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MHD Equilibrium Calculations of Wendelstein 7-X

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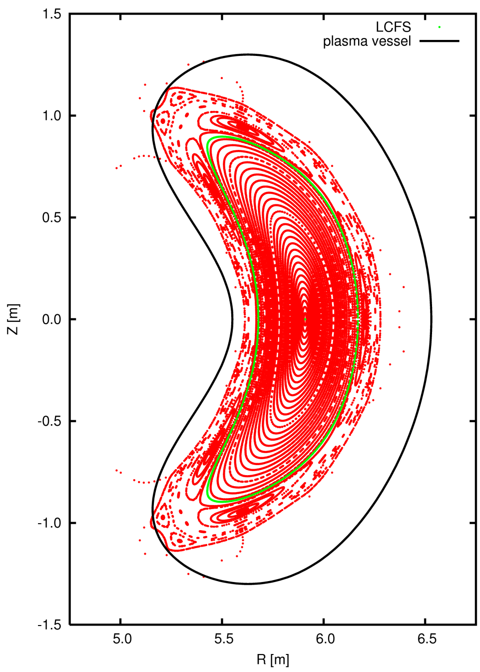
Introduction

Finite-β equilibria of W7-X are investigated by the HINT2 code [1]. HINT2 is the new version of the 3-D MHD-equilibrium code HINT which is not based on the assumption of nested flux surfaces. The study covers two topics. First, we discuss a finite-β equilibrium for the large volume configuration. This consists of a core region with good flux surfaces and a divertor region with the 5/5 island chain. Up to now, the analysis was done using the MFBE [2] and PIES [3] codes. In this study, HINT2 calculations confirm these works and add extensive new information. Special attention is given to the finite pressure effect on the ergodic region. If the ergodic region increases, the effective plasma volume decreases. We note the change of the effective plasma volume due to the presence of finite pressure. Second, we investigate other configurations of W7-X, which have been proposed for experimental scenarios, using the HINT2 code. Interesting configurations are the low- and high-ι configurations. For these cases, the island chain in the divertor region changes to 5/6 (low-ι) and 5/4 (high-ι) islands. We investigate the properties of these configurations with respect to finite-β. Special notice is given to the flux surface properties, the formation of new island chains in the core region and the ergodization of the separatrix and its impact on the effective confinement volume.

Large-Volume configuration

Figure 1 shows the Large-Volume configuration for vacuum and for β~4.36% . Puncture plots of magnetic field lines are plotted at ϕ=0 plane. The profile of the rotational transform ι of this configuration has a low shear, clear flux surfaces in the core and clear 5/5 island structures in the edge region of the vacuum field. Thus, this configuration is sensitive to finite-β effects. The configuration had already been investigated with PIES [3]. Our study finds the following results; (i) the Shafranov shift and the change of ι is very small, (ii) the edge region is ergodized and the last closed flux surface (LCFS) retreats, that is, the plasma volume decreases.



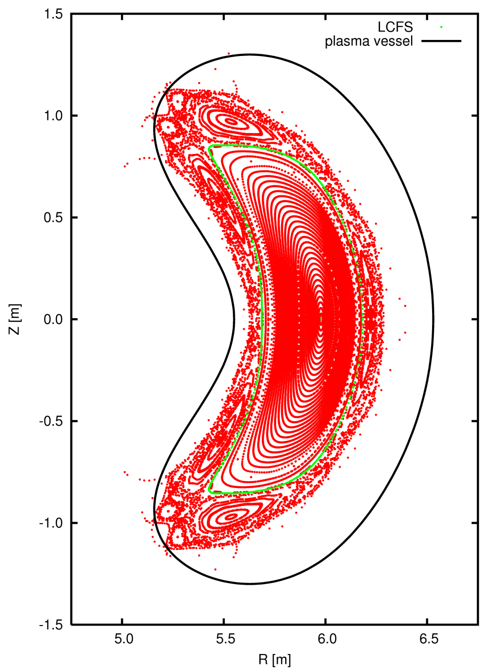


Fig.1 Puncture plots of magnetic field line for vacuum (left) and finite-β (right)

In figs, green dots indicate the LCFS. The initial pressure distribution has been set to $p \propto 7 - 11s + 4s^2$ in this study, where s is the normalized toroidal flux Φ/Φ_{edge}.conforming to the profile used in Ref [3]. For β~4.36%, the edge region is ergodized and 5/5 islands evolve. Thus, the shape of the LCFS is changing according to the change of the edge region. However, clear flux surfaces are maintained inside 5/5 islands and other large resonances dot not appear.

