§28. Structure Transition in Hall MHD Turbulence

Miura, H., Araki, K. (Okayama Univ. Science)

Structure transition in the vorticity field associated with the introduction of the Hall term to the magneto-hydrodynamic (MHD) equations are studied by means of Direct Numerical Simulation (DNS). It is found that the introduction of the Hall term brings about a drastic change of the vorticity field from the sheet structure to the tubular structure similar to that in hydrodynamic turbulence, while the current field does not show such a large change.

We have been studying Hall MHD turbulence aiming to clarify its small-scale structures and develop a sub-grid-scale (SGS) model for a Large Eddy Simulation (LES) so that it will help extended MHD simulations of a torus plasma, in which the whistler modes arising from the Hall term restrict the time step width in our simulations severely. DNSes of Hall MHD turbulence are carried out for both with and without strong background (toroidal) magnetic field. Number of grid points is 10243. The Hall parameter is set as $\varepsilon_H = 0.05, 0.025, 0.0125$. Numerical results of simulations without the background magnetic field are shown below.

It has been known for single-fluid MHD turbulence that the turbulent magnetic field forms thin current sheets while the velocity field forms thin vortex sheets. The two element structures stay almost together each other because of the frozen-in condition which is broken only in high wave number components. However, in Hall MHD turbulence, the vortex sheets make a transition to vortex tubular structures. On the other hand, current sheets remain as sheet structures although they are torn into pieces.

It is found in our simulations that the vortex tubes can be characterized by the Laplacian of the magnetic pressure, as we see in Fig.1. In Fig.1, the enstrophy density (square of the vorticity vector) and the Laplacian of the magnetic pressure are drawn in the colored and grey isosurfaces, respectively. In homogeneous neutral fluid turbulence, the vortex tubes can be characterized by the Laplacian of the pressure with an appropriate threshold. However, in Hall MHD turbulence, the Laplacian of the pressure does not give an appropriate visualization of the vortex tubes, while the Laplacian of the magnetic pressure gives it. The difference is caused by the energy exchange between the kinetic and magnetic energies in the course of evolution of turbulence. It is found in our simulations that the kinetic energy is transferred away from the large-scale Fourier components of the velocity field while the magnetic energy at the large-scale is maintained either by energy exchange associated with the dynamo action.

The scale-hierarchy of the vortex tubes and vortex sheets are also studied. By operating the sharp low-pass filter with variable cut-off wave numbers to the velocity field and the magnetic field (thus equivalently to the vorticity field and the current density field), emergence/disappearance of the structures depending on the cut-off wave numbers is studied. As is shown in Fig. 2, the vortex tubes appears even when the high wave number Fourier coefficients are truncated by the low-pass filters. It is shown by changing the cut-off wave number of the low-pass filter that the vortex tubes appear at each scale although the population and location of them are changed by the change of the cut-off wave number. Since the vortex tubes are sheets are strong dissipative structures in the resistive MHD models, it is favorable to preserve the structures when we carry out LESes of the system.

An LES with a proto-type SGS model is now undergoing. The computation will be validated by comparing the LES data to the DNS data reported here.

This study has been presented in the 55th American Physical Society Division of Plasma Physics meeting, held at Denver in November 2013.

Fig. 1: The enstrophy density (square of the vorticity vector) and the Laplacian of the magnetic pressure are drawn in the colored and grey isosurfaces, respectively.

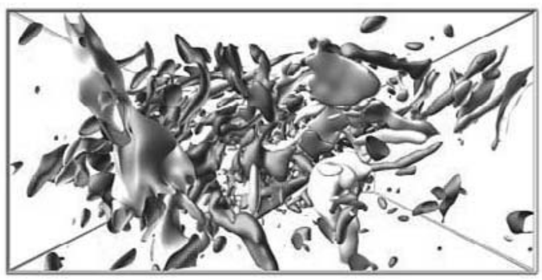

Fig.2: The enstorphy density and the current density operated by the low-pass fiter of moderate-wave-number cut-off.