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

ST - PF - LPS - 10 552

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by

L. N. Zhuzgov
Sh.Sh. Dolginov
E. G. Yeroshenko

(USSR)

FACILITY FORM 602

N67 18959
(ACCESSION NUMBER)

(THRU)

25
(PAGES)

1
(CODE)

NASA-CR-82435
(NASA CR OR TMX OR AD NUMBER)

30
(CATEGORY)

10 JANUARY 1967

ST - PF - LPS - 10 552

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Kosmicheskiye Issledovaniya
Tom 4, vyp.6, pp. 880-899
Izdatel'stvo "NAUKA", 1966

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SUMMARY

A report is given on the observations in the vicinity of the Moon of a structurewise regular magnetic field, of which the intensity during observation time varied within the limits from 24 to 40 γ in accord with the variation of the magnetic activity index on the Earth's surface. The error in the absolute value of the scalar magnitude of the field is estimated by the quantity of $\pm 10\,\gamma$.

Comparison between the measured field values in the pericenter and apocenter regions and the estimate of possible field distortions by solar wind lead to the conclusion about the absence near the Moon of a field of dipole nature.

The question is discussed whether the observed field may be identified with the interplanetary field of solar origin, either deformed or trapped by the Moon and having finite conductivity and penetrability.

Comparison of measurements during fullmoon and newmoon periods failed to make directly apparent the extension of the Earth's magnetic field on the night side to distances of 60 Earth's radii.

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INTRODUCTION

The investigation of the magnetic field in the immediate vicinity of the Moon from AMS LUNA-10 was undertaken with the view of making more precise the magnitude and of ascertaining the nature of the near-lunar magnetic field.

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* ISSLEDOVANIYE MAGNITNOGO POLYA SO SPUTNIKA "LUNA-10"

The first experimental data on the intensity of the magnetic field in the vicinity and immediately close to the Moon, at distances of $\sim$55km from its surface, have been obtained on 14 September 1959 during the flight of the probe LUNA-2. In accord with the program a three-component magnetometer was installed on board LUNA-2 with a 700γ measurement range over each component and a $\sim$30γ resolution in real conditions of flight [1].

The coincidence of experimental data obtained at distances constituting fractions of lunar radius from the Moon's surface, allowed us to consider that the effective magnetic moment of the Moon can be only less than 10^{-4} of the magnetic moment of the Earth. The measurements were completed on the illuminated side during fullmoon. After the publication of data on the first measurement of the field near the Moon in [2], ideas were expressed on a possible solar wind influence on the results of the experiment by the second Soviet cosmic rocket.

The results of the flight of LUNA-2 have shown that the estimates of the possible magnetic field of the Moon by indirect data, known in literature of previous years, are of little foundation [3, 4].

At the same time it could not be excluded that the existence of a feeble magnetic field of the Moon might be possible under the following circumstances:

a) as a result of remanent magnetization in a possibly earlier existing field of the Moon;

b) as a result of Moon's magnetization by interplanetary fields, of which the intensity might have been higher to that observed at the present time.

These circumstances, coupled with the admission that the magnetic field of the Earth may reach the Moon on the night side, rested at the basis of new attempts to make apparent the influence of the Moon in the variations of the index of geomagnetic activity [5 - 10].

Particular interest is offered by the experimental data obtained during the flight of EXPLORER-18 on the possible influence of the Moon on the results of measurements of the magnetic field inside the Moon's orbit [11]. A notable field intensity increase (to 14.6γ) was observed in the course of 4 hours on 14 December 1963, when Explorer-18 was at a distance of $28R_E$ - $31R_E$ and at an angle of 40° to the line Earth-Sun.

Comparison of Moon's, Earth's and Sun's ephemerides and of the level of geomagnetic activity led the authors of [11] to the conclusion that the observed effect is simplest of all explained by the crossing by Explorer-18 of the "tail" of Moon's magnetosphere, formed by solar plasma flow past the magnetic field of the Moon. Taking into account the distance from the Moon at that time, the length of lunar magnetosphere tail was estimated at about $150R_M$, and the width at $\sim$ $30R_M$, where R_M is the radius of the Moon.

The results of observations under similar respective positions of the Moon and the Earth in January and February 1964 were brought out in a subsequent publication [12]; however, the positions of the satellite relative to the geomagnetic

shock wave front were then different and less practical for the observation of the influence of the Moon. No effects were noted during these observations that would be similar to that observed in December 1963, though the author of [12] does not exclude the possibility of their existence. Following is the interpretation given to the observed effect: on 14 December 1964 the satellite was found to be in the midst of the shock wave region, having arisen during solar plasma flow past the Moon. The possible boundaries of the shock wave region were estimated for several values of magnetic field intensity and solar wind particle density. Since no admissions of any kind are made relative to the law of field variation with the distance from the Moon, it is postulated that the intensity of the magnetic field on the Moon's surface may reach in the equatorial plane several hundred gammas or more. Having in mind its small dimensions compared with the Larmor radius of protons, the emergence near the Moon of a shock wave appears to be little probable in the absence of a constant field. In order to coordinate the indicated deductions with the results of the experiment of [1], the possibility is indicated of field of the Moon deformation by the solar wind, fact which was referred to earlier..

The discussion of the other interpretations of the results of observations by Explorer-18 on 14 December 1963 is reported in the works [13, 14].

It was already mentioned earlier that the attempts to make apparent the variations of the index of geomagnetic activity in the fullmoon period are based upon the assumption that the Earth's magnetic field may extend on the night side to the Moon and beyond. Since the experimental data of LUNA-10 are discussed in the following on the basis of these assumptions, a brief expounding of that question is presented below. It is admitted that there exist forces capable to limit the radial and lateral extension of the magnetosphere tail: the transverse pressure of the geomagnetic field, the pressure of the plasma and that of hydromagnetic waves.

According to the estimates of [15] the length of the tail is $10^6 R_E$. Its maximum length is 100 R_E , based on estimates in [16]. The experimental determinations of the magnetic field on the night side, carried out on Explorer-10 at distances up to $43R_E$, allowed to track the tail of the Earth's magnetosphere ar least to $\sim 25R_E$ but subsequently the interpretation of the field and the ascertaining of its departure from the interplanetary field were difficult [17].

The most prolonged investigations of the Earth's magnetic tail within the bounds of the lunar orbit were carried out on Explorer-18, where the estimates of the radial extension were conducted with the aid of radiation sensors and a magnetometer.

The estimates of the length of the tail with the aid of radiation devices are based upon the fact that during solar wind interaction with the geomagnetic field part of the directed kinetic energy of the solar wind goes to particle heating to energies of several tens of kev. The accelerated electrons of such a type exist as formations limited in time and space. Since such formations were observed during the flight of Explorer-18 through the orbit apogee ($32R_E$), the conclusion was derived that the Earth's magnetic tail extends at least to $32R_E$ [18].

It was established during the flight of Mariner-4 that electrons with energies $\geqslant$40 kev were not observed in the space between 1° to 5° from the central line of the assumed Earth's magnetic tail from the distances of $23R_E$ to $3300R_E$, and, consequently, the Earth's magnetic tail is not observed in the space between $32R_E$ and $3300R_E$ [19].

Direct measurements by magnetometers completed on Explorer-18 have shown that a field of 4 to 30γ intensity was observed at the distance of $32R_E$; it was directed along the line Earth-Sun, toward the Sun above the ecliptic plane, and in a direction from the Sun below it; the most frequently observed field for $K \leqslant 2$ was of ∿16γ, and for $K \geqslant 2$, it was of ∿ 22γ. The width of the magnetic tail at $30R_E$ constitutes $40R_E$ [20].

During the measurements of the magnetic field in the vicinity of the Moon it is impossible not to assume a specific influence of interplanetary magnetic fields [20]; it follows from the combination of the longest measurements of such fields [20] that these fields have a solar origin at least inside the Moon's orbit, and they rotate with a period equal to the rotation period of the Sun. Moreover, it is established that the fields directed toward the Sun, as well as from it are observed in the outer space. The number of sign alternations in the various periods of the solar cycle was different and was apparently dependent on solar activity. A sufficient correlation was found between the sign of the interplanetary magnetic field and the prevailing sign of the fields in the active regions of the phosophere of the Sun.

