

Progress Report of the Cryo-Plants for Wendelstein-7X

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Linde Kryotechnik AG is the supplier of cryo-plants for the nuclear fusion test facility Wendelstein-7X at Greifswald in Germany. The scope includes a large refrigerator, a sub-cooling cold box with cold compressors and circulation pumps and a distribution valve box. A first paper on this task has been presented at the ICEC20 conference in Beijing [4].

In the meantime the corresponding hardware is installed and the commissioning will start soon. The paper gives an overview on the special features of the process, the dedicated equipment and the extensive control system.

INTRODUCTION

Wendelstein 7-X will be the largest and advanced Stellarator experiment worldwide. It is currently being constructed at the Greifswald Institute of the Max Planck Institute for Plasma Physics (IPP) in Germany.

The particular feature of the W7-X Stellarators is that the magnetic coils, which generate the confinement field for the plasma, in their majority are not level but have a very complicated geometry. Due to this geometry the basically ring-shaped plasma becomes twisted with a varying cross section. Configuration of coils as in the Tokamak solutions and especially the transformer coils with their transient magnetic field are not required. Therefore, the Stellarator principle enables a favorable continuous operation of the fusion process.

Just like ITER, KSTAR and all the ongoing other fusion test reactors, Wendelstein 7-X will not yet produce energy-generating fusion plasma but will provide important conclusions regarding the power plant characteristics of Stellarators. It is designed to demonstrate that this type of facility is suitable as a power plant. The core element of the facility is a coil system of seventy superconducting magnetic coils which contain the basically ring-shaped plasma.

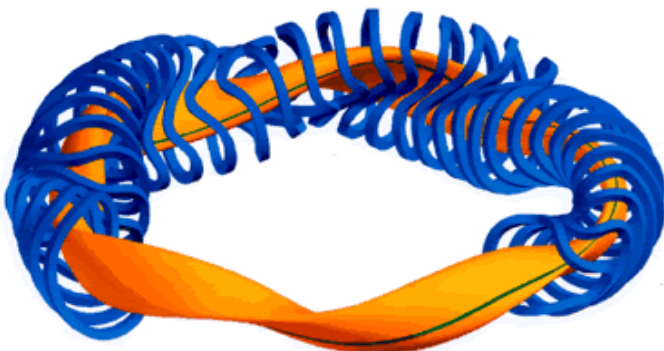


Figure 1: The basically ring-shaped plasma area (yellow) of a stellarator is enclosed in a complicated system of non-planar magnet coils (blue).

Linde Kryotechnik AG's contribution started with a technical feasibility study for the cryogenic system in 1997. Five years later, in 2002 the procurement by tender with final specification concluded and at the end of 2003 Linde Kryotechnik AG received the order for the compressor system, the refrigerator and the cryogenic distribution system with 6 different refrigeration consumers. Four years of engineering, construction and installation followed, and now for a few weeks the commissioning has been going on.

CAPACITY AND DESIGN CRITERIA

The refrigerator for Wendelstein 7-X performs an exergetic equivalent refrigeration capacity of roughly 7 kW at 4.5K, which is a mid range performance. Other existing and projected refrigerators worldwide perform capacities up to 20 kW. Likewise the lowest temperatures are modest. The lowest bath temperature in the system is 3.3 K, the lowest guaranteed temperature of supercritical flows is 3.4 K. Even so, this refrigeration system shows some interesting particularities. These are

- a) the high exergetic efficiency in a wide capacity range.
- b) the considerable load variation between standby operation and the operation during experiments
- c) the distribution system for the six different consumers which are the coils, the coil housings and coil support structures, the cryo-vacuum pumps, the current leads, the W7-X cryostat heat radiation shield, and the shield of the cryo vacuum pumps (CVPs).
- d) the striking automation level.

Table 1: Technical data sheet of the refrigerator for W7X

Warm Screw compressors	2
Expansion Turbines	7
Cold Circulators	4
Cold Compressors	2
Pneumatic cold control valves	77
Pneumatic warm control valves	29
Pneumatic warm On/Off valves	60
Temperature Sensors	157
Pressure Sensors	130
Pressure Difference Sensors	24
Flow measurements	37
PI-controllers	94

Table 1 gives a short overview on the number of equipment like machinery, valves and instruments which are part of this system.

Experts believe that there might be some very interesting discoveries and observations to be made with this plant.

PARTICULAR SOLUTIONS

Process Arrangement

As indicated in table 1, the refrigeration process is equipped with seven expansion turbines. They are arranged in five strings according to the schematic entropy-temperature-diagram in figure 2. Exceptional is, that only during cool down operation these turbines are operating at the same time. During the experimental modes, the turbines Tu1 and Tu2 are off and the total available compressor flow is expanded in the turbines Tu3 to Tu7. The necessary refrigeration capacity in the upper heat exchangers, during this time, is performed either by the supply of liquid nitrogen or, for peak power capacity, by warming up a helium gas flow which is supplied as a make-up flow from the dewar to the cold end heat exchangers. The contrary happens during standby operation, when the refrigeration requirement at the cold end is reduced. During this time the turbine Tu6 is off and turbines Tu1 and Tu2 are running again. This allows a re-liquefaction of gas from the tanks to the dewar as well as a constant temperature of the cold-box' internal adsorber units at 80K.

