Journal of the Georgian Geophysical Society,
Issue (B), Physics of Atmosphere, Ocean, and Space Plasma, v.15, 2011-2012, pp. 95-108

The magnetic boundary layer of the Earth as an energy-supplying channel for the processes inside the magnetosphere

[1]Marina Chkhitunidze, [2]Nino Dzhondzoladze

[1]*I.Javakhishvili Tbilisi State University, M.Nodia Institute of Geophysics,1 Aleqsidze str. ,0171,Tbilisi*
[2]*I.Gogebashvili Telavi State University*

Abstract

Quasi-viscous interaction between the solar wind plasma and the geomagnetic field regularly takes place at the boundary of the magnetosphere. Like the effect of reconnection of force lines of the Earth magnetic field and the interplanetary magnetic field (IMF) transported by the solar wind the intensity of the quasi-viscous interaction depends on the magnetic viscosity of the plasma. Anomalous increase of the value of this parameter in the MHD boundary layer of the Earth, the magnetopause is analogized with which, is connected with the variation of the solar wind perturbation. In such circumstances for presenting the development process of the magnetopause dynamics the numerical and analytical methods of mathematical modeling have been used. Their effectiveness depends on the quality of the model describing the energy transmission process from the solar wind to the magnetopause. Usually, adequacy of a model for the development dynamics of the phenomena inside the magnetosphere is assessed in this way. In this work one of such theoretical models is considered. This model is based on the Zhigulev "magnetic" equation of the MHD boundary layer, which is simplified by means of the Parker velocities kinematic model. In order to clearly show the physical mechanisms stipulating the energy transmission process from the magnetosphere boundary to its inner structures some new characteristics of the MHD boundary layers are presented: thicknesses of magnetic field induction and the energy driven into the magnetopause. Besides, in the magnetic field induction equation several models of impulsive time variation of the magnetic viscosity of the solar wind is used and by means of the sequent approximation method an analytical image of quasi-stationary variation of the magnetopause parameters correspondent to these models is presented.

1. Introduction

At the boundary of the Earth magnetosphere there is a distinguished structure called magnetopause – an area where the solar wind plasma screens the geomagnetic field. According to the physical properties the magnetopause may be analogized with the magnetohydrodynamic (MHD) boundary layer that is usually created during overflow of a solid surface magnetized by fluid or gas characterized with finite electric conductivity [1]. Similarity between the magnetized surface and the magnetosphere boundary is especially obvious at the boundary of the dayside of the magnetosphere. In its central area the flow of the solar wind plasma ramifies and a focal area is formed. Generally, the image of the overflow of the magnetosphere is spatial and asymmetric. According to various theoretical models the asymmetric character of the overflow of the magnetosphere is caused by the MHD nature of the flow of the solar wind plasma [2-4]. Experimentally this theoretical result is more or less proved by the work [5], and more completely- by results of computer simulations carried out recently [6].

Usually, energy dissipation always takes place in any type boundary layer (dynamic, temperature, magnetic). Therefore, during overflow of a solid surface stipulated by fluid or gas some part of the thermal flux formed by the dissipation in the boundary layer will penetrate into the overflowing body. It is natural that such an effect occurs during MHD overflow as well. Though, due to the specific nature of the overflow of the magnetosphere, thermal flux is substantially impossible on the magnetopause due to extremely low density of the solar wind. At the same time temperature change in the components of this extremely low density plasma is quite presumable. Change of the size as well as the direction of the induction flow of the magnetic field is also possible. The result of the former may appear in development of anomalous electric resistance effect in the plasma characterized with very high electric conductivity before interaction with the magnetosphere. This, in its turn, will intensify dissipation processes in the magnetopause. Both effects are connected with deceleration of the solar wind near the magnetosphere boundary. Invasion of additional flow of the magnetic field from the magnetopause into the magnetosphere is especially seen during sharp change in the distribution of the geomagnetic field induction in the MHD boundary layer. In such a case a change in the energy balance inside the magnetosphere is especially felt and it is linked with the reconnection of the force lines of the interplanetary magnetic field and the geomagnetic field [7]. Consequent to this process the corpuscular flow caused by erosion of the magnetosphere boundary will be distributed into different structures of the magnetosphere causing intensification of the radiation belts of the Earth.

Thus, analogizing the magnetopause with the magnetic boundary layer of the Earth is approved by physical similarity between the solid magnetized surface and the magnetosphere boundary. Such a view is especially suitable for analysis of the mechanisms directing the energy transition from the solar wind to the magnetosphere. However, for reliability of its qualitative physical image to strengthen it by quantitative assessments is very important. In its turn, it requires mathematically correct modeling of MHD effects developed in the magnetosheath (transitional area) before the magnetosphere and in its boundary. For the case of the magnetopause the basis for such modeling is the so called Zhigulev equation system of the plane magnetic boundary layer that corresponds to the main sections of the magnetosphere. In particular, the Zhigulev first category boundary layer corresponds to the meridional section of the magnetosphere that is directed along the central boundary force line of the geomagnetic field, and the second category magnetic boundary layer corresponds to the perpendicular equatorial section of the magnetosphere. The difference between the MHD equation systems that correspond to these layers is caused by the direction to each other of the components of the magnetic and velocity fields [1,3]. The reason for this difference is the flat characteristic of the equation system of the boundary layer and has no substantial meaning from the viewpoint of similarity of the physical processes taking place in the magnetopause.

