Max-Planck-Institut für Plasmaphysik, EURATOM Association, Greifswald

WENDELSTEIN 7-X

Final Assessment of Wendelstein 7-X Magnetic Field Perturbations Caused by Construction Asymmetries

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Motivation

Wendelstein 7-X (W7-X), currently under commissioning at the Max-Planck-Institut für Plasmaphysik in Greifswald, Germany, is a continuation of the helical advanced stellarator line, with the final goal to demonstrate the reactor capability of modular stellarators.

Most of the envisaged magnetic configurations of the machine are very sensitive to symmetry breaking perturbations which are the consequence of unavoidable construction displacements and manufacturing tolerances. In order to keep the magnetic configuration of the machine as designed and to confirm compensation capabilities provided in W7-X, the level of error fields needs to be quantified for all possible sources of perturbation. One of such sources is the sequential torus assembly procedure after the placement of magnet system modules on the machine base.

This presentation shows results of the evaluation of the influence of the asymmetrical torus assembly as well as a comparative analysis for different sources of W7-X error fields.

FIG. 1. Wendelstein 7-X, October 2014.

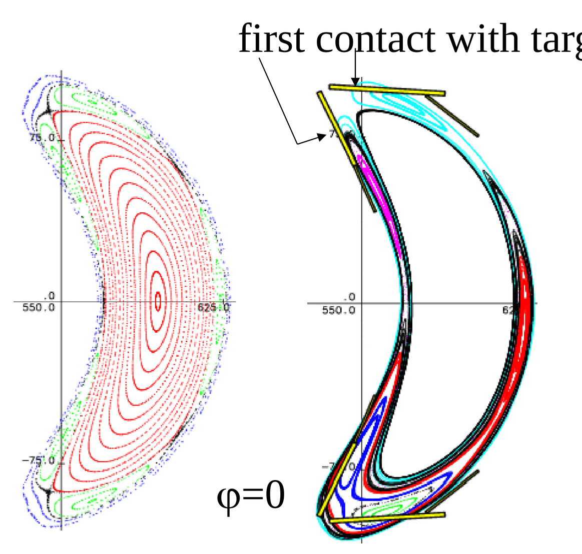
Conclusions

➢ Non-systematical coil deformations due to the sequential torus assembly: maximum WP cross-section displacements < 2 mm in each direction.

➢ Corresponding magnetic field perturbation varies from $1.17\cdot10^{-4}$ to $1.25\cdot10^{-4}$ (dependently on reference operation case), and its maximum value corresponds to the low iota case.

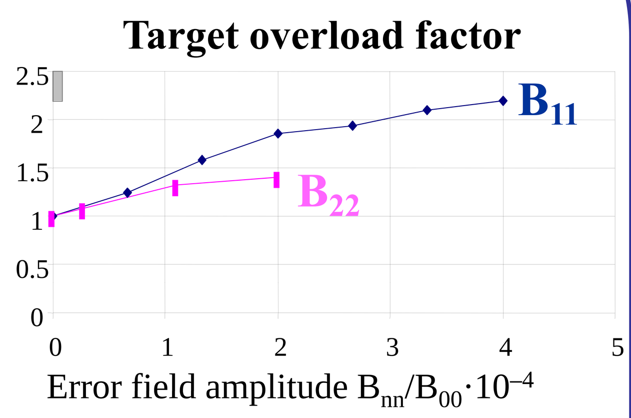
➢ A comparison of the analyzed sources of magnetic field perturbation showed that, even with a safety margin to cover calculation uncertainties and small inaccuracies of the FE models, the corresponding cumulative estimation is $S_{14} < 2\cdot10^{-4}$. This level of the magnetic field perturbation is below the compensation capacities of the installed trim coils and leaves enough potential to eliminate the impacts of possible additional magnetic field perturbations. Hence, the compromise between physical needs and engineering challenges can be successfully met.

