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Prediction of temperature profiles for helical plasmas by combining gyrokinetic transport models with integrated simulation

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To realize fusion energy, prediction of turbulent transport in toroidal plasmas is one of the most critical issues to be solved. Study of zonal flow effects on plasma confinement improvement is necessary for accurate prediction of turbulent transport and plasma profiles. A large number of gyrokinetic turbulence transport simulations have been performed for tokamak plasmas and for helical plasmas. Transport simulation coupled with gyrokinetic analysis results is performed in tokamak devices. Much larger computer resources are consumed to perform gyrokinetic simulation in helical plasmas than in tokamak plasmas, because the former needs many meshes along the field lines to resolve the helical ripple structure. Since it is not yet easy to combine nonlinear gyrokinetic simulation with integrated simulation in helical plasmas, there is a strong demand for predictive models which can reproduce nonlinear simulation results. Heat diffusivity models for electron and ion heat transport, and quasilinear flux models for particle and heat transport have been proposed in a kinetic electron condition for ion temperature gradient (ITG) turbulence in the Large Helical Device (LHD). The nonlinear simulation results are quickly evaluated by reduced models, because these models are basically functions of the quantity related with a linear growth rate and the zonal flow decay time for the linear response of zonal flows. The heat diffusivity model is the function of the linear growth rate and the zonal flow decay time [1, 2]. The quasilinear flux model includes a cross-phase between fluctuating potential and temperature or density, in addition to the linear growth rate and the zonal flow decay time [2]. The quasilinear flux is used to follow the nonlinear simulation results for the turbulent transport. The particle diffusivity is not modeled, because the flattened density profile is typical in the LHD. When the gradient of the density profile is around zero, it is difficult to accurately evaluate the particle diffusivity. The quasilinear flux formulation enables us to model particle transport for flattened density profiles. The heat diffusivity models have been installed into transport code for simulating evolutions of the plasma profiles in the LHD when additional modeling by normalized ion temperature scale length is used [3, 4]. Dynamical transport simulation with a quasilinear flux model installed has not been performed so far, because the cross-phase term in the quasilinear flux model is difficult to be modeled by temperature or density gradients. The reduced models can predict the nonlinear simulation results for the ion heat transport [5]. The simulation where the time scale separation is applied is performed in this article, because the difference between energy confinement time (around 1s) and a typical gyrokinetic time scale (around 1 μ s) is extremely large.

To obtain the temperature profiles, the transport simulation with the gyrokinetic transport models installed is performed by the integrated code in this article, where the reduced models based on direct expressions for the heat diffusivity and on the quasilinear heat flux are evaluated by the linear gyrokinetic simulation at each time step in the evolution of the integrated simulation. The zonal flow decay time is fixed in the transport simulation. The linear simulations are performed for the various temperature profiles to evaluate the reduced transport models at each time step in the integrated simulation. Stationary electron and ion temperature profiles are predicted for fixed heating power.

The transport simulation is performed by the integrated code using the reduced gyrokinetic models. The turbulent transport is evaluated by reduced models using the linear gyrokinetic simulation results for the kinetic electron response at each cycle of the integrated simulation. By performing the integrated simulation with the gyrokinetic models installed, multi time-scale simulation can be performed. The multi time-scale simulation is done in the standard field configuration and in the inward shifted field configuration of the LHD. The simulation using the quasilinear flux model, including effects of zonal flows and kinetic electrons, is performed for the first time for predicting the temperature profiles in the LHD. This is achieved by combining the two codes, TASK3D and GKV in helical plasmas. The stationary temperature profiles obtained by the transport simulation, using the reduced models which reproduce the nonlinear simulation results, are predicted within the difference of 30% at most from the experimental results in the LHD, where the ITG mode is unstable [6].

References

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