Like any equations of the boundary layer, it is possible to solve the equations of the MHD boundary layer by numerical as well as analytical methods. At the same time, it is to be taken into account that to receive a precise analytical solution, except in the cases that are very simple and less interesting in the physical viewpoint, is almost impossible. This is connected with the problem of self-consistency of the magnetic and velocity fields that is a huge problem for tasks of MHD overflow. Therefore, the hydrodynamic image of the solar wind flow is primarily determined by means of any kinematical model. Generally, the purpose of the mathematical modeling of the boundary layer is to determine its parameters by means of the characteristics of the overflowed surface and the overflowing environment. The most important among these parameters are the thickness of the boundary layer and the image of latitudinal and longitudinal varieties forming the boundary layer. In the case of the magnetic boundary layer of the Earth such a characteristics is the distribution of the geomagnetic field over the magnetopause [3]. This parameter, like the thickness of the magnetopause, is especially variable due to regular changes in the velocity and density of the solar wind plasma and the frozen interplanetary magnetic field transported by the plasma. As the gas-dynamic pressure of the solar wind depends on its perturbation value its change is especially well manifested in the distance from the Earth to the critical point R_0 of the magnetosphere. As far as this linear parameter is changing the thickness of the magnetopause must be changing as well. Nevertheless, in some cases this effect might be leveled by the change in the electric conductivity of the solar wind. It means that the thickness of the magnetopause might not always be in correlation with the R_0 parameter. The image of variation of the latter is especially made obvious by the numerical model [8], the theoretical basis of which is described in the work [9]. However, this model, like other theoretical models, is not able to clearly determine the thickness of the magnetopause. The main reason for such a circumstance is gaps of the theoretical models and limited capacity of the analytical methods for solving the MHD equation systems. In this viewpoint the numerical methods have certain advantage, though they have quite significant disadvantage as they provide only retrospective analysis. Therefore, in case of the changes of the parameters of the solar wind it is impossible to forecast the nature of changes in the magnetopause parameters. In this respect we assume that the so called Schwec successive approximation method is more effective compared to other methods [10]. It enables to receive an image of the thickness of meridional and equatorial magnetopause and the magnetic field distribution in it in a clear analytical form [3,11,12]. In these works, for simplification of the Zhigulev equation system of the first and second category MHD boundary layer, the so called wedge-like model of magnetosphere and the Parker kinematic model were used. These models primarily determined the field of the velocities of the plasma near the critical point of the magnetosphere [13]. It is noteworthy that the Parker model and also its generalization in three-dimensional event have been very popular for modeling the annihilation process of the geomagnetic field at the dayside boundary of the magnetosphere [14].

Thus, the central area of the magnetopause at the dayside of the magnetosphere represents a main energy channel, by means of which the structures inside the magnetosphere are supplied with corpuscular flow from the solar wind. This process also involves gigantic funnel-shaped structures, polar cusps. By means of them the particles of the solar wind easily reach to the polar ionosphere. However, here the bulk of these particles are lost. Consequently, polar lights and aurora are observed. Only a few protons and electrons of the solar wind reach the magnetosphere structures from the solar wind. We may suppose that a structure similar to the MHD boundary layer may be formed also at the boundary of the polar cusp, in which formation of global geomagnetic storms is most probable due to the nature of the plasma flow. Therefore, the laminar approximation and consequently the use of equations of the MHD boundary layer are quite uncertain here.

2. The basic principles and initial equation

As we mentioned above, with its abilities the Parker kinematic model is quite effective as it enables to determine the velocity field of the ideal flow of the incompressible plasma near the critical point of the overflowing body. This very model has enabled to determine the parameters of the quasi-stationary meridional magnetopause [3,11,12]. As the velocity field was stationary the time dependence value has entered the induction equation of this magnetic field by means of different models of impulsive time variation in the electric conductivity of the solar wind. Furthermore, by the Shwec successive approximation method the parameters of the MHD boundary layer were determined in the same way: thickness and distribution of magnetic and electric fields over the magnetopause, and the velocity of the electromagnetic drift. However, these works do not involve any survey of the problem of the energy balance between the magnetopause and the dayside of the magnetosphere, modeling of which is the purpose of our work. For this reason qualitative admission was made, according to which during the changes of the parameters of the solar wind the magnetopause and the focal part of the dayside of the magnetosphere are considered as a closed system. It means that within some limits in this area the law of constancy of energy is quite admissible. It is natural that such an admission is quite inaccurate approximation compared to the real circumstances. At the same time, as it will be seen, it has adequate results with regard to the experimental data.

Thus, we may admit that in the focal area of the magnetosphere the sum of the energy accumulated in the MHD boundary layer of the Earth and the energy of the surface magnetospheric global DCF-current is unchanged during the perturbation of the solar wind. It is supposed, that the components of the summarized energy are the energies of the magnetic flow and the magnetic field and the energy of the corpuscular flow penetrated into the magnetosphere. It is clear, that in spite of the perturbation value of the solar wind some partial changes in the full energy will always take place. It means that the intensity of the DCF-current may change at the expense of the variation in the distribution of the magnetic field over the magnetopause. However, increase of the DCF-current certainly causes intensification of the processes inside the magnetosphere.

