Max-Planck-Institut
für Plasmaphysik

Experience Gained during Fabrication and Construction of Wendelstein 7-X

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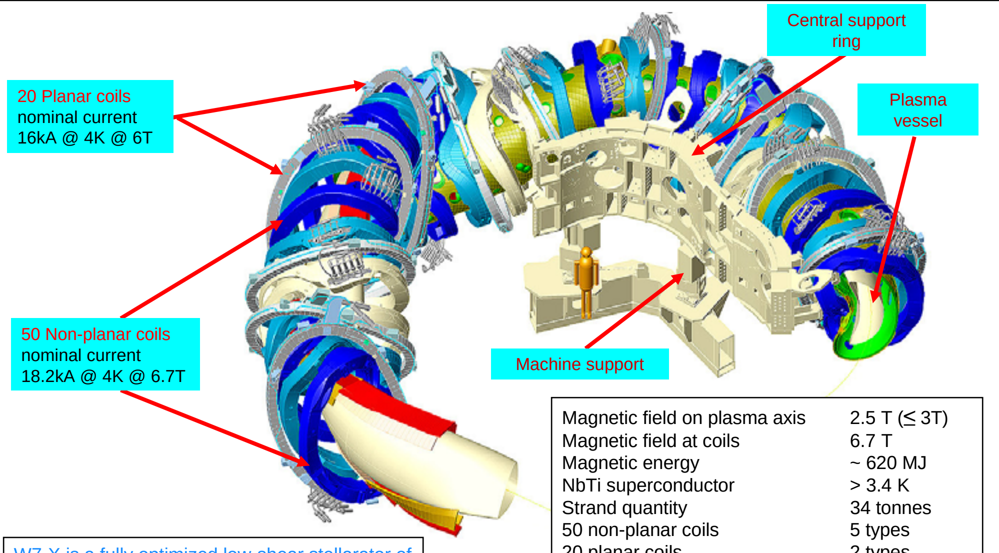
Overview

- Introduction
- Status Design and Fabrication
- Experienced Gained during Design, Fabrication and Testing of Components
- Assembly of the W7-X Stellarator
- Conclusions and Recommendations

Introduction

- W7-X is a fully optimised stellarator from a plasma physics point of view. This has resulted in a rather complex device that poses “interesting” challenges for its detailed engineering as well as for the assembly.
- For diagnostics, cooling, plasma heating and other purposes adequate port space needs to be available. Due to the large number of coils, and their 3-D shape, space for ports is rather restricted. This has led to a large number (299) of mainly relatively small ports, some of which are of complex shape.
- The remaining space in between coils for the mechanical structures is limited and has called for the development of novel designs.

Main Machine Layout

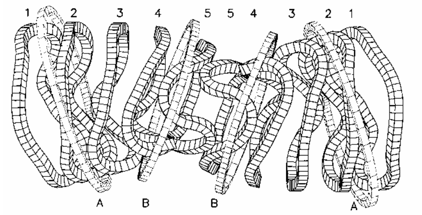


Magnetic field on plasma axis	2.5 T (≤ 3T)
Magnetic field at coils	6.7 T
Magnetic energy	~ 620 MJ
NbTi superconductor	> 3.4 K
Strand quantity	34 tonnes
50 non-planar coils	5 types
20 planar coils	2 types
Cold mass	~ 400 tonnes

W7-X is a fully optimized low-shear stellarator of the Helias type.

W7-X Superconducting Coils

W7-X module assembly (1/5th)



NbTi conductor with Al jacket

Non-planar coil

Planar coil

W7-X Plasma Vessel (Half Module)

Thermal Insulation of the Plasma Vessel

Al-coated glass fibre panel with MLI

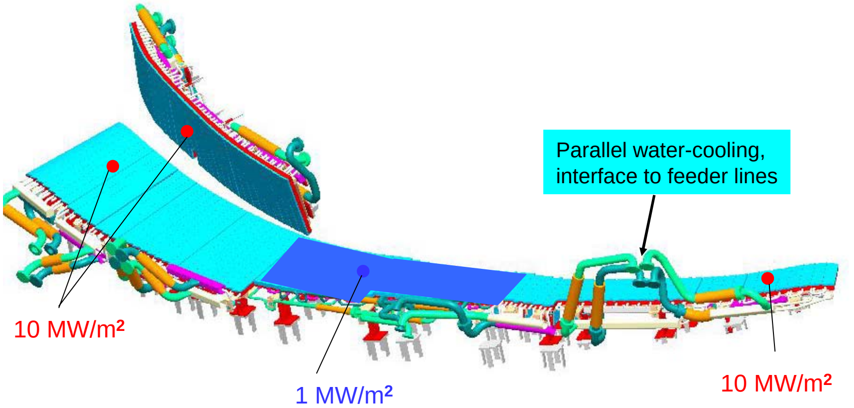
- Cu-braids for connection to He-cooling pipe
- MLI: 20 layers of crinkled, Al-coated Kapton foil

