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. W7-X is the follow-up of the WENDELSTEIN 7-AS experiment which has been closed in summer 2002 after 14 years of successful operation [1].
The standard magnetic field configuration of W7-X is the result of an optimisation of several physics criteria [2] and is characterised by a magnetic induction of 2.5 T along the plasma axis, an iota of 5/5 at the plasma boundary, a shear of about 15 % and a magnetic well of typically 1 %. The magnetic field is produced by fifty non-planar coils which are arranged symmetrically in five periods. Additional twenty planar coils allow to vary iota between 5/6 and 5/4 or to modify parameters like shear, magnetic well depth, and magnetic ripple. The magnetic induction can be increased up to 3 T on the axis to allow off-axis deposition of 140 GHz ECR beams. Steady-state operation is achieved by superconducting coils and the newly developed cw gyrotrons. The flow of energy and particles is controlled by a continuously working divertor which makes use of the island structure along the helical edge of the plasma. Plasma temperature and density can be increased by 4 MW of ICR and 5 MW of NBI heating. To reach the predicted ß-limit of 5 % at densities of up to $3x10^{20}$ m^{-3} the capacity of the NBI heating system must be upgraded to 20 MW at a later stage. A schematic view of W7-X is shown in figure 1, a summary of the parameters is given in table 1.
The construction of W7-X 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 are being placed in 2003.
This paper concentrates on the central machine and is an update of a recent more detailed publication [3].

