"Physics of Auroral Phenomena", Proc. XXXIII Annual Seminar, Apatity, pp. 46 - 48, 2011
© Kola Science Centre, Russian Academy of Science, 2010
Polar Geophysical Institute

STRENGTHENING EFFECT OF THE MAGNETIC FIELD DUE TO THE PRECIPITATION OF CHARGED PARTICLES

M.A. Volkov (*Murmansk State Technical University, 13 Sportivnaya Str., Murmansk, 183010, e-mail: mavol2006@yahoo.com)*

Abstract. During the expansion phase of the substorm in the nightside magnetosphere enhancement of the magnetic field and decrease the plasma pressure is observed simultaneously. Enhancement of the magnetic field is recorded at first in the tail of the magnetosphere, and then at more closer distances from the Earth. This process takes a few minutes and covers the region in the magnetosphere of 10 Earth radii. One of possible explanations of this phenomenon is associated with cooling magnetic flux tubes caused by the precipitation of the energetic particles in the ionosphere. We have made evaluation of the effectiveness of this mechanism.

Introduction

The expansion phase of the magnetospheric substorm is accompanied by increase of the B_z component of the magnetic field in the magnetosphere tail and decrease of the plasma pressure [1]. This process is called dipolarization of the magnetic field lines, it begins at the tail of the magnetosphere and in a few minutes covers a length of ~ 10 R_E, approaching the Earth at a speed of ~ 300 km / s. The velocity of the propagation of dipolarization of the magnetic field lines is more than Alfven speed, but noticeably less magnetosonic and is equal to the electric drift velocity of the plasma in the magnetosphere tail. One of possible explanations for this phenomenon is associated with the formation of plasma bubbles, the pressure of the plasma in the magnetic flux tube is less than the background, and the magnetic field, on the contrary, is more. Bubbles can appear during reconnection in the tail of the magnetosphere [2], or during the sudden weakening of the electric field of the magnetospheric convection at the late growth phase of the substorm [3]. The bubbles in these cases are connected with intensive field-aligned currents, flowing from the ionosphere. The electric field across such structure increased, and the bubble moves to the Earth. At the ionospheric level the moving of this structure towards the equator can be observed. Yet the auroral forms during the expansion phases of the substorms are moving toward the pole, but not toward the equator. The strengthening the B_z component of the magnetic field can also be caused by the magnetic flux tubes braking drifting from the tail of the magnetosphere to the Earth [4]. However, the mechanism of this braking is not entirely clear. In this paper we propose the explanation of the dipolarization magnetic field lines in the magnetosphere tail as a result of nonadiabatic cooling of the magnetic field tubes by precipitation of charged particles in the ionosphere.

The description of basic processes

The plasma is diamagnetic, so it tries to displace the magnetic field, if the plasma pressure is reduced, for example, due to the precipitation, the magnetic field in the tube increases. As the magnetic field is frozen into the plasma, the magnetic flux tube is compressed, and the pressure increases. A new configuration of the pressure distribution and magnetic field in the tail of the magnetosphere appears there. We have calculated the distribution of plasma pressure self-consistent with the magnetic field in the tail of the magnetosphere along the Sun-Earth line (axis *X*) for two cases, at the end of the growth phase, and after the process of dipolarization of magnetic field lines. The magnetic field in the tail of the magnetosphere is given by the magnetosphere model of Tsyganenko 96 [5]. The effect of magnetospheric convection on the distribution of plasma pressure is not taken into account; the magnetic flux tubes are not considered drifting. In this case colatitude θ of the magnetic flux tube before and after dipolarization does not change and we can calculate the kinetic energy of charged particles in the tube $3/2pV$ and entropy $S = pV^{5/3}$ (*p*-the isotropic plasma pressure in magnetosphere, *V*-the volume of the magnetic flux tube with unit magnetic flux in the ionosphere) before and after dipolarization. The decrease of the kinetic energy and the entropy should point to nonadiabatic processes and emptying magnetic flux tubes. According to observations [6] dipolarization in the tail of the magnetosphere and the auroral breakup are observed almost simultaneously at the same magnetic field lines.
In the absence of convection equation of the balance pressure of the plasma and the magnetic field has the form:

$$-m_0 \nabla p + [rot\vec{B} \times \vec{B}] = 0 \qquad (1),$$

where μ_0-the magnetic permeability of vacuum, *B*-the magnetic induction.
In the projection on *X* (the *X* axis is directed to the Sun, *Z*-to the pole), equation (1) takes the form:

$$\frac{\partial}{\partial x}(m_0 p + B_Z^2/2) = B_Z \frac{\partial}{\partial z} B_x \qquad (2)$$

Results

Equation (2) is solved numerically using the model of the magnetic field [5]. In this model, the magnitude of the current in the tail of the magnetosphere depends on the interplanetary magnetic field (IMF) and solar wind pressure. For the case prior to dipolarization we are taking the value component of the IMF B_z =- 10nT, after depolarization B_z =- 5nT, B_y = 0 for both cases. Pressure of the solar wind accepts 2nPa. Pressure in the plasma layer at colatitude θ = 30^0 prior and after depolarization was specified as 10nPa. The distribution of B_z component of the magnetic field in the magnetosphere is shown in fig.1 (1) before and after dipolarization (2), R_E-radius of the Earth. In fig.2 the distribution of the plasma pressure is shown. The strengthening of the B_z magnetic field component occurs simultaneously with the decrease of the plasma pressure ***p***.

