§16. Constant Reversals of the Dipole Field in a Magnetohydrodynamic Dynamo

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It is a well-known fact that the magnetic field of the earth is dipole dominated and suddenly reverses its polarity at irregular intervals [1]. The Earth's magnetic field is believed to be generated by the dynamo action in a rotating electrically conducting fluid [2]. In recent years, the numerical simulations have achieved self-excited dynamo action. However, the magnetic field reversal is still one of the challenging phenomena in dynamo theory.

In the Kageyama-Sato three dimensional Magnetohydrodynamic (MHD) dynamo model, we consider three-dimensional evolution of the thermal convection and the magnetic field in a self-gravitating, electrically conductive rotating spherical fluid-shell. The inner boundary and outer boundary of the spherical shell are kept at constant temperatures of T_i and T_o, respectively ($T_i > T_o$). The shell is rotating at a constant angular velocity.

In the previous work[3], a flip-flop transition of the total magnetic and convection kinetic energies with a reversal of the dipole field was observed. In our recent long time dynamo simulation, we change the electrical resistivity of the fluid and keep the other parameter unchanged, The nondimensional parameters are given as: the Taylor number $T_a = 5.88 \times 10^6$, the modified Rayleigh number $R_a = 3.36 \times 10^4$, the Prandtl number $P_r = 1.0$, the magnetic Prandtl number $P_m = 10.5$, and Roberts number $R_R = 15.7$.

Fig. 1 shows the long time evolution of the dipole field reversal. The first two panels show the evolution of the total convection kinetic and magnetic energies. We can see that they also exhibit a flip-flop alternation between a high energy state and a low energy state. Anyway, the durations of the high energy state and the low energy state do not keep constant. The third panel shows the evolution of the dipole polarity. It is evident that the dipole reverses its polarity irregularly and rapidly. Reversal appears to occur without any regular rule. It does reverse suddenly and the reversal does continue endlessly. In comparison with the first two panels, we can find that reversals occur only at high energy states. The time duration in which the dipole directs to the north or the south is nearly equal. This suggests that the dynamo action does not prefer in one polarity state rather than the other. The mean magnetic energy density on the outer boundary of the shell can be expressed as the sum of contributions from each spherical harmonic. The last two panels of Fig. 1 show the time evolutions of the two dominant magnetic harmonic modes, dipole and quadrupole, at the outer boundary. The dipole mode is stronger than the quadrupole one in most simulation time, which means that the magnetic field is dipolar-dominated. A close examination can find that the dipole reversal always occurs as the magnitude of the quadrupole mode exceeds that of the dipole mode. The quadrupole mode grows prior to reversal and becomes dominant when the reversal takes place. However, It should be noted that the growth and dominance of the quadrupole mode over the dipole mode is not the sufficient condition for the dipole reversal.

In summary, a long time MHD dynamo simulation has found that the magnetic dipole field reverses its polarity irregularly and rapidly. The total convection energy and magnetic energy make a flip-flop alternation between a high energy state and a low energy state. The reversals occur only at high energy states. The quadrupole mode grows up and becomes larger than the dipole mode when a reversal occurs.

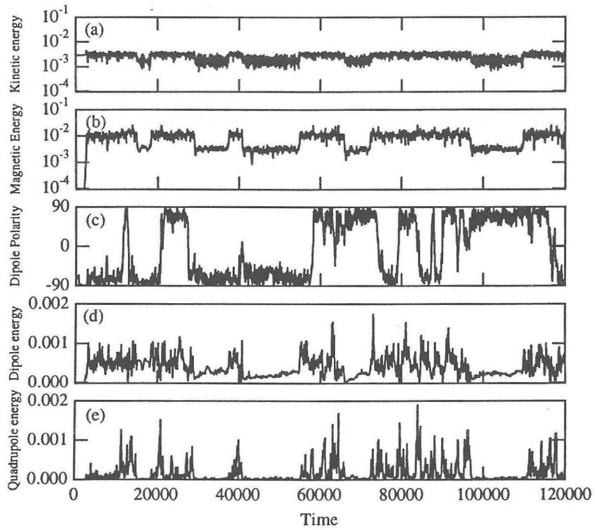

Fig. 1. The time evolution of (a) the total convection kinetic energy, (b) the total magetic energy (c) the polarity of dipole field, (d) the dipole energy density, and (e) the quadrupole energy density at the outer boundary.

References
1) Merrill, R. T. et al.: *The Magnetic Field of the Earth: Paleomagnetism, the Core, and the Deep Mantle* (Academic Press, San Diego, 1996).
2) Moffatt, H. K., *Magnetic Field Generation in Electrically Conducting Fluids* (Cambridge University Press, Cambridge, 1978).
3) Kageyama, A. et al.: Phys. Rev. Lett., **82**, (1999) 5409