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Preparation for predict-first experiments on EAST to improve performance in steady-state advanced scenarios

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Demonstrating steady-state advanced high-performance operation scenarios is one of the main goals in the EAST research plan. There is a big challenge to improve the plasma performance of steady-state scenarios on EAST in order to make the dimensionless parameters (e.g., safety factor, energy confinement factor, and/or normalized and poloidal betas) be closer to those relevant to ITER and China Fusion Engineering Test Reactor (CFETR). The theory-based "predict-first" methodology is proposed to optimize discharge schemes and provide minor upgrade options of heating and current drive based on reliable predictions of plasma performance. Accordingly, we make a research plan including three steps: (i) validating the present theoretical models for core and pedestal plasma, and clarifying the physics affecting the plasma performance in the past steady-state experiments; (ii) performing predict-first experiments based on the present machine condition; (iii) making predictive modeling for minor upgrade options of rf wave systems using physics models with different degree of physical fidelity. This talk will cover the achievements in (i) and the preparation for (ii) and (iii).

For Step (i), the validation of integrated modeling incorporating the plasma transport model and RF current drive simulations developed in the past decade has been performed based on the steady-state operation experiments on EAST. In the simulations for low density and high temperature experiments (i.e., $T_{e0} > 10^8$ degrees achieved on 2018), the heating by electron cyclotron (EC) waves and lower hybrid (LH) waves are modeled by GENRAY/TORAY/CQL3D and the energy transport is modeled by TGLF-SAT0. Given the temperatures at the boundary of core region, $T_{e0} \sim 9$ keV obtained by the power-balance profile code TGYRO is in agreement with experimental measurement. The new understanding is that T_{e0} can further increase as the turbulent transport dominated by TEM and ETG decreases due to the consistent change of the safety factor and the flattening of density profile in the deep core region beyond the direct electron heating by rf waves [1]. In the simulations for high density and high bootstrap fraction discharges (i.e., the high poloidal beta scenario since 2018), the wave propagation through SOL is included in the ray-tracing simulations for LH waves, and the particle fueling is auto-tuned to match one channel line-integrated density signal as a way to mimic the density feed-back control in experiments. By these updates, the agreement between the modeling and experimental measurement is obtained at the same time in electron and ion temperature, multi-channel line-integrated densities and Faraday angles for three discharges with different plasma shape, line-averaged density and RF power [2]. The new physic insights obtained by the modeling include that the wave propagation through SOL mitigates the inaccessibility of LH waves in high density discharges, and the increase of energy confinement with density is due to the enhancement of collisional stabilization of TEM instead of the Shafranov shift effect claimed in the past experimental analyses over 4 years [2]. The tungsten impurity profile in core region in the high poloidal beta scenario is performed by the coupled TGLF/NEO/STRAHL simulations, which obtain the results consistent with the experimental observation and a new physics explanation that the turbulent diffusion related to high T_e sustained by EC waves can counteract the turbulent and neoclassical pinch and prevent the concentration [3]. In an accompany study the same kind of simulations are also performed for the hybrid scenario experiment with strong tungsten concentration triggering tearing modes and indicate the detrimental effects due to plasma rotation and high electron density gradient by enhanced particle confinement [4]. The validation activity identifies that some improvement is necessary for the models, such as TGLF in calculating the electron energy transport with neutral beam heating and reversed magnetic shear [5], and the launch spectrum model for LH waves at high density. The on-going study for Step (i) for steady-state experiments includes the clarification of ion-heating effects due to neutral beams and RF waves at ion cyclotron frequency ranges and gyro-kinetic simulations to the cases where TGLF underestimates the energy transport.

The study for Step (ii) has been started recently focusing on three issues: (1) how T_{i0} increases as more power of ICRF waves are injected; (2) how to access reversed shear configuration with rf current drive in steady state; (3) how T_i and T_e change when the magnetic field is reduced to enable central heating by EC waves at 105 GHz. Most of the predictive modeling and analysis would be finished in this year prior to experiments and validated in the second experiment campaign this year. After the campaign, Step (iii) will be started and focused on optimized options to upgrade rf heating combinations.

References
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