§23. Development of Multi-scale Simulation Algorism Based on MHD and PIC Codes

Usami, S., Ohtani, H., Horiuchi, R., Den, M.

Magnetic reconnection is a fundamental process to lead fast energy release. For instance, solar flares and geomagnetic substorms seem to be caused by magnetic reconnection. Such high-temperature and low-density plasmas are collisionless, frozen-in condition is satisfied macroscopically, and thus, reconnection can not take place. Collisionless reconnection requires microscopic processes which violate frozen-in condition. In order to clarify the mechanism of reconnection, multi-scale simulation model to solve both microscopic and macroscopic physics consistently and simultaneously are developed.

In our multi-scale simulation algorism, microscopic physics is described by particle simulation (PIC) code [1, 2], while macroscopic physics is expressed by MHD simulation code [3]. Spatial and temporal sizes used in MHD code are much different from ones in PIC code, and thus normalization methods are totally different. For instance, in MHD code, length, velocity, and time are normalized to Δ (arbitrary), the Alfvén speed v_A, and Δ / v_A, respectively. While in PIC code, length, velocity, and time are normalized to c/ω_{ce} (c is the speed of light and ω_{ce} is electron gyrofrequency.), c, and $1/\omega_{ce}$, respectively. We have recently obtain the unit transformation scheme between MHD and PIC codes needed for multi-scale simulation. If the relation $\Delta = \alpha(c/\omega_{ce})$ (α is arbitrary constant) is defined, relations of all other quantities are also determined uniquely. For instance, following equation

$$\frac{\Delta}{v_A} = \left(\alpha \frac{\omega_{ce}}{\omega_{pe}} \sqrt{\frac{m_e}{m_i}}\right) \frac{1}{\omega_{ce}}$$

is given as the relation for time, where m_e and m_i is electron and ion mass, respectively and ω_{pe} is electron plasma frequency.

For our studies on magnetic reconnection, it is supposed that the neighborhood of reconnection points where kinetic effects play important roles is solved by PIC model, and the surrounding of the PIC region is calculated by MHD model, where ideal MHD equations are used as basic equations, since non-ideal effects such as electric resistivity and viscosity are assumed to be generated by kinetic effects. However, there is a possibility that Hall term should be added to MHD equations. Two-fluid code might be necessary between MHD and PIC code.

Fig. 1 is the schematic diagram showing how to connect MHD and PIC codes. The fine cells are used for PIC code, while coarse ones are for MHD code. We calculate Region MHD using MHD code, while in Region PIC, we solve PIC code. In Region Interface, we use both of MHD and PIC codes. We have physical quantity Q_{MHD} by calculating MHD code, and Q_{PIC} with PIC code. Physical quantity $Q(x,y,z)$ in Region Interface is determined as follows

$$Q(x,y,z) = a\, Q_{\mathrm{MHD}}\,(x,y,z) + (1\text{-}a)\, Q_{\mathrm{PIC}}\,(x,y,z),$$

where a parameter a is the function of x and y.

In the current stage, we have been constructing “connection programs” which transform the unit between MHD and PIC codes, and simulating propagation of one-dimensional linear waves or flows from Region PIC to Region MHD and *vice versa*. We optimize “connection programs” so that unphysical phenomena do not happen in Region Interface.

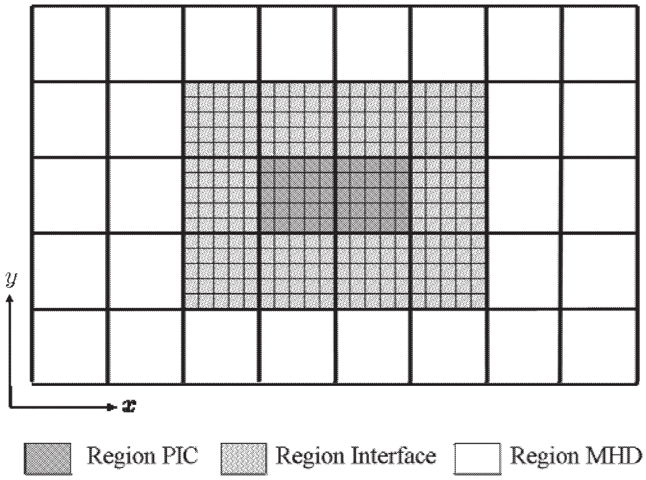

Fig. 1. Schematic diagram of multi-scale simulation model. Reconnection points are in Region PIC. Its surrounding is Region MHD. Region Interface exists between Region PIC and Region MHD.

References

1) H. Ohtani, R. Horiuchi, and A. Ishizawa, J. Plasma Physics **72**, 929 (2006).

2) R. Horiuchi, H. Ohtani, and A. Ishizawa, Comp. Phys. Comm. **164**, 17 (2004).

3) R. Horiuchi and T. Sato, Phys. Fluids B **1**, 581(1989).