Such an image enables to use physical analogy at the hydrodynamic boundary layer, inside of which for assessment of the energy changes there are two effective parameters: the thickness of the boundary layer and the thickness of loss of the mechanical impulse. For the MHD boundary layer, as the analogy of these parameters, two characteristics were used: 1) δ_a - the thickness of displacement of magnetic field induction; 2) δ_b - the thickness of magnetic energy displacement [3]. According to the explanation the thickness of displacement of magnetic field induction shows the thickness of the induction flow loss by means of comparing the distribution of the magnetic field to the corresponding distribution of the ideal profile in the latitudinal section of the magnetopause. In addition, the thickness of the energy loss of the magnetic field shows the thickness of the lost energy layer by comparing it to the ideal distribution. Generally, these parameters are defined by the following expressions:

$$\delta_a = \int_0^{\infty,\delta_H} \left(1 - \frac{H}{H_0}\right) dx, \qquad (1)$$

$$\delta_b = \int_0^{\infty,\delta_H} \left(1 - \frac{H^2}{H_0^2}\right) dx, \qquad (2)$$

where the x -coordinate from the critical point of the magnetosphere is directed to the sun, and the magnetic field induction–H, the characteristic value of which is H_0, is directed alongside the extreme force line of the geomagnetic field. The upper boundary of integration may be replaced by the finite thickness of the MHD boundary layer only in case when this parameter is defined in analytically clear form. Such a possibility is given by the Schwec successive approximation method. In the approximation of the wedge-like model of the magnetosphere the above mentioned parameters were determined for the first time by this method and this have been the only attempt to use them so far. However, in the previous results the impulsive time variation of either the electric resistance of the solar wind plasma, or the parameter depended on it - the magnetic viscosity were not considered. The further obtained experimental data proved the possibility of anomalous increase of the electric resistance of the solar wind that has been used in modern computer experiments [6]. Therefore, it is obvious that qualitative and quantitative corrections of the data works [11,15,16] carried out earlier are necessary.

MHD equations involve magnetic viscosity λ_m as a coefficient that is defined by σ specific electric conductivity (c is light speed):

$$\lambda_m = \frac{c^2}{4\pi\sigma}, \qquad (3)$$

Let us use the following expressions for modeling of the impulsive time variation of this parameter during perturbation of the solar wind:

$$1)\ \lambda_m = \lambda_{0m}[1+\beta\sin(\pi t/\tau_0)]; \quad 2)\ \lambda_m = \lambda_{0m}e^{-\frac{t}{\tau_0}}; \qquad 3)\ \lambda_m = \lambda_{0m}(1-e^{-\frac{t}{\tau_0}}), \qquad (4)$$

where λ_{0m} is the value characterizing the magnetic viscosity, τ_0 - the time characterizing the impulsive variation of the magnetic viscosity, β - the coefficient of the impulsive strengthening. It is obvious that the first model corresponds to the periodic perturbation of magnetic viscosity, and the rest of the models are physically similar and show the change of the electric conductivity of the plasma from the finite to the ideal and vice versa.

Let us not take into account the curvilinearity of the extreme force line of the geomagnetic field on the dayside and direct the y axis from the critical point of the magnetosphere to the periphery. In case of such admission for determining topologic image of nonstationary distribution of the magnetic field in the Zhigulev first category plane boundary layer we may use a single-component equation of magnetic induction

$$\frac{\partial H_y}{\partial t}+u\frac{\partial H_y}{\partial x}+v\frac{\partial H_y}{\partial y}-H_y\frac{\partial v}{\partial y}=\lambda_m\frac{\partial^2 H_y}{\partial^2 x}. \tag{5}$$

According to the Shwec successive approximation analytical method suppose that the value of the Earth's dipole magnetic field in the lower boundary of the magnetopause is constant and gradually decreases in latitudinal direction of the δ_H thickness of the magnetic boundary layer. Thus, we have the following boundary conditions for the (5) equation

$$H_y=H_0,\ \text{when}\ x=0;\quad H_y=0,\quad \text{when}\ x=\delta_H. \tag{6}$$

Near the critical point of the magnetosphere the velocity field of the noncompressible plasma is determined by the Parker kinematic model [13]

$$u=-\alpha x,\qquad v=\alpha y, \tag{7}$$

where α is the reverse value of the time characteristic for the overflow of the magnetosphere day side. Thus, by means of (6) and (7), e.g. in case of the (4.1) model, we will have the equation

$$\frac{\partial H_y}{\partial t}-\alpha x\frac{\partial H_y}{\partial x}-\alpha H_y=\lambda_{0m}\left[1+\beta\sin(\pi t/\tau_0)\right]\frac{\partial^2 H_y}{\partial x^2}. \tag{8}$$

In the (6) boundary conditions, for solving the (8) equation, also the corresponding equations of the (4.2) and (4.3) models and for gaining information on the determination scheme of the magnetopause thickness we may refer to the works [3,11,12]. Therefore, it is quite sufficient to present quasi-stationary expressions of the distribution of the magnetic field over the meridional magnetopause and the boundary layer thickness (′ means the time derivative)

(4.1) $\lambda_m=\lambda_{0m}[1+\beta\sin(\pi t/\tau_0)]$

$$\frac{H_y}{H_0}=\left(1-\frac{x}{\delta_H}\right)+\lambda_{0m}^{-1}\left[1+\beta\sin(\pi t/\tau_0)\right]^{-1}\times\left[\left(\frac{\delta_H{}'}{\delta_H{}^2}\frac{x^3}{6}-\frac{\delta_H{}'x}{6}\right)+\alpha\left(\frac{x^3}{3\delta_H}-\frac{x^2}{2}+\frac{\delta_H x}{6}\right)\right], \tag{9}$$

$$\delta_H=\left(\frac{6\lambda_{0m}}{\alpha}\right)^{1/2}\left[1+\frac{\alpha^2\beta}{\alpha^2+\pi^2/\tau_0^2}\left(\sin\left(\pi\frac{t}{\tau_0}\right)-\frac{\pi}{\alpha\tau_0}\cos\left(\pi\frac{t}{\tau_0}\right)+\frac{\pi}{\alpha\tau_0}e^{(-\alpha t)}\right)\right]^{1/2}. \tag{10}$$

