (dis)connections are managed by the Cryogenic System Master Controller (MC) and not the CTCB control system. Apart from the process and safety interlocks, process controls to be managed by the CTCB are described in the following paragraphs.

Modifications compared to earlier design [3] mainly resulted from simplifications of pressure control within the LHe plants during parallel operation [2]. Instead of individual control inside each LHe plant, the pressure of the line H and C, downstream from the first and last (forth) expansion turbine (T1 and T4), respectively, are managed by the CTCB control system. As described in [2], all SHe flows downstream T4 of each LHe plant are collected in the CTCB line C manifold and then expanded into the LHe tank via valve V C0 (or VC9), while keeping the pressure close to 5 bar. The same is applicable for the line H common pressure control downstream T1 of each LHe plant using VH0. In case only one LHe plant has to be operated and connection to the ACBs is not allowed (e.g.: liquefaction of GHe into LHe tank for inventory storage during Tokamak maintenance) the line C pressure can be adjusted by one of the valves V CN (N=1–3).

During the warm-up of the Tokamak, the SC magnet system (total mass of ~10,000 tons) acts as a cold sink. To prevent excess thermal imbalance of the HX’s inside the LHe plants (i.e. keep ΔT CD, the

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**Figure 2.** Internal component configuration of CTCB.
temperature difference of the LHe plant cold end below 20 K), \( V_C \) in closed, \( V_C'\)/\( V_C''/V_{CC} \) opened and the heaters are operated to warm-up the helium supplied to the magnets. While the heaters are in operation another criteria, which is to keep the temperature difference between the supply and return helium (\( \Delta T_{CD} \)) below 50 K, is also taken into account. When the heater power is at maximum and \( \Delta T_{CD} \) close to its limit value, \( V_{CD} \) can be opened to decrease \( \Delta T_{CD} \).

The TS temperature of the LHe-plant/tank-interfacing Cryolines and the CTCB itself is controlled by maintaining the temperature difference between the supply and return GHe within about 20 K by controlling the valves \( V_{FN} \) (\( N=0–4 \)). Such a control is applicable for all TS systems during all operation modes including the cool-down and warm-up process.

The Coriolis flow meter with a valve upstream and heater/temperature-sensor downstream will be used for the acceptance plan and performance measurement of the ITER Cryoline system as described in [6].

3. Optimizations of the Auxiliary Cold Box configuration

Due to the additional nuclear load (ANL) during the Deuterium-Tritium plasma phase, the necessary average cooling power to maintain the thermal stability of the SC magnet system can be beyond the presently contracted and manufactured specification of the Cryoplant (LHe and LN\(_2\) plants). As explained in [4], in order to allocate more cooling power to the magnet system, an arrangement with its own CCP (allowing to remove the CCB) and double PS configuration (instead of single PS in [3]) has been selected for all ACBs. A typical internal component configuration is shown in figure 3 for ACB-4 (PF&CC). Due to such modification, apart from component sizing, the internal component configuration of all five ACBs could be standardized except some differences explained in the next paragraph.

![Diagram](image)

**Figure 3.** Internal component configuration of ACB-4 (PF&CC).

Compared to ACB-4 (PF&CC), in case of other magnet ACBs (1/2/3 for CS/TF/ST), valve \( V_{HX1} \) and piping branch \( \textcircled{3} \) do not exist. Furthermore, for ACB-3 (ST), line CD/CC piping in branch \( \textcircled{1}/\textcircled{2} \), respectively, and the whole line H pipework are out of scope. In ACB-5 for the CP system shown in
figure 4, valves $V_{HX1}/V_{D2}$ are not necessary and instead of line H, line C is installed as required for the CP regeneration process. The pipework with $V_{CR1}/V_{CR2}$ is for the recovery of SHe (<6 K) into PS1 during CP regeneration.

