STATUS OF WENDELSTEIN 7-X CONSTRUCTION
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Abstract
WENDELSTEIN 7-X (W7-X), being under construction at the Greifswald branch institute of the IPP, has the objective to prove the reactor relevance of a HELIAS type stellarator. Energy and particle confinement are investigated in an optimised magnetic configuration and stationary operation of a reactor relevant divertor system will be demonstrated. After an intensive R&D programme the project is in the phase of procurement of the main components. This holds for the magnet system, the cryostat, power supplies, and various tools for the assembly. Start of operation is scheduled for 2006.

1. Introduction
W7-X is the next step in the stellarator line of IPP Garching and is being built in the Greifswald branch institute of IPP. A schematic view of W7-X is shown in Figure 1, the main parameters are given in Table 1.

Table 1: Parameters of W7-X

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major plasma radius</td>
<td>5.5 m</td>
</tr>
<tr>
<td>Minor plasma radius</td>
<td>0.53 m</td>
</tr>
<tr>
<td>Maximum field on axis</td>
<td>3 T</td>
</tr>
<tr>
<td>Maximum field at coils</td>
<td>6.7 T</td>
</tr>
<tr>
<td>Maximum coil current</td>
<td>18.2 kA</td>
</tr>
<tr>
<td>Maximum force on coils</td>
<td>3.6 MN</td>
</tr>
<tr>
<td>Machine diameter</td>
<td>16 m</td>
</tr>
<tr>
<td>Machine height</td>
<td>4.5 m</td>
</tr>
<tr>
<td>Total mass</td>
<td>725 t</td>
</tr>
<tr>
<td>Cold mass</td>
<td>400 t</td>
</tr>
<tr>
<td>Refrigeration power (4K)</td>
<td>~ 4 kW</td>
</tr>
<tr>
<td>Plasma heating power</td>
<td>15 MW</td>
</tr>
</tbody>
</table>

Figure 1: Schematic view of WENDELSTEIN 7-X
The physics, technical background, and objectives of W7-X have been described in a number of publications (e.g. [1], [2] and references therein). The design and specification of W7-X were supported by an intensive R&D programme, including the manufacture and test of a full size DEMO coil [3] and a 1/8 sector DEMO cryostat [4]. Meanwhile more than 60 % of the investments have been ordered from European industry, other components are in
the tender phase. This paper presents the status of design and fabrication of the main components of the basic machine.

2. **WENDELSTEIN 7-X device**

2.1 Magnet system

The magnet system comprises fifty non-planar coils for the standard magnetic field, twenty planar coils for field variation, the central coil support structure, and the power supplies. Central component of the coils is the NbTi superconductor which is composed of 243 strands enclosed by an aluminium jacket (CICC). The CICC is being manufactured by the consortium VAC/EM. During a time-consuming qualification process the necessary parameters for series production within tight tolerances and quality assurance procedures for safe achievement of the parameters of the CICC were established. Meanwhile series fabrication has started.

The non-planar coils are manufactured by the consortium Babcock Noell Nuclear GmbH/Ansaldo, the planar coils by Tesla. The main steps of the fabrication are winding and impregnation of the winding packs, manufacture of the coil casings, embedding of the winding packs into the coil casings, and instrumentation of the coils. All winding lines are manufactured, assembled, and commissioned. The complicatedly shaped winding moulds for the non-planar coils have been manufactured with high accuracy, producing only deviations of fractions of a millimetre over a coil diameter of 2.5 m. This accuracy is necessary to ensure the high quality of the magnetic field. Winding will start after delivery of the first superconductor. Joints for the connection of double layers of a winding pack, which must have a resistance of $< 1 \, \text{n}\Omega$, were successfully developed. Tesla achieved a resistance as low as $12 \, \text{p}\Omega$ at nominal current. Complete half-shells of the coil casings for the non-planar coils are cast and precisely machined for all types of the non-planar coils by the Swedish subcontractor, Österby Gjuteri AB. By this means complicated welding of several segments for each half-shell is eliminated. Based on results from the DEMO tests, cooling of the coil casings must be improved due to an expected heat flux of 1.5 W/m$^2$. A combination of copper plates with high thermal conductivity and sprayed copper together with four cooling pipes will handle this heat load. Each coil will be instrumented with temperature sensors to monitor cool-down as well as strain gauges to observe deformations.

