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First evaluation of cryogenic performance of Wendelstein 7-X cryostat

M. Nagel*, C.P. Dhard, H. Bau, U. Meyer, S. Raatz, T. Rummel, K. Risse, H.-S. Bosch, the W7-X Team

Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

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ABSTRACT

Commissioning [1] and the first operational phase of the stellarator Wendelstein 7-X (W7-X) have been accomplished successfully at the Greifswald branch of the Max-Planck-Institut für Plasma Physik. First helium plasma was achieved on 10th of December 2015 followed by the first hydrogen plasma in February 2016. The plasma is confined by a magnetic field of 2.5 T on the plasma axis created by a superconducting magnet system of 70 coils. The coils are located in a cryostat and protected against thermal radiation by vacuum and a thermal shield. Cooling of the coils and of the shield is provided with a helium refrigerator keeping the magnet system at 4 K and the shield at 70 K.

The paper presents the cooling concept of the thermal shield and the coils with its structures. It describes the results of the first cool down of the cryostat to 4 K and the resulting heat loads at the different temperature levels. The experimental data show that the heat loads are well below the plant capacity allowing safe magnet operation.

1. Introduction

The hot plasma of the stellarator fusion experiment W7-X [1] is confined within a magnetic cage which is generated by a superconducting magnet system consisting of 50 Non Planar Coils (NPC) and 20 Planar Coils (PLC). High Temperature Superconducting Current Leads (CL) connect the cold superconducting bus bars with current feeders at ambient temperature outside the cryostat. The coils and their support structures are cooled with supercritical helium at 3.9 K. The cooling is provided by a helium-refrigerator with an equivalent cooling power of 7 kW at 4.5 K.

Magnet system and cold structures are located inside an evacuated cryostat. 254 ports equipped with supply and return lines and plasma diagnostics pass the insulation vacuum and connect the Outer Vessel (OV) with the inside of the Plasma Vessel (PV). A schematic cross section of the cryostat is shown in Fig. 1.

The cryostat is divided in five modules based on the fivefold symmetry of the magnetic field. The symmetry of the cryostat components is partially realized leading to five similar but not identical modules, divided in two Half Modules (HM) and numbered X0 and X1 (X = 1–5).

2. Description of the thermal insulation

2.1. Design concept

The warm surfaces inside the cryostat are covered with Multi Layer Insulation (MLI) and an actively cooled thermal radiation shield. Redundant cooling pipes made of austenitic steel 316LVM with diameters Ø10 × 1.5 mm and Ø17 × 1.5 mm are attached to the shields using copper braids. They are cooled by a forced flow of gaseous helium. The thermal shield sectors cover the OV, the PV and the port insulation. Within a HM the cooling pipes supply first the OV and then the PV panels. All 10 HM are cooled in parallel. The port shields don't have their own cooling pipes. They are conductively cooled through the OV and PV panels. More details on the basic design of the thermal insulation are given in [2].

2.2. Plasma vessel shield

The thermal shield of one module of the PV is divided into 40 panels. The panels are made of 4.5 mm thick glass fiber epoxy with embedded copper meshes. Each panel is connected to two parallel cooling pipes via copper braids. Fig. 2 shows a CAD-model the PV-shield with cooling pipes and holes for the ports. The positions of the attached temperature sensors are marked.

2.3. Outer vessel shield

The modules of the OV are divided into an upper and a lower half shell. The thermal shields of a half shell are divided into panels

* Corresponding author.
E-mail address: michael.nagel@ipp.mpg.de (M. Nagel).

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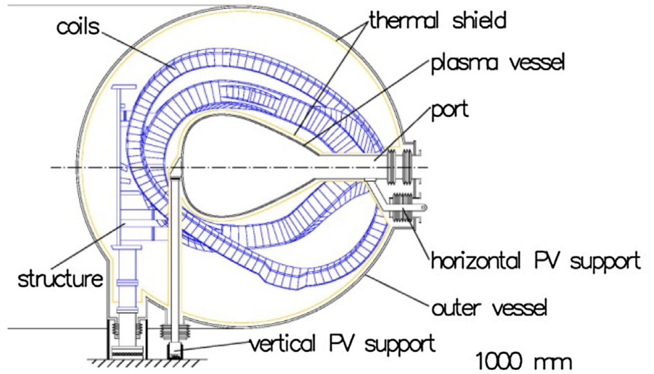

Fig. 1. Cross section of W7-X cryostat showing the plasma vessel, the coils, the cold structure and the thermal shield.

made of rolled brass sheets with a thickness of 3 mm. The cooling loops from the upper and from the lower shell are connected in series. The pipes are connected to the panel with copper strips that are welded to the panels and soldered to the cooling pipes. Fig. 3 shows a CAD-model of the lower shell panels with cooling pipes and holes for the ports. The positions of the temperature sensors are also marked.