For the sake of standardization, the design points of all five CCPs have been chosen at a vapor pressure temperature of 3.7 K (to cope with ANL) for PS2 with the possibility up to 4.2 K (case without ANL). In case of ACB-5 (CP), the 3.7 K operation will enhance the pumping capacity during the plasma experiments. However, due to the big difference in compression ratio (2.4 for 3.7 K and 1.4 for 4.2 K), for off-design operation, additional mass flow feeding to prevent the CCP from surging may be necessary.

![Figure 4. Internal component configuration of ACB-5 (CP).](image)

3.1. Standardization of components

With the standardization of the ACB internal configuration the following components also have been standardized:

i) Outer vacuum jacket (OVJ) and TS of the ACBs: Same physical dimension (with different nozzle configuration);

ii) PS1/PS2 and HX1/HX2/HX3: Same physical dimensions and specifications for all ACBs as illustrated in figure 5(a);

iii) CCL: Same type for all five except different cold casing and impeller for ACB-3 (ST) [7] as shown in the compressor maps of figure 5(b) and (c);

iv) CCP: Same warm part for all five, for cold parts (cold casing and impeller) three different types each for ACB-1/4 (CS/PF&CC), ACB-2/3 (TF/ST) and ACB-5 (CP).

3.2. Process control

As with the CTCB, valves in ACBs for the (dis)connection with interfacing systems (CTCB, client cold boxes) are managed by the MC. The ACB control system has to manage the automatic switching (when requested by the MC) among the various operation modes as described in [3] by manipulating valve openings and operating the cold rotating machines (CRMs). Active process controls to be managed by the ACB control system are:

i) Keep the LHe level of PS1/PS2 within acceptable range using $V_{JT1}/V_{JT2}$, respectively;
ii) Rotational speed control of CCP to maintain the vapor pressure of PS2 within allowed range;

iii) Surge protection of CCP using $V_{S1}$ for warm mass flow feed and $V_{S2}/V_{S3}$ for cold mass flow feed ($V_{S0}$, which is too large for fine flow control required for surge protection, is used for full flow by-pass when the CCP is not operating);

iv) Surge protection of CCL (operated at constant rotational speed) by using $V_{bp}$ as described in [8, 9] (opening of $V_{bp}$ is mechanically locked at minimum and maximum stroke to keep valve process part always cold and prevent CCL from crossing the choke line, respectively);

v) As in case of CTCB, maintain the temperature difference between the supply and return GHe of the TS’s within about 20 K by controlling the valves $V_{FN}$ ($N=0–2$);

vi) In case of ACB-4, since it is foreseen that the SHe temperature upstream from HX1 can be lower than the LHe temperature in PS1, to prevent cooling of LHe in PS1 (where LHe shall be evaporated for heat exchange), HX1 is by-passed by opening $V_{HX1}$ and closing $V_{CCLin}$.

Figure 5: (a) Standardized internal components of an ACB. Compressor map of CCLs in (b) ACB-1/2/4/5 (for CS/TF/PF&CC/CP) and (c) ACB-3 (for ST).

4. Status of the Thermal Shield Cold Valve Box

In the original configuration of the TCVB [3], two cold boxes were operated in redundancy. However, one of the two cooling-channel-manifold groups of the in-Cryostat TS had to be removed (still cooling channels welded on the TS panels are redundant) due to the complex interference with the Tokamak cooling water pipes. Such a modification resulted in the internal component configuration and 3D layout of the TCVB as shown in figure 6 which is still in the final design phase.

Figure 6. (a) Internal component configuration and (b) preliminary 3D layout of TCVB.
5. Conclusion
The ITER CD has been optimized with respect to its interfacing system process as well as clients’ requirement changes. As an in-kind contribution from the Indian Domestic Agency to the ITER project, the CD is in the final design (ACBs/TCVB) and manufacturing (CTCB) phase at Linde Kryotechnik. One CCL (for TF) was manufactured by IHI and tested at Naka Fusion Institute [7], and other CCLs are in the manufacturing phase.

The on-site delivery starts with the CTCB on May 2018 to match the commissioning of the three LHe plants’ parallel operation. ACBs and TCVB will be delivered until late 2020, installed and commissioned to be ready for the ITER first plasma in 2025.

Disclaimer
The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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