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ITER LHe plants parallel operation

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Abstract

The ITER Cryogenic System includes three identical liquid helium (LHe) plants, with a total average cooling capacity equivalent to 75 kW at 4.5 K. The LHe plants provide the 4.5 K cooling power to the magnets and cryopumps. They are designed to operate in parallel and to handle heavy load variations. In this proceeding we will describe the present status of the ITER LHe plants with emphasis on i) the project schedule, ii) the plants characteristics/layout and iii) the basic principles and control strategies for a stable operation of the three LHe plants in parallel.

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Introduction

The ITER Cryogenic System provides the cryogenics fluid required for the operation of the ITER Tokamak. The two main users are the superconducting magnet system, which generates the magnetic fields required to confine and control the plasma, and the cryopumps to maintain an appropriate vacuum in the Tokamak vacuum vessel and cryostat. As part of the ITER Cryogenic System, the LHe plants supply the 50 K and 4.5 K helium. The LHe plants themselves consist of three identical liquid nitrogen (LN_2) pre-cooled helium refrigerators. The LHe plants are

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provided with LN_2 from the ITER LN_2 plants. The cold ends of these three LHe plants are connected to the so-called Cryoplant Termination Cold Box (CTCB), where the cold streams from the plants are collected and distributed to the clients (magnets and cryopumps).

1. Project schedule

The contract for the three LHe plants was awarded by ITER Organization to Air Liquide Advanced Technologies in December 2012. The project is expected to last for a total of six years, and completion of the tests is expected by December 2018.

The project is divided in the following distinct phases: design, procurement, assembly, installation and commissioning. As shown in Fig. 1, these phases are organized and linked via three main project milestones: preliminary design completion allows beginning of procurement; final design completion allows beginning of assembly; and completion of installation allows beginning of commissioning.

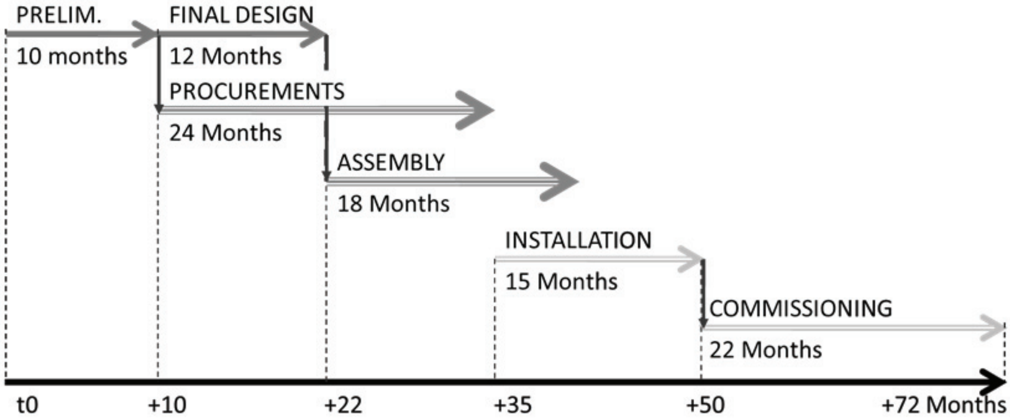

Fig. 1.Expected schedule of the project.

The LHe plants project itself is aligned with the overall ITER project schedule, which is under continuous monitoring. The on-time availability of the buildings and utilities (electricity, cooling water, instrument air, LN_2) is required to ensure the on-time completion of the project.

2. Layout

The ITER Cryogenic System consists of two main subsystems: the Cryoplant, where cooling power is produced and the Cryodistribution which distributes the cooling power to the numerous clients. The ITER Cryoplant, which includes the LN_2 plants and LHe plants, consists of one of the largest clusters of cryogenic equipment in the world. The infrastructure (road, access, buildings) required to install and accommodate the Cryoplant are a significant part of the project.

The Cryoplant will be installed in a dedicated area, and requires a tailor-made building of 120 m × 45 m. The building has to support heavy machinery with individual foundation. It will house 35 MW of electrical motors coupled to compressors and has to cope with noise insulation and HVAC (Heat Ventilation and Air Conditioning) needs.

The three LHe plants themselves almost cover the size of a soccer field as shown in Fig. 2. Each compressor station has a foot print of 33 m × 11 m, and each cold box requires 20 m × 10 m of area.