(4.2) $\lambda_m=\lambda_{0m}e^{-\frac{t}{\tau_0}}$

$$\frac{H_y}{H_0} = \left(1 - \frac{x}{\delta_H}\right) + \lambda_{0m}^{-1} e^{\frac{t}{\tau_0}} \left[\left(\frac{\delta'_H}{\delta_H{}^2} \frac{x^3}{6} - \frac{\delta'_H}{6} x \right) + \alpha \left(\frac{x^3}{3\delta_H} - \frac{x^2}{2} + \frac{\delta_H}{2} x \right) \right] \quad (11)$$

$$\delta_H = (6\lambda_{0m}\alpha^{-1})^{1/2} \left[e^{-\alpha t} + \left(1 - \frac{1}{\alpha\tau_0}\right)^{-1} \left(e^{-\frac{t}{\tau_0}} - e^{-\alpha t} \right) \right]^{1/2}, \qquad (12)$$

(4.3) $\lambda_m = \lambda_{0m}(1 - e^{-\frac{t}{\tau_0}})$

$$\frac{H_y}{H_0} = (1 - \frac{x}{\delta_H}) + \lambda_{0m}^{-1} \left((1 - e^{-\frac{t}{\tau_0}}) \right)^{-1} \left[(\frac{\delta'_H}{\delta_H{}^2} \frac{x^3}{6} - \frac{\delta'_H}{6} x) + \alpha (\frac{x^3}{3\delta_H} - \frac{x^2}{2} + \frac{\delta_H}{6} x) \right], \qquad (13)$$

$$\delta_H = (6\lambda_{0m}\alpha^{-1})^{1/2} \left[\left(1 - e^{-\alpha t}\right) + \left(1 - \frac{1}{\alpha\tau_0}\right)^{-1} \left(e^{-\frac{t}{\tau_0}} - e^{-\alpha t} \right) \right]^{1/2}. \qquad (14)$$

3.Physical analysis

By means of the (9)-(14) expressions it is possible to use the (1) and (2) expressions and determine their corresponding parameters by the magnetopause thickness. The results obtained before did not take into account the perturbation nature of the solar wind, possibility of which is given by the variation of the boundary conditions. By this way the qualitative analysis becomes easier, purpose of which is to show the so called North-South of the interplanetary magnetic field (IMF), as we have marked the B_y component, the variation of the value and direction in case of the (6) conditions changes in the image of the magnetic field distribution over the magnetopause. Such an analysis is interesting for qualitative consideration of a dynamical image of strong geomagnetic perturbations. It is known that when B_y is directed in the anti-parallel direction (i.e. to the South) of the geomagnetic field the reconnection of the force lines of the IMF and the geomagnetic field boundary may occur. Consequently, it will be followed by erosion of the magnetosphere boundary. In the opposite case, when B_y is directed to the North, the magnetosphere boundary is especially resistant to the invasion of the solar wind particles. Taking into account the first event of the B_y effect in the (6) boundary conditions leads to the following qualitative result: when B_y is directed to the North, addition of its value must not cause any change of the geomagnetic field profile screened on the magnetopause. However, when B_y is directed to the South, probably, the profile will qualitatively change and will resemble the profile characteristic for the Quetta MHD flow [17].

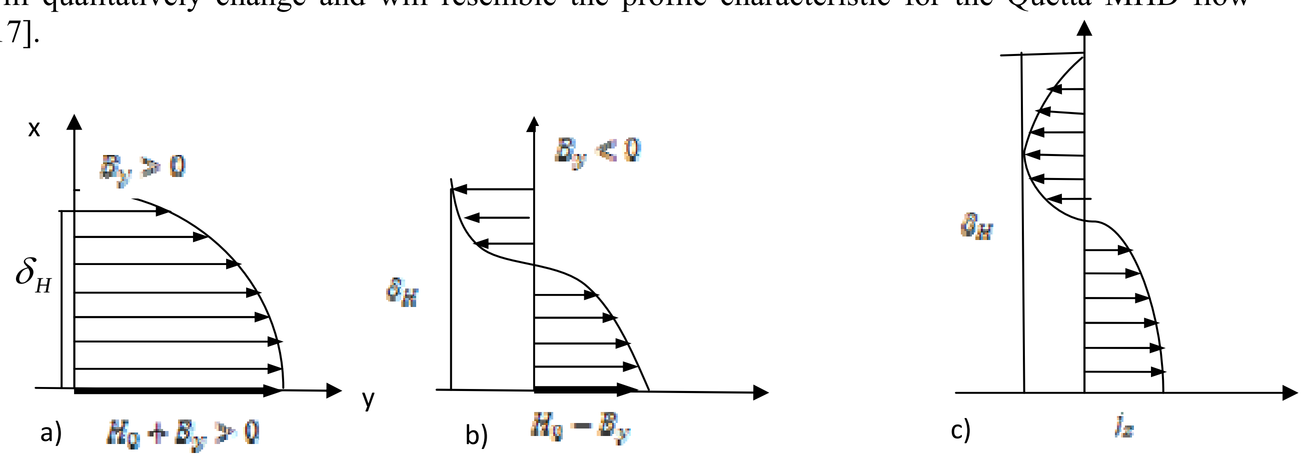


Figure 1. a) and b) The qualitative image of the geomagnetic magnetic field induction distribution over the magnetopause; c) distribution of the generated electric current for the b) case.

