MODELING OF ADVANCED TOKAMAK SCENARIOS WITH OFF-AXIS ELECTRON CYCLOTRON CURRENT DRIVE IN DIII–D*

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This paper will discuss advanced tokamak (AT) scenario modeling in DIII–D using time-dependent transport simulations. Specifically two topics will be discussed: an effort to develop scenarios of off-axis electron cyclotron current drive (ECCD) with transport coefficients based on experimental measurements; and an effort focussed on development of a more dynamic transport model, which is tested against an experiment on confinement improvement with impurity seeding in DIII–D.

The key to sustain the negative central shear (NCS) regime, the primary DIII–D AT scenario, is maintenance of a hollow current profile using off-axis ECCD. EC power on DIII–D is being upgraded over the next few years from the present 3-gyrotron system to the 6-gyrotron system for which 4 MW absorbed power is expected for long pulse operation in 2001. At the same time, multi-year experimental efforts are in progress to demonstrate NCS AT plasma performance using off-axis ECCD. The goal is to achieve high normalized performance, better than twice the conventional ELMing H–mode performance ($\beta_N H_{89P}$ ~ 10) with a bootstrap current fraction exceeding 50%. The near term experimental goal has been transient demonstration of such performance using NBI alone. Working closely with these experiments, the scenario modeling effort will employ the transport coefficients found in these target discharges to help answer the questions: (1) What scenarios will lead to the optimum q and pressure profiles? (2) Can we maintain the desired profiles in steady state with the available ECH power?

Simulations are carried out using the ONETWO[1] transport code. The ONETWO scenario simulations are based on transport coefficients determined from several different types of target discharges including ELMing H–mode, ELM-free H–mode, and L–mode discharges with an internal transport barrier. Since recently developed target discharges (with NBI alone) satisfy the scenario target requirements, the transport coefficients [$\chi_e(\rho)$ and $\chi_i(\rho)$] derived

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[1]H.E. St. John, *et al*., in Plasma Physics a d Controlled Nuclear Fusion Research (Proc. 15th Int. Conf. Seville, 1995), IAEA, Vienna (1995) 603.

[2]T.C. Luce, EPS invited paper.

[3]R.E. Waltz, *et al*. Phys. Plasmas **4** (1997) 2482.

from these discharges can be directly used as the baseline model for the time-dependent transport simulations. We replace a part of the NBI power with off-axis ECH/ECCD power, keeping total power fixed to study the impact on the *q* profiles and stability. The ECH launching direction is optimized for ECCD efficiency based on TORAY ray-tracing calculations. The code takes into account trapped electron effects, which, however, tends to underestimate the current drive efficiency, according to recent experimental measurements of ECCD efficiency.[2] The ONETWO code solves the current diffusion equation self-consistently with fixed boundary equilibrium. Then, the simulation duration is extended to near steady state (typically to 10 s). The simulation shows that 3 MW ECCD can sustain an enhanced confinement condition at β_N= 3.5, H_{89P}= 2.6 with f_{bs} = 55% for more than 10 s. The resultant profiles are stable against high-n and low-n ideal MHD modes. Stability of neoclassical-tearing modes will be discussed. Similar results obtained with other target discharges will be discussed also.

Since simulations to date with ONETWO have used temporally fixed (experimental) density profiles and thermal diffusivities, they cannot reproduce transport barrier formation and evolution dynamics. Full exploitation of profile optimization needs a more dynamic model. We are in the process of incorporating the gyro-Landau-fluid GLF23 model[3] into ONETWO. This model includes magnetic shear and E$\times$B shear effects on thermal, particle, and toroidal momentum transport. This model will be tested against experimental results from an experiment where clear increases in confinement (from $H_{89P} \approx 1$ to ≤ 2) and reductions of long-wavelength turbulence have been observed which are directly correlated with external impurity (Ne, Ar, Kr) injection in L–mode discharges in DIII–D. initial simulations with the GLF23 model will be discussed.