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MAGNETIC FIELD INVESTIGATIONS WITH AIS "VENERA-4"

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SUMMARY

This paper gives a detailed description of magnetic field observations in the interplanetary sector of VENERA-4's trajectory, between 23000 and 200 kilometers from the center of planet VENUS. Description is given of the instrumentation consisting of a three-electrode ferrosonde magnetometer. The conclusions derived from this experiment rule out the existence of any substantial proper dipole magnetic field of Venus. The pattern of field and plasma distribution in the near-planetary sector is, however far from trivial and calls for further studies. At this time this pattern is in no way inconsistent with the concept that VENERA-4 crossed the shock front near ∿23000 km. More prolonged observations are required and emphasis should be given to the diurnal side. These data may eventually throw light on the internal structure of Venus and on the interaction mechanisms between the magnetized solar wind plasma and the heavenly bodies.

INTRODUCTION

The investigations of magnetic fields in the vicinity of other celestial bodies [1-3], having started with studies of the lunar magnetic field, have already yielded important experimental data resulting in a refutal of the existing prognoses on the degree of magnetization and of concepts on the universal prevalence of celestial body magnetization. These have strongly strengthened the position of the magnetic dynamo theory which is the most developed and fruitful theory of the Earth's magnetic field.

Direct investigations of the magnetic field in the vicinity of planets yield information on the possible physical conditions in the interior of planets and on electromagnetic conditions in the upper atmospheric layers, inasmuch as the organic relationship of these conditions with the magnetic field has been studied if

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* Destined for publication in SB "Venera" and Kosmicheskiye Issledovaniya.

[N.B. Indulgence is requested from the reader, as this translation was made from a poor copy of a typewritten preprint, some of the signs being hardly legible had to be read "between the lines"] only in varying degrees with respect to the Earth.

Magnetic field measurements carried out in 1962 during the flight of MARINER-2 at the closest distance of 41 thousand km from the center of the planet allowed us to estimate [2] the possible magnetic moment of Venus as being lower by a factor of 10-20 than that of the Earth. This result is in agreement with a lower angular rotation velocity of Venus as compared with that of the Earth, within the framework of any hypothesis. Making more precise the upper limit of the possible venusian magnetic field constituted the foremost task of the magnetic investigations of the interplanetary station VENERA-4.

The formation of a shock front represents the characteristic peculiarity of the interaction between solar wind and the geomagnetic field. Its formation as a result of supersonic solar plasma flow past the geomagnetic field was predicted as early as prior to the beginning of direct experiments in outer space [4] and was experimentally confirmed during the flight of EXPLORER-18 [5].

Planets and comets devoid of proper magnetic field must also exert a perturbing action during solar wind flow past them. The nature of the perturbation must depend on the effective electrical properties of the celestial body. The extreme cases studied in [6], namely the insulator with dielectric and magnetic properties of a vacuum ($\varepsilon = \varepsilon_0$, $\mu - \mu_0$ $\sigma = 0$) and the nonmagnetic ideal conductor ($\mu = 0, \sigma = \infty$), resulted in the concept of perturbing effects of different nature to be expected in the vicinity of the Moon [7]. Even earlier similar effects were predicted for comets [8,9].

It was assumed on the basis of the gas-dynamical analogy of solar plasma flow past bodies devoid of proper magnetic field that the shock front is formed provided the fulfullment of the condition $L \gg \Pi$, where L are the dimensions of the obstacle and Π is the gyroradius of protons in the interplanetary space [10]. Direct investigations in the immediate vicinity of the Moon failed to detect a shock front [11, 12] although they did establish the fact of the perturbing action of the Moon when solar wind flows past it [1 ,13]. In order to ascertain whether or not planet Venus exerts a perturbing action in the interplanetary medium was the second task of the magnetic measurements from AIS "VENERA-4".

The present work will examine and discuss the experimental data obtained in the near-planetary tragectory sector of AIS VENERA-4, at a distance from 31,000 km to 200 km from Venus' surface. Moreover, when discussing the metrological characteristics of the experiment and the special features of the field in the immediate vicinity of the planet while drawing on the experimental data obtained in the interplanetary space, we shall report, as a preliminary result, on the peculiarities of the interplanetary field observed during the flight toward Venus in a period of significant solar activity.