1. APPARATUS AND CHARACTER OF SCIENTIFIC INFORMATION

LUNA-10 was placed into the orbit around the Moon with 72° inclination to the lunar equatorial plane, 350 km periselion and 1015 km aposelion. The rotation period in orbit constituted 2 hours 58 minutes.

The information about the operation of scientific apparatus was transmitted during separate communication session of varied duration, from a few minutes to one and one half hours, over visible portions of the trajectory. The total volume of information relative to magnetic field intensity constituted about 200 measurements over each of the three components of the magnetometer. From the total number of sessions two were conducted during fullmoon days (5 April and 4 May) and one session on the newmoon of 20 April.

A ferrosond magnetometer was utilized on LUNA-10 for the measurement of the three components of the magnetic field. The range of measurements over each component constituted ±50γ with a resolution of ∿ 1γ.

The corrections ΔX_0, ΔY_0, and ΔZ_0 to the absolute values of the "zero" of each channel were determined in the ring system with sufficient space volume of uniform field.

The magnetometer's sensors were distant from the container with scientific instrument package by ∿1.5 m. The disposition of the ferrosondes relative to the satellite is shown in Fig.1. The effect of container's magneticvand electromagnetic

deviation for such a withdrawal of sensors was determined with the help of a special nonmagnetic mobile and maneuverable stand on the fully assembled satellite. The residual effect was compensated with the aid of a system of sufficiently removed constant magnets.

Each ferrosond measures the projection of the magnetic field vector on its long axis. Radioobservations have shown that while in flight,the satellite spinned relative to a certain axis. During rotation in a uniform magnetic field, the readings of the three orthogonal ferrosondes are described by the equations

$$\begin{aligned} X &= T_{\parallel}\cos\alpha_X + T_{\perp}\sin\alpha_X\cos(\omega t+\varphi_X),\\ Y &= T_{\parallel}\cos\alpha_Y + T_{\perp}\sin\alpha_Y\cos(\omega t+\varphi_Y),\\ Z &= T_{\parallel}\cos\alpha_Z + T_{\perp}\sin\alpha_Z\cos(\omega t+\varphi_Z). \end{aligned} \tag{1}$$

Here $T_{\parallel}$ and $T_{\perp}$ are respectively the longitudinal and the perpendicular components of the total magnetic field vector $\vec{T}$ relative to the axis of rotation. (Fig.2), $\alpha_X, \alpha_Y, \alpha_Z$ are the angles between the axis of rotation withe axes of ferrosondes X, Y, Z; ω is the angular rotation velocity of the satellite; φ_X, φ_Y, φ_Z are the initial phases, β is the angle between the axis of rotation and the field vector $\vec{T}$.

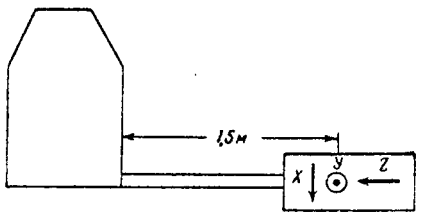

Fig.1. Mutual disposition of the container and of magnetometer's pickups

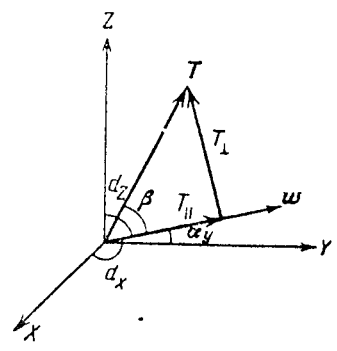

Fig.2. Orientation of the axis of rotation ω and of the magnetic field vector $\vec{T}$ in the satellite's system of coord nates

Thus, the readings of each component include the constant component and the sinusoidal component with rotation period of the satellite.

The measurements along each component were telemetered with 128 sec.intervals. The satellite's rotation period was 32.5 sec at the beginning of measurements (according to radiosignal data); it increased as the time went on. Thus the interrogation period exceeded by nearly 4 times the rotation period. With such information discreteness the obtained magnetograms are the result of stroboscopic observation of the harmonic signal. If the interrogation period is τ_0, and the rotation period is τ_B, with $3{,}5\tau_B < \tau_0 < 4\tau_B$, the phase variation of the sinusoidal signal for the period of interrogation will be

$$\Delta\varphi = -2\pi\frac{4\tau_B - \tau_0}{\tau_B}.$$

The sequence of measurement points of the sinusoidal part of the component satisfies the condition: $X_{\sim} = T_{\perp} \sin \alpha_X \cos (k\Delta\varphi + \varphi_X)$, where k is the number of the point of measurement (Fig.3a).

If the difference $4\tau_B - \tau_0$ is sufficiently small, $\Delta\varphi \ll \pi$ and the line linking the consecutive measurement points is close to the sinusoidal

$$X_{\sim} = T_{\perp} \sin \alpha_X \cos \left(- \frac{2\pi}{\frac{\tau_B}{4\tau_B - \tau_0}} k + \varphi_X \right). \tag{2}$$

The latter's amplitude coincides with the amplitude of the real component, and the observed period exceeds significantly the rotation period τ and is equal to

$$\tau_H = \frac{\tau_B}{4\tau_B - \tau_0} \text{ interrogation cycles,}$$

or (3)

$$\tau_H = \frac{\tau_B}{4\tau_B - \tau_0}$$

The increase of the rotation period τ leads to the decrease of the observed period; at $\tau_B = \tau_0/3.5$, the observed period becomes equal to two cycles. Inasmuch as the neighboring points can be purportely linked only by a straight line, the observed period τ_H can not be less than two cycles. The subsequent period increase leads to the rise of the observed period τ_H Inasmuch as now the interrogation peirod τ_0 is close to 3τ, the value of phase lead for a cycle and the observed period should be computed by formulas

$$\Delta\varphi = 2\pi \frac{\tau_0 - 3\tau_B}{\tau_B},$$

$$\tau_H = \frac{\tau_B}{\tau_0 - 3\tau_B}.$$

The variation of the observed period τ_H with the increase of rotation period τ_B, computed according to the formulas brought up, is shown in Fig.4. The values of τ_H taken down from the magnetograms are shown by circles.

It should be noted that if the condition $\Delta\varphi \ll \pi$ is not fulfilled and the phase lead for a cycle approaches π, the observed curve loses its sinusoidal character, acquiring a complex saw-like shape (Fig. 3b). If the measured field is uniform, the characteristic peculiarity of the observed curve is its periodicity.

The experimental magnetograms of every component (Fig.5) are curves of the type described by Eqs. (1), of which the shape and the period are determined by the above described stroboscopic effect.