2. Basic Machine

2.1 Magnet system

The superconducting 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

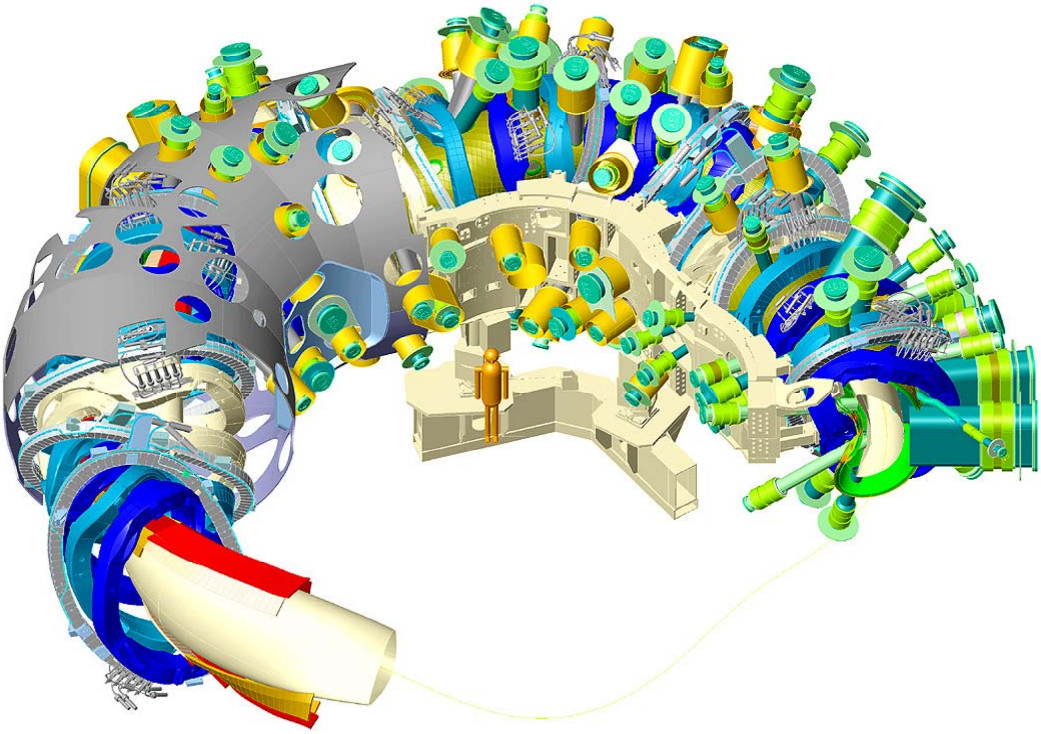

Figure 1. CAD view of WENDELSTEIN 7-X

Table 1. Main design parameters

Major plasma radius	5.5 m	Machine height	4.5 m
Minor average plasma radius	0.53 m	Machine diameter	16 m
Plasma volume	30 m^3	Machine mass	725 t
Number of non-planar coils	50	Cold mass	425 t
Number of planar coils	20	Heating power ($1^{st}/2^{nd}$ stage)	15 / 30 MW
Rotational transform	5/6 - 5/4	Plasma pulse length	30 min with
Max. induction on axis	3 T		10 MW ECR
Max. induction on coil	6.8 T		heating.

bus system for the electrical connection of the coils, the current leads from room temperature to cryogenic temperature, the central coil support structure (made up of ten identical sectors), and the seven power supplies.

2.1.1 The superconducting coils

The manufacture of the superconducting coils is a very challenging technical task which needs all available skills of the companies involved. All parts have to be manufactured with high accuracy in a reproducible manner. Strict quality control must be applied in all steps of production because a fault in the coils after start of operation would be an extremely severe case. These demands resulted in a non foreseen long period of development, a slow start of series production and a delay of the whole project. For more details on the status of the construction of the magnets refer to [4].

Central component of the coils is the superconductor. It is a cable-in conduit conductor (CICC) which is composed of 243 strands enclosed by an aluminium jacket. The aluminium alloy is a wrought alloy, which is soft before winding and which is hardened by heat treatment afterwards. The conductor is being manufactured by the VAC/EM consortium. The production steps are manufacture of the strands, cabling of the strands with a 3x3x3x3x3 cabling law, co-extrusion of the cable with the aluminium jacket and qualification of the single double layer length with respect to geometric parameters, void fraction, gaseous helium throughput and leak tightness. The qualification of all steps of manufacture and testing for the series production took almost three years. Several iterations to adjust the nozzle of the extrusion tool were required to keep the void fraction within the range between 35 – 39 % and the minimum wall thickness above 2 mm. The void between the strands and the jacket is used as channel for the helium coolant. Meanwhile more than 75 % of the total amount of conductor is produced and more than 50 % has been delivered to the coil manufacturers.

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 effort for 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.

The main parts of the coils are the winding packages, the low resistance inter-layer connections, the cast stainless steel coil casings, the cooling system and the instrumentation.

To wind the five different types of coils, three parallel winding lines have been set up at Ansaldo and two winding lines at BNN's subcontractor ABB. Winding starts with preparation of the conductor by straightening, sand-blasting, and insulating with glass tape. For each winding package, conductors with typical lengths of 150 to 180 m are wound into the complicatedly shaped winding form resulting in six double layers with a total of 108 turns. The winding forms have been produced with an accuracy of a few tenth of a millimetre compared to the CAD model. The repetition accuracy of the winding packages within one type meets the requirement of ± 3 mm in most cases. The winding is then enclosed in a 5 mm thick multi glass tape ground insulation, heat treated at 165 ^{o}C for the hardening of the conductor and finally impregnated with an epoxy resin. Special joints are developed to connect the six double layers electrically in series and for the flow of single phase helium in parallel. To limit the ohmic heat at cryogenic temperature, the resistance of a single joint must be in the order of 1 nΩ. Prototypes tested by the manufacturer showed that this stringent requirement can be met. In order to insulate the electric circuits of the windings against the helium pipes, special voltage separators were designed and successfully tested at cryogenic temperatures. Such joints are made from two stainless-steel pipes which are connected by an insulating piece of glass-fibre-reinforced epoxy. The voltage separators have to withstand a maximum voltage of 13 kV and allow for the different thermal contractions of the dissimilar materials during cool-down. During multiple cool-down to liquid-nitrogen temperature the reliable function of prototype voltage separators was demonstrated. So far twelve complete winding packages have been produced and another ten are in various stages of production.

