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中高密度ヘリカルプラズマにおける 両極性径電場・新古典エネルギー拡散の検証と装置間比較

Inter-Machine Validation Study of Neoclassical Transport Modeling in Medium- to High-Density Stellarator-Heliotron Plasmas

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In order to test a recently concluded benchmarking of calculations of NC transport coefficients [1], and extending previous studies of electron energy transport at low densities [2], this study compares experimental findings with NC transport predictions for medium- to high-density S-H plasmas.

The focus is put on recent experiments conducted in LHD and TJ-II also involving findings from Wendelstein 7-AS (W7-AS) [3]. In 3D magnetic configurations, radial electric fields (E_r) must arise to satisfy the ambipolar condition which is not intrinsically satisfied as in axisymmetric tokamaks. In the long-mean-free-path (lmfp) at sufficiently high densities above a few times 10^{19} m^{-3}, E_r is well predicted by the NC ambipolarity condition and is found to be in the so-called ion-root. E_r has particular impact on the energy fluxes of the ions.

Dedicated experiments performed in LHD and TJ-II can be summarized as follows. In LHD, discharges with high heating power with n_e>3x10^{19} m^{-3}, $T_{e,i}$>1 keV have been obtained. The variation of the heating power (ion/electron heating ratio as well), density and magnetic configuration forms a systematic database. In TJ-II, obtained parameters have been n_e~4x10^{19} m^{-3},, T_e~300 eV and T_i~120 eV. The NC particle and energy fluxes are evaluated by convoluting the mono-energetic transport coefficients calculated by DKES [4] in W7-AS and TJ-II, and by DGN/LHD [5] in LHD.

It is found that the measured negative E_r is consistent with NC ambipolar ion-root conditions for all devices. Higher density and comparable temperatures towards reactor-relevant S-H plasmas tend to weaken the bifurcation capability of E_r as reported for electron-root conditions [2]. Differently, in TJ-II the experimentally observed E_r is more negative than the predicted NC ambipolar E_r.

Steady-state energy balance analyses were performed using the integrated transport code, TASK3D [6] for LHD, and by ASTRA [7] in TJ-II. For W7-AS, the experimentally determined particle and energy fluxes were compared to NC fluxes with transport coefficients from DKES and found to be consistent with NC theory up to 2/3 of the minor radius. For an example of LHD discharge, it is found that the ion energy flux is close to the NC energy flux up to 2/3 of the plasma radius. However, since the NC energy flux has a strong dependence on the value of E_r, more systematic survey utilizing the database would be required for a conclusive statement. In TJ-II, the ion energy flux has been found to be beyond the prediction of local NC theory.

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