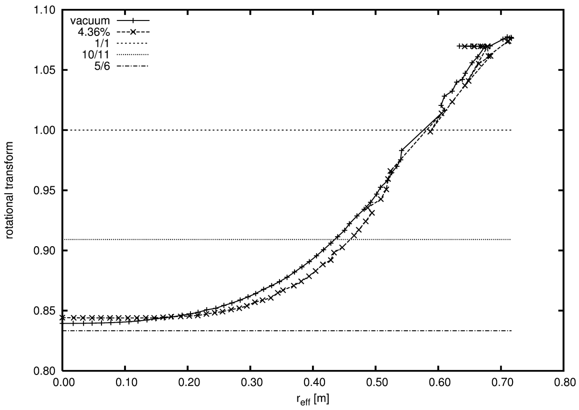


Fig.2 ι-profiles for the large volume configuration

In figure 2, profiles of ι for the vacuum and β~4.36% are plotted, respectively. The rotational transform on the axis increases slightly from 0.8394 to 0.8442 but the change of the profile is very small. This suggests the validity of the stellarator optimization. For β~4.36, no dangerous resonances do appear. However, for higher-β this needs further investigations.

We compare these results to those of PIES. In Ref [3], a finite-β equilibrium is discussed for β~4.16%. Since the finite-β equilibrium in this study is β~4.36%, this comparison is appropriate. In fig.3, puncture plots of magnetic field lines of the axis, the LCFS and the O-points of the 5/5 islands are shown. The magnetic axis shifts about 7cm toward the outside of the torus. According to the Shafranov shift, the shape of flux surfaces elongates slightly and the O-points move due to the elongation. These characteristics are the same as in Ref [3]. However, the LCFS of HINT2 is larger than the one of PIES. In both cases, 10/11 rational surfaces appear inside the LCFS. For PIES, the LCFS locates just outside 10/11 rational surface, whereas for HINT2, some more closed flux surfaces exist outside 10/11 rational surface. The LCFS of HINT2 locates outside 15/16 rational surface. In order to do a detailed comparison, the plasma volume inside the LCFS, V_{LCFS}, is studied. The volume V_{LCFS} for the vacuum is about 33.6m^3 (see Ref [3]). In the HINT2 calculation, V_{LCFS} is decreasing to ~ 31.6m^3, a volume reduction of ~ 6%. However, PIES sees a reduction of V_{LCFS} of ~ 21%, being much larger than the one of HINT2. This is a significant difference in the HINT2 and PIES results. There are some possibility explaining this difference. One is the numerical scheme of both codes. HINT2 is based on the relaxation method and calculations are done on a rectangular grid without the assumption of nested flux surfaces. On the other hand, PIES is an iterative solver on a quasi-flux coordinates system. This suggests differences in the effect of the finite pressure in the ergodic region. Another effect concerns the evolution of the pressure profile. Since HINT2 is based on the relaxation method, the pressure profile evolves during the relaxation process. The relaxed profile is almost the same as the initial profile but nev-

