National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No.NAS-5-12487

SC
Gill

N68-38173
nasa-CR-97372

ST-GM-PF-10766

MAGNETIC FIELD STRUCTURE INSIDE THE MAGNETOSPHERE IN THE RECOVERY PHASE OF A MAGNETIC STORM

by

O.A. Molchanov

(USSR)

27 OCTOBER 1968

MAGNETIC FIELD STRUCTURE INSIDE THE MAGNETOSPHERE

IN THE RECOVERY PHASE OF A MAGNETIC STORM

Geomagnetizm i Aeronomiya
Tom 8, vyp 5, pp 868-873
Izd-vo "NAUKA", Moscow 1968

by

O. A. Molchanov

SUMMARY

Herewith presented is a method of computation of geomagnetic field taking into account the external sources. The results are brought forth of field computation during the recovery phase of a magnetic storm at specific assumptions about parameters of perturbing currents.

*
*   *

In many geophysical investigations it is necessary to consider the effects, which are dependent on the configuration and the magnitude of quasi-permanent magnetic field inside of magnetosphere. In most works this field is assumed to be a dipole kind [1]. Up to the present time, there have been no works consecutively accounting for all the field's basic external sources, although there are some works describing the distortion of Earth's dipole field by one of these sources [2-4].

The author does not investigate the accuracy or applicability of external sources' hypotheses. The information deals only with the results of computation of a magnetospheric field model, which takes into account the aggregate action of these sources, and apparently could be better utilized for the interpretation of some geophysical events during the periods of moderate magnetic disturbance than the dipole approximation.

By the character of magnetic perturbations, it is possible to sort the external sources into three categories:

a) current systems in the ionosphere which generate the field $\bar{H}_i$;

b) drift currents at the expense of adiabatic motion of energetic particles inside the magnetosphere inducing the ΔH field, which we shall subsequently refer to as the perturbation field;

c) currents in the outer boundary of the magnetosphere, which in their turn may be split into currents originating at the solar wind flow past the magnetosphere (field $\bar{H}_1$) and the still hypothetical currents in the "tail" of magnetosphere (field $\bar{H}_2$).

The abovementioned division of external sources is a rather conditional one, and is the result of our limited knowledge about the mechanism of solar plasma interaction with the near-Earth magnetic field.

A method of computation of perturbed magnetic field structure is presented in this paper taking account of the described external sources; brought forth in particular, are the results of computation for the magnetic storm's recovery phase, when such current system inside the magnetosphere can be considered as symmetrical. Investigated here is the field structure at distances R = (2-8)R_E. In view of the admitted limitations of the internal field decomposition H_0, let us consider only the dipole term and ignore the ionospheric current system ($H_i \ll H_0$); let us also consider the currents at the boundary of magnetosphere as external relative to the region of investigation. The expressions for the field H_1 were borrowed from the work [3] with the consideration of the first two terms of decomposition. The expressions for the field H_2 are taken according to the model proposed in [4]. Finally let us consider the perturbation field $\Delta\overline{H}$ as quasi-stationary relative to the periods of finite drift motions of charged particles inside the magnetosphere, which for temporal scales, characterizing the magnetic storm and reasonable concentrations of energetic particls leads, as shown in [5], to the consideration of only the magnetic drift of charged particles across the magnetic field. We shall write the expressions for the drift-currents $\vec{j}$ exactly as is done in the work [6], and let us consider the drift trajectories of particles as circular and recumbent in planes parallel to that of geomagnetic equator, which permits us to reduce the calculation to the two-dimensional case.

The initial equations are as follows:

$$\begin{gathered}\operatorname{rot}\overline{H}_{SO}=0,\quad \operatorname{div}\overline{H}=0,\quad \operatorname{rot}\Delta\overline{H}=\frac{4\pi}{c}\bar{j}(\overline{H},\lambda_n),\\ \overline{H}=\overline{H}_0+\overline{H}_1+\overline{H}_2+\overline{\Delta H}=\overline{H}_{SO}+\overline{\Delta H}\\ \bar{j}(\overline{H},\lambda_n)=\frac{c}{|H|^2}\overline{H}\left[\nabla p_\perp+\frac{p_\parallel-p_\perp}{|H|^2}(\overline{H}\nabla)\overline{H}\right],\end{gathered}\tag{1}$$

where $p_\parallel$, $p_\perp$ are respectively the kinetic pressure of charged particles along and across the lines of force of the field $\overline{H}$ and λ_n are the parameters of drift-particles' distribution.

