Transport modelling of operational scenarios in W7-X

Y. Turkin, J. Geiger, H. Maaßberg, C.D. Beidler, N.B. Marushchenko
Max-Planck-Institut für Plasmaphysik, 17491 Greifswald, Germany

Introduction. The flexibility of the W7-X magnetic coil system allows the creation of magnetic configurations with different confinement properties and bootstrap current values [1]. The bootstrap current alters the rotational transform, affects the plasma-edge magnetic structure, and thus endangers proper functioning of the island divertor. The bootstrap current is not needed for producing the magnetic field in W7-X and must be avoided by using appropriate magnetic configurations or compensated by current drive (ECCD or NBCD). In this contribution two types of discharge scenarios for W7-X are studied: the scenarios of the first type are the scenarios with vanishing (less than 8kA) bootstrap current and the second one are the scenarios with bootstrap current and compensating counter-ECCD. Transport simulations have been done using the 1-D transport code NTSS [2], which consists of particle and power balance equations, diffusion equations for the radial electric field and the plasma current. The magnetic configuration and related neoclassical diffusion coefficients are recalculated self-consistently with transport modelling by VMEC[3] and DKES[4] codes correspondingly. Power deposition and current drive profiles are calculated by ECRH code TRAVIS [5] coupled with the transport code NTSS.

High density O2-mode heating scenarios without ECCD and small bootstrap current. The W7-X ECRH system with total power of 10 MW is the only heating source for the quasi-stationary operation of W7-X. At low to moderate densities, heating is with the 2nd harmonic of the extraordinary mode (X2-mode at 140GHz and B=2.5T). High-density regimes above the X2-cut-off density, i.e. from $1.2\cdot10^{20}m^{-3}$ to $2\text{-}2.1\cdot10^{20}m^{-3}$, are accessible using the 2nd harmonic of the ordinary mode (O2-mode). The O2-mode heating scheme at high densities cannot provide enough ECCD to balance the bootstrap current because of low ECCD efficiency. Below three discharge scenarios with small or even vanishing bootstrap current for the 5MW ECRH plasma in the following magnetic configurations are analyzed: 1) the *standard edge iota* ι_a =5/5 with the mirror term b_{01}=0.11; 2) the *high edge iota* ι_a =5/4 with b_{01}=0.04; 3) the *low edge iota* ι_a =5/6 with b_{01}=0.24.

The simulation results of the discharge scenario for the *standard edge iota* case are shown in Fig 1. The initial vacuum magnetic field has been chosen in such a way to provide central O2-mode power deposition for the target plasma at the density $n_0=1.5\cdot10^{20}m^{-3}$.

Initial plasma of density $0.3{\cdot}10^{20}m^{-3}$ is heated by 5MW X2-mode with strongly off-axis deposition. With increasing $<\beta>$ the magnetic field at the axis is reduced from the vacuum value 2.64T to 2.5T due to the Shafranov shift and plasma diamagnetism. The final bootstrap current is 3.4kA and does not exceed value of 6kA for smaller densities at which X2-mode heating is used. The final $<\beta>$=3.1% and τ_E=0.605s. For additional details of the results shown here see ref. [1].