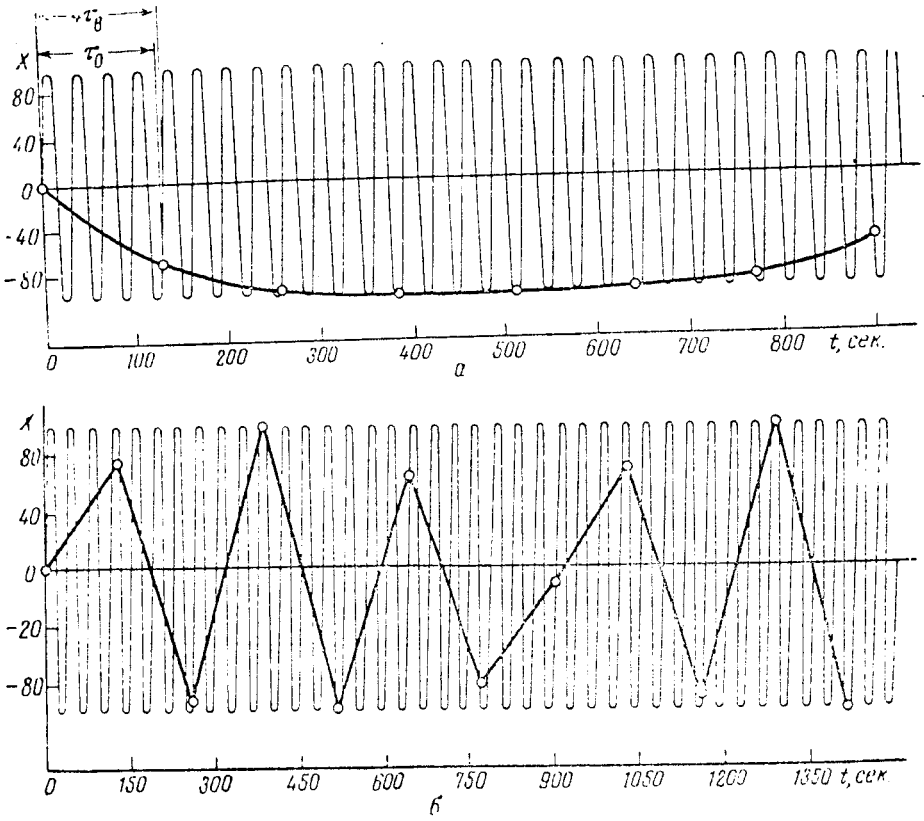

Fig.3. Shape of the observed signal during interrogation with period τ_0 = 128 sec., and container's rotation periods τ_B= 32.5 sec. (a) and τ_B= 37.5 sec. (b)

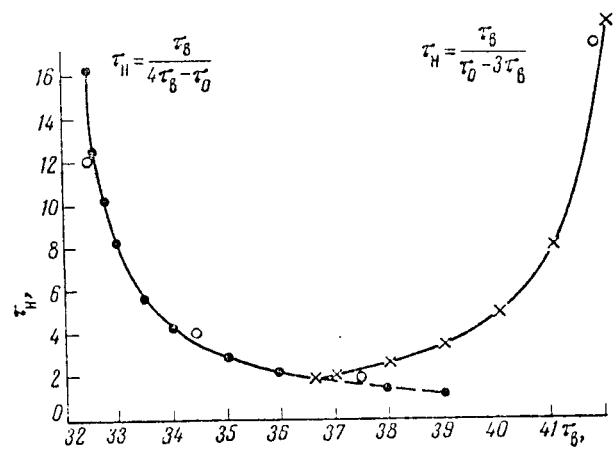

Fig.4. Variation of the period τ_H of the magnetograms as a function of container's rotation period. The period is indicated in telemetry interrogation cycles

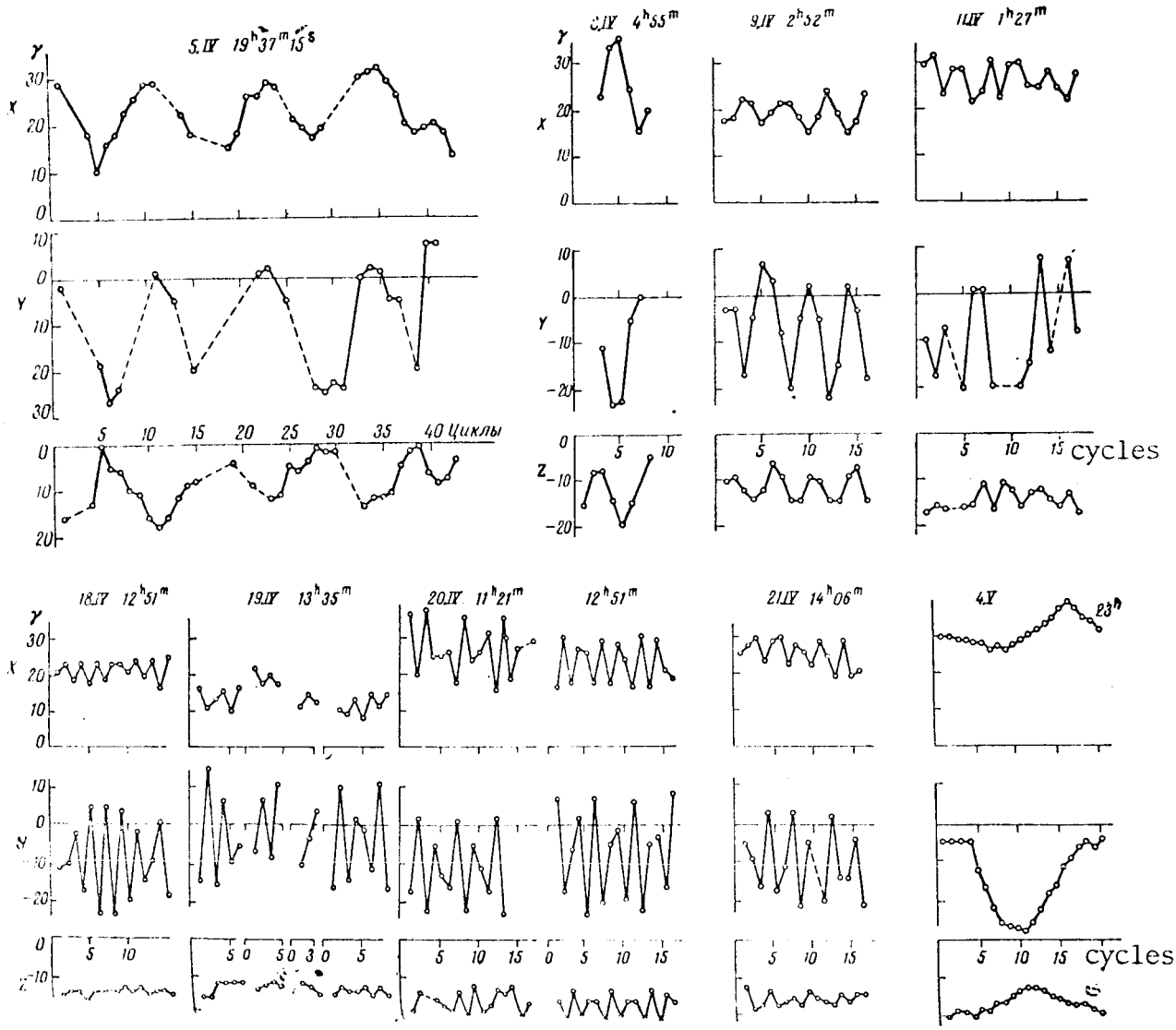

Fig.5. Experimental magnetograms of pickups XYZ for separate observation sessions.

The dashed lines link the readings between which malfunctions of information existed

The values of the components X, Y, Z were obtained consecutively during 12 seconds in the course of one measurement cycle (128 sec.). During that time and for a rotation period of about 35 sec, the satellite performed a rotation by an angle of about 120°. This, the obtained experimental values of X, Y, Z are not the orthogonal components of the field on account of the nonsimu;taneity of interrogation.

The standard formula for the calculation of the absolute value of the magentic field vector was found to be inapplicable ($T = \sqrt{X^2 + Y^2 + Z^2}$). In order to compute T from the components' magnetograms, the constant components A_X, A_Y, A_Z and the amplitude of sinusoidal components B_X, B_Y, B_Z were separated. The variations of these quantities in the course of one session were sufficiently slow and small.

Inasmuch as $A_X = T_\parallel \cos \alpha_X$, $A_Y = T_\parallel \cos \alpha_Y$, $A_Z = T_\parallel \cos \alpha_Z$ $B_X = T_\perp \sin \alpha_X$, $B_Y = T_\perp \sin \alpha_Y$, $B_Z = T_\perp \sin \alpha_Z$, the values of the longitudinal $T_\parallel$ and transverse $T_\perp$ components may be obtained from the expressions

$$T_\parallel^2 = A_X^2 + A_Y^2 + A_Z^2,$$
$$T_\perp^2 = {}^1/_2(B_X^2 + B_Y^2 + B_Z^2).$$

The absolute value of the magnetic field vector is computed by means of the values of $T_\parallel$ and $T_\perp$: $T^2 = T_\parallel^2 + T_\perp^2$.