To withstand the large Lorentz forces the winding package must be embedded into a massive stainless steel casing. In order to allow integration of the winding package the coil casings need to be fabricated in two halves. The shape of the halves is realised by a casting technique followed by a heat treatment and precision machining. Main problems during manufacture are the tight geometric tolerances, the necessary high yield strength of >800 MPa at 4 K, and the crack free cooling down of the cast. A few cases had to be repaired by welding of cracks some

others had to be discarded because they have not met the specification. Sixteen complete casings have been produced so far and further nine are in production.
Assembly of the non-planar coils has to consider that during cool-down to cryogenic temperatures the winding package of the coils tends to shrink more than the steel casing which would produce excessive stress on the conductor. Therefore the casing is heated up to about 100 ^{o}C, the space between winding package and the coil casing is filled with glass sand and a pre-stress is built up during cool down to ambient temperature. The sand is afterwards stabilised with a cold hardening epoxy resin. Meanwhile eight coils are embedded this way.
After embedding a number of surfaces and tap holes have to be machined to a precision of some tenths of a millimetre. This is done on a high precision five axis milling machine. So far four coil casings have been machined; some repair work is still necessary to fulfil the stringent requirements of the geometric accuracy. Cooling of the coil casings is achieved by four helium pipes around the circumference which are coupled to the steel casing by sheets made of high-conductivity copper. In order to reduce eddy currents in the casings during rapid shutdown of the magnetic field, the copper sheets are segmented into strips.
The first non-planar coil has passed its acceptance test on the 17th of June 2003, two other coils have meanwhile been accepted too. It is expected to have up to 2 coils per month delivered in the future.
The planar coils are being manufactured by Tesla. The construction principle and the production steps are similar as for the non-planar coils. The main differences are the much simpler planar shape of the winding package, the reduced number of 36 turns, and the technology to produce the casings from sheet metal which are screwed together. Unfortunately Tesla experienced a number of difficulties during the handling of the contract resulting in a delay of more than three years. The first coil will be available in October, further twelve winding packages and three coil casings are ready. Tesla expect to deliver one coil per month.
All superconducting coils will be subjected to an acceptance test at nominal operation conditions at the Low Temperature Laboratory of CEA in Saclay. Two test cryostats were installed, the current supply was upgraded to 20 kA, and the data acquisition system was adopted for this purpose. Special supports allow any combination of two coils to be tested in one cryostat. The facilities were successfully commissioned using the prototype coil. Meanwhile the first coil has been cooled down within twelve days and first current tests with the nominal current of 17.6 kA have been carried out. The second coil is being installed in the second cryostat.

2.1.2 The bus system and current leads

Fourteen current leads are required to connect the seven groups of superconducting coils with the power supplies. A study showed that conventional current leads designed for lower than nominal current, but operated under overload conditions, are preferable to leads based on high-temperature superconductors, which were considered as an alternative. Designing the current leads for lower current reduces the stationary heat conduction during the long idle current period at the expense of slightly higher heat loads during peak current operation.
A widely ramified superconducting bus system connects the 14 current leads with the seven groups of coils and connects the ten coils of each type. The bus is made of the same CICC as the coils. Routing of the bus lines is performed in a bifilar way in order to reduce stray magnetic fields, which would have a negative impact on the magnetic configuration of W7-X. Five bus subsystems comprising some 1000 m of conductor need to be prefabricated and assembled using some 200 low-ohmic joints. Design, manufacture, and assembly of this system has been taken over by FZJ.