Thermal insulation on a vacuum vessel sector

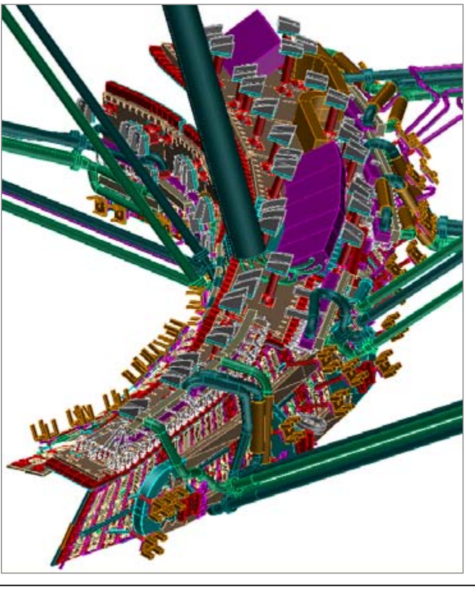
Fabrication of the Outer Vessel

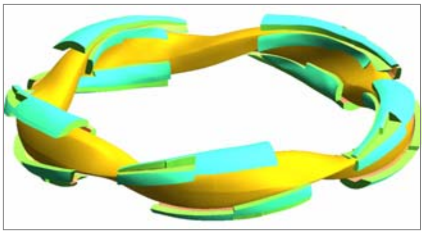
Layout of Divertor

	Target	Baffle
Max. heat flux	10 MW/m²	1 MW/m²
Total area	19 m²	5.6 m²
Target modules	100	20
Target elements	890	240



The Island Divertor





- target elements 10 MW/m²
  CFC sealed on cooled CuCrZr being prepared for testing September 2006
- baffle elements 1 MW/m²
  graphite clamped on CuCrZr

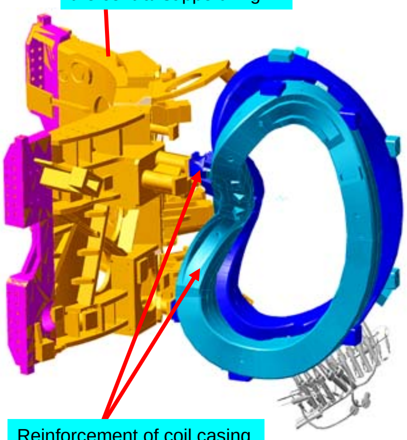
cryopumps
control coils
more than 1.000.000 pieces
more than 100.000 pieces in the shop

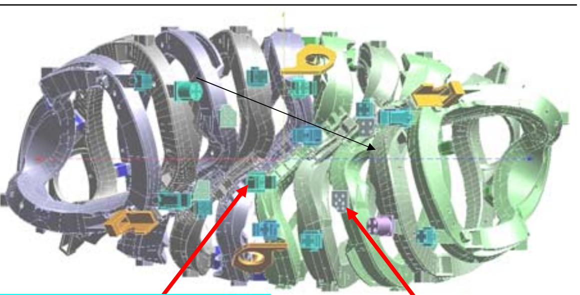
Rectification Requirements

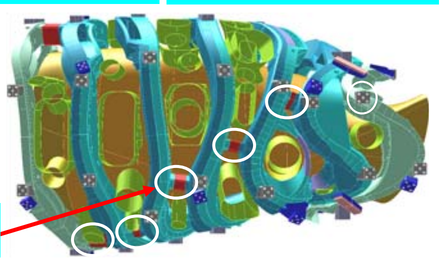
After manufacturing contracts had been placed:

- Thorough FEM re-analyses showed that several structural members required strengthening.
- Acceptance tests on non-planar coils showed, especially after warm-up following cold testing, insufficient voltage stand-off particularly in “Paschen-conditions” (low mbar range). This has required extensive repairs and re-testing, causing considerable delays to the start of machine assembly.
- To minimise the delay, the use of two parallel assembly lines is being considered, which is, in principle, feasible for all assembly operations that take place outside the torus hall.