In order to determine the amplitudes B_X, B_Y, B_Z it is required to use the portion of the magnetogram containing at least one period τ_H. Consequently, the values of $T_\parallel$, $T_\perp$ and T are average for that period. The absence of signifivant disrutpion of magnetograms' periodicity is evidence of uniform and stationary state of the observed field. Consequently, the errors introduced by such an averaging are not great.

The orientation of the rotation axis of the satellite relative to the axes of ferrosondes X, Y, Z may also be obtained from the experimental data:

$$\cos \alpha_X = A_X / T_\parallel,$$
$$\cos \alpha_Y = A_Y / T_\parallel,$$
$$\cos \alpha_Z = A_Z / T_\parallel.$$

The angle β between the axis of rotation and the magnetic field vector T (Fig.2) may be obtained from the conditions:

$$T_\parallel = T \cos \beta, \quad T_\perp = T \sin \beta, \quad \mathrm{tg}\, \beta = \frac{T_\perp}{T_\parallel}.$$

The shapes of the variable part of the magnetograms computed by formula (2) for a uniform field at $T_\perp \sin \alpha_X = 1$, $\tau_0 = 128$ sec. and of τ_B variation from 32.7 sec. to 41.9 sec. are given in Fig.6. When comparing them with the experimental magnetograms, a good agreement is revealed in the shape and in the observed period τ_H in those cases when τ_B is near the measured value. In Fig.6 are shown the days in which the corresponding experimental magnetograms are obtained. The certain dis repancies between the magnetograms of the components, different in shape, are explained by the difference of the initial φ_X, φ_Y, φ_Z, since the magnetograms of Fig.6 are constructed for $\phi_X = 0$.

Thus. the period and the shape of the observed magnetograms agree well with the stroboscopic effect and the adopted processing method is thus justified. However, we shall see below that the correlation of amplitudes B_X, B_Y, B_Z and of constant components A_X, A_Y, A_Z are not quite fully described by simple rotation relative to a fixed axis, or else they are burdened by specific errors.

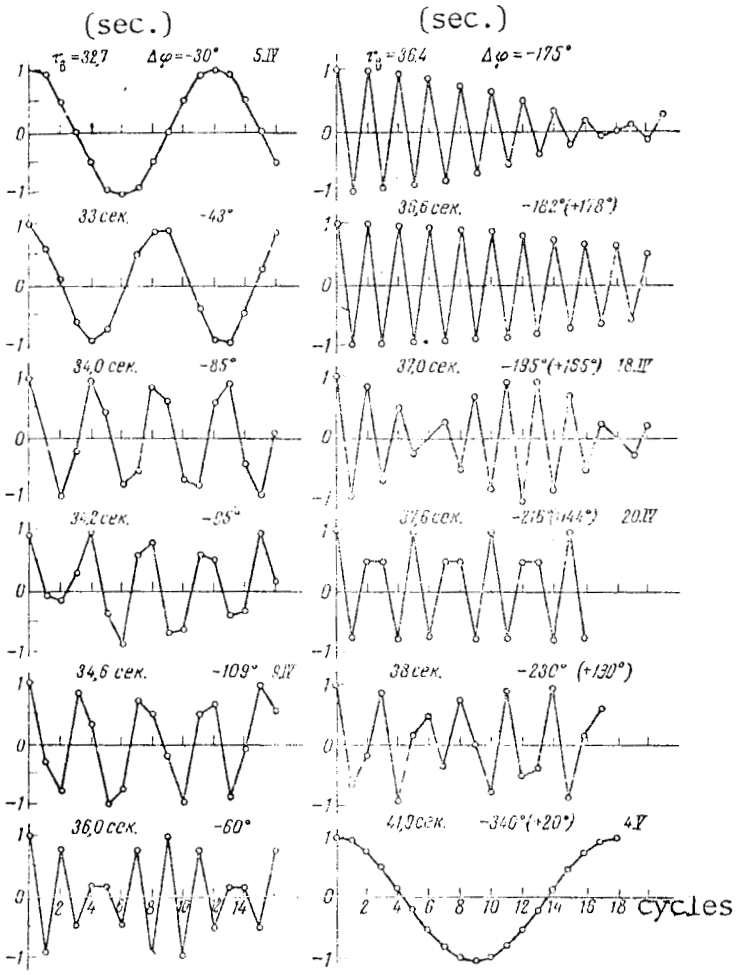

Fig.6. Computed shapes of magnetograms obtained by formula (2).

$\Delta\phi$ is the phase accretion or lead for one interr.cycle

2. SOME ESTIMATES OF EXPERIMENTAL DATA RELIABILITY

As was already mentioned, the measured values of the field may be characterized by the values of projections along $(T_{\parallel})$ and across $(T_{\perp})$ the axis of rotation of the satellite.

The transverse component does not depend on magnetometer channels' zero shift and on the effect of constant and electromagnetic deviation of the container.

But this component may depend on the variation of sensitivity of each of the magnetometer channels and on that of the stroboscopic effect. When the measurement time is limited, the maximum amplitude may be not attained. The longitudinal component is independent of the stroboscopic effect, but its magnitude may depend on zero drift, on the unaccounted magnetizability of the container and on the sensitivity variation.

Reference was made earlier to measures taken on the stages of observatory tests of magnetometers and their tests in the complex of airborne means. However, by virtue of the above-described measurement peculiarities on LUNA-10, there arises the necessity of reliable estimates of the above-indicated components of the field during every observation session.

We already pointed out the requirement for the computation of these components $T_{\parallel}$ and $T_{\perp}$ of a portion of the magnetogram hvaing at least one full stroboscopic period τ_{H}. During the session of 3 April the rotation period was close to 32 sec., which corresponds to a very large stroboscopic period ($\tau_{H} > 16$ cycles) (Fig.4). This is why in the session of 3 April, containing 16 cycles the constant components A_X, A_Y, A_Z and the amplitudes B_X, B_Y, B_Z, could not be determined, and consequently, neither could be computed the components $T_{\parallel}$ and $T_{\perp}$ and the absolute value of T.

During the subsequent session the observed stroboscopic period decreased on account of the increase of the rotation period. So long as the phase accretion (lead) for a cycle is significantly less than π, and the magnetogram is close to the sinusoidal, the maximum and minimum values of the components X, Y, Z at their periodical variation are determined exactly. This is why the sessions of 5 April and 4 May are the most reliable, for the stroboscopic effect does not introduce arrors in the determination of the amplitudes

During the sessions between 8 and 21 April the rotation period varied from 34 to 38 sec., and the phase accretion (lead) from $-85°$ to $-210°$. At the same time the observed magnetograms constituted broken lines, linking the points disposed on the stroboscopic sinusisoid. The observed period becomes less than four cycles (Fig.6). This is why every period of the stroboscopic sinusoid is represented by less than four points, and between 18 and 21 April — by only one point. With such an amount of information it is impossible to complete the sinusoid. However, for a sufficient time of observation (more than 12 cycles) expermental points close to maximum and minimum values of the component exist without fail. The shape of the magnetograms computed for the measured rotation periods (Fig.6) show that the amplitudes computed by the formula $B_X = (X_{max} - X_{min})/2$ may be underrated by comparison with the true amplitude by no more than 10 percent.

Inasmuch as for a sufficiently long session the experimental points are disposed symmetrically relative to sinusoid's zero line, the stroboscopic effect does not introduce any error in the determination of the constant components A_X, A_Y, A_Z,

Let us consider the numerical values of the errors of measurement.

Besides the projection T on the axis of the sensor, according to laboratory tests the following enters in the constant component of each component:

1) the measurement error of magnetic deviation $\pm 2\gamma$;
2) the measurement error of absolute zero $\pm 1\gamma$;
3) the measurement eroor of sensitivity $\pm 0.5\gamma$;
4) the error caused by a possible zero drift not higher than $\pm 2\gamma$.

