PREPARATION OF THE WENDELSTEIN 7-X COMMISSIONING

H.-S. Bosch, R. Brakel, M. Gasparotto, D. Hartmann, R. Herrmann, D. Naujoks
Max Planck-Institute for Plasma Physics, EURATOM Association, Wendelsteinstr. 1, 17491 Greifswald, Germany

Corresponding author e-mail: Bosch@ipp.mpg.de

***Abstract*—Assembly of the superconducting stellarator Wendelstein 7-X is well advanced, and commissioning of the device is being prepared. A first draft of the commissioning tasks has been developed and will be discussed in this paper.**

Keywords—Wendelstein 7-X; Commissioning; Operation;

I. INTRODUCTION

The "fully-optimized" stellarator Wendelstein 7-X is presently under construction at the Max-Planck-Institute for Plasma Physics (IPP), Greifswald, Germany [1]. Assembly of the device, the periphery systems and the diagnostic and heating systems is well advanced and is scheduled to be completed in fall 2014 [2]. At this phase, no divertor will installed, as operation will start with a first operation phase (OP 1.1) in 2015 with short limiter plasmas (about 1s, heating power up to 2MW ECRH) to measure the magnetic flux surfaces without the objection from the divertor plates and also to test all systems. Following this 3 month experimental phase, in a further assembly phase the inertially cooled temporary divertor units (TDU) will be installed. In the following, second part of the first operation phase (OP 1.2) plasmas with up to 10 s at a heating power of 8 MW will be investigated to confirm the stellarator optimization and to develop integrated high-density scenarios. After completion of the systems (upgrade of heating and diagnostics and installation of the High Heat Flux divertor), in the second operation phase (OP 2) the physics and technological issues of steady-state fusion device operation will be addressed [3].

Recently, a task force has started to detail the first commissioning phase, which will commence towards the end of assembly phase.

The commissioning of Wendelstein 7-X consists of two steps with increasing levels of system integration.

I. Local commissioning (LC) of technical components: This is controlled by the local control system and includes instrumentation and all other peripheral components required. In general, local commissioning will be done before the end of Wendelstein 7-X assembly.
II. The integrated commissioning (IC): This is the step-wise integration of all separate components into the overall system, the central device control and the central data acquisition system.

This paper will discuss the different phases if the Integrated Commissioning, after a remark on the CoDaC system involved in all phases of commissioning and operations, and at the end a first draft of the commissioning schedule will discussed.

II. CONTROL AND DATA ACQUISITION OF W7-X

CoDaC (Control, Data acquisition and Communication) plays a crucial role in both commissioning phases [4]: Firstly, local control and the data acquisition of single components is required already for LC of the respective components. Secondly, full documentation of engineering data and the device control is required from the start, i.e. from the beginning of the IC. In fact, central device control is separated in the Central Safety System (fulfilling all requirements for the personnel safety as primary requirement and also hardware protection controlled by the Central Interlock System) and the Central Control System which is responsible for operational management and sequence control (plasma operation, glow discharge, baking, idle state, …) for different states of the device. The main function of the central system is to guide and keep under control the global behavior of the W7-X machine. This central system will be tested during the IC phases.

In a similar way, each single component is controlled with a Local Safety System and a Local Control System. Both of these systems have well defined interfaces to the central system. The main function of the central system is then to guide and keep under control the global behavior of the W7-X machine.

III. COMMISSIONING PHASES

The following sequence of phases has been defined for the integrated commissioning:

1. Vacuum tests of the cryostat
2. Cryogenic tests of the cryostat
3. Cu-coil systems tests
4. Vacuum tests of the plasma vessel
5. Superconducting magnet coil systems tests
5. Test of the magnetic field quality
6. Preparation for the first plasma

A. *Vacuum tests of the cryostat*

While all electrical connections inside the cryostat, especially the superconducting joints [5] between the bus bars [6], have been tested after each assembly step, a global electrical test of these connections has to be performed before the cryostat is closed. Also, in this phase, the vacuum system for the interspaces of the multilayer port bellows [7] has to be commissioned and the leak tightness of these bellow interspaces has to be confirmed.

After the assembly of the last current leads into the cryostat, this vessel can be closed and pumped down. Although practically all welds on the cryostat, its domes, the ports and flanges have been checked for leak tightness after each weld, a global leak test has to be performed. Also, the extensive pipe work for water cooling of the plasma vessel, and the extensive helium pipe work for the cryogenics, i.e. for cooling the superconducting coils, the bus-bars, central support structure, and the thermal shields [8] have to be leak checked and tightness has to be confirmed. The planned duration for this phase is estimated to be 19 weeks

B. Cryogenic tests of the cryostat

As first step in this phase, the helium pipe work outside the cryostat (between cryostat and the last valve of the cryo plant) has to be leak tested, then all helium pipes have to be cleaned and purged and hydraulic flow checks to be performed. Only then the cryostat will be cooled down for the first time, for which a duration of about 3 weeks is expected.

