Fusion Power and Bootstrap Current Fraction Simulations of the PPCS DEMO Designs Using BALDUR Code

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An investigation of fusion power and bootstrap current fraction of the European Power Plant Conceptual Study (PPCS) DEMO designs is carried out using BALDUR integrated predictive modelling code [1]. The PPCS summarizes the conceptual designs for commercial fusion power plants [2]. In this work, a combination of anomalous transport model (MMM95) and neoclassical transport model (NCLASS) is used to simulate core transport. The boundary condition of the plasma is set at the top of the pedestal, which is described by the pedestal model based on normalized pressure width model [3]. The simulations aim to study the performance of the five PPCS models, i.e. PPCS A, AB, B, C and D. It was found that as the NBI heating power is changed from 20–90 MW, the fusion power varies in the range of 5.1–5.7 GW for models A and AB, 4.1–4.4 GW for model B, 0.8–1.4 GW for model C and 0.02–0.4 GW for model D. The bootstrap current fractions from the simulations are 0.40-0.41 for models A and AB, 0.38-0.39 for model B, 0.39-0.43 for model C and 0.12-0.42 for model D. Model D yields the lowest performance and is found to be in *L*-mode when NBI heating is low enough. The optimum point for fusion power under these parameters will be discussed.

Simulation Method

BALDUR code: This study investigates the time evolution of plasma profiles including electron and ion temperatures, deuterium, tritium, helium and impurity densities, magnetic q, neutrals, and fast ions. These time-evolving profiles are computed in BALDUR integrated predictive modeling code by combining the effects of many physical processes self-consistently, including the effects of transport, plasma heating, particle influx, boundary conditions, the plasma equilibrium shape, and sawtooth oscillations. Fusion heating and helium ash accumulation are also computed self-consistently. BALDUR simulations have been intensively compared against various plasma experiments, which yield an overall agreement with 10% relative RMS deviation [4,5]. In BALDUR code, fusion heating power is determined by the nuclear reaction rates and a Fokker Planck package to compute the slowing down spectrum of fast alpha particles on each flux surface in the plasma. The fusion heating component of the BALDUR code also computes the rate of the production of thermal helium ions and the rate of the depletion of deuterium and tritium ions within the plasma core.

Multimode model: MMM95 model [6] is a linear combination of theory-based transport models which consists of the Weiland model for the ion temperature gradient (ITG) and trapped electron modes (TEM) [7], the Guzdar–Drake model for drift-resistive ballooning modes (RB) [8], as well as a smaller contribution from kinetic ballooning modes (KB). All the anomalous transport contributions to the MMM95 transport model are multiplied by κ^{-4}, since the models were originally derived for circular plasmas.

Simulation results and discussion

The engineering parameters for the simulations are shown in table 1.

Table 1 Main parameters of the PPCS models [2]

Parameter	***A***	***AB***	***B***	***C***	***D***
Fusion power (GW)	5.00	4.29	3.60	3.4	2.53
Aspect ratio	3.0	3.0	3.0	3.0	3.0
Elongation (95% flux)	1.7	1.7	1.7	1.9	1.9
Triangularity (95% flux)	0.25	0.27	0.25	0.47	0.47
Major radius (m)	9.55	9.56	8.6	7.5	6.1
TF on axis (T)	7.0	6.7	6.9	6.0	5.6
Plasma current (MA)	30.5	30.0	28.0	20.1	14.1
Bootstrap fraction	0.45	0.43	0.43	0.63	0.76

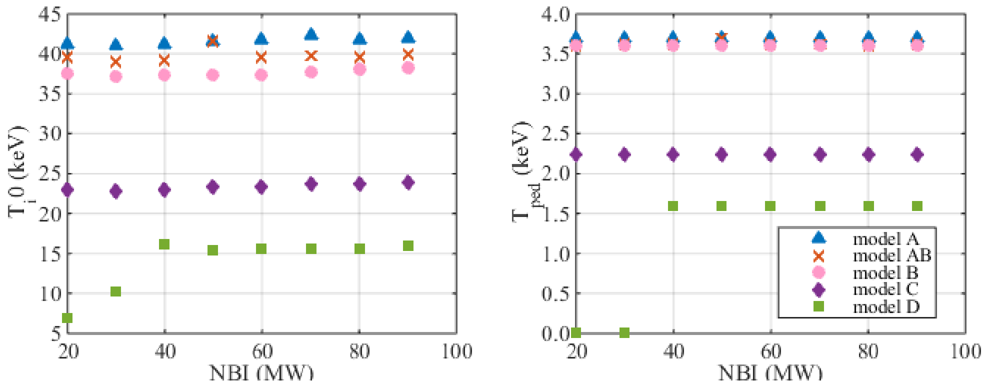

Figure 1 Ion temperature at the center (left) and at the pedestal (right) are plotted at functions of NBI heating.