The aggregate error of the constant component of each component thus constitutes 5.5 γ, which leads to the maximum possible $T_{\parallel} \sim 9\gamma$. Such is the possible error in the knowledge of the absolute value of $T_{\parallel}$. The variations from session to session are subject to error only on account of zero drift and sensitivity variation. The fluctuation error of telemetry is averaged for a sufficiently large number of points.

The amplitude of the variable component in the sessions when it can be computed does not depend on magnetic deviation, the zero shift and its drift. The error in the determination of the amplitude of the variable component of each component consists of the error caused by the possible variation of sensitivity ($\pm 0.5\gamma$), and of that induced by the stroboscopic effect. The last error does not exceed 10 percent, as already stated. The observed amplitudes do not exceed 16γ, and consequently, the aggergate error along each component is not more than $\pm 2\gamma$. The total error in the determination of $T_{\perp}$ does not then exceed 2.5γ. It should be stressed that the stroboscopic effect always leads to a decrease of the transverse component $T_{\perp}$.

The error in the determination of the absolute value of the modulus T is mainly determined by the error of $T_{\parallel}$, for the longitudinal component exceeds in all sessions the transverse component by a factor of 2 — 3, and the error of the transverse component in 2 to 4 times smaller than the error of the longitudinal component. Therefore, the possible error in the knowledge of the absolute value of the modulus T may be evaluated at $\pm 10\gamma$.

The stability of the counts from session to session is mainly determined by the stability of the zero-point,for no substantial variation of container magnetizability or electromagnetic deviation can be expected in orbit. Thus the precision of the relative measurements may be estimated at $\sim 2\gamma$.

Analysis of the experimental material of all sessions made apparent certain discrepancies relative to the regularities indicated in section 1. In particular the value of the transverse component of the magnetic field, computed by formula $T_{\perp}^2 = (B_X^2 + B_Y^2 + B_Z^2)/2$, is found to be somewhat less than the amplitude of the variable component B_Y. During the session of 5 April we had $T_{\perp} = 12\ \gamma$, $B_Y = 13\ \gamma$; on 5.5— $T_{\perp} = 10\gamma$, $B_Y = 13\ \gamma$. This contradiction is particularly sharply expressed on 18 April, when the stroboscopic magnetogram departs strongly from the sinusoid: $T_{\perp} = 11\ \gamma$, $B_Y = 15\ \gamma$. This can be explained by the fact that, because of the stroboscopic effect the amplitudes B_X and B_Z were found to be strongly underrated. The possibility is not excluded that the motion of the container departed from the proper rotation and might have led to additional magnetogram distortions. Because of that the angles α_X, α_Y, α_Z, computed throught the amplitudes B_X, B_Y, B_Z ($\sin\alpha_X = B_X / T_{\perp}, \sin\alpha_Y = B_Y / T_{\perp}$, $\sin\alpha_Z = B_Z / T_{\perp}$), reveal departures from the conditions of orthogonality $\sin^2\alpha_X + \sin^2\alpha_Y + \sin^2\alpha_Z = 2$. The values of these angles differ also

from the values computed through the constant components ($\cos\alpha_X = A_X / T_{\parallel}$, $\cos\alpha_Y = A_Y / T_{\parallel}$, $\cos\alpha_Z = A_Z / T_{\parallel}$). This difference may be explained by a possible error in the constant components and $T_{\parallel}$ (to 10γ).

The indicated contradictions may in certain cases be eliminated by introduction of corrections into the constant components, whereupon the value of the corrections lies within the limits of the admissible of ∿10γ. However, inasmuch as the problem of computation of these corrections in conditions of the given experiment is not unambiguous, discuseed in the following are the values obtained from the magnetograms taking into account the nominal characteristics of the apparatus and the results of ground determination and compensation of the magnetic deviation.

3. CONDITIONS IN THE INTERPLANETARY MEDIUM DURING THE LUNA-10 EXPERIMENT

The magnetic measurements on LUNA-10 could have been started only after the satellite's emergence into orbit of the Moon. Because of that no field measurements were available in free space, far from the Moon, which would have been important for the interpretation of measurements near the Moon. When discussing the nature and the possible sources of the observed near-lunar field, the material characterizing the general conditions in interplanetary medium in the period of the experiment is useful.

Their combination is sufficiently clearly represented on the synoptic chart of the Sun, complete with various indices of activity. This chart is drawn by the forecast division of IZMIRAN (Fig. 7) During the entire period of observations the active regions of the Sun were observed only in the Northern hemisphere of the Sun and not below 20° latitude as is characteristic for the period of the new solar activity cycle. These groups are recurrent and they can be traced in the preceding (1505) and the subsequent (1507) revolutions of the Sun. The active region passing through the central meridian on 3 – 4 April, had a lesser activity in the preceding and subsequent revolutions. Another group, passing through the central meridian on 18 — 19 April was active and induced a series of perturbations in the preceding revolution, but was quiet in the subsequent one. The groups of active regions having crossed the central meridian on 23 — 24 and 26 – 27 April, were of little activity in all the revolutions. The other events on the Sun are indicated by conventional signs explained in figure captions. The prevailing polarity in the leading spots is Southern. As already mentioned, a specific correlation is established between the sign of magnetic fields in the active regions on the Sun and the sign of interplanetary fields. However, the current state of knowledge of either does not allow so far to determine unambiguously the field sign in interplanetary space by the combination of solar observations. There is nevertheless a specific probability that during the period of observations on LUNA-10 the sign of interplanetary fields did not vary and that the radial component of the field was directed at the Sun. The entire period of observations on LUNA-10 was marked by a low magnetic activity. The index of geomagnetic activity was maintained within the limits 1 ÷ 3, and only during the second fullmoon period, on 4 May, the index was equal to 4 during the observation session (K_p = 4).

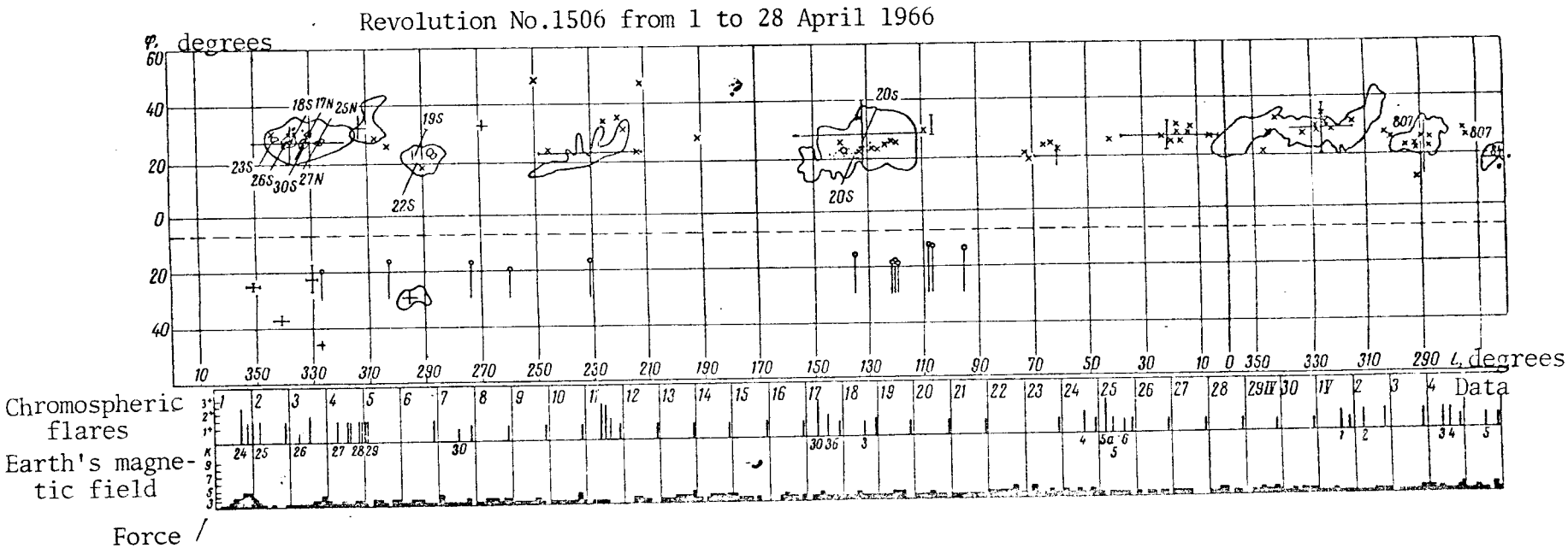

Fig.7. Synoptic Chart of the Sun during observation period (UT)

The dashed line indicates the position of the solar equator. The magnetoactive regions are outlined with indication of polarity and field intensity in hundred oe. Crosses denote the radioemission sources. The numerals near the nonoutlined regions represent the flocculus intensity

4. DISCUSSION OF THE EXPERIMENTAL RESULTS

The experimental data were described in detail in the separate observations in sections 1 and 2, where estimates of reliability of the values of $T_{\parallel}$ and $T_{\perp}$ and of modulus T were also given.