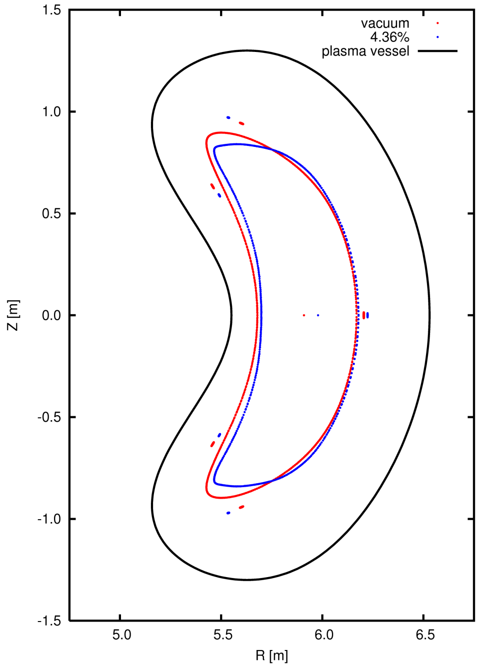


Fig.3 Puncture plots of O-points on 5/5 islands and the LCFS

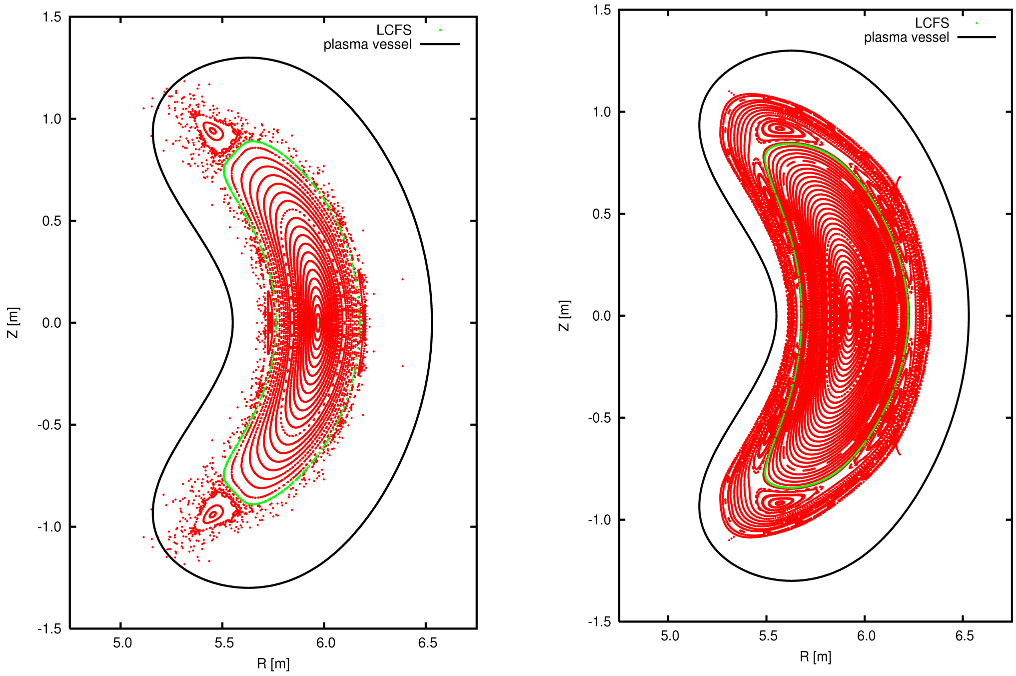


Fig.4 Puncture plots of magnetic field lines for the high-ι (left) and low-ι (right) configurations

ertheless slightly different. In order to confirm such effects more clearly, further studies and benchmarking are necessary.

High- and Low-ι configurations

Figure 4 shows Puncture plots of magnetic field lines for vacuum high- and low-ι configurations, respectively. In fig.5, profiles of ι are shown. The profile of the large volume configuration is also plotted for comparison. The profile forms are similar but ι on axis is different in the three cases. For the high-ι configuration, ι on clear flux surfaces changes between 5/5 and 5/4, and, instead of 5/5 islands for the large volume configuration, 5/4 islands appear in the divertor region. For the low-ι configuration, ι changes between 5/7 and 5/6, and 5/6 islands appear in the divertor region. These configurations are sensitive to β because the magnetic shear is small. In figure 6, finite-β equilibria for high- and low-ι configurations are shown, respectively. The initial pressure profile is the same as that in the case of the large volume configuration. Beta values are 3.36% for high-ι and 3.75% for low-ι, respectively. In the figs, the LCFS and a contour line of the plasma pressure with p/p_0=0.01 are also plotted.

In spite of the lower β when compared to the large volume configuration, the edge region is strongly ergodized in the high-ι configuration. An island chain of the 10/9 resonance evolves, where-

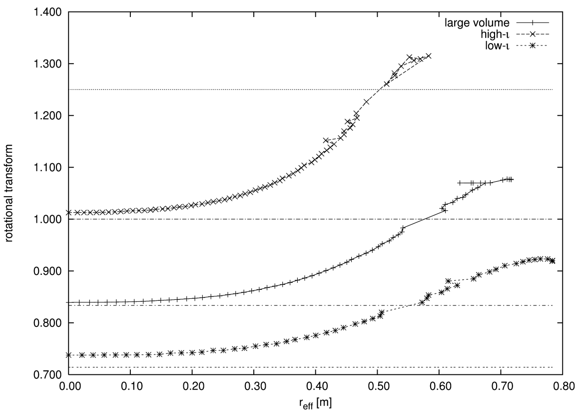


Fig.5 ι-profiles for the high-ι and low-ι configuration. ι-profile for the large volume configuration is also plotted for comparison.