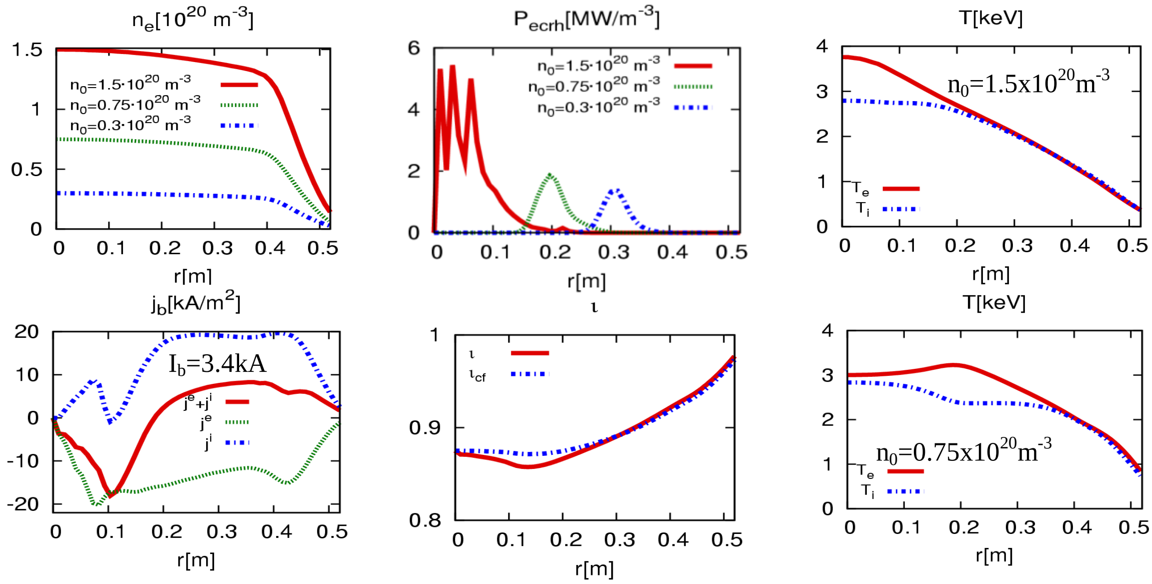

Fig. 1. Standard edge iota(~1) case; b_{01}=0.11. Top row: density profiles (left), the ECRH power deposition profiles (center), the *Te* and *Ti* profiles for the O2 case with $n_0=1.5\cdot10^{20}m^{-3}$ (right). Bottom row: the bootstrap current density profiles for the O2 case (left), the corresponding ι profile (center), and the *Te* and *Ti* profiles for the X2 case with $n_0=0.75\cdot10^{20}m^{-3}$ (right)

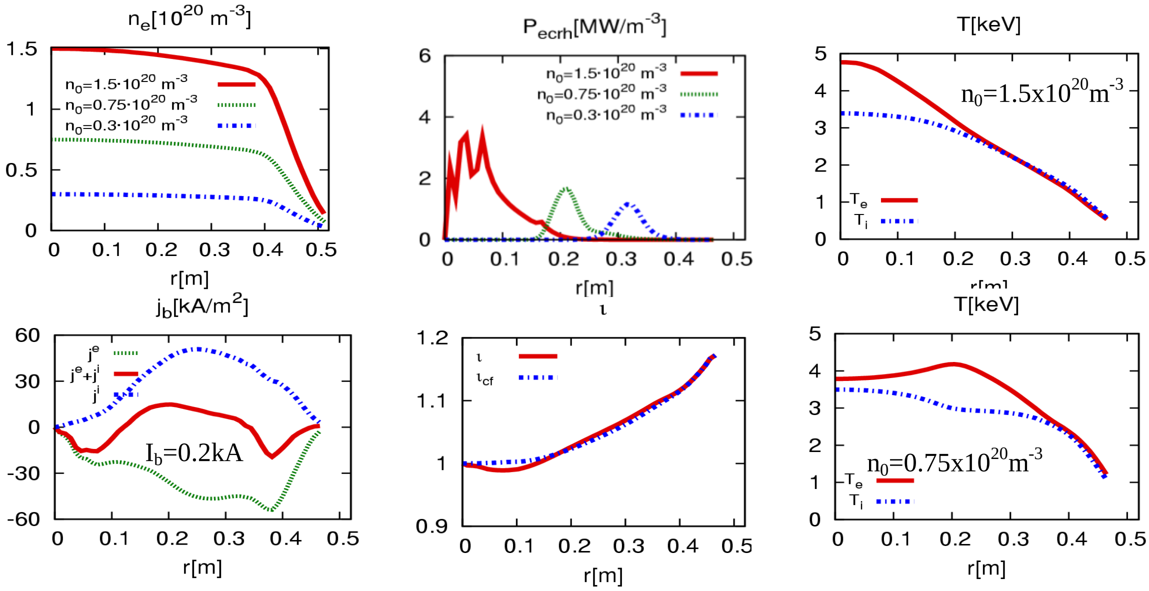

Fig. 2. High edge iota (>1) case; b_{01}=0.04. Top row: density profiles (left), the ECRH power deposition profiles (center), the *Te* and *Ti* profiles for the O2 case with $n_0=1.5\cdot10^{20}m^{-3}$ (right). Bottom row: the bootstrap current density profiles for the O2 case (left), the corresponding ι profile (center), and the *Te* and *Ti* profiles for the X2 case with $n_0=0.75\cdot10^{20}m^{-3}$ (right)

The simulation results of the discharge scenario for the *high edge iota* case are shown in Fig 2. The modelling procedure was the same as for the previous case. The final bootstrap current is 0.2kA and does not exceed value of 8kA for smaller densities. The final $<\beta>$=3.3% and τ_E =0.6s.