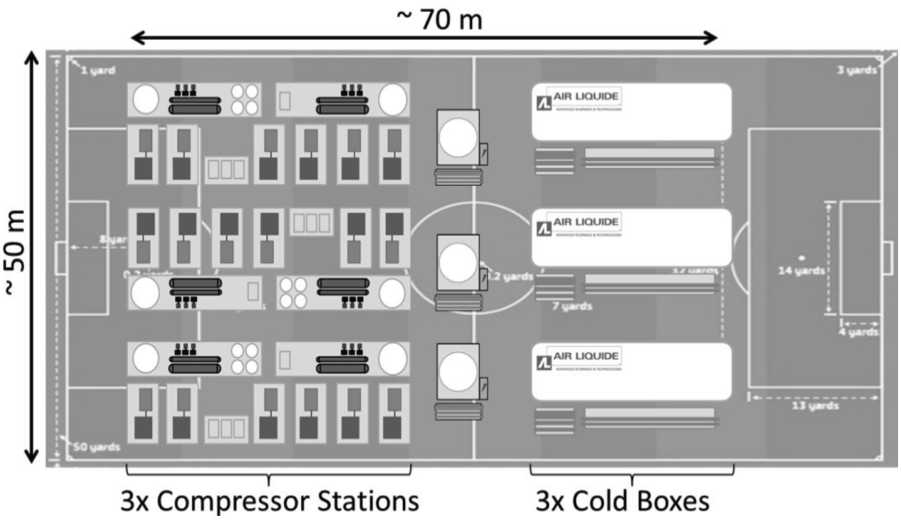

Fig. 2. Layout of the three LHe plants.

Individual components also have considerable dimensions. Each cold box is 21 m long, and 4.2 m in diameter, with a weight of roughly 140 tons. Each compressor requires individual concrete foundation with a height of 3.6 m and a footprint of 6.0 m × 3.4 m.

It was necessary to confirm all dimensions during the preliminary design phase to allow adequate and on-time completion of the building.

3. LHe plants characteristics

3.1. Overall characteristics

The LHe plants produce each, in average, 25 kW (75 kW total) of equivalent refrigeration power at 4.5 K, which ranks among the most powerful LHe refrigerators in the world as compared in Fig. 3. The LHe plants are designed to handle pulsed loads corresponding to the Tokamak operation which vary between 40 kW and 110 kW over 30 minutes.

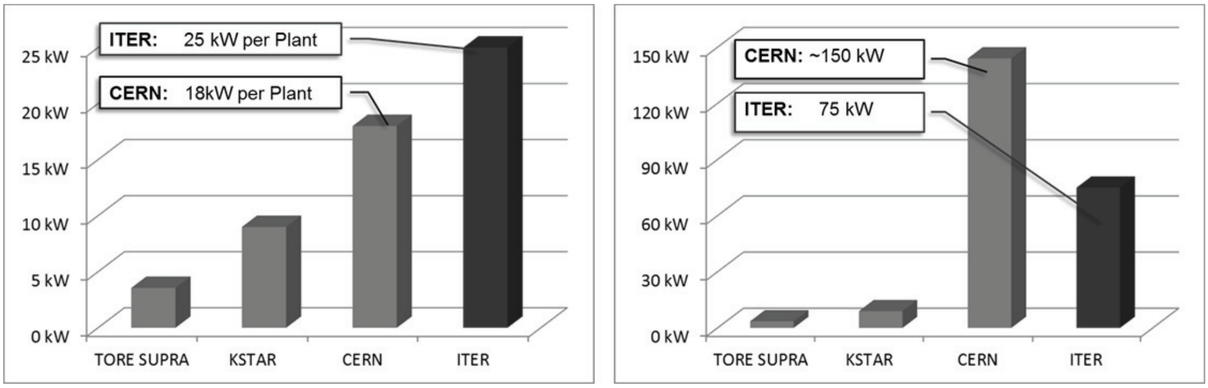

Fig. 3. Individual and total LHe plants power.

The LHe plants require a total of 23.4 MW of electrical power, 85,000 Liters of LN_2 per day and 510 kg/s (1,800 m^3/h) of cooling water with an allowed temperature rise of 11 K. These numbers have been consolidated and confirmed during the preliminary design phase, in order to allow adequate design, and timely availability of the electrical network, LN_2 plants and of the cooling water system.

With 23.4 MW of electrical power injected to the compressor stations and the corresponding heat to be removed by cooling water, recycling of the compression heat has been considered. Consequently, a heat recovery system connected to the ITER building heating network is included in the compressor station. Up to 12 MW of heat can be recovered to cover the ITER heating needs, the remaining heat of compression being removed by the conventional water cooling system.