Consequences of the magnetic field perturbation



Standard case: no perturbation

Standard case: perturbation $B_{11}/B_0 \sim 2.7\ 10^{-4}$



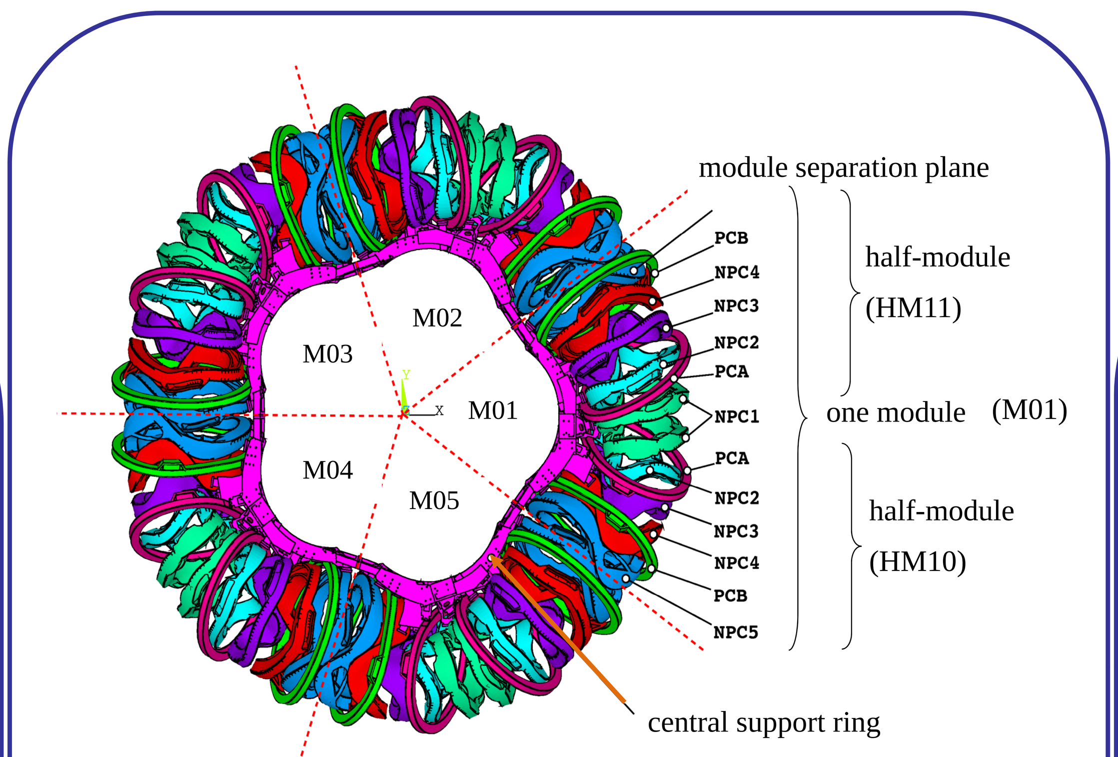


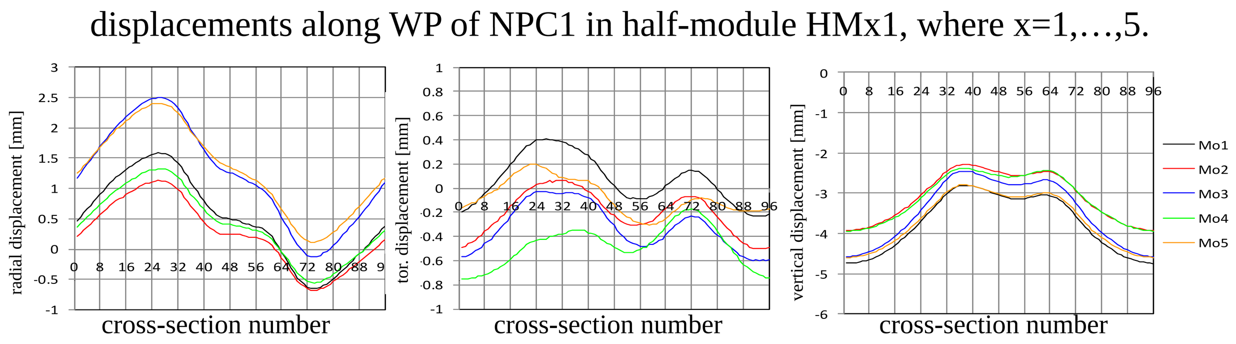
FIG. 2. Wendelstein 7-X magnet system, top view. NPC – non-planar coil, PC – planar coil.