The central coil support structure must keep the coils at their precise position under varying local forces of up to 3.6 MN. The structure is manufactured by the Spanish contractor, Equipos Nucleares. The design combines a welded construction and precisely cast elements for
the coil fixtures and the support legs. The manufacture is well advanced. The main challenge is to guarantee precise fitting of the modules to form a perfect circle (pentagon) without the necessity of a pre-assembly.

The seven power supplies, providing currents of up to 20 kA at voltages of less than 30 V, are manufactured by the Swiss company, ABB. Fast and reliable discharge of the magnets in case of a quench is realised by arc shoot breakers and pyro-breakers. The energy stored in the magnets will be dumped to nickel resistors. These resistors feature a high heat capacity and a strong increase of the resistance with temperature.

2.2 Cryostat

The cryostat provides the thermal protection of the coil system and comprises the plasma vessel, the outer vessel, ports, and the thermal insulation. The plasma vessel must provide enough space for the plasma and consider restrictions given by the coils. An iterative optimisation process led to a complicated shape and the demand of tight tolerances. The outer vessel must have 1200 openings for ports, inter-coil connections, current leads, cooling-water supply lines, and feed-throughs for instrumentation. For assembly the segments of the outer vessel need to be horizontally divided. Both vessels are manufactured by the German company, Deggendorfer Werft. For diagnostic, heating, and supply 309 ports of different shape will be installed. The ports are produced by the Swiss company, Romabau. Most of the manufacturing drawings have been prepared, material has been ordered, and tools for the installation of the ports into the cryostat have been designed. Actively cooled shields with multilayer insulation will protect the cryogenic components against thermal radiation. These shields are made from sheet metal, covered with several layers of reflecting foils, and cooled by helium. Based on an optimised thermal effectiveness and economic mounting of the insulation the specification of the thermal insulation is being prepared.

2.3 In-vessel Components

All plasma-facing surfaces of W7-X will be covered with low-Z material. Three different types of surfaces can be distinguished: The divertor target plates with heat loads of up to 10 MW/m², the baffle plates with heat loads up to 0.5 MW/m² and the inner surface of the plasma vessel with heat loads of up to 0.1 MW/m². All surfaces must be cooled for steady-state operation. For the divertor, which must handle a power of 10 MW, standardised plane elements with flat carbon fibre composite (CFC) tiles made from SEPCARB® will be brazed or welded to a cooled support structure. Different designs have been tested successfully at stationary power loads of up to 12 MW/m². A prototype target, comprising 10 to 15
target elements, is now being designed in detail. For baffle elements and wall protection two concepts (flat carbon tiles clamped to water-cooled structures or panels with an integrated cooling circuit and a surface coating of B₄C) are being considered. Prototypes were manufactured by industry.

3. **WENDELSTEIN 7-X Assembly**

For good confinement of the plasma, the exact five fold symmetry of the magnetic cage must be guaranteed. Errors in the shape or position of individual coils must be smaller than $10^{-4}$. Such tolerances require precision tooling, stringent quality assurance and careful control during assembly. Mobile computer-controlled theodolites and a laser tracker will be used during assembly.

Assembly starts with stringing the coils of one half-module across the plasma vessel, adjusting them at their correct position and connecting them to a sector of the central support. A CAD study was conducted to model the mounting sequence and define the optimum size of the plasma vessel segments and thermal insulation. In a next step two half-modules are joined. This unit is moved into the torus hall and lifted into the lower half of the outer vessel. After integration of support legs the outer vessel is closed and the ports and the in-vessel components are installed. Finally the five modules will be moved simultaneously towards their final positions in the torus on gliding rails. After an integral check of the machine all supply lines and the heating units are installed before evacuation and cool-down can start.

4. **Status of other components**

Beside the components of the main machine, many other parts are being designed in detail: The control and data acquisition system, the cryogenic system, the ECR (provided by FZK), NBI and ICR heating systems, the high voltage power supply for heating (manufactured by Thomcast/Siemens) and the many diagnostics necessary to exploit W7-X. Assembly of W7-X will start in 2002 and will last for approx. four years. In 2006 the device will be commissioned, the magnetic field will be mapped, and the scientific operation will start.

References