

Status of WENDELSTEIN 7-X Construction

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Abstract: The WENDELSTEIN 7-X (W7-X) stellarator is the largest fusion experiment presently under construction. W7-X has the main objective to prove the reactor relevance of a stellarator, based on the HELIAS principle, as an alternative to the tokamak. Details of the optimisation criteria and the scientific and technical objectives can be found in several publications. At present the construction of W7-X is close to the start of the assembly. The first superconducting non-planar coil is undergoing acceptance test, the first sector of the plasma vessel has been leak tested, the main parts for the outer vessel have been fabricated, the first ports are close to delivery and many rigs for the assembly are already installed. The assembly will start at the end of 2003 with the attachment of saddle coils for magnetic diagnostics on the plasma vessel and will last until 2009 when the torus will be closed. Start of plasma operation is scheduled for the middle of 2010.

1. Introduction

W7-X is the next step device in the stellarator line of IPP Garching and is being built at the Greifswald branch institute of IPP. Details of the optimisation criteria, the scientific and technical objectives and the technical description can be found in several publications [1,2,3 and references therein]. The project W7-X construction started in 1996 with a detailed design based on specifications outlined in the preferential support application. The first contract for the superconducting non-planar coils was placed at the end of 1998 followed by the contracts for the planar coils and major parts of the cryostat. The contracts for the thermal insulation, refrigeration plant and in-vessel components will be placed in 2003.

2. Basic Machine

2.1 Magnet system

The magnet system comprises fifty non-planar coils for the standard magnetic field (five different types), twenty planar coils for field variation (two different types), a bus system for the electrical connection of the coils, the central coil support structure (made up of 10 sectors), and seven power supplies. The superconducting coils are wound from a cable-in

conduit conductor which is composed of 243 strands enclosed by an aluminium jacket. The conductor is being manufactured by the VAC/EM consortium. The qualification of all steps of manufacture and testing for the series production took almost three years, one of the reasons for the delay of the project. Meanwhile more than 65% of the required superconductor have been manufactured and more than 45% have been delivered.

The non-planar coils are being manufactured by the Babcock Noell Nuclear (BNN)/Ansaldo consortium. Due to the delay of the superconductor and also due to an underestimation of the various difficulties in each of the production steps (winding and impregnation of the winding pack, manufacture of the coil casing, embedding of the winding pack into the coil casing, precise machining of the various connection elements of the casing, application of the cooling system, final instrumentation and test) it took 54 months from signing of the contract to the delivery of the first coil to the test bed. However, the production will now be accelerated considerably: Three further coils are being machined, two coils have been embedded and further thirteen winding packages are being worked on. In 2003 another eleven coils are expected and by mid of 2005 all coils should be available.

The planar coils are being manufactured by Tesla, the production steps are similar as for the non-planar coils. Unfortunately Tesla experienced a lot of difficulties during the handling of the contract resulting in a delay of more than three years. The first coil will be available in July, further ten winding packages and two coil casings are ready. Tesla expect to finish the delivery in 2004.

All coils will be accepted only after a test at nominal operational conditions at the Low Temperature Laboratory of CEA at Saclay. Two test cryostats were installed and are ready for operation. In each cryostat any combination of two coils can be tested simultaneously. It is expected to test up to 24 coils per year; these tests will last until the end of 2006.

Each coil is supported by a central coil support structure which has to carry the electromagnetic forces of up to 3.6 MN and bending moments of up to 0.4 MNm. The forces and moments differ significantly between the seven coil types. Each coil is fixed by means of two extensions, which are either screwed or welded to the support structure. In addition there are a number of elements which connect the coils among each other. The structure is manufactured by the Spanish company Equipos Nucleares S.A. and is made from steel plates and precisely cast steel elements for the coil fixtures. The production of the structure is well advanced, the first sector will be delivered in the 2nd half of 2004.