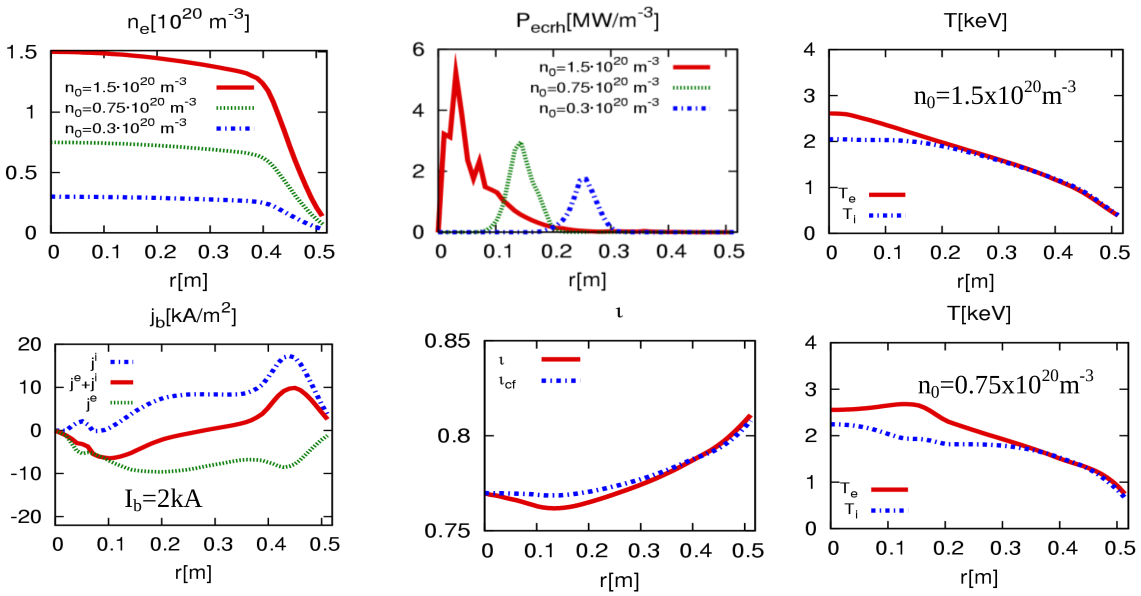

Fig. 3. Low edge iota (<1) case; b_{01}=0.24. Top row: density profiles (left), the ECRH power deposition profiles (center), the Te and Ti profiles for the O2 case with n_0=1.5 $\cdot10^{20}m^{-3}$ (right). Bottom row: the bootstrap current density profiles for the O2 case (left), the corresponding ι profile (center), and the Te and Ti profiles for the X2 case with n_0=0.75 $\cdot10^{20}m^{-3}$ (right)

The simulation results of the discharge scenario for the *low edge iota* case are shown in Fig 3. The same modelling procedure as for the previous cases has been used. The final bootstrap current is 2kA and does not exceed value of 5kA for smaller densities. The final temperatures is much smaller than that in the previous cases, $<\beta>$=3.15% and τ_E=0.46s. The rather large $<\beta>$ at smaller temperature is due to the reduced average magnetic field.

X2-mode heating scenarios with ECCD for compensating bootstrap current.

The *standard magnetic configuration* with identical currents in the modular coils and standard edge ι_a=5/5 has been used for the modelling of bootstrap current compensation by the counter ECCD. This configuration is characterized by improved neoclassical confinement but rather large bootstrap current and has moderate mirror term b_{01}=0.04. The simulation results of 7MW ECRH plasma with the density n_0=0.67 $\cdot10^{20}m^{-3}$ in this configuration are shown in Fig. 4. The heating position, heating power, and the plasma density have been adjusted during iteration steps in order to create a scenario with vanishing total current and with a reduction of ι limited to the value of 0.4 (to prevent a strong increase of the bootstrap current that scales as $1/\iota$ at low collisionalities). The bootstrap current of value 82kA is compensated by ECCD. <β>=2.2% and τ_E=0.34s is obtained.