3.2. Compressor stations characteristics

Each compressor station (for one LHe plant) is designed with six MYCOM 400 screw compressors as summarized in Table 1. The low pressure (LP) stage, which processes a large volumetric flow, requires four large (L-type) 400 compressors. The high pressure (HP) stage, which processes a much smaller volume, requires only two smaller (S-type) 400 compressors.

Table 1. Compressor station characteristics

Per compressor station	Compressors	Total flow	Motor power	Consumed power	Pressure
LP Stage	4 × 400L*	1,600 g/s	1,100 kW	820 kW	1 → 5 bara
HP Stage	2 × 400S	2,200 g/s	2,500 kW	2,130 kW	5 → 22 bara

Note: one LP compressor is equipped with a Variable Frequency Drive (VFD) and operates at 60 Hz while all other compressors operate at 50 Hz. Data provided are given for compressor operated at 50 Hz.*

The compressor station including the compressors are designed based on the heavy duty oil and gas standard EN-10440. This standard values robustness over efficiency and ensure reliable long term operation as required for the operation of the ITER Tokamak. However, since it requires hydrodynamic bearing technology, which imposes higher clearances and more brake power, impacts on the volumetric efficiency and required drive power cannot be avoided. This leads to an overall efficiency loss of about 10%.

3.3. Cold boxes characteristics

The LHe plant cold boxes are LN_2 pre-cooled and are each equipped with four Air Liquide TC-4 and 5 standard static gas bearing turbo-expanders as summarized in Table 2.

Table 2. Cold boxes characteristics.

Per cold box	Type	Efficiency	Flow	Power	Pressure
LN_2	-	-	800 g/s	110 kW	-
Turbine 1	TC-4	77 %	115 g/s	15 kW	20 → 5 bara
Turbine 2	TC-4	77 %	170 g/s	13 kW	20 → 5 bara
Turbine 3	TC-4	77 %	230 g/s	11 kW	20 → 5 bara
Turbine 4	TC-5	74 %	1,300 g/s	11 kW	20 → 5 bara

4. LHe plants process and parallel operation

4.1. Pulsed loads

The LHe plants have to cope with the pulsed operation of the Tokamak. They are designed to handle load variations between 40 kW and 110 kW (~65% loads variations) during one plasma shot period (30 minutes). During this large variation, the LHe plants are maintained at full capacity. When, the capacity exceeds the clients' needs, the excess cooling power is converted into LHe and sent to the 175 m^3 LHe tank.

On the opposite, during the clients' peak loads when the LHe plants lack capacity, LHe is withdrawn from the tank for cooling power boosting. Eventually, the LHe accumulated will be exactly withdrawn, and the average LHe tank level remains constant over time. The expected fluctuation within the 175 m^3 LHe tank is expected to be about 1.2 m^3, i.e. less than 1% (the main function of the LHe tank is the helium inventory storage during the ITER down time). The cooling power of the LHe plants will be adjusted over several runs to avoid over accumulation of LHe.

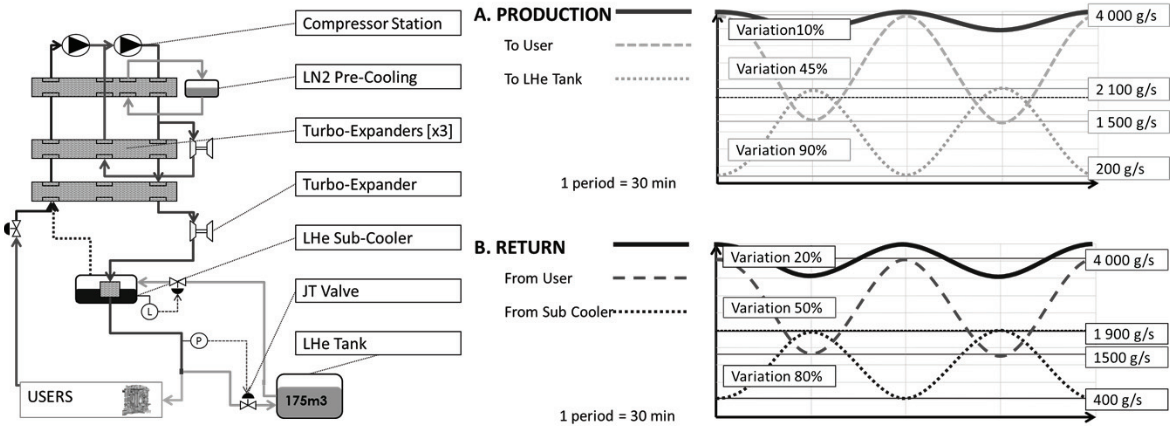

Fig. 4. LHe plants operation philosophy (flow given for total of the three LHe plants).

