CHARACTERISTICS OF MAIN CONFIGURATIONS OF WENDELSTEIN 7-X

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For nine main magnetic configurations of Wendelstein 7-X the vacuum magnetic fields, Fourier coefficients, rotational transform profile, magnetic well, helical and effective helical ripple values are computed and results of modeling are available now for general use [1]. The influence of the shaping of the pressure profile on the plasma equilibrium and stability properties has been investigated for the Standard case, <β>=4%. Simulation has shown that the edge region is almost independent of the pressure profile, while plasma properties inside the last closed magnetic surface (LCMS) are considerably changed.
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INTRODUCTION

The coil system of Wendelstein 7-X consists of 50 modular non-planar coils and 20 auxiliary planar, non-circular coils, that is, ten modular and four auxiliary coils for each of the five periods. The coils are superconducting and for the cases considered produce a magnetic field strength of 2.5 T on the magnetic axis. Because of the periodicity and the stellarator symmetry only five modular and two auxiliary coil currents of half a period are free for variations that means that there are seven different currents to produce various magnetic fields. Also there are ten control coils in Wendelstein 7-X (that is two per period or one per half period), but for the cases considered here zero current in the control coils has been assumed. Values of the currents in modular and auxiliary coils for nine main magnetic configurations are shown in the table 1. I_n [MA] is the nominal coil current for the related magnetic field $<B_0>$ = 2.5 T. F_c is the related factor for each coil type given in the table, with an individual coil current $I_c=I_n F_c$. For each of these cases, Poincaré plots in different cross-sections (fig.1), Fourier coefficients, magnetic well, helical and effective helical ripple values as a function of a surface label and contour lines of constant mod B were computed.

Table 1. Current distribution for modular coils 1..5 and planar coils A and B.

	Case	I_n	$< B_0 >$	F_c						
				1	2	3	4	5	A	B
A	Standard case	1.45	2.5	1.0	1.0	1.0	1.0	1.0	0.0	0.0
B	Low ι	1.32	2.5	1.0	1.0	1.0	1.0	1.0	0.25	0.25
C	High ι	1.60	2.5	1.0	1.0	1.0	1.0	1.0	-0.23	-0.23
D	Low mirror	1.49	2.5	0.94	0.98	0.98	1.06	1.06	0.0	0.0
E	High mirror	1.44	2.5	1.08	1.05	1.0	0.95	0.92	0.0	0.0
F	Low shear	1.47	2.5	1.13	1.12	1.05	0.85	0.84	-0.20	0.20
G	Inward shifted	1.47	2.5	0.96	0.95	0.97	1.07	1.08	0.10	-0.20
H	Outward shifted	1.46	2.5	1.04	1.04	1.01	0.96	0.96	-0.14	0.14
I	Limiter	1.43	2.5	1.07	1.1	1.02	0.92	0.89	-0.1	0.2

To model the plasma equilibrium and stability properties the dependency of the pressure profile on a magnetic surface label is used as an input parameter. Three pressure profiles with a different steepness of the gradient have been used to investigate the influence of the pressure profile on the edge region properties and the results of the simulation of plasma stability. It has been shown for the standard case of W7-X with <β>=4% that the form of the pressure profile does not influence on the position of the islands, while plasma properties inside LCMS significantly differ in these cases. Simulation of the stability criteria showed that the most peaked pressure profile was almost unstable against ballooning, Mercier and resistive-interchange modes, while first and second pressure profiles appeared to be stable, with two chains of 5/6 islands inside LCMS in the second case.