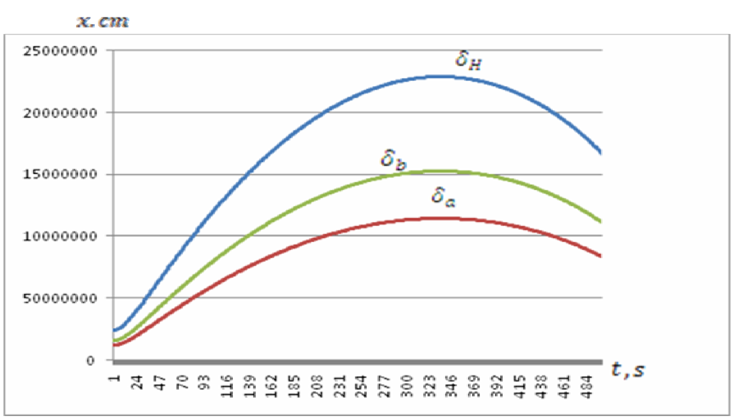
The above mentioned is illustrated by Figures 1a and 1b, which show corresponding profiles of varieties of B_y. The most interesting is fig. 1c. It clearly shows that the electric current generated in the magnetopause must be a partial component of the surface magnetospheric DCF-current.

The Figure 1c shows the profile of the inducted current that corresponds to the 1b event. Seemingly, like the magnetic field induction, in this case the direction of the electric current generated in the magnetopause is inverted as well. Similar behaviour must be characteristic for the corresponding component of the electric field intensity. It is obvious that formaly the electric current generated in the magnetopause is a partial component of the surface magnetospheric DCF-current. Therefore, this event is especially interesting in the viewpoint of analysis of the geomagnetic effects caused by the DCF- current intensity varieties.

Thus, the Fig.1a corresponds to the event when the IMF has a quite strong northern constituent. According to strong magnetospheric perturbation, e.g. the dynamics of the global geomagnetic storm development, this event is one of the reasons for the increase in the surface DCF- current intensity. The indicator is intensification of the screening effect in the magnetosphere boundary. Indeed, as in the $B_y > 0$ event the electric current generated in the magnetopause is parallel to the DCF-current it causes intensification in the latter. Though, meanwhile the change of the R_0 parameter may not be conspicuous. However, if the velocity and density of the solar wind increase violently, i.e. the gasodynamic pressure of the plasma increases and the magnetosphere boundary comes close to the Earth, it refers to a positive jump of the geomagnetic field. Usually it means that the initial phase of sudden commencement geomagnetic storm (SSC) is being formed. When $B_y < 0$ an opposite event, i.e. the geomagnetic field depression takes place. This event corresponds to the main phase of the geomagnetic storms. Its development is caused by the erosion of the magnetosphere boundary due to the reconnection of the force lines of the IMF and the geomagnetic field. On the other hand, it means that the effect screening the DCF- current that connects the plasma particles is weakened, due to which the intensity of the DR- the circular current inside the magnetosphere is increased [2,7]. Such a situation must be expressed by the figure 1c, according to which when there are anti-parallel and spatially distant from each other currents on the magnetopause their interaction is quite possible. It is natural that a summarized effect in the form of the global DCF- current takes place on the surface of the magnetosphere. However, due to the superposition of the partial currents which have opposite directions their contribution in the DCF- current decreases. In such a case the magnetosphere boundary moves again away from the Earth, and in the magnetosphere an injection of the additional corpuscular flow and magnetic field flux will take place. We may imagine the latter as the part of the geomagnetic field flux driven to the magnetopause, which appeared in the erosive area of the magnetosphere boundary. It is noteworthy that suggested by us the qualitative scheme of the development of the global geomagnetic storm with sudden commencement (SSC) is in principal accordance to the up-to-date global numerical model of the interaction of the magnetosphere and the solar wind [18]. This work, besides the complete simulation, considers the results of virtually strong geomagnetic storms in order to imagine the whole section dynamics of the magnetosphere. In particular, the records of the geostationary satellite GEOS and the records of the geomagnetic field on the Earth are compared to each other. Their analyses proved complete synchronism of the effects developed in the magnetosphere and on the Earth surface. The global geomagnetic storms, besides the variation in the intensity of the geomagnetic field, are followed by other effects as well. Among them is the increase of electron concentration in the ionosphere, the main radiation belt of the Earth. In its upper F- layer this event is especially felt. This effect is especially promptly observed in the main phase of the geomagnetic storm in the polar and high-latitude ionosphere. Therefore, it was considered that the ionosphere was mainly supplied with the energy from the polar cusp. However, according to [19] in the lower D-layer of the ionosphere, in low and middle latitudes, during day time, increase of electron concentration and intensification of very low frequency electromagnetic radiation are observed. As this effect occurs with certain time delay the author of the work [19] supposes that the energy electrons are distributed from high latitudes to the low ones. However, the force lines of the geomagnetic field corresponding to the low latitudes form a boundary of the plasmasphere, the main plasma reservoir of the almost entirely closed magnetosphere. Consequently, on the dayside this ellipsoid-shape structure that represents the spatial projection of the central area of the magnetopause must be supplied with energy mainly from the focal area of the magnetosphere. Indeed, high energy electrons, concentration of which is always insignificant in unperturbed solar wind, may appear in the low latitudes as a result of reconnection of the force lines of the IMF and the geomagnetic field. Acceleration of the electrons that have penetrated into the magnetosphere from the erosive area of the magnetosphere boundary is caused by a vast electric field, the direction of which is anti-parallel to the electric field of the DCF- current in the focal area. It is natural that these fields influence on each other. In particular, according to the figure 1c the intensity of the surface magnetospheric electric field must decrease due to the weakening of the summarized field generated in the magnetopause. Consequently, the value of the electric field inside magnetosphere must increase that is equal to activation of acceleration mechanism in low energy electrons. However, it must be emphasized that such a scheme of development of the above described events is appropriate only for the dayside of the magnetosphere. However, there are up-to-date data that prove that concentration increase of the energy electrons in the low latitude ionosphere is also possible in the nightside of the plasmasphere [20]. By this time, intensification of the VLF electromagnetic radiation and short-time geomagnetic pulsation generation are observed here. This work involves a detailed morphological analysis of a similar event on the example of one concrete case. According to the conclusion, such events are connected not with the development of global geomagnetic storms but with the generation of sufficiently strong magnetic substorms in the polar area.