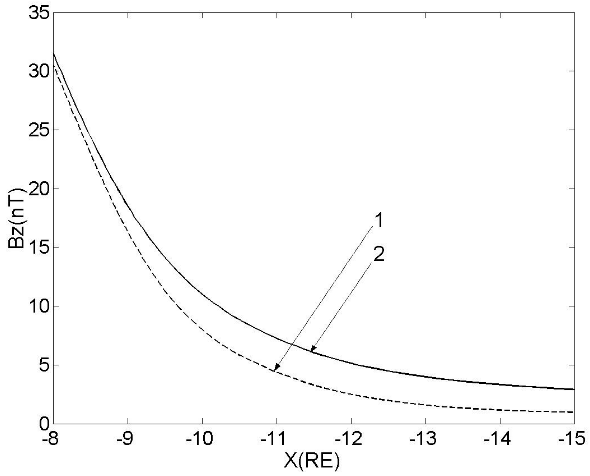

Fig. 1. The distribution of B_z component of the magnetic field in the magnetosphere before (1) and after dipolarization (2).

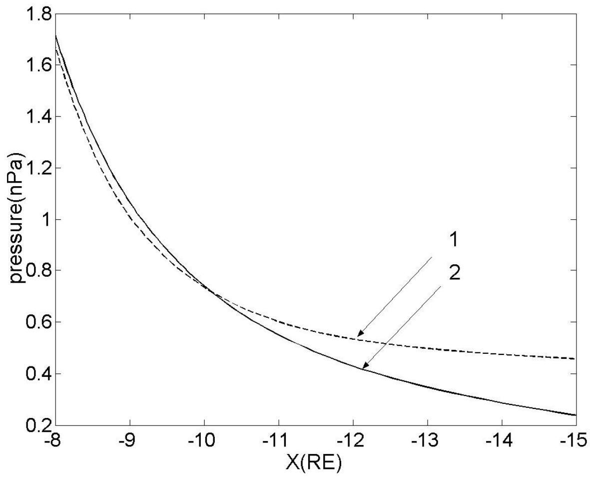

Fig.2. The distribution of the plasma pressure before (1) and after dipolarization (2).

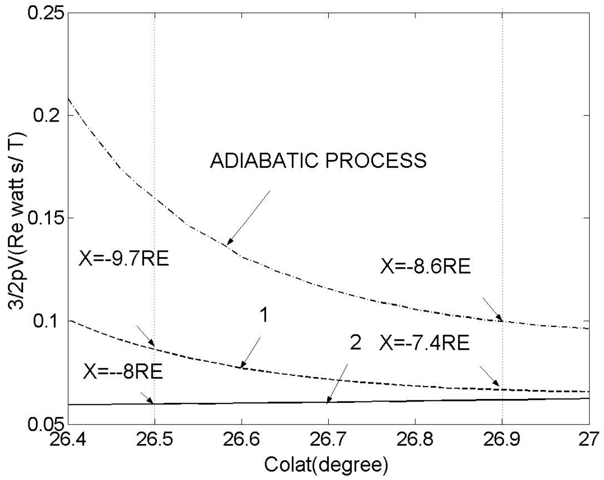

Fig. 3. The distributions of the kinetic energy of charged particles in magnetic flux tubes vs colatitude θ before (1) and after dipolarization (2).

In fig.3 the distributions of the kinetic energy of charged particles in magnetic flux tubes 3/2pV versus colatitude θ before (1) and after dipolarization (2) have been shown, it allows to determine changes of these quantities in the magnetic flux tubes. The fig. shows that the value of the kinetic energy of charged particles decreases significantly after dipolarization. The same fig. shows the value of the kinetic energy of particles in the magnetic flux tubes in the case of an adiabatic process.

Let us appreciate the cooling tubes of the magnetic field due to the precipitation of the particles. The current in the arcs of the aurora can reach values of 10 A/km^2, the average energy of injected particles will take as 5 keV. The time of depolarization is 5 minutes. Then the amount of heat lost by a magnetic tube with a single magnetic flux is equal to 0.055 R_E (J/ Wb). This value is sufficient to explain the cooling of the magnetic flux tubes at distances of up to 10

R_E. At large distances cooling is more intensive and other factors such as inhomogeneous magnetospheric convection should be taken into account.

Conclusions

The precipitation of the charged particles effects the redistribution of plasma pressure and the B_z component of the magnetic field in the magnetosphere tail. This effect is manifested as the dipolarization of the magnetic field lines. This effect, according to the results, is essential for a distance not exceeding 10 R_E. At larger distances the cooling of magnetic tubes is difficult to explain only by precipitation of the particles.

References

1. Runov, A., V. Angelopoulos, M.I. Sitnov, V.A. Sergeev, J. Bonnell, J.P. McFadden, D. Larson, K.- Glassmeier, and U. Auster, THEMIS observations of an earthward-propagating dipolarization front, Geophysical Research Letters, Vol.36, L14106, doi:10.1029/2009GL038980, 2009.
2. Birn, J., J. Raeder, Y. L. Wang, R. A. Wolf, and M. Hesse (2004), On the propagation of bubbles in the geomagnetic tail, Ann.Geophys., 22, 1773–1786.
3. Lyons, L. R., C.-P. Wang, T. Nagai, Substorm onset by plasma sheet divergence, J . Geophys. Res., 108(A12), 1427, doi:10.1029/2003JA010178, 2003.
4. Shiokawa, K., W. Baumjohann, and G. Haerendel (1997), Breaking of high-speed flows in the near-Earth tail, Geophys. Res. Lett., 24, 1179–1182.
5. N. A. Tsyganenko, Modeling the Earth's Magnetospheric Magnetic Field Confined Within a Realistic Magnetopause, J.Geophys.Res., 100, 5599-5612, 1995.
6. Liou, K., C.-I. Meng, A. T. Y. Lui, P. T. Newell, and S. Wing (2002), Magnetic dipolarization with substorm expansion onset, J. Geophys. Res., 107(A7), 1131, doi:10.1029/2001JA000179.