I. METROLOGICAL CHARACTERISTICS OF THE EXPERIMENT.

AIS VENERA-4 was equipped with a three-component ferrosonde magnetometer*. The measurement range for each component constituted $\pm 50\ \gamma$, its telemetry resolution was $\pm 1.6\ \gamma$. The sensing element of the magnetometer was fixed on a rod 3.5 m long but owing to the inclination of the rod toward the container axis the maximum distance from the sensing elements to the body of the station was 2.2 m. During the preparation for the flight the hard component of container's magnetic deviation was measured and compensated with permanent magnets. However, the uncertainty as to the magnitude of electromagnetic deviation - a soft component magnetic deviation - could cause zero creeps.

For the purpose of determining the values of fixed biases due to the effect of magnetic and electromagnetic deviations of station's frame on August 16 the station was imparted a spin motion relative to the axis close to the direction toward the Sun. At such a motion the readings of magnetometer channels are described by equations

$$X = T\cos\beta\ \cos\alpha_x + T\sin\beta\ \sin\alpha_x\ \cos(\omega t + \phi_x) + X_0,$$
$$Y = T\cos\beta\ \cos\alpha_y + T\sin\beta\ \sin\alpha_y\ \cos(\omega t + \phi_y) + Y_0,$$
$$Z = T\cos\beta\ \cos\alpha_z + T\sin\beta\ \sin\alpha_z\ \cos(\omega t + \phi_z) + Z_0.$$

where T is the field vector modulus,
β is the angle between T and the rotation axis,
α_x, α_y, α_z are the angles defining the position of the rotation axis in the magnetometer sensor system of coordinates,
ω is the angular rotation velocity of the station,
ϕ_x, ϕ_y, ϕ_z are the initial phases,
X_0, Y_0, Z_0 are the fixed biases caused by magnetic deviation.

Fig. I shows the disposition of sensing elements X, Y, Z, relative to the system of coordinates X_0', Y_0', Z_0', linked with the object. Axis X_0', normal to the plane of solar batteries, coincided with the rotation axis and was directed toward the Sun. The angles $\alpha_x = 42°$, $\alpha_y = 64°$ and $\alpha_z = 120°$ were determined from structural data.

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* The three-component magnetometer SG-59M was developed at the Special Design Office of the USSR Ministry of Geology.

