MF-O29 AAPPS-DPP2019

3rd Asia-Pacific Conference on Plasma Physics, 4-8,11.2019, Hefei, China

Progress in Design of CFETR Plasma

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The Chinese Fusion Engineering Testing Reactor (CFETR), complementing the ITER facility, is aiming to demonstrate fusion energy production from 200 MW to eventually1~1.5 GW (DEMO relevant power level), to be operated with a high duty factor of 0.3–0.5 and with tritium breeding ratio larger than 1 [1]. Engineering design requires strong coupling with physics. Plasma design has been providing reference scenarios for engineering design and miscellaneous advanced physics research such as evolution of energetic particle, fueling and particle control, divertor design, simulation of full discharges and et al. The key challenge in plasma design to meet the missions of the CFETR is to prepare scenarios for both steady-state and hybrid-mode operations for 1 GW fusion power with the same heating and current drive (H&CD) facilities and with the total H&CD power constrained by engineering design. In this talk the modeling method, the features of scenarios, plasma transport and H&CD design are presented as well as the compatibility with the engineering design. The issues for advanced research are discussed.

Starting from the 0D concept design, plasma design has advanced to the core-pedestal coupled integrated modeling simulation in which the theory-based turbulent transport model TGLF is used for transport in the core and the EPED-1 model is used for the pedestal structure. The preliminary results could be found in Ref. [1], which describes the starting point of the design and new results are given in this talk (see Table I for some 0D parameters).

For the hybrid-mode operation, a conventional H-mode plasma has been obtained to support the flat top phase with some finite Ohmic current. The simulations scanning density at pedestal show that a high Greenwald fraction is necessary to achieve 1 GW fusion power, which is adverse for CD. Thus high CD efficiencies are pursued by locating the CDs to be in the deep core region. Particularly, helicon waves are used to provide significant CD in the region. The comparison between helicon waves and LH waves are presented. Tangential neutral beam injection with high beam energy is used to drive a substantial current near axis. To be compatible with the engineering design, the total power of the neutral beams is reduced (to be about 40MW) and the injection angle is modified. Top launched electron cyclotron (EC) waves are used also for high CD efficiency in the deep core region. With these CDs the safety factor profile sustains a weak (positive/negative) shear in the deep core region (ρ<=0.4). For the transport the particle pinch by turbulence are analyzed, which is extremely important since no deep fueling is assumed. The global stability for ideal MHD modes and the type of ELMs are checked. Advanced issues beyond this work include the control of fuel particles and impurities, the alpha particles driven instabilities and transport, the possibility for the onset of tearing modes, the entry to the burning phase and so on.

For the steady-state operation an advanced H-mode plasma with internal transport barrier (ITB) at mid-radius and higher β_P is proposed. The turbulent transport is greatly reduced by the magnetic shear reversal in the region of the ITB, but it still dominates over neoclassic transport. Using localized RF current drives to tailor the safety factor profile is the key to control the location of the magnetic shear reversal, which yields good confinement and moderately high beta limit ($\sim 4l_i$) related to ideal MHD stability. So far this scenario is demonstrated in simulations only with very high power EC waves (>~80MW) which is incompatible with the H&CD design for hybrid scenarios. Work is going on to improve the compatibility by a better design with the composition of helicon waves and EC waves and possibly with some off-axis neutral beam current drive by steering the neutral beam vertically. The advanced issues peculiar to the steady-state operation include resistive wall modes with high β_N, the emergence of ITB during the discharge and so on.

References

[1] G. Zhuang et al 2019 Nucl. Fusion 59, 112010

Table I. Simplified 0D Table for Hybrid and Fully Non-Inductive Scenarios

	Hybrid NB+EC+HW	Fully Non-Ind NB+EC
Fusion Power (MW)	918	992
β_P	1.5	2.2
β_N	2.3	2.8
Bootstrap fraction	0.49	0.71
$H_{ITER98y,2}$	1.16	1.3
P_{CD} (MW)	93	102
Ip (MA)	13	11
$q_{95\ iter}$	5.98	7.4