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Status of WENDELSTEIN 7-X construction

J.-H. Feist for the W7-X Team
Max-Planck-Institut für Plasmaphysik, Euratom Association
Teilinstitut Greifswald, Wendelsteinstraße 1, D-17491 Greifswald, Germany

Abstract
The WENDELSTEIN 7-X (W7-X) stellarator is presently under construction in Greifswald, Germany. W7-X is an optimised stellarator of the HELIAS type and will proof the reactor relevance of this concept. It is designed for long pulse operation using a superconducting magnet system. After a long period of design and manufacture of components which is partly still ongoing, the project is now starting the assembly of the first two half modules out of ten. The paper summarizes the status of the manufacture of the magnet system, the cryostat, the plasma facing components and the supply systems. The sequence of assembly is outlined.

1. Introduction

The W7-X stellarator is the next step in the stellarator line of the Max-Planck-Institut für Plasmaphysik, Garching, Germany and is being built in the Greifswald branch of IPP. W7-X has the objective to prove the reactor relevance of a HELIAS type stellarator. Energy and particle confinement will be investigated in an optimized magnetic configuration and stationary operation of a reactor relevant divertor system will be demonstrated. A description of the scientific basis and the technical realization of W7-X can be found in [1]. W7-X comprises 50 superconducting non-planar coils to produce the main magnetic field and 20 planar coils to vary it. The coils are arranged in five identical modules composed of two half-modules (HM) which are flip-symmetric to each other. The coils are fixed to a rigid central ring and have other connection element between each other. They have to be kept at a temperature of 4 K. Electrically they are connected via a bus system with the current leads and the power supplies. For thermal insulation they are surrounded by a cryostat which consists of an inner vacuum vessel for the plasma (PV), an outer vacuum vessel for the insulation vacuum (OV), 299 ports for heating, diagnostics and coolant supply, super-insulation and heat radiation shields on all warm surfaces (TI). The power from the plasma is absorbed by high heat flux panels and actively cooled wall protection elements inside the PV. The plasma will be heated by ECRH, NBI and ICRH with a total power of up to 25 MW.

2. Components of W7-X

2.1 Magnet system

Details of manufacture and testing of the non-planar and planar coils can be found in [2]. The manufacture of the coils is delayed by almost 5 years. Technical parameters had to be changed during manufacture due to more precise structural calculations. Manufacture steps turned out not to result in the required quality in mechanical and electrical aspects. At present 47 coils have been produced and 23 are still in production. The last coil is expected for cold testing mid of 2008. To connect the coils with each other (7 groups) and with the current leads, a superconducting bus system is used which is being designed and manufactured by the research centre Jülich (FZJ, Germany) [3]. The routing is done in a bifilar way to reduce error fields. The design has been finished and manufacturing is under way. Six conductors (out of 24 for the first module) have been delivered. The connection between the power supplies and the bus system requires 14 current leads that bridge the temperature from 300 K to 4 K. The design for this leads, able to carry 20 kA and using high temperature superconductor inserts, is made by the research centre Karlsruhe (FZK, Germany). Manufacturing is now under way at FZK. The coils are powered by 7 power supplies. Each can deliver 20 kA at 30 V. This system has proven an accuracy of 2×10^{-3} [4], which results in a sufficient stability of the magnetic field. The quench detection system is developed by FZK. It will consist of almost 400 units that check permanently the differential voltages between double-layers and between all sectors within the bus system. The first prototype units have been tested successfully.

The coils will be fixed to a central ring. This ring is composed of 10 identical, welded segments which are bolted together to form a pentagon-shaped structure [5]. The segments must be machined to a high accuracy of a few tenth of a millimetre to fit together. Cast extensions for holding the coils are welded to this ring. Refinement of structural calculations resulted in modifications to the design, thereby delaying the manufacture. The first two segments of the ring have been delivered in February 2007. Each coil is fixed to the ring at two locations, which take up the magnetic forces (< 4 MN) and bending moments (< 350 MNmm). A bolted solution using long and slender Inconel bolts and sleeves to limit the loss of pre-load during cooling down to 4K has been developed to keep the coils in place [6]. The size of these bolts ranges from 25 mm to 90 mm. Also in toroidal direction, the coils have to be supported against each other with a system that can take up forces and moments and keep the positions of the coils to a high accuracy. On the inner side sliding elements are used which allow relative movement (< 5mm) under large contact forces (< 1.5 MN) [7]. The problem here is to avoid stick slip. On the outer side the connections between the coils are welded. The control of welding shrinkage and distortion is essential to comply with the assembly tolerances. The He-supply to all cold components is done via a complicate system of tubes which have to be installed together with the bus system and all instrumentation cable trays. The design of this system is in its final stage, call for tender will start soon. 10 cryo-supports will carry the load from the magnet system and provide a thermal barrier between the cold magnet system and the machine base. Design has been finished, fabrication will start in summer.