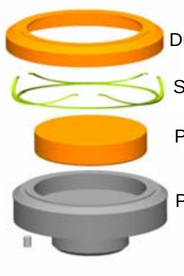
Design Changes after Placing Manufacturing Contracts



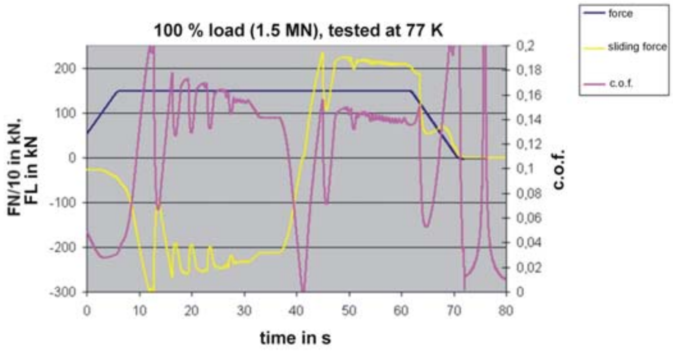




Narrow Support Elements (NSE)

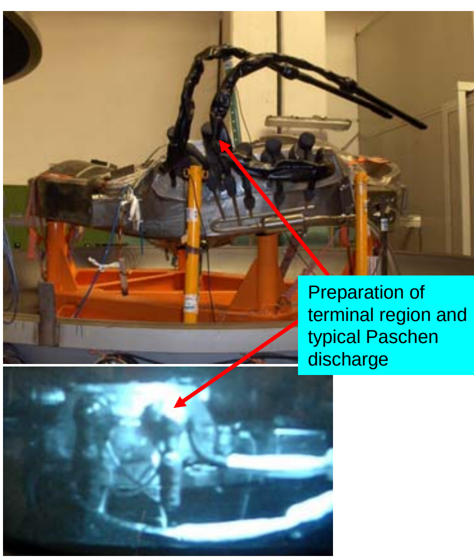


Exploded view on NSE



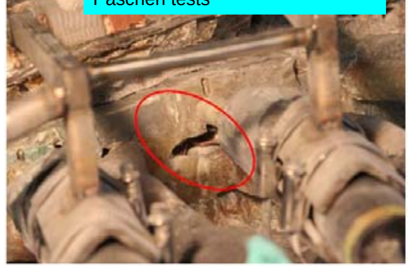
Graph showing stick slip

Paschen Tests

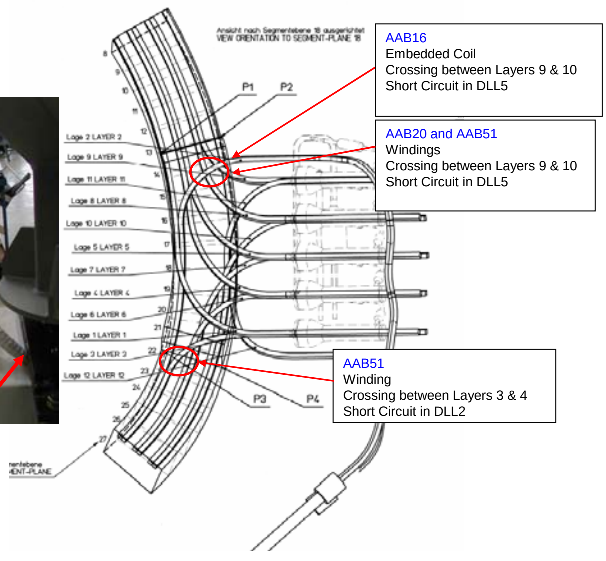


Preparation of terminal region and typical Paschen discharge

Cracks and cavities detected by Paschen tests



Short Circuits in Type 1 & 5 Windings



Locations with high probability of turn-to-turn insulation fault

Pre-assembly - Coil Threading

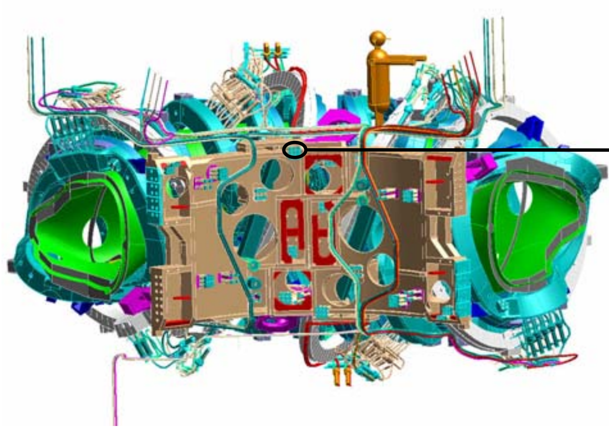
Threading of non-planar coil type 3 across the PV sector.