The observed data may in principle constitute the superimposition of three sources: 1) The Moon's proper field, 2) the field of the Earth's magnetic tail and 3) the interplanetary fields of fundamentally solar origin.

In the present section we propose to discuss a series of peculiarities of the observed near-lunar field, providing a specific representation on the nature of this field and on the possible contribution of each of the above-enumerated possible field sources by the results of measurements of the magnetic field only.

a) Regularity of the Near-Lunar Magnetic Field

The fact that nearly in all observation sessions the shape of the signal is determined by the character of the stroboscopic effect, and at the same time to such degree that it may be forecast on the basis of radiodata on the variation of satellite's rotation period, is evidence that the near-lunar field in the investigated portions of space is quite regular in its character.

During one two-minute measurement by each of the channels and an interrogation of all channels during $\sim$10 seconds, no field fluctuations were revealed that would be characteristic for the transitional region of the terrestrial magnetosphere between the magnetopause and the shock front [21]. Note that such an irregularity was detected on the AES ELECTRON-4 in the same frequency in all the cases when the satellite crossed the boundary of the magnetosphere [22]. This indicates that at a distance of at least 1000 km above the surface of the Moon the near-lunar field does not reveal peculiarities inherent to the boundary region of solar wind interaction with the Earth's proper field.

b) Variability in Time of the Near-Lunar Magnetic Field

Another important singularity of the observed near-lunar field is its variability in time in correspondence with the variation of the magnetic activity index on the Earth's surface. Plotted in Fig.8 are the values of the longitudinal ($T_{\parallel}$) and transvers ($T_{\perp}$) components of the field relative to the axis of rotation in all cases for which these values could be determined. This figure includes also the differences ΔH between the average hourly values of the horizontal component H in the periods of observation on LUNA-10 and the mean values of the field for the same hours of the day of the quietest day of April 1966 (22 April). These differences serve as the standard of magnetic activity on the Earth's surface.

Attention is drawn by the good correlation between the variations of $T_{\parallel}$ and $\Delta H = H_{quiet} - H$ in most of the cases. The transverse component $T_{\perp}$ varies within comparatively small limits. These variations do not reveal any notable correlation with the variations of ΔH.

The orientation of satellite's axis of rotation in space is unknown. This is why it is difficult to link the different variability in time and the different degree of correlation with H of the longitudinal and transverse components with the properties of the near-lunar field. As is well known, there exists a correlation between the variations of the index of magnetic activity on the ground and the intensity of the interplanetary field in free space [23, 24]. The field intensity in the boundary region of the magnetosphere also varies in close correspondence with the variations of the index of magnetic activity on the ground [25].

It is therefore natural to expect that the near-lunar field must vary with the intensity variation of the solar wind, whether this field is the proper field of the Moon or an interpanetary field deformed by the Moon.

c) Possibility of Existence of the Proper Field of the Moon

In order to understand the cosmic theory of the Moon, the Earth and the hypotheses concerned with the origin of the geomagnetic field, it is of extreme importance to know whether or not the Moon is presently endowed if only with a feeble but proper magnetic field. At the same time we have in mind first of all a field of uniform magnetization or a field of dipole nature. A field of dipole nature near the Moon can be visualized as a result of action of two different mechanisms:

1) Terrestrial"dynamo-type" if the physical state of the Moon admitted, if only in the past, the generation and the sustaining of the dynamo mechanism [4]. If these conditions varied during the subsequent stages of Moon's cosmic history and the field died out, one may assume that the Moon might have "memorized" the action of such a field in the past, having preserved, for example, a certain magnetization in a direction close to that of the axis of rotation.

2) The Moon may have been magnetized by the interplanetary fields and by fields of corpuscular streams, whose intensity might have been greater than that observed during the current epoch.

It may be assumed with a specific probability that in this case too the Moon may have a magnetization along the rotation axis, for the latter is inclined to the ecliptic plane. The components in the direction of the equator might possibly be not preserved on account of Moon's rotation. However, the Moon's rotation and the change of sign in interplanetary fields may exert a demagnetizing action. It is not excluded that under the action of external fields of solar origin the Moon may be magnetized and subject to multipolar magnetic reversal.

A chart of the Moon in Mercator projection is shown in Fig.9 with the trajectories of satellite's convolutions. The black lines indicate the portions of trajectory, over which scientific information was available. The portions where magnetic measurements were obtained are somewhat shorter. As may be seen from the drawing, the information is distributed quite irregularly.

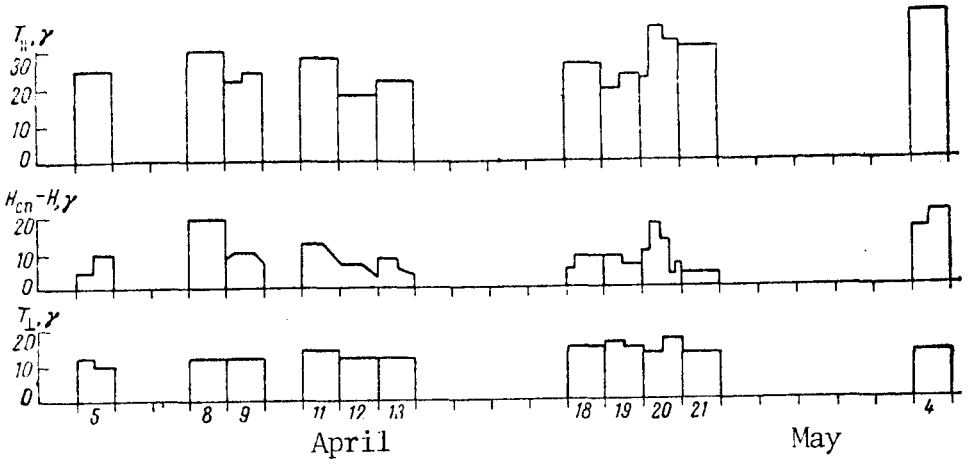

Fig.8. Correlation between the observed values of $T_{\parallel}$, $T_{\perp}$ and the magnetic activity on the Earth's surface

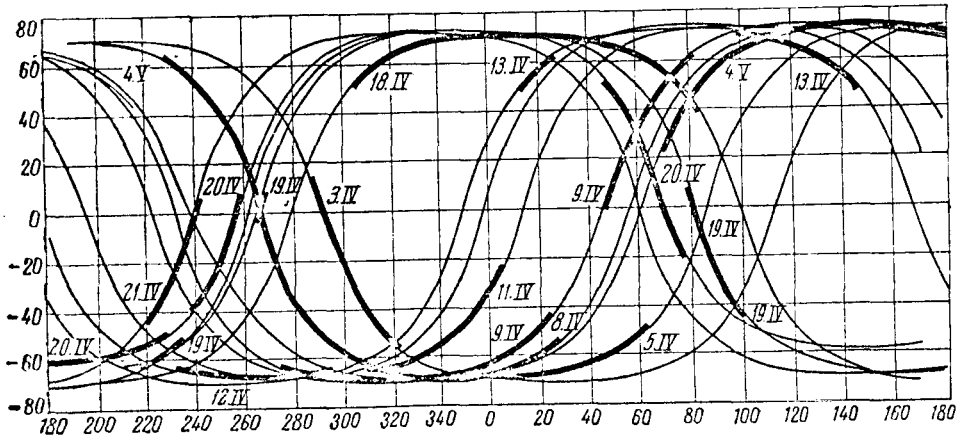

Fig.9. Portions of trajectories of LUNA-10, over which magnetic measurements were obtained