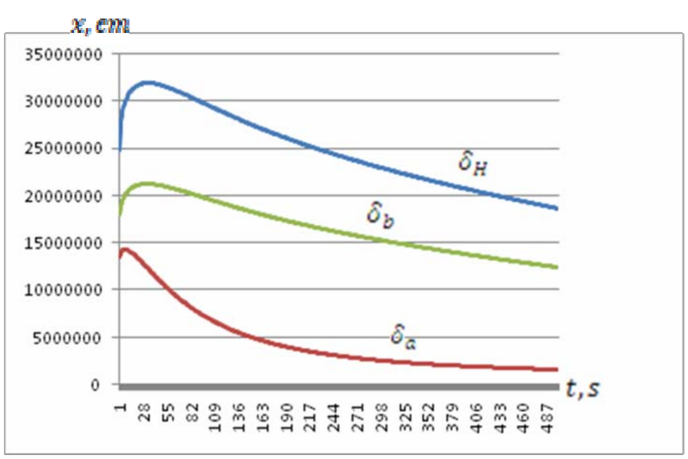
4.Results of numerical analysis

According to the specification of the Parker kinematic model in the stationary event the thickness of the magnetic boundary layer, as it is obvious in the corresponding analytical expressions, is constant. As the time correlation has entered the task from the magnetic viscosity coefficient, and the equation (5) has no starting condition all its solutions (9)-(16) are quasi-stationary [16]. The admission that the thickness of the magnetic boundary layer does not vary alongside the magnetosphere boundary is quite inaccurate and it is natural that it decreases the value of the results. Though this defect is rather quantitative than qualitative. Consequently, the above mentioned must have no substantial influence on the vast MHD image of the magnetopause. In order to corroborate this fact we carried out analysis of the (9)-(14) expressions. For quantitative and qualitative assessments we used the following parameters characterizing the magnetosphere overflow: $\lambda_{0m} = 10^{12}$ cm^2.s^{-1}, $\beta = 10^2$, $\tau_0 = 500$ s and $\alpha = \frac{V_0}{l_0} = 0.01$ s^{-1} . According to the model the last parameter is determined by the velocity characterizing the solar wind in the focal area of the magnetosphere and the linear scale of this structure: $V_0 = 2 \cdot 10^7$ cm.s^{-1} , $l_0 = 2 \cdot 10^9$ cm [16]. In the first model, as $\sin(\pi t / \tau_0)$ the function argument varies in the interval /0-π/, increase in the magnetic viscosity is possible by two rates. Such increase is natural for perturbated solar wind in case when all the conditions for development of anomalous electric resistance in the space plasma are fulfilled. In such a case generation of either global geomagnetic storms or high latitudinal magnetospheric substorms becomes especially probable [19]. The perturbation of the second type in the magnetosphere is usually much briefer compared to the first one. Therefore, in the fig. 2 the minimal time for development of a storm is used as a characteristic of impulsive time variation of the magnetic viscosity.

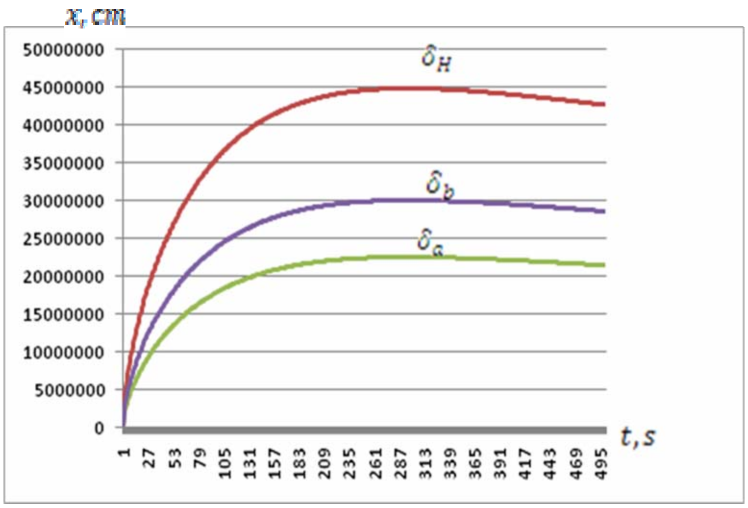


a) $\lambda_m = \lambda_{0m}[1 + \beta \sin(\pi t / \tau_0)]$

.