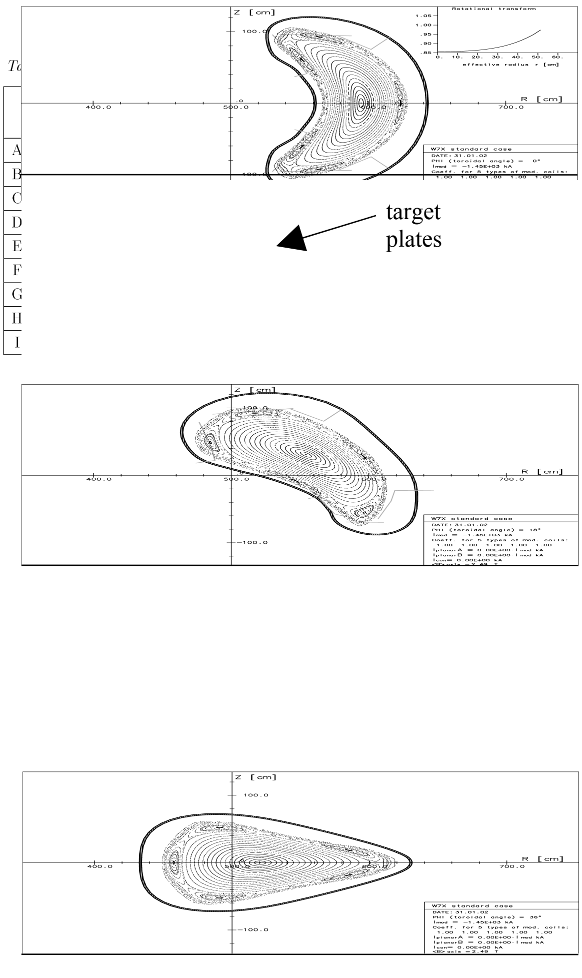

Fig. 1

NUMERICAL CODES SYSTEM AND CALCULATION PROCEDURE

For the computation of the magnetic fields in W7-X the system of numerical codes, described in details in [2], was used. Vacuum magnetic configuration is taken from the Gourdon code, which allows to calculate vacuum magnetic fields from the given plasma currents by using Biot-Savart's law or by the interpolation from the grid points, calculated once from Biot-Savart's law and stored on a grid. The grid covers the plasma region and the boundary region including the first wall and the cell size is small enough to obtain a high accuracy for the magnetic field interpolation. The plasma equilibrium and its corresponding magnetic field is computed with help of NEMEC [3], MFBE [4] and Gourdon code by an iteration procedure. The NEMEC code requires as an input an initial guess of the plasma boundary, given in a Fourier representation, vacuum magnetic configuration and a "mass" profile, which related to the pressure profile through the adiabatic low. Fourier representation of the magnetic field, flux surfaces and the potential on the LCMS computed by NEMEC are the input parameters for the MFBE code, which calculates the magnetic fields outside the LCMS and determine the full magnetic field representation on a grid. The results, obtained by MFBE code, are used in the field line tracing computation in the Gourdon code. If obtained value of the toroidal flux through the LCMS, got by the Gourdon code, does not coincide with it's initial value, used as an input parameter for the NEMEC, we should change the toroidal flux according to the obtained Gourdon computation and repeat the loop of calculations, made by NEMEC, MFBE and Gourdon codes. If the value of the toroidal flux through the LCMS, calculated by the Gourdon code, equals to the value used in the NEMEC input file, we consider the equilibrium computation is finished and can use the results of this calculation in the stability properties simulation, which is done by JMC code [5].

RESULTS OF SIMULATION

Poincaré plots at three cross-sections for the Standard case, which was taken as a relevant case [6] and characterized by the equal currents in the modular coils and zero currents in the planar coils, you can see at the fig. 1. In this case there are 5 large islands ($\iota(a)=1$) outside the last closed magnetic surface (LCMS). Low ι case is characterized by a chain of six islands surrounds the LCMS. In order to obtain four islands in the High ι case the negative currents through the planar coils were added. Low mirror and High mirror cases have another mirror ratio in comparison with a Standard case, that is why they are interested from the neoclassical transport properties point of view. Low shear case has a very gradual dependency of the rotational on a surface label. In the cases G and H the plasma column is radially shifted respectively inward and outward by a vertical magnetic field. In the Limiter case plasma has the largest value of the volume inside the LCMS and target plates plays a role of a limiter. The detailed description of these nine magnetic configurations can be found in [1]. Main characteristic data are summarized in the tabl.2. Here $\iota(0)$ – rotational transform on the magnetic axis; $\iota(a)$ – rotational transform on the LCMS, $\delta V'(r)/V'(0)$ – depth of a magnetic well at different radii, ε_{eff} – effective helical ripple, r – average radius of a magnetic surface, a – average radius of the LCMS.

In the NEMEC free-boundary equilibria simulation, the adiabatic conservation of the mass between neighboring flux surfaces requires for the pressure profile

Table2. Characteristic data of Wendelstein 7-X magnetic configurations.

p(s): $p(s)=m(s)(V'(s))^{-\gamma}$, where s – radial coordinate label of the magnetic surface, $V'(s)$ – differential volume element, m(s) – mass profile, which has to be provided as an input, and $\gamma>=0$ is the adiabatic index, which equaled 2 for considered here calculations [7]. To understand the influence of the pressure profile shaping on the results of computation the standard configuration of W7-X $<\beta>=4\%$ was chosen. Results of simulation are compared for the three different pressure profiles, shown at fig.2.