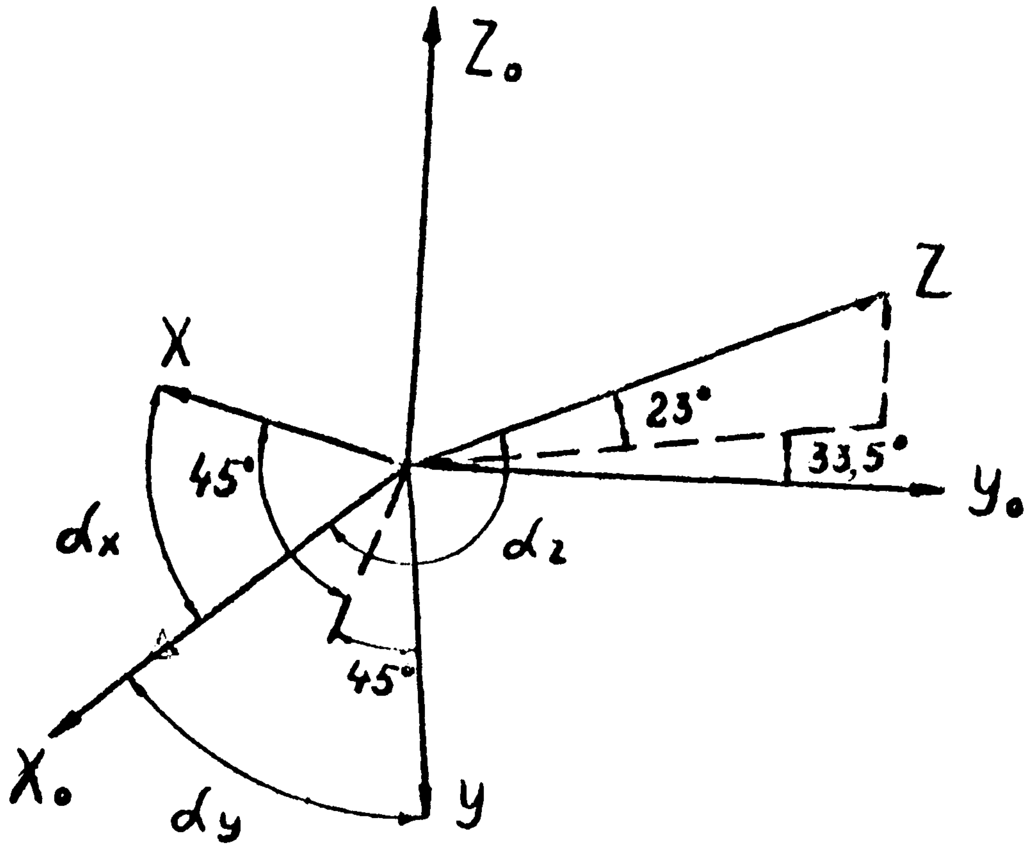


Fig.I.

Position of magnetometer sensing elements X,Y,Z in station coordinate system X_0', Y_0', Z_0'.

Fig. 2 shows the magnetograms of components X, Y,Z, obtained from aboard the station during the rotation session of August 16, 1967. The amplitude values of the components are:

$$\beta_x = T \sin \beta \sin \alpha_x = 5\gamma$$

$$\beta_y = T \sin \beta \sin \alpha_y = 7\gamma$$

$$\beta_z = T \sin \beta \sin \alpha_z = 6.5\gamma$$

These values make it possible to determine the field component perpendicular to the rotation axis: $T_\perp = T \sin \beta = \sqrt{1/_2 (B_x^2 + B_y^2 + B_z^2)}$ and (correct to the sign) the angles α_x, α_y, α_z, from the conditions: $\sin \alpha_x = \frac{B_x}{T_\perp}$; $\sin \alpha_y = \frac{B_y}{T_\perp}$; $\sin \alpha_z = \frac{B_z}{T_\perp}$

but $\alpha_z = 57°$ also satisfies the data.

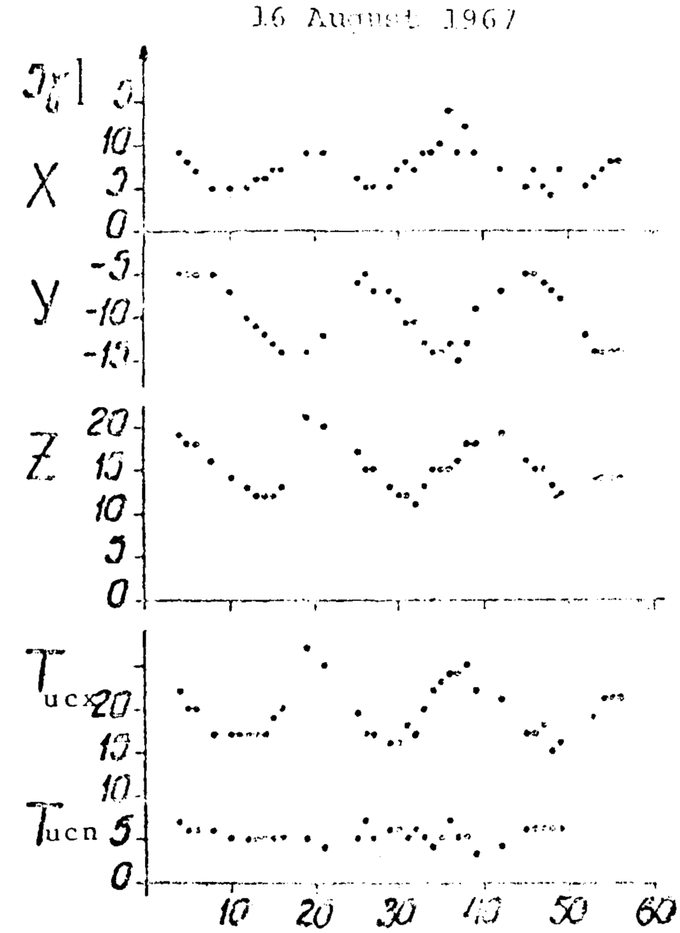


Fig.2

The magnetometer readings during the twist session of August 16, 1967. X, Y, Z are the curves of field component in the sensor coordinate system; T_{ucx} is the curve of the total vector without exclusion of corrections; T_{ucn} is the total vector following the introduction of corrections.