b) $\lambda_m = \lambda_{0m} e^{-\frac{t}{\tau_0}}$



c) $\lambda_m = \lambda_{0m}(1 - e^{-\frac{t}{\tau_0}})$

Figure 2. a),b) and c)- quantity change of characteristic magnetopause parameters $\delta_H, \delta_b, \delta_a$

5.Conclusion

Interpretation of experimental data correctly is an actual problem of the magnetosphere physics. Modeling of MHD interaction effects of the solar wind and the geomagnetic field in the magnetopause is particularly connected with this problem. Mathematically, this task, is especially complex, though in the boundary layer approximation it is quite simplified. For this purpose, this work involves a theoretical model that enables to receive a clear vast MHD image of dynamic variation of the magnetopause parameters. In particular, it is possible to adequately express the physical mechanisms for energy transmission from the dayside boundary of the magnetosphere to its inner structures during the perturbation of the solar wind. The fig. 2 shows the behaviour of the thicknesses of the magnetopause, the magnetic field induction displacement and the magnetic field energy loss within the frameworks of each model of the impulsive time variation of the magnetic viscosity of the solar wind plasma. In all the three cases synchronous time variation of the magnetopause thickness and the (1) and (2) parameters was observed. The quantitative dissipation effect of the surface DCF-current during the screening process of the geomagnetic field in the magnetopause was clearly seen that may be considered as the main indicator for the physical value of the magnetopause model presented by us.

This project was carried out by grant (contract № 12/70) obtained through Shota Rustaveli National Science Foundation.
Nonprofit Edition

References

[1] Krimski G.F. Romashenko U.A. Magnetohydrodynamic model of the Magnetosphere. Investigation of Geomagn. Aeron. and Solar phys. Moscow,"Nauka",1975, v. 36, pp.174-199. (in Russian)

[2] Pudovkin M.L.,Semenov V.S. The reconnection theory and interaction of solar wind with the Earth's magnetosphere. Moscow,"Nauka", 1985, 125p. (in Russian)

[3] Kereselidze Z.A. MHD Effects of finite electric conductivity of solar wind near the Earth's Magnetosphere. Tbilisi,State Univ. Press.,1986, 122p. (in Russian)

[4] Russel C.T., Zhuang R.J., Walker L.G., Crooker N.U.. Note on the location of the stagnation point in the magnetosheath flow. Geoph. Res., Lett. 1981, v.8, pp.948-86.

[5] Crooker N.U., Siscoe G.L., Eastman T.E.,Frank L.A.,Zwiscl R.D. J.Geophys.Res.,1984, vol.89, pp.9711-19.

[6] Dorelli J.C., Hesse M., Kuznetsova M.M., Rastaetter L. A new look at driven magnetic reconnection at the terrestrial subsolar magnetopause. J. of Geophys. Res., 2010, v.109, A12216, doi:10.1029/2004JA010458.

[7] Liperovsky V.A., Pudovkin M.I. Anomalous Resistivity and double layers in the magnetospheric Plasma. Moscow,"Nauka", 1983, 183p.(in Russian)

[8] http:/pixie.spasci.com/DynMod, 2007.

[9] Shue, J.-H.; Song, P.; Russell, C. T.; Steinberg, J. T.; Chao, J. K.; Zastenker, G.; Vaisberg, O. L.; Kokubun, S.; Singer, H. J.; Detman, T. R.; Kawano, H. Magnetopause location under extreme solar wind conditions. J. of Geoph. Res., 1998,Vol. 103, Issue A8, pp. 17691-17700.

[10] Shwec M.O. About of approximate solution of same task of hydrodynamic boundary layer. Appl.Math and Mech. 1949, vol. 3, Issue XII, pp.253-266.

[11] Zhonzholadz N., Chkhitunidze M. Modeling of the Magnetic Boundary Layer in the Polar Cusp. The works compilation of Telavi State University, 2007, pp-15-19. (in Georgian)

[12] Vanishvili G.K.,Gabisonia I.A.,Kereselidze Z.A. Plasma model with variable conductivity on the boundary of day-side magnetosphere. Proceed. of Inst. of Geophys., Tbilisi, 2003, pp.285-293.ussian)

[13] Parker E.N. Comments on the reconnection rate of magnetic fields. J. Plasma Physics, 1973, v.9. p.1, pp. 49-63.

[14] Sonnerup B.U.O. and Priest E.R. Resistive MHD stagnation-point flows at a current sheet. J. Plasma phys., 1975,v.14, pp.283-294.

[15] Kereselidze Z., Chkhitunidze M. On the problem of simulation of the magnetic viscosity in the vicinity of the magnetosphere boundary. Georgian Engineering News, 2005, №2, pp.48-50.(in Russian)

[16] Kereselidze Z. Kirtskhalia V., Chkhitunidze M., Kalandadze I. On Modeling of Magnetic Boundary Layer on the Dayside Magnetosphere. Georgian International Journal of Sci. and Teq.,2008, ISSN 1939-5925,vol.1№3, pp.249-256.

[17] Sutton G.W. Sherman A. Engineering magnetohydrodynamic. McGarow-Hill Book Company , 1965.

[18] Pulkkinen A., Rastätter L., Kuznetsova M., Hesse M., Ridley M., Raeder J., Singer H.J. and Chulaki A.. Systematic evaluation of ground and geostationary magnetic field predictions generated by global magnetohydrodynamic models. J. Geophys. Res., 2010, 115, A03206, doi:10.1029/2009JA014537.

