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DCF- current Magnetic Effect in the Focal Area of the Magnetosphere and the Gratton Model Modification in a Compressible Medium

Marina Chkhitunidze

I.Javakhishvili Tbilisi State University, M.Nodia Institute of Geophysics,1 Aleqsidze str.,0171,Tbilisi

Abstract

The article considers possibility of change inDCF- surface current contour curvature caused by quasi-periodic oscillation of the magnetosphere boundary in the focal area of the magnetosheath. It is supposed that magnetic effect (dynamo-effect) of the periodic change of the focal segment curvature of the DCF-current contour stabilizes the stability of the meridional magnetopause in perturbed solar wind conditions. The article deals with comparative analysis of kinematic models of Parker and Gratton that is very important for solving the problem of modeling MHD image that is asymmetric to the MHD flow around the magnetosphere. It considers the meridional magnetopause and puts forward arguments in favour of using the modified Gratton kinematic model in case of compressible, magneticallyviscous plasma medium.

***Key words**: Solar wind, magnetosphere, magnetosheath, critical point, stagnation zone.*

1. Introduction

The magnetopause is a magnetic boundary layer of the earth, existence of which is provided by global surface magnetosphericDCF-current. The magnetic field, which is generated by this current, causes screening the geomagnetic field fromthe solar wind plasma all along the magnetosphere boundary. In the magnetopause a magnetohydrodynamic (MHD) interaction takes place, in which the most important function has the so called frozen interplanetary magnetic field (IMF)transported by the solar wind. As a result of the MHD interaction between the bowshock front and the boundary of the magnetosphere dayside a magnetosheath is formed. It is characterized with a specific structure of the plasma flow with a focal area and peripheral segments. Due to the solar wind gasodynamicand the IMF magnetic pressure variationscertain perturbation permanently takes place in the magnetosphere boundary of the Earth. Consequently, the distance from the Earth to the magnetopause changes as well. Thisdistance is measured from the Earth to the critical point of the magnetopause. In case of calm and less perturbed solar wind the motion of the magnetosphere boundary is characterized with quasi-periodicity with rather great amplitude. There is a modern numerical model describing the variation of thisparameter [1]. It instantly defines the displacement of the magnetosphere boundary. In such a case,together with the DCF-current contour shape the thickness of the magnetosheath area and size characterizing the focal area change as well.

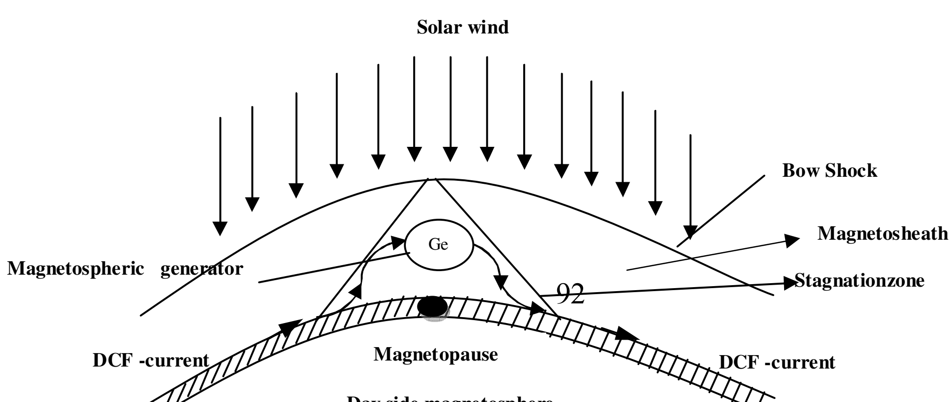
2. The solar wind flow specificity near the magnetosphere boundary