The values of these angles were found to be equal to $\alpha_x = 39°$; $\alpha_y = 70°$; $\alpha_z = 123°$, which is close to the values obtained from structural data. This circumstance is much rather evidence of the fact that by then the magnetometer's response did not noticeably change. The agreement between structural and magnetometric angles α_x, α_y, α_z would take place also if the sensitivity of the three independent channels were to change absolutely identically.

During the August 16 session the field component transverse to the rotation axis was equal to $T_\perp = 7_\gamma$. In order to determine the field component parallel to the rotation axis $T_\parallel = T\cos\beta$, it is necessary to know the quantities $A_x = T\cos\beta\cos\alpha_x$, $A_y = T\cos\alpha_y$, $A_z = T\cos\alpha_z$, which are inseperable from biases α_x, α_y, α_z. The knowledge of angles α_x, α_y, α_z, yields only the ratio between them

$$A_x/A_y/A_z/ = \cos\alpha_x/\cos\alpha_y/\cos\alpha_z$$

In order to find the absolute values of A_x, A_y, A_z, it was assumed that on the average the interplanetary magnetic field lies in the ecliptic plane and is inclined at an angle of 45° to the direction at the Sun. This assumption is based on theoretical conclusions and experimental results [14-17]. Hence follows

$$\beta = 45°; \; T_{\parallel} = T_{\perp} = 7\gamma$$

The values of A_x A_y A_z and X_0 Y_0 Z_0 for the case $\beta = 45°$ are compiled in the table hereafter:

A_x	A_y	A_z	X_0	Y_0	Z_0
+6	+2,5	-4	+5	-18	+28

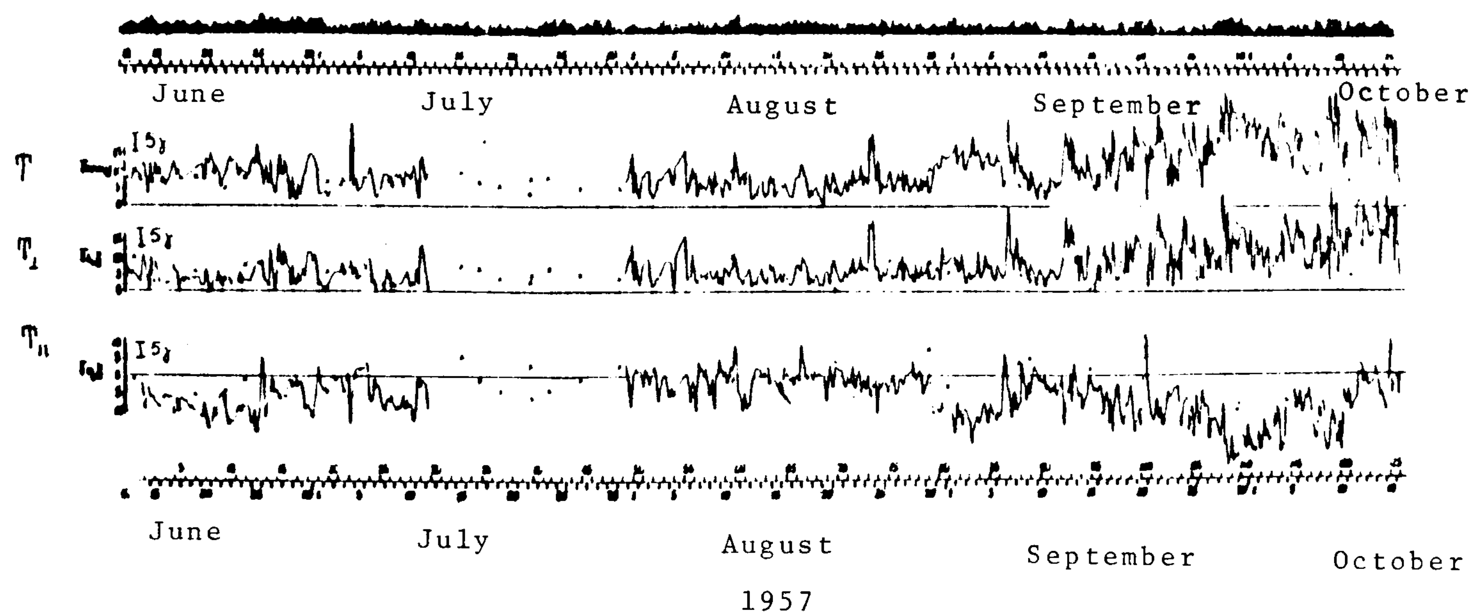
The value of the magnetic field vector modulus was found to be equal to 10_γ which is noticeably higher than median field values. This might be explained by the increased activity on that day ($K_p = 3$) which in its turn pointed to the definite probability that angle β differed from $\beta = 45°$. If this difference was within ±15°, the values of $T_{\parallel}$ and T could be respectively:

