§24. Study on Multi-Hierarchy Phenomena in Plasmas with Theory and Simulations

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Purpose

Plasmas is a cross-hierarchy phenomenon; it is controlled by multiple spatiotemporal scale physics from macroscopic process, which cover the entire system, to microscopic motions of individual particles. In this research subject, as a part of fundamental studies supporting the Numerical Simulation Reactor Research Project in NIFS, we promote studies on cross-hierarchical phenomena such as magnetic reconnection, macroscopic instabilities, and plasma coherent structures (blob dynamics) in fusion plasmas by means of theories and simulations.

Result

1. Magnetic reconnection has been investigated with theories and multi-hierarchy and first-principle simulations as follows

(1) In order to understand driven magnetic reconnection as a cross-hierarchy phenomenon, we have developed and improved a multi-hierarchy simulation model based on the real-space decomposition method. In this multi-hierarchy model, the dynamics in the macroscopic hierarchy is expressed by an MHD algorithm and the physics in the microscopic hierarchy is solved by a PIC algorithm. For interlocking hierarchies in the downstream direction in a more exact manner, we are coupling an extended MHD code, which can treat non-ideal terms such as the Hall effect and the finite Larmor radius effect, and a PIC code. In this fiscal year, as validation of this model, we have performed simulations of whistler waves.

(2) When we simulate a wider region of magnetic reconnection with our multi-hierarchy model, it would be required that memory size and CPU time are reduced. We have implemented the Adaptive Mesh Refinement (AMR) method to our MHD code. With the new model based on coupling AMR-MHD and PIC codes, we have successfully simulated magnetic reconnection, in which magnetic reconnection is driven in the PIC domain by plasmas and magnetic flu supplied from the AMR-MHD domain [1].

(3) On the other hand, we have investigated microscopic physics of magnetic reconnection by means of the first-principle calculations. In 2015FY, we have studied ion heating in the downstream region. Analyzing ion velocity distributions in detail, it is found that the pickup mechanism plays a major role as an effective heating mechanism. This result would be applied to ion heating reported in plasma merging experiments of spherical tokamaks.

2. Particle simulations of plasma blob dynamics

In order to realize a holistic simulation of fusion peripheral plasma, we have investigated the kinetic (microscopic) dynamics on propagation of a plasma coherent structure with the three-dimensional electrostatic particle code as the first step [2]. In this fiscal year, we have improved our particle simulation code in order to investigate the dynamics of a “hole” structure. Here, the hole structure is the filamentary coherent structure where the plasma density is lower than that of background plasma. In the preliminary simulation, we have observed the formation of a dipole potential structure in a hole and the hole propagation in the grad-B direction.

2. Investigation on macroscopic instabilities with extend MHD simulations

(1) As a study for small scale effects on macroscopic instability, the effect of parallel heat flux in the gyroviscous term in an extended MHD model on the two-fluid tearing mode is numerically investigated. The matrix code for the linear eigenmode analysis of the two-fluid tearing mode has been developed and benchmarked with the analytical solution in a wide range of parameters.

(2) The theoretical model to analyze the macroscopic structure and dynamics of low collisionality plasmas effectively is being developed based on the so-called kinetic MHD that can include the effect of particle motion along the magnetic field. The formulation for the kinetic effects such as wave-particle interaction on equilibria of toroidal plasmas with flow has been started.

(3) We have studied Large Eddy Simulation (LES) of two-fluid magneto-hydrodynamic equations, which include the Hall term and cause the equations very stiff. We have shown by comparing numerical results of LESes to those of large-scale direct numerical simulations that the Smagorinsky-type model developed by Hamba and Tsuchiya (2010) can be applicable to an LES including the Hall term.

1) T. Ogawa, S. Usami, R. Horiuchi, M. Den, and K. Yamashita, Plasma Fusion Res. in press.
2) H. Hasegawa and S. Ishiguro, Phys. Plasmas **22** (2015) 102113.