Simulation of Plasma Flow Injection with Multi-Hierarchy Model Aiming Magnetic Reconnection Studies

S. Usami[1,*], H. Ohtani[1,2], R. Horiuchi[1,2] and M. Den[3]

[1] *Department of Helical Plasma Research, National Institute for Fusion Science, Toki, 509-5292, Japan.*
[2] *The Graduate University for Advanced Studies (Soken-dai), Toki, 509-5292, Japan.*
[3] *National Institute of Information and Communications Technology, Koganei 184-8795, Japan.*

Abstract. A multi-hierarchy simulation model aiming magnetic reconnection studies is developed and improved in which macroscopic and microscopic physics are computed consistently and simultaneously. Macroscopic physics is solved by magnetohydrodynamics (MHD) algorithm, while microscopic dynamics is expressed by particle-in-cell (PIC) algorithm. The multi-hierarchy model relies on the domain decomposition method, and macro- and micro-hierarchies are interlocked smoothly by hand-shake scheme. As examination, plasma flow injection is simulated in the multi-hierarchy model. It is observed that plasmas flow from a macro-hierarchy to a micro-hierarchy across the magnetic field smoothly and continuously.

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1 Introduction

Collisionless magnetic reconnection is one of the fundamental processes in which energy is converted from magnetic field energy to kinetic energy. It plays an essential role in the rapid energy release in laboratory fusion device and astrophysical plasmas [1–3]. Furthermore, of particular interest is an aspect of the coupling phenomenon between multiple spatial and temporal scales. When magnetic reconnection occurs, the field topology changes on a macroscopic scale and global plasma transport takes place. On the other

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*Corresponding author. *Email addresses:* `usami.shunsuke@nifs.ac.jp` (S. Usami), `ohtani.hiroaki@nifs.ac.jp` (H. Ohtani), `horiuchi.ritoku@nifs.ac.jp` (R. Horiuchi), `den@nict.go.jp` (M. Den)

hand, an electrical resistivity controlled by a microscopic process is necessary as a trigger. A grand challenge is to understand a magnetic reconnection process as multi-hierarchy phenomenon completely [4].

Magnetohydrodynamics (MHD) simulations [5,6] is one of the popular tool for investigation of magnetic reconnection. However, the MHD algorithm assumes artificial electrical resistivity and viscosity, and can not describe their generation mechanism. On the other hand, fully kinetic electromagnetic particle-in-cell (PIC) simulations [7–10] treat dynamics of plasma by calculating motions of electrons and ions in the first principle, thus can express electrical resistivity and viscosity self-consistently [11–13]. However, the PIC algorithm requires huge computer resources in memory and CPU time, consequently large-scale simulation which deals with entire geomagnetosphere can not be executed. In order to conquer this problem, we develop a multi-hierarchy simulation model, which deals with both microscopic and macroscopic physics consistently and simultaneously as the MAgnetic Reconnection Interlocked Simulation (MARIS) project.

Recently we succeeded in the first demonstration of multi-hierarchy simulation in which plasma inflows come from the macroscopic domain and drive magnetic reconnection in the microscopic domain [14, 15]. Examining validity of our multi-hierarchy model was done in the previous work. In 2008, we simulated the propagation of Alfvén wave and observed that waves smoothly propagated in the multi-hierarchy simulation box [16, 17]. Now in this paper, in order to demonstrate validity of our model moreover, we simulate plasma flow injection in the multi-hierarchy model. This work plays a role to emphasize that magnetic reconnection phenomena found in the multi-hierarchy model as shown in [14, 15] exhibit true physics.

In Section 2, we describe the method of our multi-hierarchy simulation model for magnetic reconnection studies. The simulation domain is divided into three domains, and the macroscopic (MHD) and microscopic (PIC) domains are interlocked via the interface domain. Also, it is shown that the MHD and PIC algorithms have different time steps and how data are exchanged each other. In Section 3, we perform multi-hierarchy simulations of plasma injection. Plasmas are observed to smoothly and continuously flow in multi-hierarchy simulation box. In Section 4, we discuss a numerical error accumulated when thermal velocities are computed. Section 5 gives a summary of our work.

2 Multi-hierarchy simulation method

2.1 Multi-hierarchy structure of magnetic reconnection

In the multi-hierarchy structure of magnetic reconnection, the characteristic spatial and temporal scales are different by domains. In the vicinity of the reconnection point, phenomena are microscopic. For instance, the width of a current sheet and the gradient scale of magnetic field are of the order of ion gyroradius (strictly describing, the ion meandering scale). On the other hand, as being away from the reconnection point, phenomena relax to large-scale and slow behavior. As a result, plasma behavior can be expressed