$$\beta = 30°; \; T_{\parallel} = 12_\gamma; \; T = 14\gamma$$

$$\beta = 60°; \; T_{\parallel} = 4_\gamma; \; T = 8\gamma$$

Thus, during the session of August 16 the constant error in the absolute value of the modulus could reach $+4_\gamma$ and -2_γ. After subtracting the quantities X_0, Y_0, Z_0 from the readings of the field components measured during the twist session, the vector modulus has no modulation with the rotation period. Since during the nearest magnetoquiet days the values of T were found to be close to the mean value of the interplanetary magnetic field (Fig.3), this served as the basis for accepting the corrections $X_0 = 5_\gamma$; $Y_0 = 18_\gamma$; $Z_0 = 28_\gamma$ to the processing of magnetic field measurements prior and following those of August 16. There were no other twist sessions. This represents a substantial limitation of the experiment since, in principle, ferrosonde magnetometers are subject to zero creeps.

The consideration of combined experimental data obtained during the interplanetary space flight yields definite possibilities for estimating the stability of the magnetometer.



<u>Fig. 3</u>

Measured field magnitudes in the interplanetary space. T is the total vector; $T_\perp$ is the component normal to the radial direction toward the Sun, $T_\parallel$ is the component parallel to the radial direction toward the Sun

MAGNETIC FIELD MEASUREMENTS IN THE INTERPLANETARY SPACE

Magnetic field measurements on the route Earth-Venus were conducted discretly once every 4 hrs and recorded in a memory device. Moreover, during some of the communications short-term measurements were conducted with readouts taken every 34 sec or 7 sec in 10-15 min. All magnetic measurement data were processed taking into account the initial zero-points obtained during the session of August 16, 1967. Fig.3 shows the measured magnetic field values for the whole period of the flight. The results of the measurements are represented by scalar field quantity T, and components $T_{\parallel}$ along, and $T_{\perp}$ across the rotation axis of the station. The rotation of the station could take place around the normal to the solar batteries with a very low angular velocity ($\sim$ 0.01°/sec). Therefore, $T_{\parallel}$ virtually coincides with the radial direction toward the Sun. The direction of $T_{\perp}$ relative to the ecliptic plane is unknown. Crosses designate the mean values of the readouts received during direct transmissions. Plotted on the upper curve are the values of the K-index of magnetic activity of the Krasnaya Pakhra Observatory.

The entire flight period may be characterized as moderately perturbed with values $K \geqslant 2$.

From the onboard magnetograms of scalar magnitude T, and fields $T_{\parallel}$ and $T_{\perp}$ two noticeably differing periods can be detected namely June-August and September-October. For the first period the mean values of the field constitute $\sim 7_{\gamma}$. For the second period the mean field values are notceably different: for the period from September 20 to October 15 field modulation is clearly observed and a substantial increase in the mean value of the field is also noted. It is natural to examine to what degree the observed values can be explained by variations in the level of heliophysical activity and by a decrease of the distance to the Sun.

Comparison of onboard magnetograms and magnetic activity indices has made it possible to establish that the observed geomagnetic and solar activity events were definitely reflected in the onboard magnetograms. We shall deal first of all with the September-October period.

I. A magnetic disturbance (K = 5) was observed on September 1-2, 1967. This disturbance was most probably, caused by the active region of the Sun (ϕ = +25°; L = 90°). A class 3 flare was observed in this region at 1330-1410 hours on August 29. The active region passed through the central meridian on August 25. The recurrent magnetic disturbance of September 28-October 1, 1967 can be connected with the residues of this region. Increases in the K-index of magnetic activity during the days centered around these dates are clearly visible on the curve K of Fig.3 and are in good agreement with the increase in T in the onboard magnetograms.