2.4. Port insulation

Ports are circular, oval or rectangular tubes with diameters varying between 200 mm and 1000 mm. They run from the OV to the PV inside the cryostat. The port shields cover the ports and are divided in the inner and the outer tube made of brass and copper respectively (see Fig. 4); as the port shields have no cooling pipes, the inner tube is thermally connected to the PV shield, the outer tube to the OV-shield.

2.5. Location of temperature sensors

The thermal shield of a HM is equipped with 5 PT100 temperature sensors on the PV-shield panels, 1 sensor at the inner port shield and two sensors at the OV-panels. Additionally 3 TVO sensors are used to measure the He- temperatures of the shield cooling circuit, inlet and outlet of the OV- shield cooling named CT603, CT601, and the outlet temperature of the PV-shield cooling (CT604).

Three PV-shield sensors of a HM are located on the panel surface not far away from the cooling pipes and represent an ideal design configuration (CT101, CT102, CT105). Two sensors are located close to big port shields and see the thermal loads coming from the port shields (CT102, CT103).

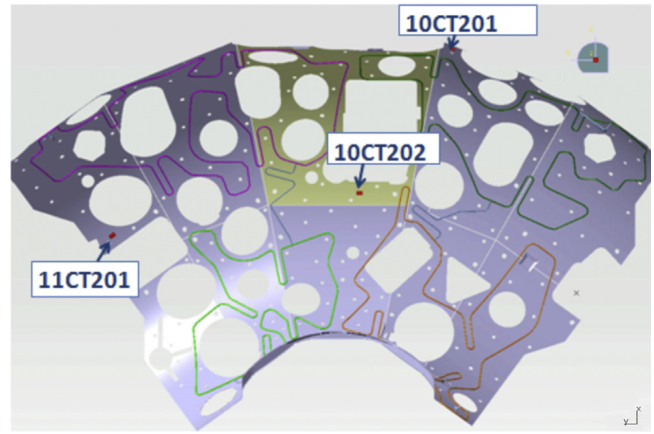

Fig. 3. Lower half shell of OV-shield with cooling pipes. The locations of temperature sensors are marked (11CT201, 10CT201, 10CT202).

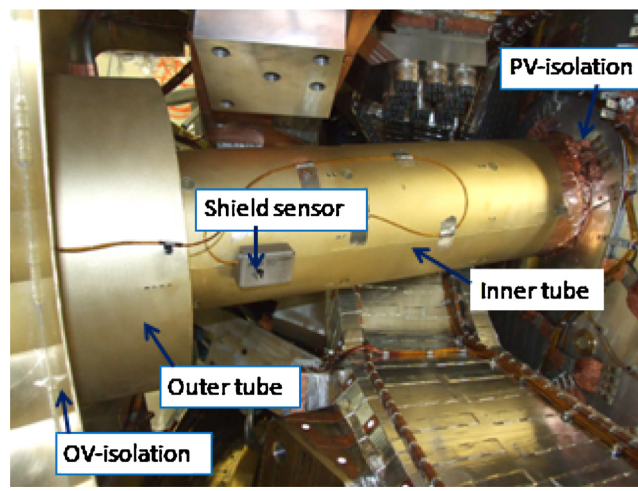

Fig. 4. Port thermal shield consisting of outer tube and inner tube. In addition the temperature sensor is marked.

The outer vessel panels are equipped with 4 sensors for a module, three in the lower half shell and one in the upper shell. Two sensors are located close to big ports but not far away from the cooling pipes (10CT201, 10CT202). The third sensor is far away from a cooling pipe and is close by big domes and port shields (11CT201). The same is true for the fourth sensor that is located in the upper shell (11CT202). The third and the fourth sensors give temperature information on hot spots only. The sensor positions are the same

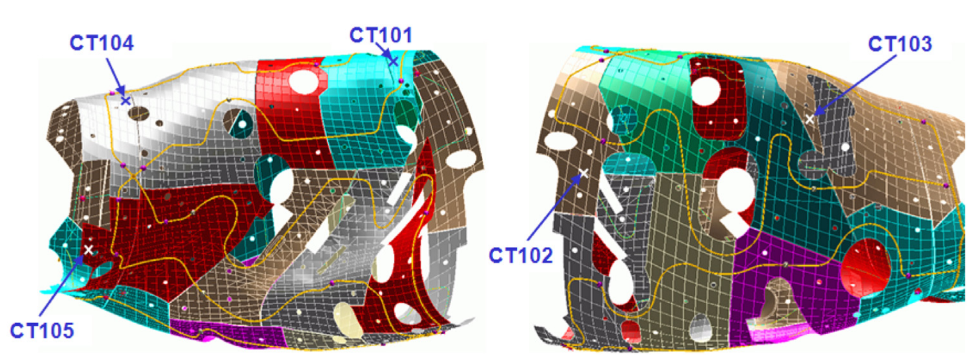

Fig. 2. PV-shield with cooling pipes (yellow) and the location of temperature sensors CT101, CT102, CT103, CT104, and CT105. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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