Finite element calculations on deformations of W7-X magnet system and resulting magnetic error field

➢ sequential torus assembly after module positioning

- deviations are partly systematic, max variation in non-symmetrical part: 2.0 mm
- reason of possible magnet system deformation: the sequential loading of the machine base, the connection of adjacent modules to each other and the removal of temporary supports. Deformations are calculated with 360° ABAQUS FE Model, including W7-X machine base.
- simulation of error field: deformed filaments of 70 coils derived from FE analysis served as an input. Corresponding magnetic field perturbation S_{14} varies from 1.17 to $1.25\cdot10^{-4}$, its maximum value is found in low iota case, dominating component B_{11}.

TYPICAL RESULTS OF FE ANALYSIS: displacements along WP of NPC1 in half-module HMx1, where x=1,…,5.



RESULTS OF ERROR FIELD MODELLING:

Reference case	$B_{11}/B_0/10^{-4}$	$B_{22}/B_0/10^{-4}$	$B_{33}/B_0/10^{-4}$	$B_{44}/B_0/10^{-4}$	$S_{14}/10^{-4}$
Standard case	1.20	0.13	0.09	0.02	1.21
Low shear case	1.19	0.10	0.10	0.02	1.20
Inward shifted case	1.19	0.14	0.08	0.02	1.20
Outward shifted case	1.21	0.12	0.09	0.02	1.22
Low mirror case	1.22	0.13	0.08	0.02	1.23
High mirror case	1.18	0.12	0.09	0.02	1.19
Limiter case	1.21	0.11	0.10	0.02	1.22
Low iota case	1.24	0.11	0.08	0.03	1.25
High iota case	1.16	0.14	0.1	0.01	1.17

➢uncertainties of parameters of the magnet system

- deviations are partly systematic, max variation in non-symmetrical part: 1.8 mm
- reason of possible magnet system deformation : variations of coil case thickness, gap sizes and friction factors at various sliding contact support elements, differences in bolt preloads and structure material properties in the five modules. Deformations are calculated with 72° ANSYS Global FE Model .
- simulation of error field: 50 random sets derived from FE analysis of 5 modules were compiled and served as an input.The average value of the magnetic field perturbation S_{14} is $0.2\cdot10^{-4}$, the maximum value $0.32\cdot10^{-4}$, dominating component B_{11}.