After reaching this important milestone, the three most important operation modes of the cryo plant [9] have to tested:

a) Long stand-by mode. In this mode the cold components are held at a temperature of about 100 K during longer breaks between experimental operation, e.g. weekends.

b) Short stand-by mode: For shorter interruptions of the experimental operation, e.g. during nights, the cold components have to kept at a temperature of about 10 K.

c) Standard mode for operation of Wendelstein 7-X with magnetic fields up to 2.5T. In this mode, the helium inlet temperature into all cold components will be 3.9K.

The planned duration for this whole phase is estimated to be 17 weeks

C. Tests of the normally conducting coils

For the modification of the plasma edge, especially of the magnetic islands which determine the power loading of the divertor plates, two flexible saddle coils systems have been implemented:

Ten so-called control coils are installed behind each of the 10 divertor target plates. These will be used to adjust the plasma strike point and equalize the power load onto the 10 divertor targets [10]. To do so, each coil has a separate power supply to be independent from the others.

In addition, 5 so-called trim coils are assembled outside the cryostat (symmetrically to the midplane) [11]. These, again independently supplied, coils would be able to correct for asymmetries in the stellarator magnetic field, as it could result from an out-of-tolerance assembly of the 70 modular field coils, or for physics studies on the plasma edge. For this, each of the power supplies can provide the maximal coil current with an sweep frequency of up to 10 Hz. This coils system has been fabricated by PPPL, USA within an US DoE-W7-X collaboration.

During this part of the Integrated Commission,, each of the 15 coils will be charged up to their nominal current, before all the coils are charged up to the full current field simultaneously. This phase is expected to take 7 weeks

D. Vacuum tests of the plasma vessel

While the phases 1. – 3. can be performed when there is still assembly work in the plasma vessel going on, for (almost) all following phases the plasma vessel has to be closed. After pumping down the plasma vessel [6], a global leak test of all welds performed on-site on the vessel and the ports will be performed. Next, all the water pipe-work (for cooling in-vessel components and diagnostics) and the helium-pipe-work (for cooling the cryo-pump to be installed later) inside the plasma vessel will be leak-checked. This phase is expected to take 10 weeks

E. Superconducting coils system test

In this phase the superconducting coil system of Wendelstein 7-X, consisting of 50 non-planar coils (NPC) [12] and 20 planar (PC) coils [13], which has been cooled down in phase 3, will be loaded with current for the first time. Due to the symmetry of the device, these 70 coils are from 7 types, i.e. 10 identical coils. All coils of the same type are supplied in series, with one power supply. Each of these seven coils units will be charged up separately to full nominal current. During this process, also the trigger levels of the quench detection units will have to be adjusted, and the magnet safety system will be tested with a fast discharge. During the loading of the coils with currents, the mechanical behavior of the coils will be monitored with strain gauges and contact sensors to detect unexpected movements and deformations. This mechanical behavior has been calculated with FEM modeling, also giving the limits for these movements. The experimental measurements in this commissioning phase will be used to validate the FEM-calculations [14].

At the end of this phase, the interaction of the seven, inductively coupled, coil circuits has to be evaluated and the controllers of the power supplies have to be adjusted. About 7 weeks are expected for these tasks.

F. Preparation for first plasma

While the local commissioning of the diagnostics will be performed in parallel to the previous IC phases, those diagnostics needed to guarantee safe operation (density control, impurity monitor, magnetic diagnostics…) will be tested in this phase of IC. The neutron counter system will have to be calibrated with the final state of the Wendelstein 7-X device to have the neutron scattering environment as close as possible to the final state. A neutron source will be moved along a toroidal rail along the midplane in order to mimic a toroidal line source.

The ECRH system will be installed and aligned before the closure of the plasma vessel in January 2015, and local commissioning will performed during the first phases of IC.

The commissioning of all the other main components, and diagnostics, needed to operate W7-X in OP1.1 and OP 1.2, will be performed in this phase, e.g. baking system, glow discharge system, gas injection system, ….).

Since in a stellarator the magnetic flux surfaces in principle are created by external coils only, these so-called vacuum magnetic flux surfaces (without the influence of the plasma pressure) can be measured without plasma [15]. An electron-beam running toroidally through the vacuum vessel interacts with a fluorescent detector in a fixed plane, thereby creating a 2-dimensional Poincare-Plot of the magnetic flux surface. These measurements show the quality of the vacuum flux surfaces, i.e. deviations of the desired magnetic field, e.g. due to coil positioning being outside the tolerances required.

After this test of the magnetic field quality, the plasma vessel has to be cleaned by baking to 150° C (flattop time of 3 days) and by glow discharge cleaning. After taking the plasma gas fuelling system into operation, the first plasma trials can be perfomed, thereby concluding the integrated commissioning. About 9 weeks in total are expected for the tasks in this last phase.