2. In the interval between these dates a number of onboard magnetogram peculiarities are also in agreement with the variation of the magnetic activity index. Thus, the quiet September 9-12 period was broken by a new disturbance on September 13 ($K = 5$), which lasted until September 14. On September 18 the index of magnetic activity began to increase and one may visualize in the September 20-22 period the development of a magnetic storm ($K = 6$). It could be induced by the active group of the northern hemisphere in which a class 3 flare ($\phi = +15°$; $\lambda = 60°$) was observed on September 18 at 2318 hours or by the development of a southern hemisphere group which passed through the central meridian on September 19 [19]. All these events were also clearly visible in the onboard magnetograms.

3. Following the recurrent storm of September 29-October 1 permanent weak disturbances took place on Earth on October 4, 5-7, 9-10 and finally 15-16. Thus, the end of the first half of October was moderately disturbed. October 17-18 and 19-20 were magnetoquiet days. The last measurements before the planetary portion of the trajectory refer to October 15. The depth of modulation (difference between the mean readout values in magnetically calm and magnetically disturbed days according to the onboard magnetometer was $12\text{-}15\gamma$.

4. The onboard magnetograms are also in sufficiently good agreement with magnetic and geomagnetic indices for other observation periods. These periods are: June 14-15, the active period of June 25-July 1 which started with a moderate SC-storm on June 25 at 1433 hours and the disturbance of July 11 ($K = 4$); then, through July 26, followed a quiet period in the magnetic field which was reflected in the onboard magnetogram by only scarce direct transmission readouts. Such readouts are typical of the interplanetary field in quiet periods or quiet intervals of an active period. However, solitary peaks represented by a few readouts are not unreliable. For instance, the peak of August 24 ($\sim 20\gamma$) marked in Fig.3, can be connected with three class 2-flares recorded in the Sun on August 24, 1967 [20].

Therefore, notwithstanding the scarcity of measurements (6 readouts a day), the onboard magnetograms, make it possible to establish a 27-day recurrence period in interplanetary field intensity linked with the rotation of the Sun. This result is in agreement with the concepts of solar origin of the interplanetary field [15] and of the link existing between the interplanetary field and the Sun [16].

Moreover, the correlation between the value of the magnetic activity index and interplanetary field intensity is sufficiently clearly outlined. This link was statistically established during the period of the minimum of magnetic activity on the basis of the data of EXPLORER-18 [17].

5. Dash curves are plotted on curves for $T_\perp$ and $T_\parallel$ (Fig.3). They are obtained by smoothing out the curves plotted along points with a minimum readout of scalar quantities $T_\perp$ and $T_\parallel$ First of all it should be noted that the field values counted from this curve reveal the most evident agreement with the magnetic activity index. Therefore, it can be assumed that the dotted curves represent the interplanetary magnetic field in intervals of magnetic activity minimum, while the variability of the curves is linked to spatial variations in the intensity of a quiet and regular interplanetary field. According to Parker [14] increase in the intensity of field's radial component should be expected according to the law $^1/_{r^2}$, while increases for the transverse component would follow the law $^1/_r$, where r is the distance to the Sun. Consequently, with station's shift from the Earth's to Venus' orbit, an increase can be observed of the $T_\perp$ component by a factor of 1.4, and of the radial component - by a factor of 2. It is rather complicated to plot a curve on the basis of the readouts of radial component $T_\parallel$. Curves $T_\perp$ and $T_\parallel$ reveal a satisfactory numerical agreement with such a model. At the distance of the Venus orbit, the field determined on the basis of the dotted curve is 11γ. One cannot fail to consider whether or not the rise of dotted curves for $T_\parallel$ and $T_\perp$ is the result of zero creep in magnetometer channels. Laboratory ground tests of the equipment are in contradiction with such an assumption because the instruments do not detect a monotonic creep. However, onboard magnetograms do not exclude such a possibility. The dotted $T_\parallel$ and $T_\perp$ curves pass close to the mean field in the vicinity of August 16 when the zero readouts of the magnetometer were determined. In this case it is possible to estimate that the ultimate possible drift of the magnetometer did not exceed 6γ at the moment of time when the station approached the orbit of Venus.