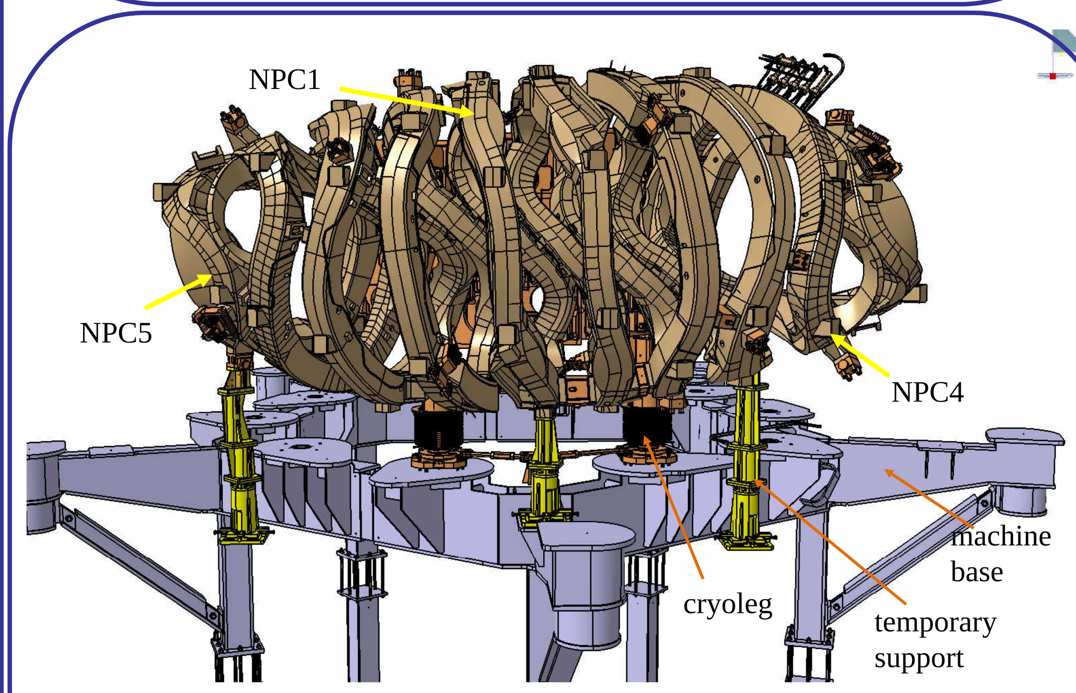


FIG. 3. CATIA view of one module with temporary supports (yellow) under NPC5, NPC1 and NPC4.

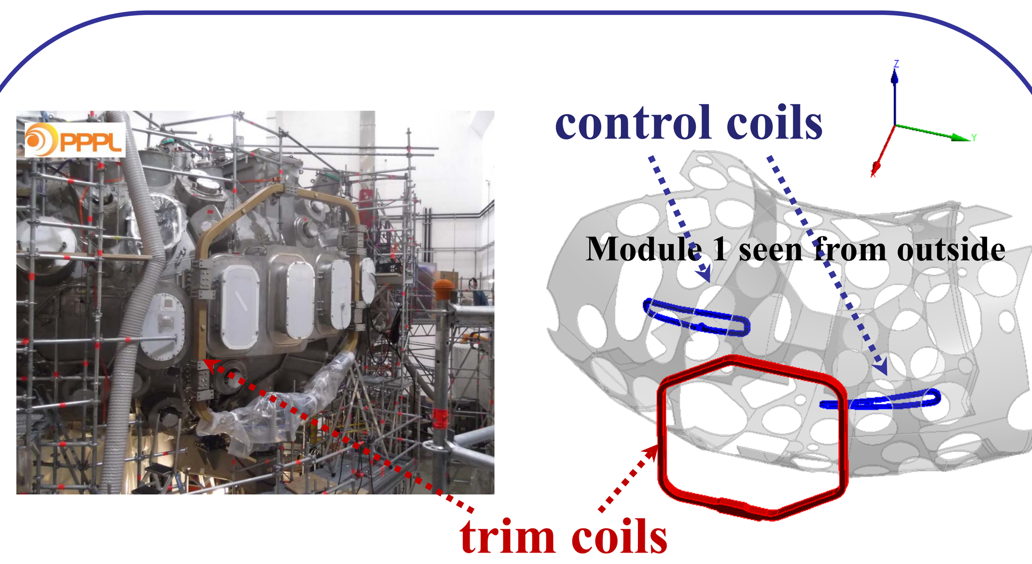


FIG. 4. W7-X trim and control coils.