The seven times ten coils of one type are electrically connected in series and powered by seven independent power supplies with direct currents up to 20 kA at voltages up to 30 V. The stability of the current is better than 2×10^{-3} . The power supplies are manufactured by the Swiss company, ABB; parts of the first module will be delivered in summer 2003, the complete installation will be finished in 2004. The bus system which interconnects the coils and connects the coils with the current leads is designed and manufactured by Forschungszentrum Jülich. The first module must be available early in 2005.

2.2 Cryostat

The thermal insulation of the 400 t of cold mass of the magnet system is provided by the cryostat. Its main components are the plasma vessel, the outer vessel, the ports and the radiation shield with the multi-layer insulation. The plasma vessel fits closely inside the coils to provide enough space for the plasma and the in-vessel components. It is manufactured by the Deggendorfer Werft und Eisenbau GmbH (DWE). It is being constructed from 200 steel rings bent precisely to the required shape and carefully welded together to keep the surface of the vessel within local tolerances of 3 mm. The sectors of the first module are completely welded and successfully leak-tested. The openings for the ports have been precisely manufactured using the water jet technique. Presently the cooling tubes and the supports for the in-vessel components are adjusted and fixed. The delivery of the first half module is planned for the end of September. Manufacture of the next modules is on schedule. The outer vessel is also being manufactured by DWE. The vessel itself is completely manufactured, at present the 1200 openings are machined in which require special stiffening of the vessel for mechanical integrity. Production of the 299 ports by the Swiss company Romabau is well advanced. The ports required for the first module will be delivered in autumn. The contract for the thermal insulation, comprising the 80 K shield and the multi-layer super insulation, will be signed in July. The first part to be insulated will be a segment of the plasma vessel which will take place early in 2004.

2.3 In-vessel Components

The in-vessel components comprising the divertor target plates, the baffle plates, the wall protection, the sweep and control coils, and the cryo-pumps are designed for steady state operation at the full heating power of 10 MW and for 15 MW pulsed for 10 s. The design of the in-vessel components has been completed and for most components industrial offers are available or are in the state of negotiation. The manufacture and test will be co-ordinated by IPP Garching. Installation will start early in 2006.

2.4 System Control

The operation of W7-X will be controlled by a master control system with local controllers for all subsystems such as magnets, cryogenics, heating, diagnostics, and data acquisition. In order to structure operation of the experiment, all periods of operation will be divided into segments. A segment programme defines the operational rules and parameters which determine the state and activity of each unit in use. Precise timing and synchronisation of all actions on a time scale of microseconds are based on a Trigger-Time-Event System.

3. Assembly

The assembly of W7-X is a complicated process which must be carried out with utmost care to meet the stringent requirements of accuracy in the positioning of the magnet coils and of vacuum integrity. It starts with stringing of the coils of one half module across the plasma vessel and attaching the coils to the support structure sector. The positioning of the coils must be within < 0.5 mm of the ideal position. Next two half modules will be connected to a module and the bus system will be installed which requires the installation of joints between the superconductors. A module will then be transported into the torus hall and will be installed inside the lower half of the outer vacuum vessel on the machine bed in the best theoretical position. The module will then be completed with the upper half, the ports and the in-vessel components. In the end, when all five modules are in place a final small adjustment of each module can be made in order to get the best fivefold symmetry of the magnetic field. The modules will then be joined and supply lines will be connected before pump down and cool down can start.

The rigs for the assembly of the half modules and modules are installed at Greifswald and many handling tools are available. The design of the machine bed is being detailed. All steps of the assembly will be described in working instructions. The quality assurance will strictly control each step and qualification tests (vacuum, high voltage, geometric measurements etc.) will be carried out as close as possible to the envisaged operational conditions. In parallel to the assembly the installation of the periphery (supply lines, diagnostic and heating systems) will take place. Start of plasma operation is scheduled for the middle of 2010.

References

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- [3]: Wanner, M. et al., Nucl. Fusion **43**, 416-424 (2003)