Purification-System

The W7X-refrigerator is designed for long time operation. This is why the importance of a perfect purification system for helium has been emphasized in the specification. A first double bed adsorption unit for moisture is installed in the helium stream between the oil removal system and the coldbox. Also, there are switchable double bed adsorber units at 80 K and a single bed adsorber near 20 K. The operation and the regeneration of all these adsorber units are automatic. During operation, the bed temperatures are actively kept constant. Even during warm-up operation of the W7X cryostat, the 80 K-Adsorbers are kept cold by the refrigeration capacity of the turbines Tu1 and Tu2. This allows

the unit to purify the helium mainstream from impurities which are released by the cryostat during this period. The regeneration process of all the adsorber beds is released by impurity detectors.

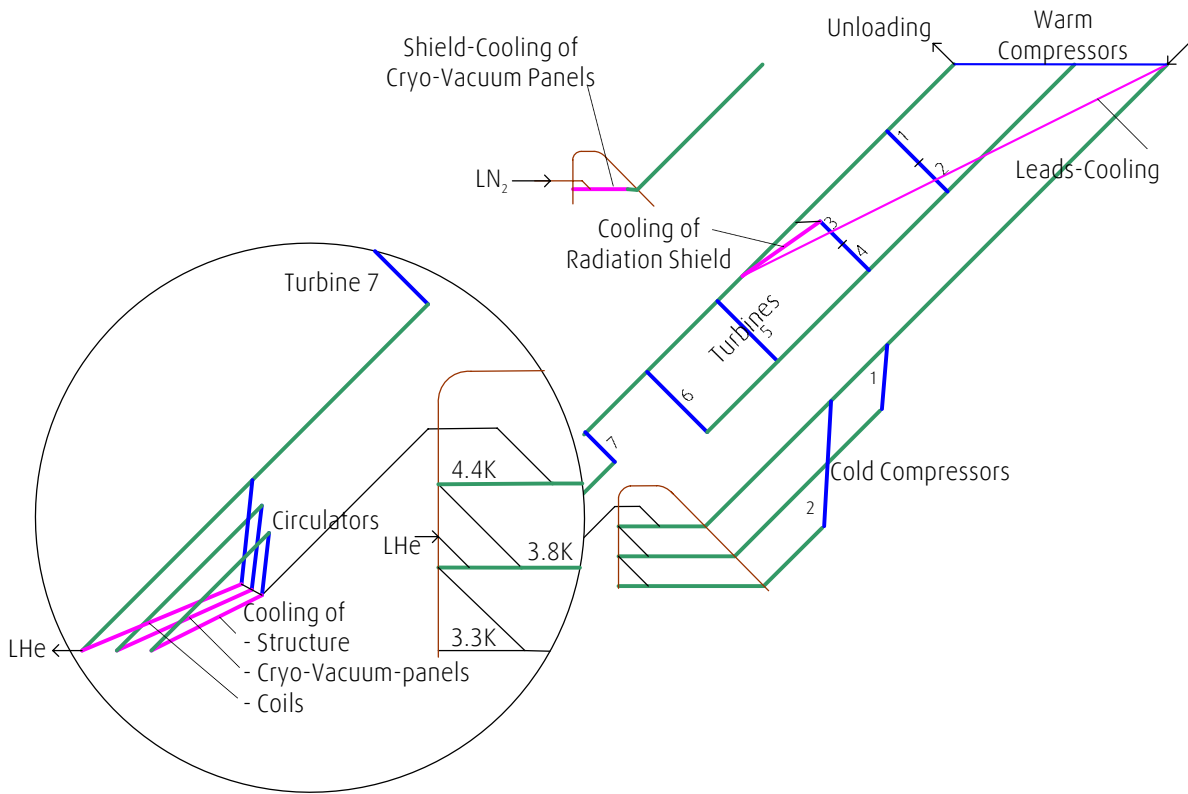


Figure 2: Schematic Entropy-Temperature Diagram of the W7X-refrigeration process

The Cold End Arrangement

Special attention is paid to the sub-cooling and distribution system. Forced flows of supercritical helium are used for the refrigeration of the magnet coils, the housings, the support structures and the cryo-vacuum. During standby operation as well as during the cool-down and warm-up of the cryostat, these flows are in the range of 200 g/s and are provided as parts of the main compressor flow at temperatures above 5 K. During experimental modes and mainly during the so called Peak-Power mode, the total of these flows can be increased to 1500 g/s and the supply temperature is adjustable down to 3.4 K. The exceptional detail about the applied solution is that the re-cooling of this refrigeration flow is not simply performed by a single heat-exchanger in a helium bath of the lowest temperature level. With the objective of an increased exergetic efficiency, the re-cooling is distributed to three different helium baths at temperature levels of 4.4 K, 3.8 K and 3.3 K. These temperatures correspond to helium bath pressures of 119 kPa, 66.2 kPa and 36.6 kPa whereas the two sub-atmospheric pressures are provided by two centrifugal cold compressor units operating in parallel according to Figure 2.

