§33. Simulation Study on the Magnetic Helicity Transfer in the Magnetospheric System

Miyoshi, T., Kusano, K. (Dept. Sci., Hiroshima Univ.)
Hayashi, T.

The substorm is the most distinguished energy liberation process in the Earth's magnetospheric system. Although it has been pointed out by many researches that the interplanetary magnetic field (IMF) must play an important role for the substorm process, the onset mechanism of the substorm expansion phase is still uncertain. On the other hand, it is well known that, in the magnetohydrodynamic (MHD) relaxation processes such as the sustainment of the reversed field pinch (RFP) plasma, the conservation of the total magnetic helicity, which characterizes the complexity of the magnetic field configuration, may become a guiding principle [1]. In particular, a noteworthy relaxation model was presented as a solar flare model, where the rapid energy liberation is triggered by the annihilation of the magnetic helicity due to the cancellation of the opposite signs of the helicity [2].

The final goal in our study is to understand the substorm as a framework of the MHD relaxation process. However, in the magnetospheric studies, a viewpoint from the magnetic helicity transfer has not been investigated thoroughly so far. Thus, the objective in the present study is to discuss the magnetic helicity transfer in the IMF-magnetospheric system. In order to investigate the magnetic helicity transfer in the whole system of the magnetosphere precisely, highly resolved global MHD simulation of the interaction between the magnetosphere and the solar wind including with the IMF must be performed. Therefore, in this year, efficient and high resolution global MHD code has been developed. Also, preliminary results have been presented.

In order to avoid numerical errors caused by the background potential magnetic field, the MHD equations are modified to exclude the effects of the potential field from the conservative variables [3]. This modified form of the MHD equations is solved by the finite volume method (FVM). Since the FVM is flexible for the grid structure, the stretched cubed-sphere grid system as seen in Fig.1 is adopted. It is found that the grid sizes of this grid system are almost equivalent around the inner sphere. Also, at the magnetotail, a number of the grids are accumulated near the equator to resolve the reconnection current. Thus, numerical efficiency and accuracy are greatly improved in this grid system. Also, as an evaluation method for the numerical fluxes in the FVM, multi-state HLL-type Riemann solver is newly developed [4]. In this method, lower computational cost than the cost in the Roe-type Riemann solver, which is the standard method in the community of computational fluid dynamics (CFD) researches, is achieved with keeping numerical accuracy. It is also found that new method is more robust than Roe's method in the low density regions. To maintain the divergence-free condition for the magnetic field, the hyperbolic divergence cleaning method [5] is adopted. Using above numerical techniques, the MHD simulation of the interaction between the dipole magnetic field and the external super-sonic/Alfvenic flow is performed to study global IMF-magnetosphere interaction.

As a preliminary simulation model, a uniform IMF, $\boldsymbol{B}_{\rm IMF}=(0,B_y,B_z)$, is imposed on the inflow boundary after quasi-steady magnetosphere without the IMF is formed, where $B_y>0$ and $B_z<0$, i.e., the growth phase of the substorm (pre-onset phase) is considered. Here, the geocentric solar magnetospheric (GSM) coordinate is used. In this case, the IMF has no magnetic helicity. However, as seen in Fig.2, the topology of the magnetic field lines is changed from the potential field. (The solid line with × indicate the result for quasi-steady magnetosphere without the IMF where the topology of the closed lines is the same as the dipole field.) This fact indicate that the magnetic helicity is generated even for the case with zero helicity IMF. The structure of the field lines is generated by magnetic reconnection at the tail where the lines labeled by different longitudes are reconnected. As a viewpoint of the magnetic helicity conservation, the plasmoid may have opposite sign helicity from the closed field lines. From this preliminary study, it is expected that B_y of the IMF may induce the magnetic helicity transfer in the magnetosphere.

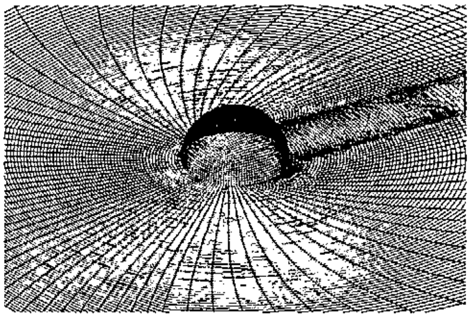

Fig. 1. The structure of the stretched cubed-sphere grid system around the inner sphere.

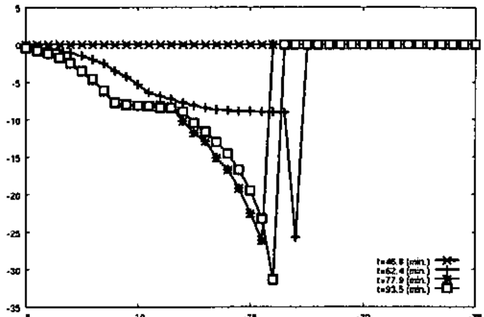

Fig. 2. Azimuthal angles between the roots on the inner sphere of the closed field lines traced from the sun-earth line (y=0, z=0) at the tail (x<0).

Reference
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