The ion temperatures at plasma center and pedestal as functions of the NBI heating power between 20–90 MW are shown in figure 1. The results from these simulations show that the central ion temperature for model A is 41.6±0.4 keV, AB 39.8±0.8 keV, B 37.6±0.4 keV, C 23.4±0.4 keV and D 13.9±3.4 keV. The mean pedestal temperatures in H-mode are 3.70, 3.61, 3.60, 3.24 and 1.59 keV for model A, AB, B, C and D respectively. Model D with NBI heating 20-30 MW is found to be in *L*-mode (T_{ped} is 0).

The fusion power and the bootstrap fraction as functions of the NBI heating power between 20–90 MW are shown in figure 2. The fusion power varies in the range of 5.1–5.7 GW for A and AB, 4.1–4.4 GW for B, 0.8–1.4 GW for C and 0.02–0.4 GW for D. The bootstrap current fractions from the simulations are 0.40-0.41 for models A and AB, 0.38-0.39 for model B, 0.39-0.43 for model C and 0.12-0.42 for model D. Model D yields the lowest performance and is found to be in *L*-mode when NBI heating is 30 or lower MW.

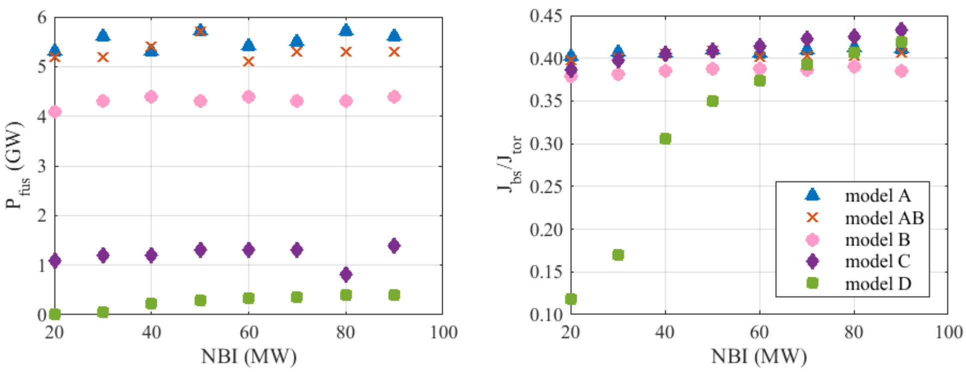

Figure 2 Fusion power (left) and bootstrap current fraction (right) are plotted as functions of NBI heating power.

The details of the ion and electron thermal diffusivities from the simulations for PPCS-A model are shown in figure 3 (1) and 3 (2), respectively. The Multi-mode transport model consists of the ion temperature gradient (ITG), the drift-resistive ballooning modes (RB), the kinetic ballooning modes (KB) and the neoclassical transport. It can be seen that for both panels, the ITG mode is the main contribution to most of the plasma region, but only the ion thermal diffusivity are dominant in small regions close to the edge. The details of the hydrogenic particle diffusion coefficients and the impurity particle diffusion coefficients from the simulation using MMM95 model and PPCS model A are shown in figure 3 (3) and 3 (4), respectively. It can be seen that for the hydrogenic particle diffusion coefficients, the KB mode at the core plasma are dominant and this mode is the main contribution to most of the plasma. The ITG mode only exists as a small region near the edge of plasma. In addition, the

RB mode is monotonically growing from the center to the edge of the plasma for both of the hydrogenic and the impurity particle diffusion coefficients. For the impurity particle diffusion coefficients, the KB mode is the main contribution to most of the plasma region and also found that the ITG mode is dominant at the edge and the minor radius at 1.0 – 2.5 m.

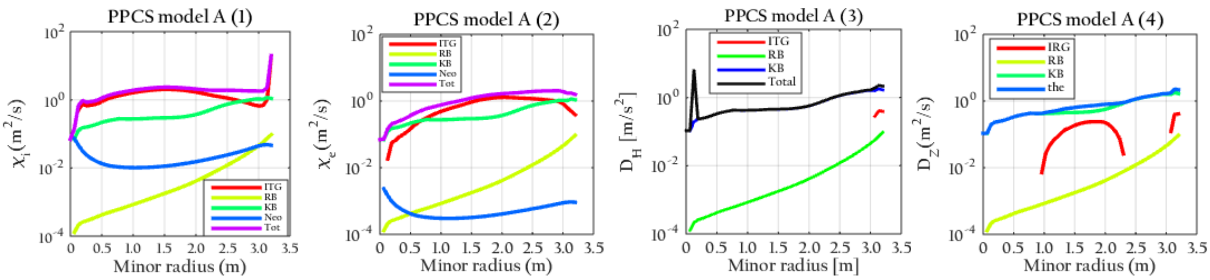

Figure 3 The PPCS model A profiles of the ion thermal diffusivity (1), the electron thermal diffusivity (2), the hydrogenic particle diffusion coefficients (3) and the impurity particle diffusion coefficients (4) with NBI 40MW as functions of minor radius.

Conclusion

The performance of the five PPCS models is evaluated using the 1.5D BALDUR integrated predictive modelling code. It was found that as the NBI heating power is changed from 20–90 MW, all the models are found to be in H-mode and Model D yields the lowest performance and is found to be in *L*-mode when NBI heating is 30 MW or lower.

Acknowledgments

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