Automation level

The W7-X cryo-plant is further characterized by its automation. The steady state operation in all the specified modes (Figure 3) as well as the transitional steps between these modes are automatically controlled and do not need further attendance.

The control philosophy in all the modes is that overcapacity of the refrigerator is used for liquefaction. For the compensation of temporary deficiencies in capacity, liquid helium is redrawn from the dewar and warmed up. When this compensation is not possible the capacity of the refrigerator is adjusted by varying the pressure levels and the compressor frequency.

Electrical heaters, which are commonly used for capacity control in other cryogenic applications, are not applied at W7X.

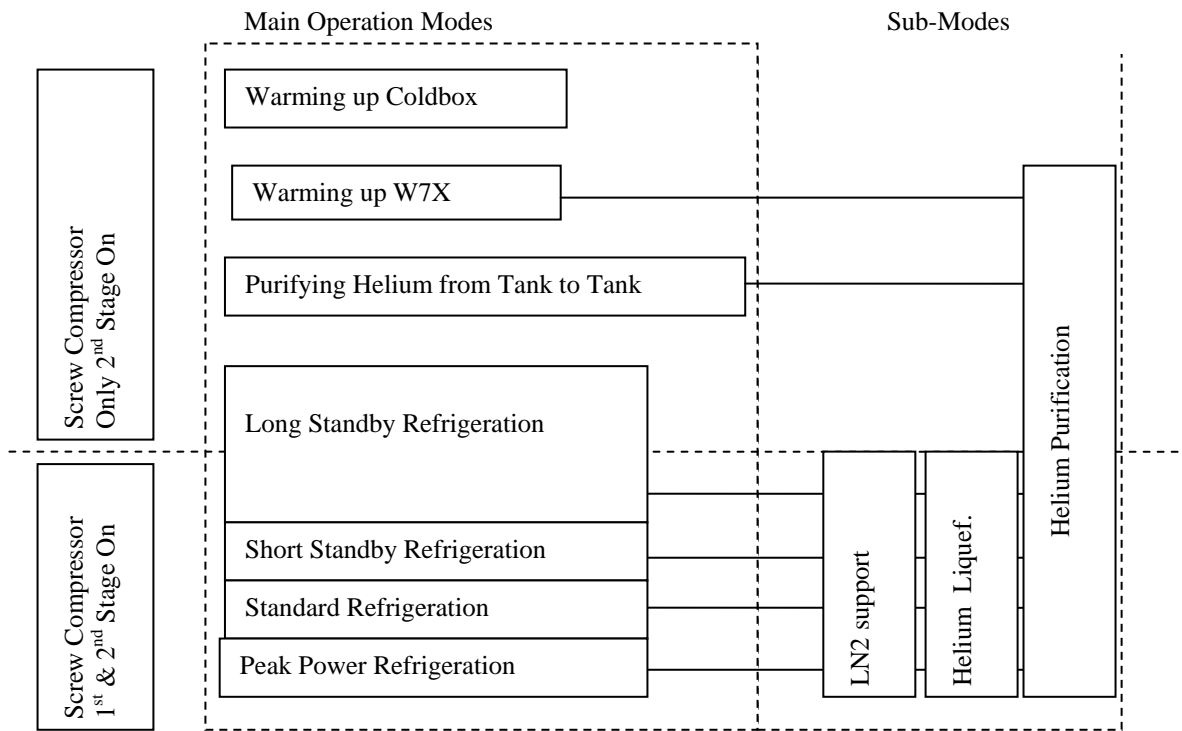


Figure 3: Selectable operating modes of the W7X-refrigerator. By setting an operating mode the running expansion turbines, cold compressors and cold circulators are evaluated. Within the modes the set points of temperatures and flows as well as maximal change rates for temperatures within a limited range can be assigned to the different consumers.

SUMMARY

With the W7X-cryo-plant Linde Kryotechnik AG and the Max Planck Institute for Plasma Physics broke new grounds. Thanks to the cleverly devised combination of the refrigerator and the distribution system as well as the perfectly optimized process control, this unit will save energy and operating costs.

The four year engineering and fabrication period of the W7X cryo-plant is now completed. All equipments is installed and the commissioning will start soon. Acceptance tests are scheduled for spring 2009 and first experiments with refrigerator will be started in 2013. Linde Kryotechnik AG and the Max-Planck-Institute for Plasma Physics will provide further information about our experiences and progress with this project during future conferences.

REFERENCES

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