When the solar wind is calm and less perturbed the flow around the magnetosphere is produced in laminar-flow conditions that also depend on the value and direction of the interplanetary magnetic field. Some early researches stated that in the event of ideal electrical conductivity of the solar wind plasma the existence of symmetric flow of the plasma on the magnetopause is theoretically impossible [2]. In particular, near the critical point of the magnetosphere, due to deceleration of the plasma flow, depending on the frozen IMF direction, theoretically there can be two versionsof the flow around the magnetosphere: 1. Due to strain of the IMF force lines near the magnetosphere boundary so called magnetic barrier may be formed; 2. In the focal area base instead of the critical point there may appear stagnation lines of equatorial or meridional directions. In any case, in the magnetosheath the spatial flow of the plasma that was in the beginning symmetric in the main sections of the magnetosphere must become two-dimensional in the magnetopause. Both these versions were included in the model of the stagnation zone in front of the magnetosphere that was constructed later [3]. At the same time, the first experimental work really outlined a similar structure to the Chaplygin stagnation zone in the front area of the magnetosphere, though the Pudovkin-Semenov model was denied [4].Finally, modern computerized simulation (numerical experiment) proved that the solar wind plasma flow is symmetric afar from the magnetosphere boundary. However, in the focal area that can be analogized with the stagnation zone, the flow becomes two-dimensional [5]. However, unlike the Pudovkin model, in the numerical experiment the asymmetry of the plasma flow in the magnetopause is not caused by the solar wind perturbation.

Generally, the magnetopause is considered especially stable in the calm and less perturbed solar wind conditions when the IMF has the direction of the boundary force line of geomagnetic field on the dayside of the magnetosphere, i.e. it is directed to the north. The magnetopause thickness that is much less than the magnetosheath thickness is determined by the value of the surface magnetosphericDCF-current. According to the numerical experiment, afar from the focal area the solar wind flow is in fact three-dimensional. In the focal area the flow asymmetry is observable in both main sections of the magnetosphere – in the equatorial as well as in the meridional magnetopause. Namely, in the meridional magnetopause the plasma supposedly flows in thegutters formed by the geomagnetic field force lines. Much earlier than the numerical experiment, possibility of such an effect, although in the equatorial magnetopause, was predicted by the Pudovkin-Semenov theoretical model [2]. We suppose that the contradictory character of the modern numerical experiment results and the early theoretical ones is not occasional. It is possible that the topologic image of the flow that corresponds to the numerical experiment requires correction depending on the magnetosphere perturbation level. The [1] numerical model enables to make the correction in the event that in the process of the quasi-periodic oscillation of the magnetosphere boundary the magnetic effect of the surface global DCF current is observed.

In case the solar wind perturbation, that is mainly determined by intensification of the IMF southern constituent, exceeds its critical limitthe meridional magnetopause may become unstable. Usually, it is caused by the DCF- current intensification due to reconnection of the force lines of the IMF and the geomagnetic field. Destabilization here is resisted to a certain extent as the magnetic viscosity of the plasma increases due to violent fall of electric conductivity in the focal area. The value of this parameter before interacting with the magnetosphere is too little: $\lambda_m \approx 1{,}2 \cdot 10^5$ cm^2s^{-1}.Followinga violent change of the thermodynamic characteristic of the solar wind in the bow shock front the value of magnetic viscosity of the plasma in the magnetosheath becomes $\lambda_m \approx 1{,}2 \cdot 10^{12}$$cm^2s^{-1}$.Due to development of anomalous resistivity effect of plasma in the focal area this value may increase by two orders [6]. Certainly, this effect will influence the behavior of the plasma flow in the magnetopause. As mentioned above, in the numerical experiment only calm magnetosphericsituationis modeled, when the meridional magnetopause is stable. It is easy to imagine the degree of change inthe flow aroundthe magnetosphere in case the solar wind is perturbed. However, we assume that at the same time meridional magnetopause stabilization factor may arise, activity of whichseems to be againlinked with the main factor causing destruction – magnetic effect of the DCF -current. In order to prove this assumption let us refer to the magnetospheric surface DCF-current topology analysis in the Chaplygin stagnation zone.