It is easy to conduct the computation in curvilinear orthogonal coordinates L, M, ϕ to which a transfer from spherical coordinates $\underline{r}$, Θ, λ is realized by formulas

$$r = L\cos^2\Theta,\quad r = M\sqrt{\sin\Theta},\quad \phi = \lambda \tag{2}$$

As is seen from (2), the lines of constant L are the lines of force of Earth's dipole field, but lines of constant M are perpendicular to the lines L and cross the lines of poles at the distances M.

The system (1) is nonlinear and complex for its consideration in general form; that is why it is resolved by the method of consecutive approximations.

A coordinate network is constructed by breaking down the lines L and M into a specific number of segments $\underline{l}$ and $\underline{m}$ with a certain step, and the values of field perturbation components in the nodes of the coordinates net ΔH_L, ij, k+1, ΔH_M, ij, k+1, ($0 \leqslant i \leqslant l$, $0 \leqslant j \leqslant m$) as well as the element shift of the line of force across the direction ΔL_{ij}, k+1 are found in each (k+1)-th iteration. The values derived by this means will depend on the dispersion parameters of particles in the zero approximation from the values of the field H_{so}, ij, and from the values of perturbed component and deformation elements of the lines of force obtained in the preceding k-th iteration.

Regarding the distribution of particles by pitch-angles $P(\psi)$ and energies $P(W)$ the following simplifying hypotheses are made

$$P(\psi) = C(\alpha)\sin^{\alpha+1}\psi, \quad P(W) = W_0\delta(W - W_0), \tag{3a}$$

where W_0 has the meaning of mean particle energy; α is the anisotropy parameter of particles by pith-angles; **C** (α) is the normalization constant.

The calculation of particle distribution along the lines of force L in the dipole of the condition (3a), fulfilled in [5] leads to the following equation:

$$n_д(L, M) = n_{эд}(L)\left[\frac{M_{эд}}{M}\right]^{\alpha/2}, \quad p_{\|д} = W_0 n_д/(\alpha+3),$$
$$p_\perp = W_0 n_д(\alpha+2)/2(\alpha+3), \tag{3b}$$

where $n_{эд}$ and $H_{эд}$ are respectively the particle concentration and the field on equator in the dipole approximation.

In the assumption of the frozen-in state of energy particles in the magnetic field, their distribution in the perturbed field at the point with coordinates L + ΔL, M taking into account the elementary geometrical considerations will be expressed in the following manner

$$n(L+\Delta L, M) = n_д(L, M)H(L+\Delta L, M)L/H_д(L, M)(L+\Delta L). \tag{3c}$$

Expressions for $\rho_\perp$ and $\rho_\|$, analogous to (3b), are obtained by susbstitution of $n_д$ by $\underline{n}$ from (3c) and a rearrangement of elements in matrices $\rho_\|$, $\rho_\perp$ (L_i, M_j).

Let us admit as initial the following distribution of energy particles on the equator

$$n_{эд} = \begin{cases} n_0\exp[-(L-L_0)^2/\Delta L_1^2], & L < L_0, \\ n_0\exp[-(L-L_0)^2/\Delta L_2^2], & L > L_0, \end{cases}$$

where parameters L_0, ΔL_1, ΔL_2 determine the center and the dimensions of particle zone in the equatorial plane. With a precision to terms of the order $|H_L/H|^2$, we reduce (1) to a simplified expression

$$
\begin{aligned}
\vec{j} = \frac{c\vec{\varphi}}{|H|^2} p_r H_m \Bigg[\Bigg(\frac{1}{p_r}\frac{\partial p_\perp}{\partial s_r} + \frac{H_M^2}{|H|^2}\frac{1}{R_1}\Bigg) + \\
+ \frac{H_L}{|H|}\Bigg(\frac{H_M}{|H|}\frac{1}{R_2} + \frac{1}{|H|}\frac{\partial H_M}{\partial s_1} - \frac{|H|}{H_M}\frac{1}{p_r}\frac{\partial p_\perp}{\partial s_1} - \frac{1}{|H|}\frac{\partial H_L}{\partial s_1}\Bigg)\Bigg],
\end{aligned}
\tag{4}
$$

where H_M, H_L are respective the componenets of the field along and across the coordinate lines L; $\rho_1 = \rho_\parallel = \rho_\perp$; $ds_1 = k_1 dM$, $ds_2 = h_2 dL$ are the elements of length in coordinates L, M; h_1 and h_2 are the corresponding Lamé coefficients; R_1 and R_2 are respectively the curvature radii of lines L and M. Since $H_{L,0} = 0$ an adequate precision of expression (4) is assured by the choice of coordinates.