2.1.3 Central coil support structure

The coils need to be kept at their precise position during assembly, cool-down and operation. Therefore each coil is fixed by means of two extensions to a massive support structure which has to carry the electromagnetic forces of up to 3.4 MN and bending moments of up to 0.4 MNm per coil. The forces and moments differ significantly between the seven coil types, resulting in individual solutions of the different connections between coils and structure. The structure consists of ten identical sectors with a total weight of 72 t. The sectors will be joined by screws to span a central pentagon. Special shims between the modules will allow a final alignment. The structure is made from steel plates and precisely cast steel elements at the Spanish contractor Equipos Nucleares S.A. Precise fitting of the segments requires machining to a precision of a few tenths of a millimetre. Since the coil support structure needs to be kept at the same low temperature as the coils, helium cooling pipes are contacted on the surface of the structure. The originally foreseen time schedule for the manufacture of the support could not be kept, since a very complicated structural analysis turned out to be necessary in order to verify the structural integrity of the design. A special task force was set up, including also experts from EFDA, ITER and FZJ. A feasible solution has been found recently and manufacture will recommence soon. The first sector must be available in August 2004.

Ten vertical supports carry the structure and provide the thermal barrier between the cold parts and the machine foundation. The design of the supports considers that the coil system shrinks during cool down by approx. 15 mm. A special mechanism will ensure self-centring of the coil support structure during cool-down. The detailed technical specification is in preparation.

The lateral forces between the coils are taken by special connections which are arranged along the inner and outer circumference of the coil assembly and which will be either welded to the coils or will be attached to the coils and are subjected to compression forces only. The design of these components is on its way.

2.1.4 The power supplies

All ten coils of one type are electrically connected in series and powered by one power supply with direct currents of up to 20 kA at voltages of up to 30 V. The Swiss contractor, ABB, selected the concept of twelve-pulse rectifiers to ensure that the currents will be stabilised to an accuracy of $2x10^{-3}$ and hence to adjust the magnetic induction with an accuracy of 6 mT. The field ripple produced by the power supplies at a frequency of 600 Hz has a negligible effect on the plasma confinement. Magnetic induction can be varied up to 5 mT/s to allow for scans during long plasma discharges.

For fast and reliable discharge of the superconducting magnets in case of a quench the coils are short-circuited and the magnet energy of 600 MJ in the standard case is dumped to nickel resistors within 5 s. These resistors feature a high heat capacity and a strong increase of the resistance with temperature, the switching voltages can thus be kept low. A resistor has been tested successfully at IPP Garching using the energy stored in the fly wheel generator of IPP`s power supplies. The results of tests with arc shoot breakers and a newly developed ignition device are in accordance with the specification. The first unit has been delivered in August 2003 and is presently being installed; the other six units will also be delivered in 2003. Final acceptance is planned for 2004.

2.2 Cryostat

The cryostat provides the thermal insulation of the 425 t of cold mass of the magnet system. Its main components are the plasma vessel, the outer vessel, the ports, and the radiation shield with the multi-layer insulation.

2.2.1 Plasma vessel

The German company, Deggendorfer Werft und Eisenbau GmbH (DWE), is responsible for manufacturing the plasma vessel [5]. A major challenge of the design of the plasma vessel was to optimise the shape in order to give maximum space for the plasma while keeping the necessary clearance against the cold coils. Matching of the shape of the plasma vessel for the case iota = 5/4 reduced the distance between the inner wall of vessel and the plasma edge locally to 50 mm. This small distance asked for reduced tolerances of ± 3 mm for the plasma vessel shape.

The plasma vessel is being constructed from 200 steel rings. Each ring is carefully welded together from four segments which are either bent or hot formed precisely to the required shape. For the ease of assembly (see below) the rings are welded together into twenty sectors which are connected by welding during the assembly process. Water pipes around the outside of the vessel allow bake-out at 150 °C and control of the vessel temperature during plasma operation. The openings for the ports are cut by a water jet technique. Delivery of the first sectors of the plasma vessel is planned for autumn 2003.

