Turbulent thermal convection in liquid metal and the effect of magnetic field

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The Earth's outer core consists of molten iron, and its flow generates the geomagnetic field. In general, liquid metals have low viscosity and large thermal diffusivity; moreover they are good conductor of electricity. The flow occurring in liquid metals is very different from the flow with viscous non-conducting fluid. Hence, it is very important to make up clear image of the flow with liquid metals for understanding the dynamics of the Earth's outer core. The convective flow in the outer core is supposed to be extremely turbulent, because its spatial scale is large. It is essential for the outer core dynamics that the flow behaves turbulent under the influence of rotation and magnetic field. But it is very difficult to directly simulate the convection in the outer core numerically in MHD calculation. The laboratory experiment is a useful way to understand such highly turbulent flow.

Liquid metals, however, are opaque fluids, so any optical methods for the flow measurement cannot be applied. We have been improving the Ultrasonic Velocity Profiler method to measure the fine-scale velocity field of the flow occurring in the liquid metals. The principle of this method is as follow. A series of ultrasonic pulse emitted from an ultrasonic transducer is reflected by the particles suspended in fluid, and is received by the same transducer. Position information is given by the time of flight from emission to reception of the ultrasonic pulse, and velocity information is obtained by analyzing the Doppler shift of the received echo signal. If the number density of the particles is enough, ultrasonic pulse is reflected everywhere on the passing line of the pulse. Thus, the this method can measure an instantaneous velocity profile along the line. By scanning the measurement lines, we can visualize the whole flow pattern existing in the tank.

We succeeded in the direct measurement of velocity profile for the Rayleigh-Benard convection in liquid metal, with and without uniform magnetic field. Measuring the horizontal velocity at several sites in the tank, many fluctuations are observed, that reflect turbulent behaviors of the flow. When we see the long-term tendency, we can reconstruct two-dimensional roll-like pattern. This roll-like pattern is supposed to be a kind of mean-flow which is the organized structure in the turbulence, and the small fluctuations may show the behavior of small plumes. The roll-like pattern shows clearly regular periodic behavior. This means that the roll structure gets longer and shorter laterally and periodically. When we apply horizontal magnetic field along the roll axis of this convecting system, the fluctuating components are reduced remarkably and the mean velocity of the roll-like flow pattern is increased. The lateral movement of the rolls decreases with the magnetic field, but the typical frequency of this periodic behavior is unchanged.