Non-planar coil type 3 fixed on top by adjustable poles.

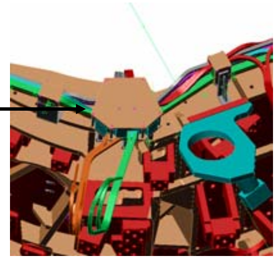
Achieved alignment accuracy is about 1 mm.

Pre-assembly of Modules – Bus-bars

25 single bus-bars manufactured and mechanically mounted by Forschungszentrum Jülich

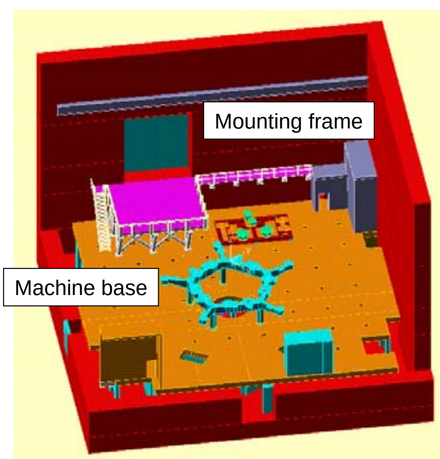


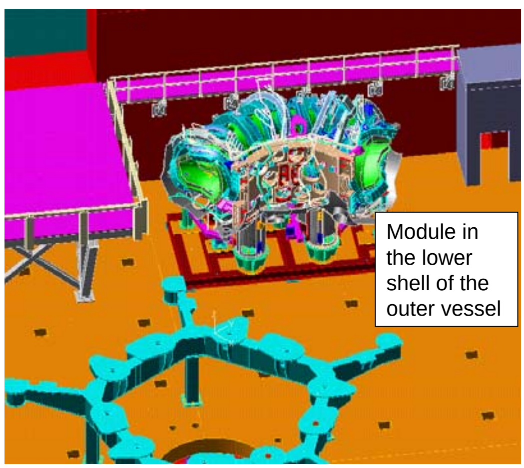
Many different bearings which hold the bus-bars in bundles on the CSS



Final Assembly 1st Stage – Module Completion

Torus hall - 1st ground-floor





Conclusions and Recommendations

Prototype testing of key components, like coils, heavily loaded structural components, etc. is important to demonstrate the principal feasibility of the design. However, for the series production it is often common to introduce, for various reasons, changes with respect to the prototypes, which can reduce the validity of the prototype tests by such an amount, that tests should be repeated. Moreover, in W7-X it has been found necessary to introduce changes after component fabrication had already started.

For a complex first-of-a-kind machine, like the W7-X stellarator, the experience has shown that:

(i) It is essential that at the start of such a project a thorough estimate is made of the manpower requirements for the various stages of the project and that manpower of adequate quality and quantity is recruited.

(ii) It is essential to have adequate expertise within the project team to ensure that the designs elaborated within the project are sound and that design and manufacturing proposals by manufacturers can be thoroughly reviewed by experienced and knowledgeable engineers and scientists. It is of utmost importance that the project is fully aware and understands the risks involved in the fabrication and test procedures that are commonly agreed. Although design reviews with external experts are a useful tool to find weaknesses in designs, in-house expertise is needed to control and supervise the work in-house and in factories.

Conclusions and Recommendations

(iii) The engineering design of main components must have reached a mature status before manufacturing contracts should be placed.

(iv) A thorough investigation of the preparedness of industries for the manufacturing and testing contracts is essential in judging the quality of work that can be expected as well as the expected punctuality of deliveries.

(v) Instrumentation must be qualified for its intended use by testing under simulated conditions.

(vi) Cold testing of coils, at least one or a few of each type, has been found to be mandatory in W7-X. Submitting coils to a few charge/discharge cycles at low temperature has been found useful in detecting manufacturing weaknesses.

(vii) Tests in Paschen conditions after at least one cool-down/warm-up cycle are highly recommended.

(viii) Divertor target elements should be tested in a HHF test facility prior to be assembled into components.

(ix) Significant acceleration measures for machine assembly are possible by parallel work, but incur considerable additional investment costs.

It is recommended that above experience be used for other fusion machines and that in particular cold testing of at least one coil of each type be carried out followed by tests in Paschen conditions.