§21. Magnetic Field Structure Generated by Thermal Convection in a Rotating Spherical Shell

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The Earth magnetic field is created and maintained in its metalic core by dynamo action, in which fluid motions generate a magneic field. Dynamo action has many interesting features such as reversal of magnetic dipole moment[1], saturation of magnetic field. To understand these phenomena, it is important to investigate the spatio-temporal correlation between the velocity and magnetic fields[2,3]. Here, we report the spatial structure of velocity and magnetic fields in a rotating spherical shell.

The magnetic field structure is investigated by solving numerically a full set of MHD Boussinesq equations. We consider an MHD fluid which is confined between two concentric spheres rotating at a common constant angular velocity. The temperature on the inner boundary is higher than that on the outer and being kept constant all the time. There is vacuum outside of the shell. All the physical quantities are assumed to be uniform. The gravity is acted on the fluid in the direction toward the center of the shell.

We perform direct numerical simulations in two steps. First, a purely thermal convection is simulated starting with a slightly unstable thermal conduction state with uniform random small perturbations. Six pairs of cyclonic and anticyclonic vortex columns appear alternately around the rotating axis. A cyclone (an anticyclone) has the same (opposite) direction as (to) the rotation of the shell. They drift eastward relative to the shell with a constant angular velocity without changing their relative positions. The field is symmetric with respect to the equatorial plane. Second, we add a seed of weak magnetic field to the above thermal convection state. At the initial stage of evolution, the magnetic field grows exponentially in time. As soon as the magnetic energy exceeds the kinetic energy, the latter abruptly drops because of a feedback effect due to the Lorentz force, and then a quasi-steady state is attained. The total magnetic energy is about three times larger than the kinetic.

The magnetic field structure is different between the linear growing and nonlinear saturation stages. In the former, the shape of the velocity field is quite similar to that of the purely thermal convection state. There are 24 stagnation points on the equatorial plane. Stagnation points are classified into two types in terms of flow pattern. One is spiral and the other is hyperbolic. There are two special directions around a hyperbolic point : a fluid element goes into (comes out of) the point along a stable (unstable) manifold. Strong magnetic field is generated mainly in two regions, that is, at the eastern periphery of anticyclones and along unstable manifolds (see Fig 1).

In the latter stage, the velocity field is much deformed by the Lorentz force. There are only eight stagnation points left on the equatorial plane. These points are located near four cyclones except two of the six cyclonic columns which are much distorted near the equatorial plane. The magnetic field is generated along those distorted streamlines over two adjacent pairs of convection columns (see Fig 2) . This field is of two-fold symmetry around the rotation axis.

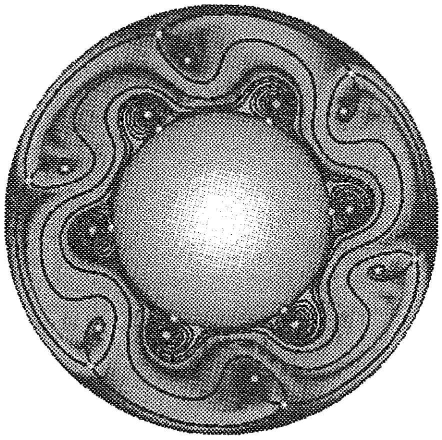

Fig 1 : Streamlines and distribution of magnetic field intensity on the equatorial plane in linear stage ($t = 20$).

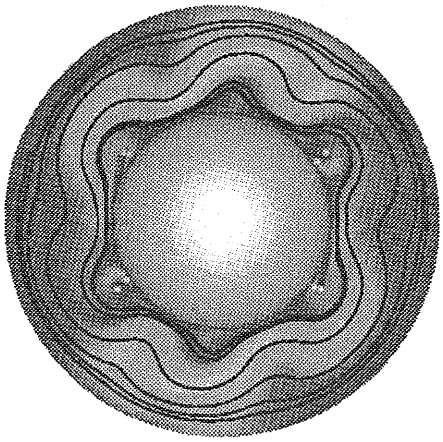

Fig 2 : Same as Fig 1 but in nonlinear stage ($t = 100$).

References

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[3] S. Kida and H. Kitauchi, J. Phys. Soc. Jpn. **67** (1998) 2950.