Trim and control coils compensation capacities

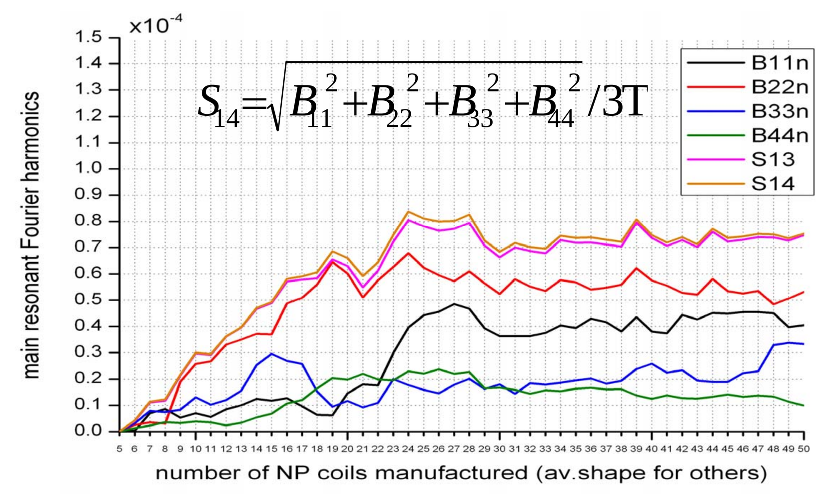
current	B_{11} / 3T / 10^{-4}	B_{22}/ 3T / 10^{-4}	B_{33}/ 3T / 10^{-4}	B_{44}/ 3T / 10^{-4}
trim coils 86.4 kA	6.67	2.67	1.67	0.87
control coils 20 kA	1.07	2.67	3.47	2.93

Comparison of different sources of magnetic field perturbation for standard operation case

➢ manufacturing tolerances

Magnetic field perturbation with 50 as-built non-planar winding packs (NP WPs), real W7-X coil allocation and CAD coil positioning:

$S_{14} \approx 0.75\cdot10^{-4}$ (mostly compensated by optimized module positioning)

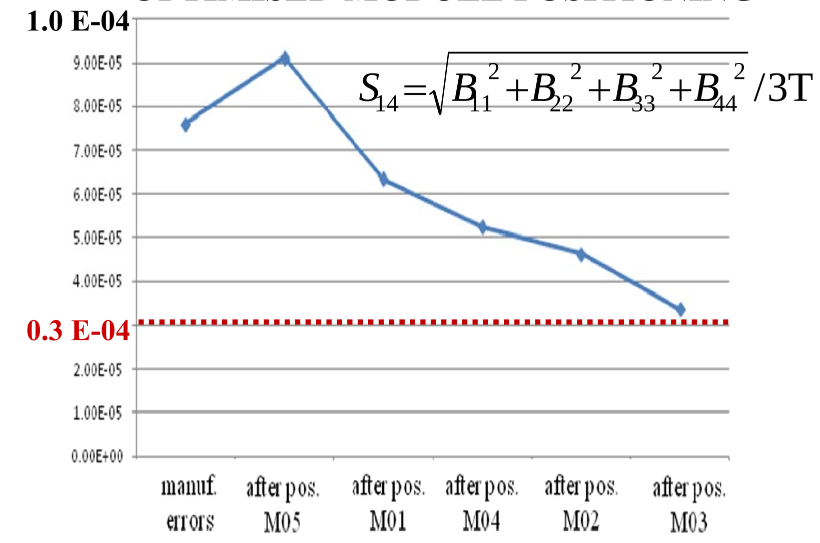


➢end of module positioning

Magnetic field perturbation with 50 as-built NP WPs, real W7-X coil allocation and real W7-X coil positioning:

$S_{14} \approx 0.34\cdot10^{-4}$ (will be compensated by trim coils)

EVOLUTION OF MAGNETIC FIELD PERTURBATION DURING OPTIMISED MODULE POSITIONING



➢ sequential torus assembly after module positioning (mainly removal of temporary supports)

For 50 initially ideal NP WPs with CAD positioning derived from FE analysis deformations contribute to magnetic field perturbation as following:

$S_{14} \approx 1.21\cdot10^{-4}$ (will be compensated by trim coils)

➢uncertainties of parameters of the magnet system (variation of structural characteristics)

For 50 initially ideal NP WPs with CAD positioning derived from FE analysis deformations contribute to magnetic field perturbation as following:

$S_{14} \approx (0.2\text{-}0.3)\cdot10^{-4}$ (will be compensated by trim coils)

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