The value characteristic velocity to the hydrodynamic movement of the plasma in the stagnation zone is much less than the solar wind velocity in the interplanetary space [4]. Therefore, in this area the DCF- surface magnetospheric current generator is activated due to the solar wind corpuscular current deceleration. At the same time, the plasma compressibility effect is especially strong [6]. As the reason of the deceleration is the geomagnetic field, it is obvious that the stableris the magnetosphere boundary, the more effectively works the magnetosphere generator and consequently, the stronger is the DCF-current. It seems that after reconnection of the IMF and the geomagnetic fieldforce line in the stagnation zone base, due to the magnetosphere boundary erosion, the current generator strength must decrease. However, taking into consideration that in the focal area the DCF-current contour is bow-shaped, than its magnetic effect may intensify. According to the [1] numerical model, if the DCF-currentarc is of the stagnation zone boundary contour shape than its curvature permanently varies. Consequently, the value of the magnetic effect of the DCF-current changes as well. Let us see the *figure 1* that depicts the scheme ofthe equatorial section of the focal area (stagnation zone). As shown in the scheme, the DCF -current arc supposedly consists of two anti-parallel current segments. The anti-parallel currentsare deflected from each other. This is caused by the increase of the magnetic field intensity, i.e. magnetic pressure in the space between the currents. In conditions of quasi-periodic oscillation of the magnetosphere boundary this effect must be temporarily variable. However, as the DCF- current direction is always the same the magnetic effect caused by its contour curvature will, more or less, always support the meridional magnetopause boundary stability. It means that in the base of the focal area there supposedly exists a periodically active source that actsagainst theerosion of the magnetosphere boundary. Therefore, the asymmetric MHD flow image in the meridional magnetopause, obtained by the numerical experiment for the calm magnetosphere conditions, supposedly, will be reasonable for perturbed situations as well.



Modeling of the magnetopause in kinematic approximation.Thus, due to the change in the DCF- surface current contour curvature a dynamo-effect takes placein the focal area. It means that intensity of the magnetic field increases in a certain segment of the magnetopause. To some extent the dynamo-effect makes the magnetospheric generator work, which transforms the solar wind energy into the DCF-current energy.

It is noteworthy, that even nowadays there is no general theory that would perfectly describe physical phenomena taking place in the magnetosphere boundary and would convincingly present the roles of each of these phenomena in the global process of providing the magnetosphere's inner structures with the solar wind energy. In this respect the MHD approximation, according to which the magnetopause is the Earth's magnetic boundary layer [2, 3], seems the most convenient. However, the MHD theory has a serious lack that significantly decreases the fundamental value of its results. Namely, there is no possibility for self-consistency of the plasma velocity field and the geomagnetic field and obtaining on its basis a general analytical solution to the equation system describing the MHD interaction. Therefore, modeling a dynamic image of the main parameters of the magnetopause, the thickness of the magnetic boundary layer and the geomagnetic field induction distribution in the magnetopause, appears to be especially difficult task in mathematical view point. Obtaining analytical solutions is possible only in relatively simple cases, whenthe solar wind flow structure in the magnetopause is a priori known. Such a simplification is usually madeby means of different kinematic models describing the velocity field. For example, the well-known Parker kinematic model for incompressible ideal liquid or its any modification was used for a long time [2,3]. According to the Parker model the velocity field corresponding to the incompressible flat flow of the solar wind plasma in the magnetopause near the critical point of the magnetosphere is defined by linear correlation

$$V_x = -\alpha x\,,\ V_y = \alpha y\,, \qquad (1)$$

where V_x, V_y are the components of the solar wind velocity, α is the inverse value of the time characterizing the flow around the magnetosphere. The beginning of the orthogonal coordinate system is placed in the critical point of the magnetosphere,the x-axis is directed to the sun, and y – along the extreme force line of the geomagnetic field.

