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THE INFLUENCE OF ELECTRIC FIELD INCREASING ON THE SUBSTORM CURRENTS FORMATION

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Abstract
The stable state of the magnetic flux tube with the current and finite magnetosphere conductivity has been studied in this work. The appearance of the finite anisotropic conductivity can be caused by thinning of the near-Earth plasma sheet in the night- side magnetosphere. The finite conductivity leads to the increasing electric field and to the formation of the longitudinal plasma pressure gradients also. The field-aligned currents flowing out of and into the ionosphere (the currents of the substorm expansive phase) appear in this region of the magnetosphere.

Introduction
The expansive phase of the substorm begins in the ionosphere with sudden brightening one of the most equatorial auroral arc in the late evening sector of the ionosphere. Then the arc breaks up on some auroral forms. The area of the luminescence auroral forms extends to the pole with the speed of ~1 km/c and to the west with the speed ~1-2 km/c [1] and takes the form of the auroral bulge, having sharp western edge. The intense Hall current having western direction flows in this region of the ionosphere. The currents flow out from the ionosphere along the magnetic field lines on the western edge of the bulge and it flows in on the east [2-3]. In the magnetosphere these currents have closed the magnetosphere current. The system of the ionosphere and field-aligned currents has received the name of current wedge of the substorm. In the night side of the magnetosphere at that time the magnetic field lines become more dipolar. The dipolarization of the magnetic field lines is caused by disruption of the magnetospheric current and appearance of currents systems of the substorm. What can cause formation currents wedge of the substorm? During the growth phase of the substorm the plasma layer on the night side of the magnetosphere makes more thin, it is connected with strengthening magnetospheric convection and stretching magnetic field lines in the tail of the magnetosphere. Ions in these conditions become nonmagnetized whereas electrons remain magnetized, in this case there are conditions for the development of two-stream instability. Electromagnetic disturbances propagate along magnetic field lines in the ionosphere and are partially absorbed in it. Absorption energy in the ionosphere can be considered as energy output by collisions of particles with waves. In this case it is possible to speak about anisotropic Pedersen and Hall magnetospheric conductivity. Occurrence of anisotropic conductivity will lead to change of the electric field in this region of the magnetosphere, the electric field will increase in the north-western direction. The strengthening of the convection in the ionosphere, caused by this electric field, is observed in some cases [4-5]. The changes of the electric field will lead to redistribution of the plasma pressure in the magnetic tubes and to occurrence of the currents up and down magnetic field lines or currents wedge of the substorm. It is possible to consider, that currents of an expansive phase of a substorm provide balance or stability of a magnetic tube in which the electric field has changed suddenly.

The description of processes in the magnetosphere and system of basic equations
It is impossible to consider processes in the magnetosphere in adiabatic approach taking into account finite conductivity of the magnetospheric plasma. The freezing-in of the magnetic field lines in the magnetosphere will be broken in this case. The change of the magnetic field will be caused by both the process of the magnetospheric plasma transfer and the magnetic field diffusion:

$$\Delta\vec{H} = \sigma\mu_0\left(\frac{\partial\vec{H}}{\partial t} + rot[\vec{\upsilon}\times\vec{H}]\right) \qquad (1),$$

where $\vec{H}$ -the intensity magnetic field in the magnetosphere, σ –the conductivity of the magnetosphere, $\vec{\upsilon}$ -the velocity of the magnetospheric plasma.
If conductivity is very great, change of the magnetic field is caused mainly by the second term in the right part of equation (1), the left part of the equation then can be neglected. In this case magnetic field lines move together with plasma, i.e. as though "frozen" in it. Absolutely other can be a situation with final magnetosphere conductivity if the second term in the right part of equation (1) can be neglected, the equation of the diffusion for the magnetic field will be received. In fig.1 the magnetic field line in the beginning of the expansive phase 1 and after dipolarization 2 is shown, the region of the finite conductivity is marked S. The source of the expansive phase of the substorm in the beginning is more close to the Earth or more equatorial of the given magnetic field line, and during the expansive

phase is displaced to the pole. The displacement of the magnetic field lines during dipolarization relative of the region final conductivity on the ionospheric altitude seems as the movement auroral forms to pole.

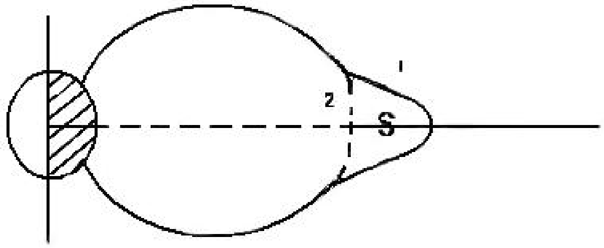

Fig.1

Knowing the velocity of auroral forms movement to the pole, it is possible to make an estimation of value of the conductivity from equation (1). We shall consider, that process of diffusion is determinative and we shall reject the second term in the right part of (1). Let LR_E be the characteristic spatial scale of the change magnetic field, where LR_E – the distance from the Earth up to the magnetic field line in the equatorial plane of the magnetosphere. From equation (1) we shall receive:

$$\frac{H}{(LR_E)^2} = \sigma\mu_0 \frac{H}{t}$$

or $$\frac{LR_E}{t} = \frac{1}{\sigma\mu_0 LR_E} \qquad (2).$$

The left part of this expression can be interpreted as velocity of moving of the magnetic field relative to the source of the expansive phase of substorm S or, on the contrary-the movement of the source of the auroral activity relative to the magnetic field. The displacement in the equatorial plane of the magnetosphere from the Earth on distance R_E dL corresponds to pole displacement in the ionosphere equal $R_E d\theta$ (θ-colatitude). For the dipolar magnetic field $L=1/\sin^2\theta$ and $dL=-2d\theta/\sin^3\theta$. The relation of the velocity in the ionosphere to velocity in the magnetosphere equals $2/\sin^3\theta$ or $2/L^{3/2}$. From (2) we shall receive the formula for estimation of conductivity:

$$\sigma = \frac{2}{\mu_0 R_E \upsilon_a L^{5/2}},$$

where υ_a –the velocity of the auroral forms movement to the pole, which we accept equal to~2km/c. For L=10 (θ=18^0) it is received σ=4·10^{-7} *S/m*. It is interesting to compare the integrated conductivity of the magnetic flux tube with the integrated ionospheric conductivity. Considering the scale of the region with final conductivity is of order $0.5R_E$, we shall receive value for integrated conductivity ~ $0.5\sigma R_E L^{3/2} \approx 40$ *S*. This value is noticeably greater than the value of the integrated ionosperic conductivity (~10 *S*). Thus, the appearance of the currents of the expansive phase of the substorm cannot be considered as process of simple disruption of the magnetospheric current. The final conductivity in this region leads to change of the electric field and formation of the azimuthal gradients of pressure and as consequence of it to the currents flowing along magnetic field lines.

Processes in the magnetosphere and the ionosphere of the Earth are considered more slow then time propagation Alfven waves into ionosphere and back ~1 minute, then it is possible to consider an electric field potential E=-gradφ, whereφ-the electric potential of a magnetic field line.

The connection of the electric field or potential with pressure in the magnetospheric plasma layer is set by equations:

$$div(\hat{\Sigma}\, grad\varphi) = j_{//} \qquad (3),$$

$$j_{//} = \frac{1}{B_I}(\vec{e}_z[\nabla p \times \nabla V]) \qquad (4),$$

were $\vec{e}_z$ – the unit vector, directed along magnetic field lines, $j_{//}$–the density of a current along the magnetic field lines, the current flowing from an ionosphere in northern hemisphere is considered positive, $\hat{\Sigma}$ -the tenzor of

integrated ionospheric conductivity, $V = B_I \int \frac{ds}{B}$ - the volume of the magnetic flux tube with the unit magnetic flux in the ionosphere, B_I –the induction of the magnetic field in the ionosphere, all gradients are calculated on the ionospheric level, the pressure p is considered constant along the magnetic field lines.
To the system of equations (1,3,4) should be added by the equation of movement for the charged particles, for example, ions:

$$-\nabla p / n - m_i \nu_{coll} \vec{\upsilon} - e\nabla\varphi + e\mu_0[\vec{\upsilon} \times \vec{H}] = 0 \qquad (5),$$

where ν_{col}- the frequency of collective collisions, n-the concentration of the charged particles, m_i –the mass of the particles.
In the right part of equation (5) the inertial member $m_i\ dv/dt$ hase been neglected. The value of the frequency of collective collisions can be received from estimation of final conductivity in the magnetosphere σ:

$$\sigma = \frac{ne\,\nu_{coll}\omega_i}{B(\omega_i^2 + \nu_{coll}^2)} \qquad (6),$$

where ω_i –the cyclotron frequency of ions, considering that $\nu_{coll} >> \omega_i$, $\sigma = ne^2/(m_i\ \nu_{coll})$ or $\nu_{coll} = ne^2/(m_i\ \sigma)$,
accepting $n=10^6$ 1/m3, $\omega_i = 10\ c^{-1}$, it is received $\nu_{coll}=40\ c^{-1}$.
The conductivity of the magnetic field is anisotropic, expression (6) defines conductivity in the direction along the electric field, in the direction to the perpendicularly electric field the conductivity $\sigma_H = ne/B$ in approach $\nu_{coll} >> \omega_i$ and coincides with the magnetospheric conductivity.

Conclusion

The currents system of the expansive phase magnetospheric substorm appears as a result of change (strengthening) of the electric field in the magnetosphere night sector. The reason of electric field change is formation of the final conductivity region in the magnetosphere. The current system of the expansive phase of a substorm provides balance of the magnetic flux tube with magnetospheric plasma pressure and the electric field.
The author of this work considers that process of dipolarization magnetic field lines in the magnetosphere and movement of the auroral forms to the pole in the ionosphere may be interpreted as a process of a diffusion of the magnetic field in the final conductivity region of the magnetosphere.
From the velocity of the auroral forms movement estimation of the integrated conductivity of the region with final conductivity in the magnetosphere has been made, this value is noticeably greater than the value of the integrated ionosperic conductivity.

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