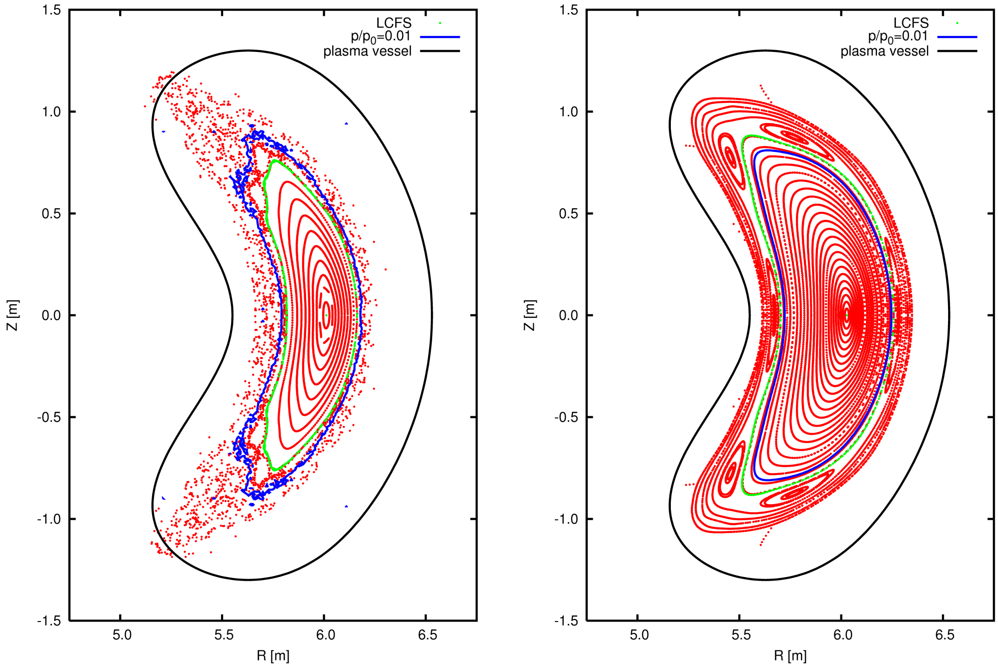


Fig.6 Puncture plots of finite-β field lines for high-ι (left) and low-ι (right) configurations

as the 5/4 islands disappear due to ergodization. The LCFS is found near the 15/14 rational surface resulting in a reduction of the volume V_{LCFS} of about 30%. However, finite pressure still exists in the ergodic region outside the 10/9 islands. The plasma volume inside the contour lines with p/p_0=0.01 reduces slightly compared to vacuum, but it is still larger than V_{LCFS}. Plasma pressure can be sustained in such regions, since the connection length of field lines is very long. This suggests one possibility that ergodic field lines can sustain the plasma pressure on themselves.

For the low-ι configuration, clear flux surfaces exist in the core region and the ergodization at the edge is small. Since a clear separatrix structure appears and since it does not change with finite-β, the LCFS does not change, too. However, the phase of 5/6 islands changes. Pressure-induced islands overlap with the vacuum islands and grow larger than the vacuum islands. This suggests the possibility that the vacuum islands vanish when vacuum and pressure-induced islands balance each other.

Summary

MHD equilibria of Wendelstein 7-X are investigated by 3D MHD equilibrium calculation code HINT2. For the large-volume configuration, the shape of flux surfaces changes and field lines in the edge are ergodized due to finite-β effects. We compare this equilibrium to PIES results. The results are similar but differ in details. High- and low-ι configuration are also studied at intermediate β. For the high-ι configuration, the edge is strongly ergodized. On the other hand, for low-ι configuration, the ergodization in the edge is small but the phase of the 5/6 islands changes.

[1] Y. Suzuki "Development and Applications of HINT2 code to Helical System Plasmas" in Joint Meeting of 2nd 21COE Plasma Theory Workshop and US-Japan JIFT Workshop on "Progress of Theoretical Analyses in Three-dimensional Configurations", submitted to Nuclear Fusion

[2] E. Strumberger, Nucl. Fusion **37** (1997) 19

[3] M. Drevlak, *et al*. Nucl. Fusion **45** (2005) 731