Utilizing the standard expressions for the elementary field [6], we reduce (1) to the final expression

$$
\begin{aligned}
&\Delta H_{L,k+1} = C_1 I_1 + C_2 I_2, \quad \Delta H_{M,k+1} = C_3 I_1 + C_4 J_2, \\
&I_1(L, M, \lambda_n) = \int\int j_k(L', M', \lambda_n)[K(a) + C_5 E(a)]\, h_1 h_2 dL' dM', \\
&I_2(L, M, \lambda_n) = \int\int j_k(L', M', \lambda_n)[C_6 K(a) + E(a)]\, h_1 h_2 dL' dM',
\end{aligned}
\tag{1a}
$$

where C_1, C_2, C_3, C_4 are polynomials from arguments L, M, a; C_5, C_6 are polynomials from the arguments L, M, L', M'; K(a), E(a) are elliptical functions of the I and II kinds.

The elements of the transverse deformation ΔL_{ij} of the fixed line L (and consequently, of a fixed i), which enter very implicitly into the formulas and represent independent interest for the plotting of deformed lines of force are found by the formula

$$
\Delta L_{ij} = \sum_{t=1}^{j} H_L(L + \Delta L_{t-1})/H_M(L + \Delta L_{t-1})\Delta s_{1t}. \tag{5}
$$

In order to complete computations, it is important to choose correctly the distribution parameters of drift particles L_0, ΔL_1, ΔL_2, α, $\varepsilon = n_0 W_0$ (parameters n_0 and W_0 enter in the expressions (2), (3) only in the form of a product and that is why it is convenient to unite them), and also parameter r_b which is the distance to the magnetosphere boundary from the diurnal side, by which the characteristics of solar wind are expressed in model [3], and parameters r_1, r_2, H_x are the distances to the boundary of the current surface and the field magnitude on this surface from model [4].