In the Southern hemisphere (region of orbit apocenter) observations are mainly available within the latitudes —50° —70° and longitude ranges 0 —60°, 180 — 360°. In the Northern hemisphere (pericenter region) they are within 50 — 70° latitude and 0 — 180, 300 — 360° longitude ranges. Continuous information from pericenter to apocenter was obatined in the course of one session on 5 April 1966. Aside from this session, the most practical from the standpoint of completeness of stroboscopic magnetograms for subsequent analysis in this section are the sessions of 9 April in the 840 — 1015 km altitude range, and further from 860 to 520 km and the session of 11 April, symmetrical relative to the apocenter.

As is well known, the most characteristic singularities of the dipole field consist in the decrease of intensity according to the inverse cube law from the planet's center and the simple dependence of inclination angle I of the field variation with latitude: $\mathrm{tg}I = 2\mathrm{tg}\,\phi$ (in the assumption that the magnetic latitude ϕ_m coincides with the latitude ϕ)

The intensity values of the dipole field at pericenter and apocenter of the orbit of LUNA-10, situated on identical latitudes, must differ by a factor of 2.2.

The consideration of the initial magnetograms X, Y, Z of 5 April (Fig.5) and of the values of $T_{\parallel}$, $T_{\perp}$, β, computed on the basis of these magnetograms, convinces one that during displacement from perigee to apogee, only small variations of the field intensity are noticeable; they are not decreases, as might be expected, but increases of the field.

The values of $T_{\parallel}$, $T_{\perp}$ and β, determined by the amplitude values of the graphs X, Y, Z of this session are compiled below :

Cycle	2	6	12	18	23	28	34
$T_{\parallel}$, γ	26	27	27	27	27	28	28
$T_{\perp}$, γ	11	12	13	11	12	12	13
T, γ	28	30	30	29	30	30	31
$\beta°$	23	24	26	22	24	23	25

The angle β between the direction T and the axis of rotation also varies then very little. Therefore, the near-lunar field in the altitude range 350 to 1015 km from the surface of the Moon does not reveal any signs of dipole field in the latitude range $\pm 70°$ judging from the character of scalar magnitude variaion and the direction relative to a certain conditional trend. The consideration of the experimental data obtained nearly during all the days of observation in the apocenter and pericenter regions also leads to the same conclusion.

But can the observed feeble dependence of the near-lunar field intensity on distance to the center of the Moon arise as a result of strong deformation of the hypothetical proper dipole field of the Moon by the solar wind ?

As already mentioned, the singularity of the near-lunar field resides in its regularity. Consequently. it should be admitted that we found ourselves in all cases of obsefvation inside the cavity of the ljnar magnetosphere. The boundaries of the cavity of lunar magnetosphere for probable values of solar wind and various intensities of the possible lunar field on the surface are plotted in Fig.10, where the ratio of the magnetic cavity $R_{\text{п}}$ to the radius of the Moon $R_{\text{л}}$ is plotted along the horizontal and the most probable values of particle velocities of the solar wind -- along the vertical. The vertical dashed lines bound the values of $R_{\text{п}}/R_{\text{л}}$, investigated by the satellite. The numerals near the curves correspond to the intensity of the field near the equator; they are expressed in gammas. These values have been computed for densities of particles $n = 1.5$ and $10\ \mathrm{cm}^{-3}$.

As follows from Fig.10, in order that the measurements be conducted inside the cavity the intensity of the field must be no less than 150 - 200γ on the surface of the Moon near the equator. The value of the field, undistorted by the solar wind at 350 km altitude must then be ∿ 90 - 115γ and at 1000 km ∿40 - 50γ.

By analogy with the Earth's magnetosphere at low latitudes the field may be contracted by the solar wind, reaching then values of 60 - 70γ . To the contrary, at high latitudes, the field may also be possibly attenuated to values ∿20γ at apogee altitudes. But at low altitudes substantial fields should be expected.

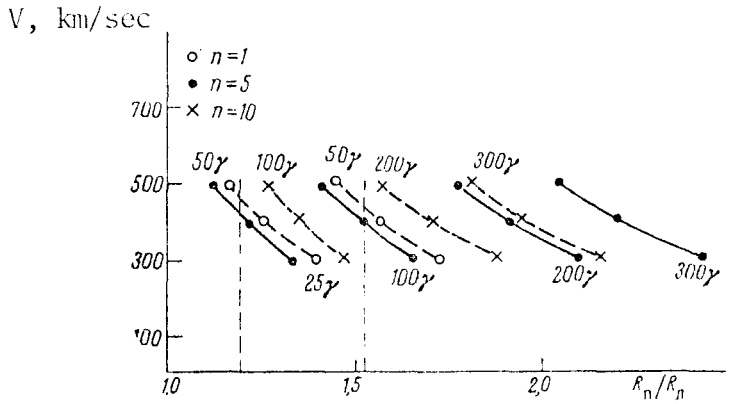

Fig.10. Position of the boundary of lunar magnetosphere as a function of solar wind velocity for various densities of particles in the assumption of dipole nature of the magnetic field of the Moon

In reality, as already mentioned, no field of indicated intensities was observed and consequently, the posiibility of exostence by the Moon of fields ∿ 150 - 200 γ must be rejected. A dipole field of lesser intensity, say 25 - 50 γ near the Moon must lead to cavity boundaries near orbit pericenter. The turbulent region beyond the lunar magnetic cavity must then coincide with the region of investigation on satellite's orbit. However, the regular character of the near-lunar field would not agree with such a model.

As already mentioned, the information on the magnetic field was obtained from the visible parts of the orbit in the course of separate sessions, and its distribution relative to the surface of the Moon is quite irregular. Sufficient information from the far side of the Moon is lacking altogether. In this sense it is impossible to speak in terms of Magnetic "survey" of the Moon. Against the background of obvious dependence of the value of field intensity on the magnetic activity one does not succeed in establishing any dependence of the field value on the position of the satellite relative to the lunar surface. Nevertheless, the combination of experimental material supplied by LUNA-10, does allow us to identify the observed near-lunar field with the proper field of the Moon in the sense emphasized above.

d) The Near-Lunar Field as a Deformed or Trapped Interplanetary Field

Being endowed with finite effective conduction and effective receptivity, the Moon can not exert any specific action on the topology of the interplanetary field in the direct neighborhood of the heavenly body.

Attention was drawn for the first time in the work [26] on a possible specific mechanism of interaction of heavenly bodies (comets), devoid of proper magnetic field, with the magnetic fields of corpuscular streams. In the assumption that as a result of interaction of the corpuscular stream with the head of a comet the latter is ionized to a significant measure, it was pointed out that the magnetic field of the stream was frozen into comet body as it moved, that it was somehow "hanged" and trapped by the comet, as is clearly shown in Fig.11. Subsequently, these ideas were considered at length. Their review is included in the work [27].

Similar mechanism was considered for the Moon in 1964 in the assumption that the Moon lacks a proper magnetic field, has a finite conduction σ and an effective permeability μ [28]. The development of the mechansim is determined by process' $L^2\mu\sigma$ time constant, where L is the diameter of the Moon. The magnetic lines of force of the solar wind accumulate in the forward part of the Moon and contract. Contrary to Fig.11, it is admitted that the lines of force running past the Moon in a streamline fashion, may unite and close on the rear part of the Moon, forming in the final count a cavity in the wake of the Moon.