[19] Sokolov S.N. Magnetic storms and their effects in the lower ionosphere: Differences in storms of various types. Geomagnetism and Aeronomy. 2011, vol. 51, N 6, pp. 741-752.

[20] Kleimenova N.G., Kozyreva O.V., Manninen J., Raita T., Kornilova T.A., Kornilov I.A. High-Latitude Geomagnetic Disturbances during the Initial Phaze of a Recurrent Magnetic Storm (from February 27 to March 2, 2008). Geomagnetizm and Aeronomy, 2011, vol.51, N6, pp. 730-740.

(Received in final form 20 December 2012)

Магнитный пограничный слой Земли, как канал снабжения энергией процессов внутри магнитосферы

М.С. Чхитунидзе, Н.И. Жонжоладзе

Резюме

На границе магнитосферы происходит перманентное квазивязкое взаимодействие между плазмой солнечного ветра и геомагнитным полем. Подобно эффекту пересоединения силовых линий вмороженного в солнечный ветер межпланетного и земного магнитных полей, интенсивность квазивязкого взаимодействия зависит от магнитной вязкости плазмы. Аномальное возрастание величины этого параметра в МГД пограничном слое Земли, с которым отождествляется магнитопауза, зависит от уровня возмущения солнечного ветра. Исходя из необходимости явного представления динамических изменений крупномасштабной картины магнитопаузы, до настоящего времени используются различные численные и аналитические методы математического моделирования. Эффекетивность этих методов зависит от того, как удачно описывает модель передачу энергии солнечного ветра магнитосфере. Обычно, таким образом дается оценка адекватности модели относительно процесса развития различных магнитосферных явлений. В данной работе рассматривается одна из таких теоретических моделей магнитопаузы, основой которой является «магнитное» уравнение МГД пограничного слоя Жигулева, упрощенное при помощи кинематической модели Паркера для скорости плазмы. Для представления в явном виде физических механизмов, направляющих процесс передачи энергии от границы магнитосферы к ее внутренним структурам, вводятся дополнительные характеристики МГД пограничного слоя: толщины вытеснения индукции и энергии магнитного поля на магнитопаузе. При этом в «магнитном» уравнении Жигулева используются различные модели импульсного изменения во времени магнитной вязкости солнечного ветра. В результате при помощи метода последовательных приближений определена соответствующая этим моделям квазистационарная аналитическая картина изменения параметров магнитопаузы.

დედამიწის მაგნიტური სასაზღვრო ფენა, როგორც შიდამაგნიტოსფერული პროცესების ენერგომომარაგების არხი

მარინა ჩხიტუნიძე, ნინო ჟონჟოლაძე

რეზიუმე

კვაზიბლანტი ურთიერთქმედება მზის ქარის პლაზმასა და გეომაგნიტურ ველს შორის პერმანენტულად მიმდინარეობს მაგნიტოსფეროს საზღვარზე. მზის ქარის მიერ ტრანსპორტირებული საპლანეტათაშორისო მაგნიტური ველისა და დედამიწის მაგნიტური ველის ძალწირების გადაერთების ეფექტის მსგავსად, კვაზიბლანტი ურთიერთქმედების

ინტენსივობა დამოკიდებულია პლაზმის მაგნიტურ სიბლანტეზე. ამ პარამეტრის სიდიდის ანომალური ზრდა დედამიწის მჰდ სასაზღვრო ფენაში, რომელთანაც გაიგივებულია მაგნიტოპაუზა, დაკავშირებულია მზის ქარის შეშფოთების დონის ცვლილებასთან. ასეთ ვითარებაში მაგნიტოპაუზის დინამიკური სურათის განვითარების პროცესის ცხადი სახით წარმოდგენის აუცილებლობიდან გამომდინარე, აქამდე გამოიყენება მათემატიკური მოდელირების როგორც რიცხვითი, ასევე ანალიზური მეთოდები. მათი ეფექტურობა დამოკიდებულია იმაზე, თუ როგორ აღწერს მოდელი მზის ქარიდან მაგნიტოსფეროსათვის ენერგიის გადაცემის პროცესს. ჩვეულებრივ, ასე ფასდება მოდელის ადეკვატურობა შიდა მაგნიტოსფერული მოვლენების განვითარების დინამიკასთან. მოცემულ ნაშრომში განხილულია მაგნიტოპაუზის ერთ-ერთი ასეთი თეორიული მოდელი, რომელიც საფუძველს წარმოადგენს პარკერის სიჩქარეთა კინემატიკური მოდელის საშუალებით გამარტივებული ჟიგულევის მჰდ სასაზღვრო ფენის "მაგნიტური" განტოლება. მაგნიტოსფეროს საზღვრიდან მისი შიდა სტრუქტურებისათვის ენერგიის გადაცემის პროცესის წარმმართველი ფიზიკური მექანიზმის ცხადად წარმოჩენის მიზნით შემოტანილია მჰდ სასაზღვრო ფენის ახალი მახასიათებლები: მაგნიტოპაუზაზე მაგნიტური ველის ინდუქციისა და ენერგიის გამოდევნის სისქეები. ამასთან, მაგნიტური ველის ინდუქციის განტოლებაში გამოყენებულია მზის ქარის მაგნიტური სიბლანტის დროში იმპულსური ცვლილების რამდენიმე მოდელი და მიმდევრობითი მიახლოების მეთოდის დახმარებით მიღებულია ამ მოდელების შესაბამისი მაგნიტოპაუზის პარამეტრების კვაზისტაციონარული ცვლილების ანალიზური სურათი.