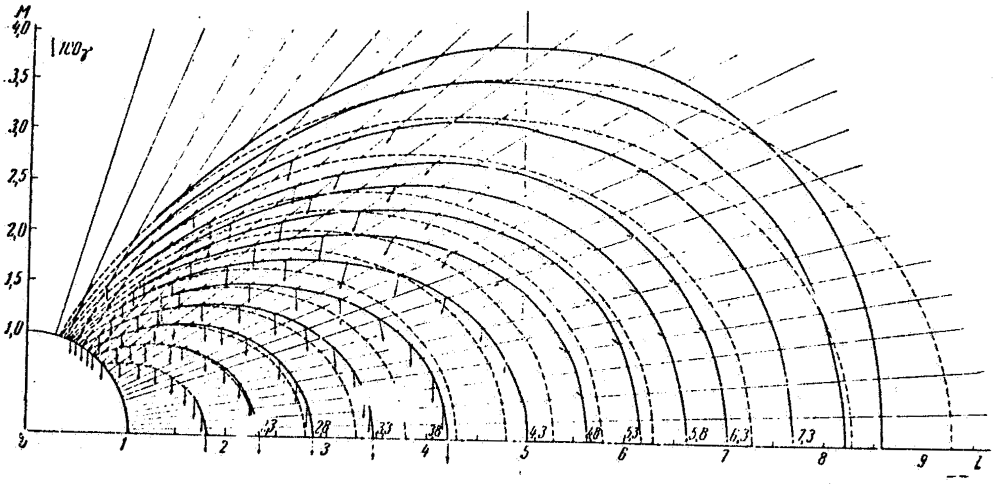

Fig.1

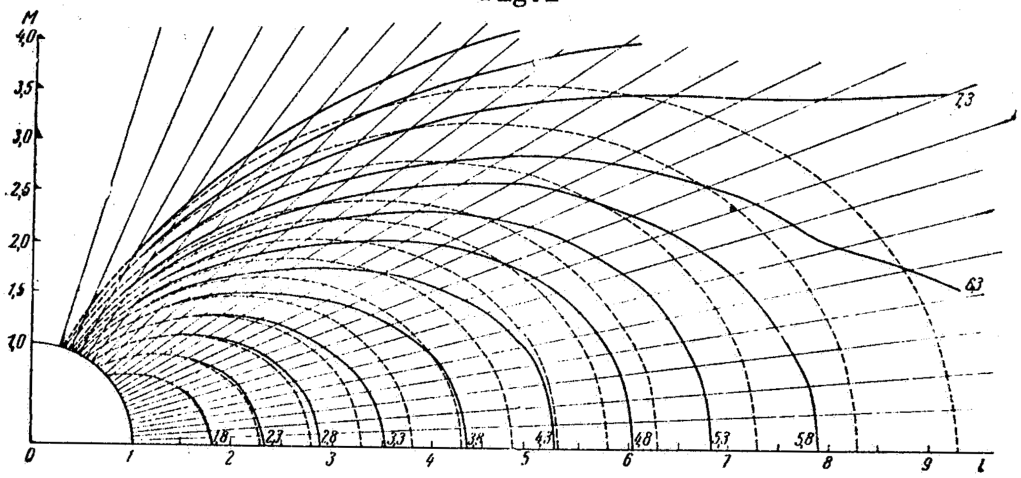

Fig.2

The experimental results could be criteria for such a choice. Unfortunately at the present time they are not numerous. We bear in mind, first of all, the magnetic field measurements inside the magnetosphere, carried out on the AES "Elektron-2", "Elektron-4" [8] and "Explorer-26" [9], the measurements of field structure in the tail [12] and of longitudinal asymmetry of trapped particles near the reflection points characterizing the longitudinal asymmetry of the field [4], and a series of measurements on registration of parameters of solar wind particles and of distances to the boundary of magnetosphere [13]. The results of computation, presented here, were conducted for the following parameters:

$$L_0 = 3.55,\ \Delta L_1 = 0.5,\ \Delta L_2 = 1.41,\ \alpha = 1.0,\ \varepsilon = 500\ \text{kev/cm}^3;\ r_b = 10,\ r_1 = 8,\ r_2 = 40,\ H_x = 40\gamma.$$

The structure of the lines of force and of the field vector of the ring current after two iterations is shown in Fig.1 (diurnal side) and Fig.2 (nighttime side). The broken lines are the lines of force of the dipole field, and the solid lines, are those of perturbed field.

Plotted by strokes in Fig.3, are the field deviations in equatorial are at 1200-1600 hrs LT measured on "Explorer-26", and for the comparison by (solid curve) are the computation differences $H - H_{д}$ on the equator in the meridional plane, corresponding to 1400 hrs LT. Considering the fact the the parameters of sources taken at computation time, may not coincide with the current characteristics during the experiment, we may assume that in principle, the computed model reflects correctly the peculiarities of the real perturbation inside the magnetosphere.

It is seen from Figs. 1 and 2, that the external sources significantly deform the lines of force of the dipole field. This is confirmed in Fig.4, where the unperturbed (dipole equatorial distances of the lines of force $L_{д}$ are plotted in abscissa, and the corresponding distances R_{equ}, in the perturbed field in ordinates (solid line is day, broken line is night). With the $L_{д}$ increase, the displacement of the lines of force increases. On the diurnal side this displacement reaches a maximum on $L_{д} \sim 55$, then its drop takes place, for greater $L_{д}$ the lines of force are crowding at the expense of solar wind's pressure. On the nighttime side, the dynamic pressure of solar wind is substantially less, therefore the release of internal lines of force is greater.