Starting from the equality

$$\rho V^2 = H^2 / 8\pi,$$

where ρ is the density, V is the velocity of the solar wind, the intensity of the field is determined in the forward part of the Moon for a normal solar wind (n = 4 particle/cm^3 , V = 300 km/sec). This field constitutes $\sim 30\gamma$. The possibility is admitted of shock front formation ahead of the region with the compressed magnetic field. The region of increased field is postulated to be disposed quite close to the Moon's surface. The accounting of Moon's rotation and field sign change leads the author to a complex field pattern in the equatorial plane and to the admission of substantial magnetization along the axis of rotation.

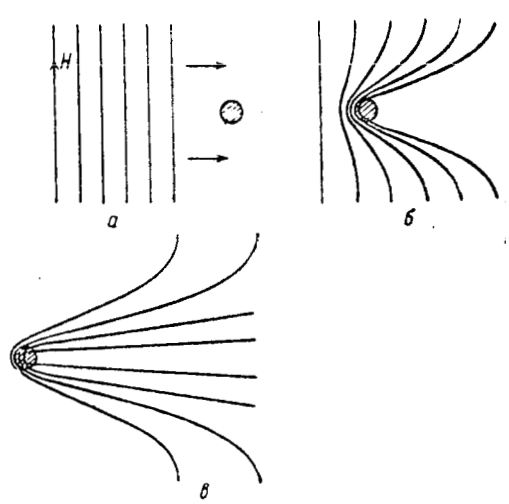

Fig.11 Mechanism of interplanetary field trapping by the comet, according to Alfvén

Returning to the question as to what measure such a model is confirmed by the results of measurements of LUNA-10, it is necessary to note the close agreement as far as the field value is concerned.

The simple configuration of the field (Fig.12), admitted by the model of [28], is also in agreement with the results of measurements of LUNA-10. The observed variability in the intensity of the near-lunar field correspondingly with the variation of magnetic activity is not in contradiction with the nature of the near-lunar field of this model. The effects that should have been anticipated in the presence of the shock wave front assumed in the model of [28] were not observed.

We lacked measurements along the entire orbit, in particular in the "tail of lunar magnetosphere", and this is why a more detailed comparison with the model is impossible.

d) INFLUENCE OF THE EARTH'S MAGNETIC TAIL

The effect of the Earth's magnetic tail may be made apparent by comparison of magnetometer readings during newmoon $T^{\bullet}$ and fullmoon T°, on the condition of identical magnetic activity. This condition was not fulfilled. Comparing the values of $T_{\parallel}^{\circ 1}, T_{\perp}^{\circ 1}$ and $T^{\circ 1}$ for the day of the first full moon (5 April) with the values of $T_{\parallel}^{\bullet}$, $T_{\perp}^{\bullet}$ and $T^{\bullet}$ on the newmoon day (20 April), we obtain

$$T_{\parallel}^{\circ 1} - T_{\parallel}^{\bullet} = -5\gamma,$$
$$T_{\perp}^{\circ 1} - T_{\perp}^{\bullet} = -2\gamma,$$
$$T^{\circ 1} - T^{\bullet} = -5\gamma.$$

The difference $\Delta H^{\circ 1} - \Delta H^{\bullet}$, being the measure of magnetic activity in the hours of new moon and fullmoon observation is -4γ and has the same sign. The same differences for the second fullmoon (4 May) and newmoon (20 April) have the opposite sign

$$T_{\parallel}^{\circ 2} - T_{\parallel}^{\bullet} = +8\gamma,$$
$$T_{\perp}^{\circ 2} - T_{\perp}^{\bullet} = -2\gamma,$$
$$T^{\circ 2} - T^{\bullet} = +7\gamma.$$

The sign variation of the difference T is found correspondingly with sign variation od the activity level $\Delta H^{\circ 2} - \Delta H^{\bullet} = +4\ \gamma$ for the same days.

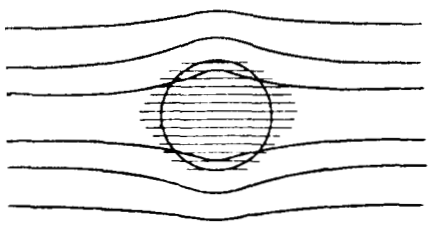

Fig.12. Topology of the Moon-trapped interplanetary field (after Gold)

For the assumed width of the tail of the magnetosphere at the distance of 60 R_E it makes sense to compare the mean results of measurements during the days close to fullmoon and newmoon. This is possible only for the first newmoon in the days of observation of 5, 8, 9 and 19, 20 and 21 April

$$\bar{T}_{\parallel}^{\circ 1} - \bar{T}_{\parallel}^{\bullet} = -1\gamma,$$
$$\bar{T}_{\perp}^{\circ 1} - T_{\perp}^{\bullet} = -1\gamma,$$
$$\bar{T}^{\circ 1} - \bar{T}^{\bullet} = -1\gamma.$$

The difference between the average field values during newmoon and fullmoon days is substantially less than the differences in the values of the field between

separate session of the averaged days and it lies within the limits of relative errors of measurement.

Turning back to the differences $T^{\bigcirc 1} - T^{\bullet} - T^{\bigcirc 2}$ and $T^{\bullet}$, it may be noticed that they have an opposite sign, just as is the case for ΔH.

Therefore, it may be concluded that the differences in the fullmoon and newmoon days are determined by the difference in the magnetic activity, without making apparent the effect of the Earth's magnetosphere tail.

CONCLUSION

Measurements of the magnetic field from the visible portions of the orbit of the first artificial satellite of the Moon were completed in separate days of the time interval encompassing a lunar nonth. These measurements were performed with the help of a three-component high-sensitivity magnetometer. The error in the determination of the absolute value of the scalar magnitude is estimated by the quantity $\pm 10\gamma$.

It is established that in the near-lunar space investigated the field has a sufficiently uniform structure and regular character.

During the period of measurements a field variation in intensity within the limits $24 \div 40$ was observed. The variations of the field correlate with the variation of the index of magnetic activity on the Earth's surface.

The measured values of the field in the pericenter and apocenter regions and at various longitudes do not reveal variations characteristic for a field of dipole nature. The considerations of possible distortions in the field structure that might have been induced by solar wind, do not allow us to identify the observed field with the proper field of the Moon of dipole nature.

The measured values of the field are not in accord with the estimates of Moon's proper field given in the work [12] on the basis of measurements from Explorer-18.

The magnetic data of LUNA-10 are not in contradiction with the representations whereby the near-lunar field may be an interplanetary field of solar origin, either distorted or trapped by the Moon, and having a finite conduction and permeability.

Comparison of measurements in fullmoon and newmoon days failed to ascertain the influence of the tail of the Earth's magnetic field on the night side of the Earth. Its extension to the Moon was not revealed by the direct magnetic measurements of this experiment.

It is quite obvious that the experimental data thus obtained are insufficient for the final judgement along such a broad circle of important questions of space physics. The magnetic measurements were subject to limitations due to satellite rotation, to interrogation frequency and other circumstances. An optimum experiment

implies measurements along the entire orbit, a precise knowledge of the direction of the axis of rotation of the satellite in the absolute space; it assumes sufficiently long observations, encompassing at least two solar revolutions.

From the above expose it is also clear how vast are the potential possibilities of magnetic measurements in the investigation of the nature and of the cosmic history of the Moon and of the system Moon -- Earth.

The authors consider it to be their assumed duty to express their gratitude to Yu. V. Afanas'yev, V. P. Lyulik and G. N. Alekseyeva for their participation in the preparation of the apparatus.

**** THE END ****

Received on 20 Sept. 1966

Contract No.NAS-5-12487
VOLT TECHNICAL CORPORATION
1145 19th St. NW
WASHINGTON D C. 20036; Tel: 223-6700 and 4930.

Translated by ANDRE L. BRICHANT
on 9 -- 12 January 1967

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