The (1) model together with the analytical model of temporal impulsive variation of the magnetic viscosity of thesolar wind was used in the work [7]. Here the magnetic field induction equation was solved by the Schwec successive approximation analytical method, by means of which the thickness of the meridional magnetopause and nonstationary (quasi-stationary) analytical image of the magnetic field distribution in the meridionalmagnetopause was defined. It is known that precision of such solutions is about

15-20% [3]. This error is caused by the Parker model besides the Schwec method. It is obvious that the degree ofits adequacy to the real process of the flow around the magnetosphere is sufficient only in short distances from the critical (focal) point of the magnetosphere. In case of strict requirement it refers to the whole focal area of the magnetosphere, in which the compressibility effect of the plasma is especially strong [6]. Therefore, in order to obtain correct results it is necessary to take into account the plasma compressibility and expand the scopeof the plasma flow model,it requires using a kinematic model that considerscompressibility effect and at the same time is reasonable for the whole focal area from the critical point of the magnetosphere to the bowshock front. In our opinion, such features are partially characteristic to the Gratton kinematic model for the incompressible medium [8]. However, in order to make this model adequate to the quasi-periodic oscillations of the magnetosphere boundary itsmodificationin considerationof compressibility effect is necessary. It is obvious that such model, compared to the Parker model, is more appropriate for compressible and magnetically viscousplasmic medium like the solar wind. Therefore, in our viewpoint a modification of the two-dimensional Gratton model that considers the solar wind compressibility and magnetic viscosity, that at the same time, adequately to the numerical experiment, describes the solar wind flow structure in the whole focal area, is acceptable. Thus, let us apply to the Gratton model and present the velocity field corresponding to the plasma flow in the meridional section of the magnetosphere as follows:

$$V_x = -V_0\left(1 - e^{-\frac{V_0}{\lambda_m}x}\right), \qquad V_y = \frac{\beta V_0^2}{\lambda_m} y e^{-\frac{V_0}{\lambda_m}x}, \qquad (2)$$

where V_0 is the characteristicvelocity to the solar wind before interaction with the magnetosphere, λ_m is the magnetic viscosity of the plasma, β is a compressibility coefficient of the solar wind in the focal area [6].

Thus, according to (2), like in the numerical experiment, quite afar from the critical point of the magnetosphere there is only longitudinal component of the solar wind velocity. As at this distance the model (1) deprives its physical substance it is obviously more correct to replace it with the Gratton model modification presented here in the flow-around-magnetosphere task.

3. Conclusion

Thus, in the mathematical viewpoint it is obvious that the Gratton kinematic model has advantage compared to the Parker model. The advantage is caused by the fact that, due to interaction with the magnetosphere, the magnetic viscosity of the solar wind substantially increases in the focal area. Taking into account this factor will undoubtedly increase the value of the analytical solutions in the magnetopause modeling tasks. This will provide correct theoretical interpretation of results obtained by means of numerical experiments.

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Магнитный эффект DCF- тока в фокальной области магнитосферы и модифицированная модель Гратона в сжимаемой среде

М.Чхитунидзе

Резюме

В статье рассматривается возможность изменения кривизны контура DCF-поверхностного тока, вызванного квази-периодическим колебанием границы магнитного слоя в фокальной области магнитосферы. Предполагается, что магнитный эффект (динамо-эффект) периодического изменения фокусного сегмента кривизны контура DCF-тока стабилизирует стабильность меридиональной магнитопаузы в условиях возмущенного солнечного ветра. В статье рассматревается сравнительный анализ кинематических моделей Паркера и Граттона, что очень важно для решения проблемы моделирования асимметричного МГД изображения МГД обтекания магнитосферы. Рассмотренно меридиональная магнитопауза и выдвигается аргументы в пользу использования модифицированной кинематической модели Граттона в случае сжимаемой, магнитно вязкой плазменной среды.