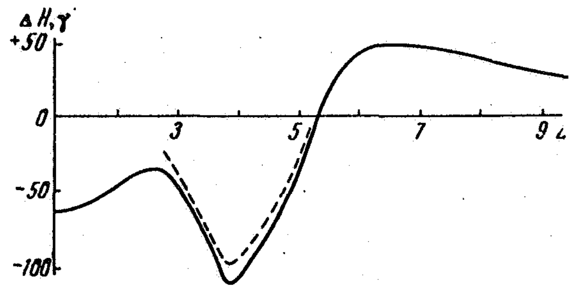

Fig.3

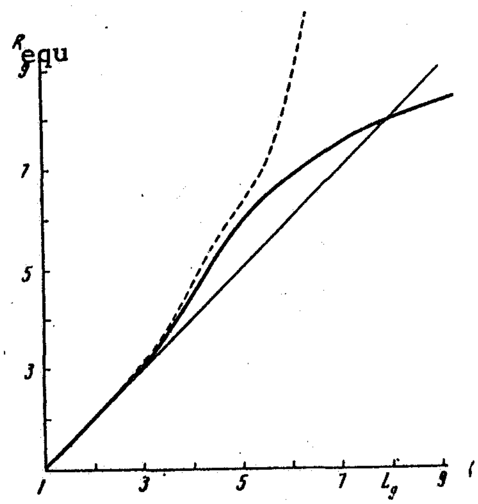

Fig.4

Beginning with $\Theta_0 = 67°$ ($L_{д} = 6.3$) the high-latitude lines of force form a tail. It may be seen that in the presence of a ring current, the minimum latitude of tail-lines lowers considerably (cf. Fig.2 here with Fig.2 in [4]), which is confirmed by the experiment of [14].

As is seen from this exposé, the computation scheme of the most essential (for L = = 2-8) of external sources, namely, the ring current, does not differ much from those of [1]. The most important differences are as follows:

1) Introduction of orthogonal curvilinear coordinates L, M, ϕ are not orthogonal and the expression analogous to (3) is not quite correct.

2) Computation of field structure of lines of force, is made in [1] only for the ring with $L_0 = 6$. In our work a more probable value of L_0 [8,9] is taken, and at field structure computation the boundary currents are taken into account.

A certain incorrectness of the above computation scheme consists in that, during the accounting for the inverse action of the perturbed field in the ring current, the longitudinal asymmetry of the ring current, brought in by boundary currents, was not, in fact, taken into account. However, from the results of [2,3], it can be seen that such asymmetrical distortion for the region $L = 3-5$ is not great by comparison with the symmetrical distortion of ring current under the influence of its proper field ($H_1 + H_2 << \Delta H$). In any case the taking into account of asymmetry leading to three-dimensional problem and to a considerably more cumbersome calculations, is hardly justified.

In conclusion I express my most profound gratitude to Ya.I. Lichter, whose valuable suggestions I followed, and also to Yu.D. Kalinin and N.P. Ben'kova for the helpful discussions.

Institute of Earth Magnetism
Ionosphere & Propagation of
Radiowaves
AN SSSR

Manuscript received on
16 January 1968.

*** THE END ***

R E F E R E N C E S

1. R.A. HELLIWELL, Whistler and Related Phenomena, Stanford University Press, 1965.
2. S.I. AKASOFU, Space Sci. Rev., 1963, 2, 91.
3. G.D. MEAD, J. Geophys. Res., 1964, 69, 1181.
4. D.I. WILLIAMS, G.D. MEAD, J. Geophys. Res., 1965, 70, 3017.
5. C.O. HINES, Space Sci. Rev., 1964, 3, 342.
6. E.N. PARKER, Phys. Rev., 1957, 107, 924.
7. D.A. STRATTON, Teoria Electromagnetizma, OGIZ, 1948.
8. S.Sh. DOLGINOV <u>ET AL</u>, Kosmichesskiye Issledovaniya, 1965, 3, 342.
9. L.J. CAHILL, J. Geophys. Res., 1966, 71, 4505.
10. S.N. VERNOV <u>ET AL</u>, Geofizicheskiy Bulleten' 1965, No.14, 96.
11. L.A. FRANK, Univ. Iowa Rept., 1966, 66, 8.
12. N.F. NESS, J. Geophys. Res., 1965, 70, 2989.
13. L.I. CAHILL, P.G. AMAZEEN, J. Geophys. Res., 1963, 68, 1835.
14. N.F. NESS, D.I. WILLIAMS, J. Geophys. Res., 1966, 71, 322.

CONTRACT No.NAS-5-12487
Volt Information Sciences, Inc.,
1145 19th Street, N.W.
Washington, D.C. 20036
Telephone: [202] 223-6700 X 36,37.

Translated by
Ludmilla D. Fedine
October 22/24 1968
Revised by
Dr. André L. Brichant
October 25, 1968