The plasma vessel is mechanically supported from below by 15 adjustable supports. Additional supports allow to adjust the horizontal position of the plasma vessel w.r.t. the magnetic configuration within a range of ±5 mm. After adjustment an additional mechanism keeps the plasma vessel self-centred during temperature variations.

2.2.2 Outer vessel

The outer vessel is also manufactured by DWE. To allow assembly of the cryostat the sectors of the outer vessel need to be divided horizontally and delivered as half-shells. The design considered approx. 1,200 openings for ports, manholes, and feed-throughs. After the manufacture of the complete torus, made of 15 cylindrical segments, the work had to be put on hold for one year due to missing structural calculations. Meanwhile the calculations are finished, the design is being adapted to the result and the work has recommenced. 1200 openings have to be machined, requiring special stiffening elements of the vessel for mechanical integrity. The first half-shells will be delivered in 2004.

2.2.3 Ports

The 299 ports of the cryostat are being manufactured by the Swiss company, Romabau. Dimensions of the ports range from 100 mm circular diameter up to 400x1000 mm^2 rectangular. Small movements during thermal expansion of the plasma vessel are compensated by steel bellows. Manufacture of the ports is well advanced; the first ports will be delivered in 2003.

2.2.4 Radiation shield and multi-layer insulation

Efficient insulation of the superconducting coils requires careful reduction of heat conduction and thermal radiation by high vacuum and many layers of reflecting foils. Efficiency of the thermal protection is improved by metallic shields which cover all areas at ambient temperature. The shields are kept at temperatures between 40 K and 70 K by circulating cold helium gas. The contract for this components was signed recently also with DWE. The manufacture of the parts for the first sector of the plasma vessel is on the critical path of the time schedule; the parts must be available in February 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. For details of the physics see [6].

With respect to plasma interaction three different types of surfaces can be distinguished in W7-X: The divertor target plates are hit predominantly by hot particles from the plasma and have to withstand heat loads of up to 10 MW/m^2. Baffles, which influence the fluxes and density of neutralised particles in front of the target plates, need to be designed for heat loads of 0.5 MW/m^2. The wall protection of the plasma vessel is mostly interacting with neutral particles and radiation from the plasma boundary and has to withstand heat loads of up to 0.2 MW/m^2. To control the reflux of impurities to the plasma and to minimise radiation losses all plasma-facing surfaces have to be covered with low-Z material. For conditioning the target plates, baffles and wall protection will be baked at a temperature of 150° C.

2.3.1 Target plates

Appropriate positioning of target plates relative to the magnetic field lines allows the particle and energy flows from the plasma to be controlled. With two target plates per divertor unit, a total of twenty target plates are arranged along the plasma column. To allow for the full operational range of W7-X the target plates need to cover an area of 20 m^2. The shape of the target plates follows the 3-dimensional boundary of the plasma and is approximated by standardised flat target elements with a typical width of 55 mm. After assembly of the target elements, the plasma-facing surface is machined to the required 3-dimensional shape to avoid leading edges for the flux bundles which interact at nearly grazing incident angles of up to 3° only.

Each target element is composed of a water-cooled metallic support and a flat CFC tile. Based on the development for ITER, W7-X will use targets with cooled supports from CuCrZr alloy which are armoured with 6 mm thick tiles of CFC of a new type SEPCARP® NB31. This combination was successfully tested and has the advantage of a high tensile stress property and a good heat conductivity perpendicular to the tile surface. The good heat conductivity of the copper alloy helps to keep the temperature of the divertor well below the tolerable limit of 1200 $^\circ$C. To enhance heat transfer to the cooling water by turbulence, the cooling channels are equipped with a twisted tape.

The first elements of the NB31 have been delivered by the French company SNECMA and are being characterised especially w.r.t the tensile strength properties. The contract for the manufacture of the single target elements will be signed in autumn 2003 . In order to reduce the investment costs these elements will be assembled and tested at the central workshop of IPP.