2.2 Cryostat

Details of the manufacture of the components for the cryostat can be found in [8]. The PV is a welded structure following the narrow space between the coils and the plasma with a tolerance of sometimes only ± 3 mm. All 10 sector of the PV have been delivered before the end of 2005. The OV is produced in 5 modules, each divided in an upper and lower half-shell to allow the insertion of the magnet module. The OV has more than 500 openings for different purposes. These openings present a stability problem of the vessels during assembly. Sophisticated stiffeners must be used to keep the module in shape. All 10 half-shells have been welded, the first module is ready. Delivery of the complete vessel is scheduled for mid 2008. W7-X will be equipped with 299 ports of different shape and dimensions to allow access from the outside to the plasma vessel for diagnostics, heating, pumping and supply of the in-vessel components. All ports have been delivered. Operation of the coils requires effective reduction of heat input. The TI of all warm surfaces is composed of 20 layers of aluminized Kapton-foils and a rigid thermal shield. To fulfil the stringent tolerance requirements for the shape of the shield on the PV, it is fabricated from glass-fibre panels with embedded Cu-meshes. Cooling pipes on the outboard side are connected to the Cu meshes through Cu-braids. The 8 segments of the shield for each half module are assembled on the PV in parallel with the threading of the coils. For the OV and the ports the shields are made from copper and brass.

2.3 In-vessel components

The in-vessel components are composed of 10 units. Each unit comprises a cryo-pump, a control coil for the variation of the magnetic field structure at the edge, a baffle unit for the control of the neutral particle flux, the divertor unit for the power and particle exhaust, and the wall protection which covers the rest of the plasma vessel. All components have been designed for steady-state operation at the full heating power [9]. The most challenging components are the target plates for the divertor which will experience high power fluxes of up to 10 MW/m^2. Prototype testing is still on its way. All other elements are manufactured in close collaboration between various industries and the central workshop at Garching. The manufacture is well advanced and first components have already been delivered to Greifswald.

2.4 Supply systems, periphery and diagnostics

Beside the electrical power supplies which have all been delivered, the main other systems are the water cooling system, especially for the in-vessel components and the cryo-supply (4.5 kW at 4 K) [10]. Both systems are presently being installed. The planning of the whole periphery is a constantly ongoing work which needs a large amount of coordination considering space allocation, assembly and maintenance requirements.

3. Assembly

The assembly comprises four major steps [11]. The first is the assembly of the HM comprising the magnet system, PV and TI which is performed in parallel on two assembly stands. The seven coils are strung over the PV which is then covered step by step with the TI. Then all coils are fixed to the support ring with high precision of the pre-load to the bolts and the support elements are mounted by welding or adjustment of an accurate gap for the sliding. Secondly two HM are joined (bolting of the support ring and welding of the vessel) and the busbar system will be assembled together with the cryo supply lines. In the third step the magnet module will be inserted into the lower OV-Module and both units will be transported to the machine base which is already installed in the torushall. There the upper OV-Module will be welded to the lower module and the ports will be inserted and welded to the PV and OV. In the fourth step the modules are joined to a torus. In parallel to this the installation of the in-vessel components will start. For all these steps different specialised handling tools have been developed, mostly they are already manufactured and detailed procedures have been set up. Recently assembly of the first two HM has started after many preparatory tests. As of June 2007, two non-planar coils and one planar coil are mounted on each HM. The further assembly schedule is presently undergoing a detailed review in order to speed up the assembly process of W7-X. It is the goal of the project to start commissioning of W7-X in 2014.

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