Fusion Engineering and Design 96–97 (2015) 22–27

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Experience with the commissioning of the superconducting stellarator Wendelstein 7-X

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HIGHLIGHTS

- Present status of W7-X assembly.
- Preparation of commissioning.
- Recent results of commission.
- Further step in the commissioning of W7-X.
- Lessens learned.

ARTICLE INFO

Article history:
Received 25 September 2014
Accepted 5 May 2015
Available online 10 June 2015

Keywords:
Stellarator
Wendelstein 7-X
Commissioning

ABSTRACT

The super-conducting stellarator Wendelstein 7-X is presently under construction at the Max-Planck-Institute for Plasma Physics in Greifswald, Germany. Assembly of the device is almost completed and the periphery systems and the diagnostic and heating systems are well advanced. Commissioning of the device has been prepared over the last 2 years and has started in April 2014. This is the first time since decades that a superconducting fusion device is commissioned in Europe.

1. Introduction

After an extended time of design and fabrication of the Wendelstein 7-X (W7-X) stellarator [1,2], the assembly of this device comes to a close. W7-X is the first 'fully optimized' stellarator, which combines a quasi-isodynamic magnetic field configuration sustained by superconducting coils with a steady-state exhaust concept, steady-state heating at high power and a size sufficient to reach reactor relevant $nT\tau$-values [3].

The W7-X configuration has a fivefold symmetry and therefore the device comprises five nearly identical magnet modules. The magnetic field configuration is described by a rotational transform $\iota/2\pi$ of about 1, i.e. in the range 0.72–1.25, with low shear (i.e. a small variation of $\iota/2\pi$ across the magnetic surfaces). The major radius of the plasma is 5.5 m, the effective (i.e. averaged) minor radius is 0.55 m, and the magnetic axis is helical. The machine height is 4.5 m, the diameter is 16 m. The total mass of the basic device (without diagnostics and heating devices) is 725 tons, the cold mass (superconducting coils, central support ring, inter-coil support elements, bus-bars and pipes) amounts to 425 tons.

After the start of machine assembly in 2005, about 900.000 man hours have been performed inside the assembly work. Assembly of the basic device is coming to an end rather soon. In June 2013 the last weld on the torus (inner and outer vessel) has been closed and in April 2014 the last of the 14 current leads [4] has been installed at the torus. With this action, the cryostat – consisting of the outer vessel, the inner vessel and the ports in between – has been closed and the commissioning could start.

Parallel to these works, the installation of the in-vessel components has been continued [5] and will be finished in November 2014: The plasma vessel walls are covered with normal-graphite tiles on CuCrZr-structure in the inner side and stainless steel cushions in the outer side of the plasma vessel (both components are foreseen for water-cooling, but are not cooled in the first

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http://dx.doi.org/10.1016/j.fusengdes.2015.05.010
0920-3796/

operation phase 1.1). For this first operation phase, no divertor will be installed, but five graphite limiters are installed in the five modules in the bean-shape cross-section of the plasma [6].

The most important work package in this phase of the assembly is concerned with the peripheral systems, first of all, the experiment platform [7] installed in 2013, but also a complex support tower in the center of the stellarator which supports all the cryo-lines coming from the basement to the stellarator, water cooling circuits, cable trays and other elements. This tower also allows access to the center of the stellarator. Water cooling circuits are also installed, including the lines from the pumps in the basement to the torus, the ring lines below the torus, but also the very detailed distribution from the ring lines to the cryostat vessel (for cooling of the ports and diagnostics), or the feed-throughs through the cryostat (for cooling the outside of the plasma vessel) or to the plug-ins into the plasma vessel interior (for cooling the in-vessel components, the glow discharge electrodes or diagnostics). Although the in-vessel components will not be water-cooled in the operations phases 1.1 and 1.2, the water-lines in the torus hall (but also within the plasma vessel) have to be installed now for space-reasons.

Due to the tight space environment inside the torus hall, the platform, support frames, water lines and cable trays had to be designed simultaneously [8], and the assembly of these peripheral systems demands extreme logistical efforts. Due to the interaction of these components also during assembly, the assembly schedule is very sensitive and is prone to delays. Only at the very end of these steps, the cable trays can be fixed to the platforms and the support structures, and then the cables can be laid out and connected to the components, power supplies and computers.