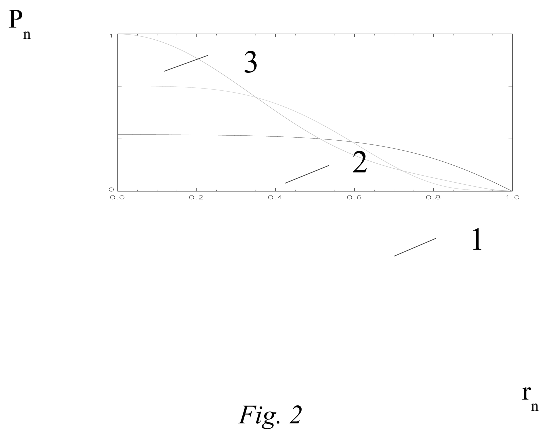

Fig. 2

Figure 3 shows Poincaré plots at the bean-shaped cross-section for the three different pressure profiles. Standard case is characterized by the $\iota=5/5$ in the edge region. The positions of the X- and O-Points of the macroscopic islands are almost unchanged, that is also confirmed by Poincaré plots at other different toroidal angles . In all cases islands are cut by the target plates in the proper position. That means that W7-X is well optimized in a sense of the divertor concept and shaping of the pressure profile does not effect the edge region.

The plasma properties inside LCMS are considerably different for these three cases. The Shafranov shift increases with the increase of the peakedness of the pressure profile. In the set of Fourier harmonics the main ones for each of these three cases are B_{00}, which describes the main magnetic field, B_{11} which represents the helical curvature, B_{10} which describes the toroidal curvature and B_{01} – the mirror field. B_{00} component, which contains the depth of the magnetic well, at the axis changes from 0.96 for the first profile until 0.9 for the third one. Changes in other Fourier components are not so noticeable.

The lower maximum β-value belonging to the first pressure profile leads to a weaker decrease of the rotational transform with increasing β and to a better stability behavior with respect to the Mercier, resistive interchange and ballooning criteria. These criteria are completely satisfied in the cases 1 and 2, while the case 3 was nearly unstable everywhere, that shows that the shape of the pressure profile and the position of the pressure gradient are very important for the stability properties of a configuration. In the case 2 we observed two regions with the 5/6 internal resonances. The small reduction of the average β leaded to the not significant increase of ι and avoid the 5/6 value, showed that these instabilities had a local behavior.

SUMMARY

1.The documentation of the interesting vacuum magnetic configurations has been completed and now is available for the diagnostic purposes [1].

2.Configuration of W7-X is good optimized in a sense of the divertor plates position. Shaping of the pressure profile does not change the position of the islands outside LCMS. In all considered cases islands cut the target plates in the same position.

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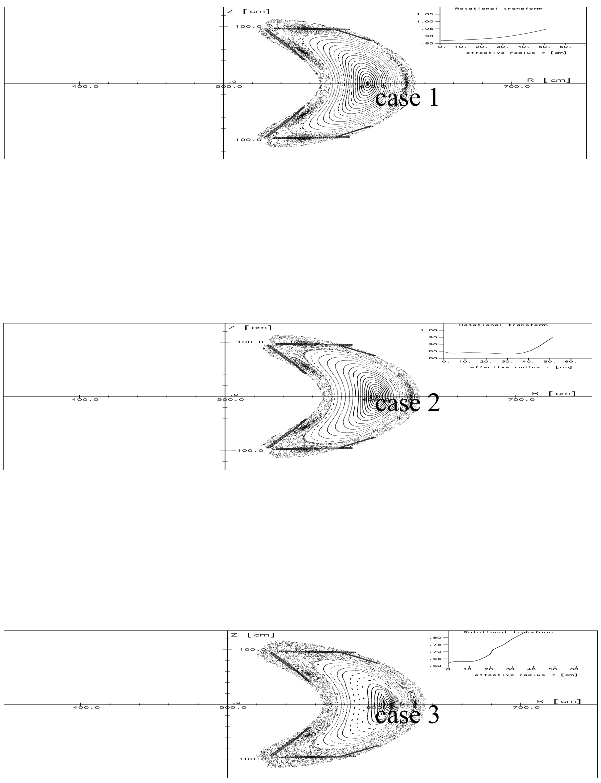

Fig. 3