While the user loads fluctuation can reach 65%, the LHe plants shall remain stable and balanced. To stabilize production, the excess power is turned into liquefaction; this strategy allows maintaining the production flow within 10% variations (refer to Fig. 4 A).

While the production flow is stabilized, the clients' return fluctuation can reach 50%, which could significantly unbalance the LHe plants. However, the full production is fed to the LHe sub-cooler (refer to Fig. 4) and in the case the temperature upstream the sub-cooler rises, more vapor is produced. Eventually, the sum of the clients' return flow and of the vapor produced in the sub-cooler, which is returned to the LHe plants heat exchanger LP line, remains within a 20% variations range (refer to Fig. 4 B).

As a result, while the LHe plants are connected to loads with variations up to 65%, the flow within the LHe plants is stabilized and remains within a 20% variations range.

4.2. Parallel operation

The cold ends of the three LHe plants are connected to the CTCB where the cold streams from the plants are collected and distributed to the clients (magnets and cryopumps) as requested.

The operation of the three LHe plants in parallel is based on two main control loops (refer to Fig. 5):

- pressure control in the clients' supply header;
- level control in the sub-coolers of the LHe plants.

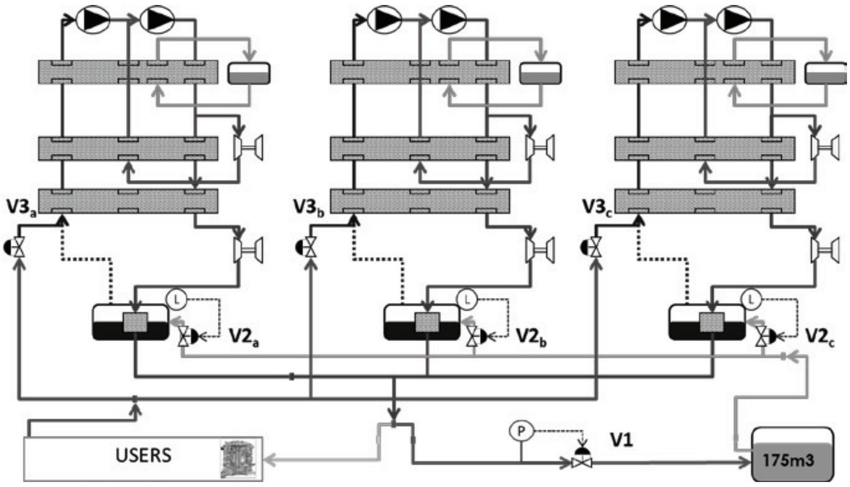

Fig. 5. LHe plants parallel operation.

The pressure control in the clients' supply header allows redirecting the excess production to the LHe tank. As the flow required by the clients decreases, the pressure in the common header increases, the valve V1 opens and diverts the flow to the LHe tank. This control is achieved inside the CTCB, and is common to the three LHe plants. Each plant operates at in full load mode.

The level control "L" in the sub-cooler of the LHe plants is individual. Each plant drains all it needs to operate using V2. In consequence, if one of the LHe plants is less performing (partial failure), it is possible to drain more from the LHe tank than it produces. If the excess of consumption of the clients cannot be compensated by the two other plants, operation can be sustained as long as the level in the LHe tank is sufficient.

The redistribution of the clients' return flow throughout the three LHe plants shall also be addressed. When the three LHe plants operate under similar conditions (same performances: compressors, turbines, heat exchangers), the flow will be evenly distributed, and no action is required. The pressure head across the heat exchangers is common to the three LHe plants, which results in natural equal flow sharing.

However, in the case of a partial failure of one plant, as shown in Fig. 6, the partially failed LHe plant does not require the same amount of return flow to maintain adequate mass and power balance. The parameter selected for return flow distribution is the LHe plant temperature gradient: this gradient shall be maintained similar throughout the three LHe plants, and the flow to the coldest LHe plant will be throttled using V3.

The compressor stations of the three LHe plants are interconnected, which simplifies the mass balance between the plants, especially in the event of a partial failure. This also reduces the impact of a single compressor failure.

Disclaimer

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

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