2.3.2 Baffle elements

Baffles are installed in front of the target plates to enhance the concentration and improve pumping of the neutral particle fluxes. These baffles span a total area of 30 m^2 and will be covered by flat graphite tiles of approx. 150x100 mm^2. These tiles are clamped to water-cooled support structures made of CuCrZr alloy. Water tubes are brazed to the cooling structures to get high cooling efficiency. These elements will be completely manufactured in the central workshop of IPP.

2.3.3 Wall Protection

The wall of the plasma vessel spans a total area of approx. 120 m^2. Two different concepts will be used to protect the plasma vessel: At critical areas where the distance between the plasma boundary and the wall is small the clamped tiles as developed for the baffles will be applied. For the major part of the area, covering 70 m^2, a panel concept with an integrated cooling loop and a surface coated with B_4C is envisaged. This approach reduces the carbon inventory and simplifies mounting within the plasma vessel. Prototypes made of stainless

steel with an area of approx. 200x600 mm² with representative curvature were built by industry to the required accuracy using different manufacturing techniques. The contract for the manufacture of the elements will be signed in autumn 2003.
B_4C is to be applied to the stainless-steel panels by the vacuum plasma spray technique. Layers with a thickness between 0.2 mm and 0.5 mm were applied to stainless-steel samples and showed a smooth surface, good homogeneity and adherence under thermal loads, as well as sufficient heat conductivity and electrical resistivity.

2.3.4 Control Coils

Ten copper control coils, which are wound with eight turns of a hollow copper conductor and cooled by water, will be installed in the plasma vessel behind the baffle plates. They are used to correct minor field errors, influence the extent and location of the magnetic islands, and allow the power deposition area to be swept across the target plates. The design of the coils has been finalised, the call for tender documents are being prepared.
Dedicated power supplies provide each coil with a direct current of 3 kA at a maximum voltage of 30 V, which can be modulated at frequencies of up to 20 Hz. The ten power supplies have been designed and manufactured by the Spanish contractor, JEMA, and are already installed in the basement of the torus hall at Greifswald.

2.3.5 Vacuum System

Vacuum pumps are required to evacuate the plasma vessel, to pump out neutral particles from the divertor chamber, and to control the density of auxiliary gases injected into the divertor chamber. For details see [7]. Turbomolecular pumps backed by Roots and rotary pumps will provide an effective pumping speed of 42.000 l/s for H_2. Since operation of the turbomolecular pumps in a magnetic environment is restricted to typically 5-7 mT positioning of the pumps and magnetic shielding are being detailed. The Roots and rotary pumps are already bought and are mothballed; the Turbomolecular pumps are of standard type and will be ordered from the stock in due time.
Each divertor unit will be equipped with four cryopump modules behind the baffles, providing a total pumping speed of 150.000 l/s. These pumps will be manufactured by the central workshop at Garching.

2.3.6 Water Cooling System

Removal of a maximum heating power of 15 MW from the divertor and the wall requires a water flow of 2750 m³/h. The water cooling of each divertor unit is divided into several circuits which can be independently controlled to allow economic distribution of the cooling water. The pressure in the water cycle will be kept above 10 bar to avoid boiling. Process design of the water cycles and routing of the pipes inside the cryostat as well as in the torus hall are being detailed.

2.4 System Control

W7-X will be controlled by a master control system with local controllers for all subsystems such as magnets, cryogenics, heating systems, diagnostics, and data acquisition. The local controllers will run automatically according to predefined routines and parameters, which will be set from the master control system whenever the units have to operate together. In order to structure operation of the experiment, machine, and related subsystems, all periods of operation will be divided into segments of variable duration. A "segment programme" defines the operational rules and parameters which determine the state and activity of each unit in use.
Programmable Logic Controllers will be used mainly to control those machine components and diagnostic systems which do not require short response times. Segment processing and

fast feedback control, which require data processing in real time, will be performed by PCs running the VxWorks real-time operating system. Real-time information such as measured values will be shared between all units using a switched Ethernet. Precise timing and synchronisation of all actions on a time scale of microseconds are based on a Trigger-Time-Event system with a central clock running at 50 MHz, a message manager, and signal distribution along glass fibres.