However, since the cryostat is closed, commissioning has been started, and this paper describes the preparation and processes (Section 2), the relevant CoDaC activities (Section 3), the results of the commission activities up to now (Section 4) and an outlook (Section 5). In Section 6 we discuss lessons learned in the start of commissioning.

2. Preparation of W7-X commissioning

In 2012 a Task Force started to detail the commissioning processes [9,10]. In general, our commissioning process for the Wendelstein 7-X is divided into two steps of increasing levels of system integration.

(1) Local commissioning (LC) of a single technical component: The instrumentation and all other peripheral components are included as required, and the component is run by its local control system.
(2) The integrated commissioning (IC) handles the step-wise integration of all separate components into the overall system Wendelstein 7-X including the central data acquisition and storage system and the central device control.

The sequence of commissioning W7-X can be divided into six phases, which can be treated separately [9], as they build up a sequence [HSB14]. Only some tasks in this sequence can be performed in parallel, but the main process has to follow a serial sequence:

(1) Vacuum tests of the cryostat.
(2) Cryogenic tests of the cryostat.
(3) Normal conducting coil systems tests.
(4) Vacuum tests of the plasma vessel.
(5) Superconducting magnet coil systems tests.
(6) Preparation for the first plasma.

In the summer of 2013, after these processes for the commission of W7-X had been presented to an international workshop of experts, the commissioning group was set up, the formal processes were defined, and the technical detailing of the six phases mentioned above, was started (sequentially).

2.1. Organization of the commissioning

The process instructions for the commissioning of Wendelstein 7-X have been set up according to the best engineering standards and are described in Ref. [11].

For each commissioning (local or integrated) the responsible officer for a system (RO) has to prepare a commissioning instruction, the so-called commissioning assurance template (CAT), which contains all necessary work and test steps in the right sequence. The CAT is based on the technical, functional or project specification of the system and the instruction manual as well as the safety analysis.

An operation manual must be prepared for each system. It must contain the description of all relevant technical details, a description of the intended use of the system and instructions for putting into service. Instructions for the training of operators and for short-term maintenance must be added if necessary.

The CAT must include the necessary input documents for each commissioning step and the corresponding checks to confirm the achieved states. Hold points for the verification of achieved operational states must be defined. On arriving at hold points, current states shall be compared with previously planned states. Furthermore, it must be checked if all conditions and requirements are fulfilled to allow the continuation of commissioning. Test protocols and check lists serve to verify exact examinations.

Based on the operation manual, the CAT and the safety analysis the Health & Safety group prepares a special health and safety briefing. They monitor the briefing of all the personal working in the torus hall. It should be noted, that the commission is performed in parallel to the final phases of the assembly.

2.2. Management of the commissioning

The W7-X Project Board appoints the responsible Chief Commissioning Manager (CCM), the overall responsible for all local and integrated commissioning. The CCM coordinates all activities such as planning, performance, evaluation and he approves all relevant documents. He is supported by the division head “Assembly”, who coordinates simultaneously ongoing activities in the torus hall and other assembly areas.

The CCM is the head of the Central Commissioning Group (CCG). Members of the group are the heads of CoDaC, group leader “Machine Safety”, division head “Assembly”, the Health & Safety group (or staff members who were appointed by them). The subdivision heads (TBL), responsible for the system currently under commissioning, are also members of the CCG to provide the full competence. The positions of chief mechanical and electrical engineers are foreseen for later commissioning phases and shall be appointed later.

The members of the CCG organize and supervise the execution of commissioning and the entire documentation from the instruction manuals to the final reports. The CCM is directly responsible to the W7-X Project Board. Urgent problems can be cleared also in meetings of the Configuration Control Board in which the scientific requirements are represented by the Scientific Director of W7-X. Strategic decisions are made in the W7-X Project Board.

The CCG is supported by staff members of the technical groups involved in the commissioning processes (Cryo-genics, Cryostat, Magnet System, Vacuum Systems, Diagnostics, and Heating departments, . . .). Necessary work contributions from other groups shall