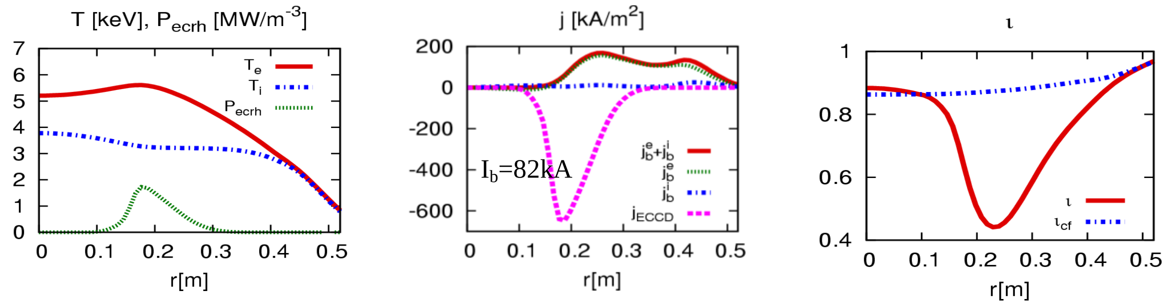

Fig. 4. Plasma profile in standard magnetic configuration: P=7MW; n_0=0.67 ·$10^{20}$$m^{-3}$; <$\beta$>=2.2%. *Te* and *Ti* profiles with the off-axis ECRH power deposition (left); the current density profiles, j_{ECCD} and bootstrap current j_b (center); and the ι profile (right).

The example of the on-axis heating scenario is shown in Fig. 5. In this case the rotational transform hole (ι = 0) is formed, where no flux surfaces exist [1]. To model this situation, artificially large transport coefficients are assumed within the central region where a flat ECCD leads to (ι = 0. Resulting ECCD with -72.4kA compensates 67.7kA of the bootstrap current; <β>=1.63% and τ_E=0.325s.

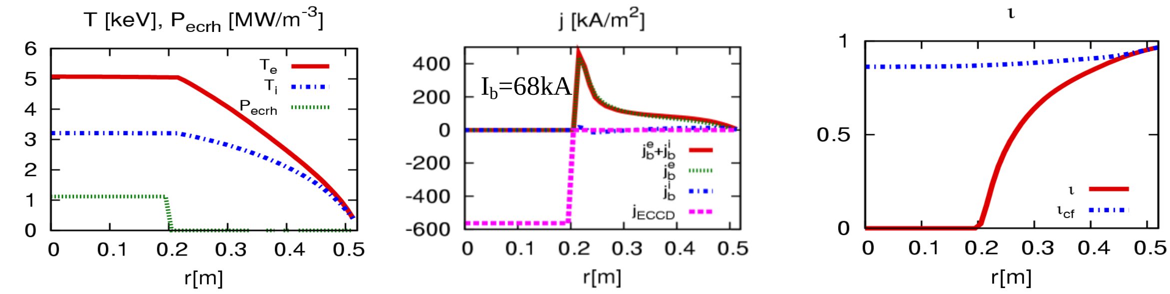

Fig. 5. Plasma profile in standard magnetic configuration: P=5MW; n_0=0.5 ·$10^{20}$$m^{-3}$; <$\beta$>=1.63%. *Te* and *Ti* profiles with the on-axis ECRH power deposition (left); the current density profiles, j_{ECCD} and bootstrap current j_b (center); and the ι profile (right)

Summary. The currentless scenarios are more attractive for quasi-stationary operation with the island divertor. The clear disadvantage of the strong counter-ECCD schemes is the significantly reduced plasma performance since they are restricted to low densities (~$10^{20}$$m^{-3}$); no access to high densities with ECCD in O2-mode exists. These scenarios are very sensitive to the current density, the plasma density and temperature profiles. However such scenarios should be investigated within the W7-X scientific program.

1. J. Geiger. *Physics in the magnetic configuration space of Wendelstein 7-X*.. This conference.
2. Y. Turkin, C.D. Beidler, H. Maaßberg *at al.*, Phys. Plasmas **18**,022505 (2011).
3. S.P. Hirshman, W.I. van Rij, and P. Merkel, Comp. Phys. Comm. 43, 143 (1986).
4. W.I. van Rij and S.P. Hirshman, Phys. Fluids B 1, 563 (1989).
5. N.B. Marushchenko, Y. Turkin, and H. Maaßberg, Comp. Phys. Comm. **185**, 165 (2014).