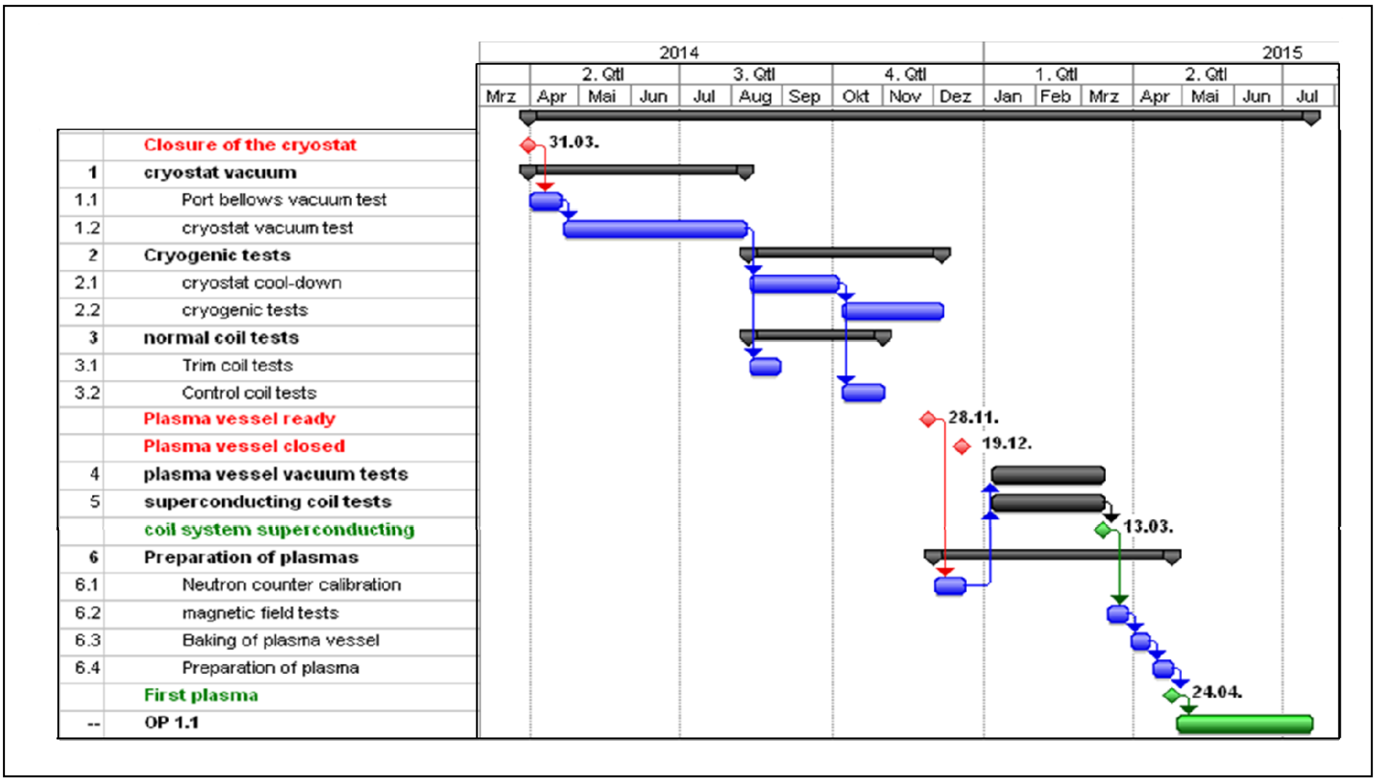

Fig. 1. Draft schedule for the Wendelstein 7-X integrated commissioning schedule (as of June 2013).

IV. Scheduling of the Integrated Commissioning

With the definition of the task to be performed in the different phases (see chapter III), a draft schedule for integrated commissioning can be set up, considering the following boundary conditions:

- Some of the IC phases can be performed in parallel to assembly in the Plasma Vessel and in the Torus Hall. However, two important assembly milestones will tripper the IC: Closure of the cryostat (March 1214) is a pre-condition for phase 1 (Vacuum tests of the cryostat), while phase 4 (Vacuum tests of the plasma vessel) can start only after Closure of the plasma vessel (December 1214).
- Also some of the IC-phases could overlap, i.e. PV vacuum test and cryogenic tests.
- Local commissioning of auxiliary systems required for any of the main systems mentioned above, has to be completed in time. Compatibility of the schedules of all the required systems is being verified at this moment.
- The schedule for integral commissioning will be success-oriented: No major problems will be considered in the schedule. One can expect lots of problems with leaks, cold leaks, insulation problems, and so on, but it's difficult to quantify this beforehand, and to schedule for such events. On the other hand, such a success-oriented schedule also predicts the earliest start of each phase which allows for a reliable planning of all tasks that are required to be ready for this phase.

Following these boundary conditions, the schedule for the integrated commission for op 1.1 has been derived as shown in Fig. 1. There is a clear distinction between phases 1.-3., which require a closure of the cryostat, but still allow for further work in the plasma vessel, and the remaining phases 1.-4.. Phase 6, "Preparation for first plasma" also includes a task, which has to be performed before closing the plasma vessel, namely the neutron counter calibration, and is therefore split in two parts.

V. SUMMARY

In the fall of 2012, a Task force has been established to plan in detail the commission of Wendelstein 7-X. The main phases of integrated commissions have been defined and discussed in an international workshop in January 2013. Now these phases are being worked out in further detail and the interfaces to the auxiliaries are considered. In parallel, also the procedures and forms for the integrated commission are being developed [16].

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