2.5 W7-X 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. Basically, assembly of the stellarator is performed by joining five prefabricated modules to a torus. Each module is composed of two half-modules which are symmetric to each other. A paramount prerequisite for proper confinement of the plasma is the exact fivefold symmetry of the magnetic field. As a consequence, errors in the shape of individual coils or deviations from their ideal position which break the symmetry must be smaller than 10^{-4}. Such small tolerances require high precision during manufacture of the components and during assembly.

The assembly is done at different locations in the assembly and the torus hall. The assembly sequence starts on the first assembly rig with stringing the coils of one half-module across the plasma vessel. A special handling tool was constructed to move and rotate the non-planar coils with masses of up to 6 t precisely across the plasma vessel. A second coil-handling tool will be used to mount the planar coils. The small clearance between the coils and the plasma vessel means that the plasma vessel of each half-module has to be divided to allow the innermost coil to be strung across the vessel. When the vessel is welded together, part of the thermal insulation is mounted. After the precise alignment of the seven coils of one half-module, the coils will be joined with the sector of the support structure.

Next, two half-modules are joined on a second assembly device. Hydraulic cylinders will allow precise alignment of the half-modules in all directions. The sectors of the coil support structure are bolted, the plasma vessel is welded, and the bus bar and cooling lines are connected.

Assembly is continued by transporting the modules into the torus hall, lifting them into the insulated lower half of the outer vessel at an intermediate place and transporting the two components to their final position on the machine bed, supported by a number of provisional stilts, since modules alone are not stable. Next the outer vessel of each module is closed with the insulated upper half and some sixty ports and the in-vessel components are installed. If all five modules are in place, the position of each magnet module can be optimised within ± 5 mm in a final adjustment step. The optimisation will be based on the magnetic flux surface calculation using as input data the shape and position of each coil as built and assembled. For details see [8, 9, 10]. The modules of the central support structure will be bolted together; a small gap between the modules, which is intentionally left free, will be filled with precisely machined shims. Next the sectors of the plasma vessel and the outer vessel are welded together. The temporary supports are removed, some remaining ports are mounted, the thermal insulation is completed, and the final bus connections are made.

Due to the fact that the modules are very close to their final position on the machine support structure, the assembly of the periphery (supply lines, diagnostics, heating systems) can start very early.

3. Auxiliary systems

A helium refrigeration system is required to cool the magnet system down to 3.4 K as well as to provide liquid helium for the current leads and the cryo pumps. The system has a refrigera

tion power equivalent to 5.1 kW at 4.5 K. Its operation is optimised considering the pulsed nature of the experiment which will operate only at full current during approx. 80 days per year. Liquid helium is produced overnight and stored in storage tanks to be used during peak loads during operation. The cryo plant will be ordered in 2003. The storage tanks for liquid and gaseous helium as well as liquid nitrogen are already available.
A central gas supply has been installed which allows local, remote, and automated controlled supply of the gases hydrogen, deuterium, helium, nitrogen, methane, and mixtures thereof. In addition diborane or silane mixtures can be provided for wall coating. Safety of the system is ensured by continuously venting the gas cabinets, by interlocks, and by safety alarms. To vent the plasma vessel after an experiment a high-purity nitrogen gas supply is available.

4. Time schedule

Due to the delay in the production of the coil system and the complexity of the assembly, the project is appr. 4 years delayed. The assembly will start at the end of 2003 with the preparation of the plasma vessel and the first coils and will continue up to the middle of 2009. Commissioning will be split into a phase for the cryostat, where in parallel the in-vessel components will be installed in the last module, and the final characterisation of the magnetic flux surfaces. Start of plasma operation is expected for the middle of 2010.

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