6. Measurements carried out by means of parabolic antennas during isolated communications sessions are of great importance. During these sessions the station was turned away from the Sun and the current of the solar batteries was minimum. This mode differs from the mode of the twist test of August 16, 1967 but is quite analogous to the mode of the station over the near-planetary portion of trajectory. The components of the measured field in the solar-ecliptic coordinate system were determined on the basis of data on orientation taking into account the magnetometer zero-points obtained on August 16, 1967 and the structural disposition of sensors in the station.

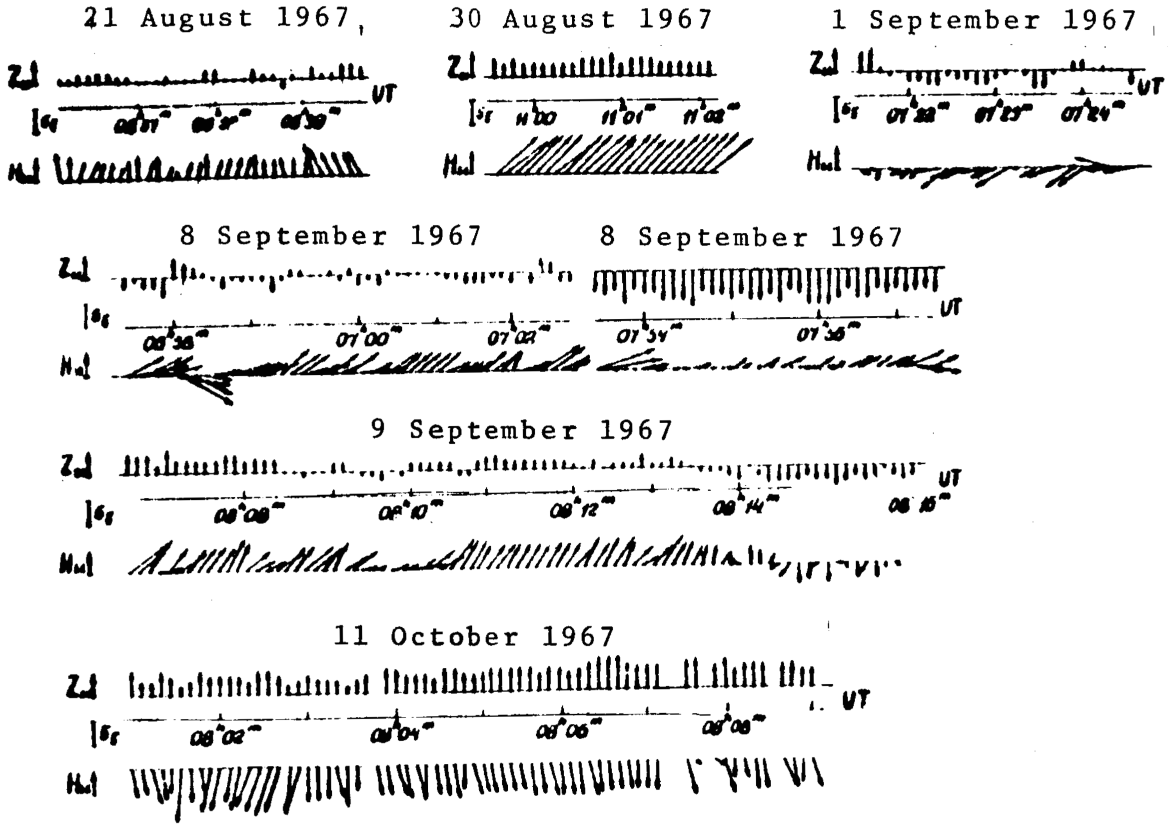


Fig. 4

Measured interplanetary field components in quiet periods. Z_{se} is the component normal to the ecliptic plane, H_{se} is the component within the ecliptic plane.

Shown in Fig.4 are the field components in the interplanetary space on August 21, 30, September 1, 8, 9 and October 11 (quiet periods), and in Fig.5 - the field components on August 11 and September 30 (disturbed periods. In these figures Z_{se} denotes the component perpendicular to the ecliptic plane and H_{se} - the component in the ecliptic plane. The positive component directions (indicated by arrows) are oriented toward the North pole of the ecliptic for Z_{se}, and toward the Sun for H_{se}.

As may be seen from Fig.4, in magnetoquiet periods the normal component Z_{se} is in the majority of cases smaller than the longitudinal component H_{se}. On the average, the position of component H_{se} corresponds to the Archimedean spiral of the

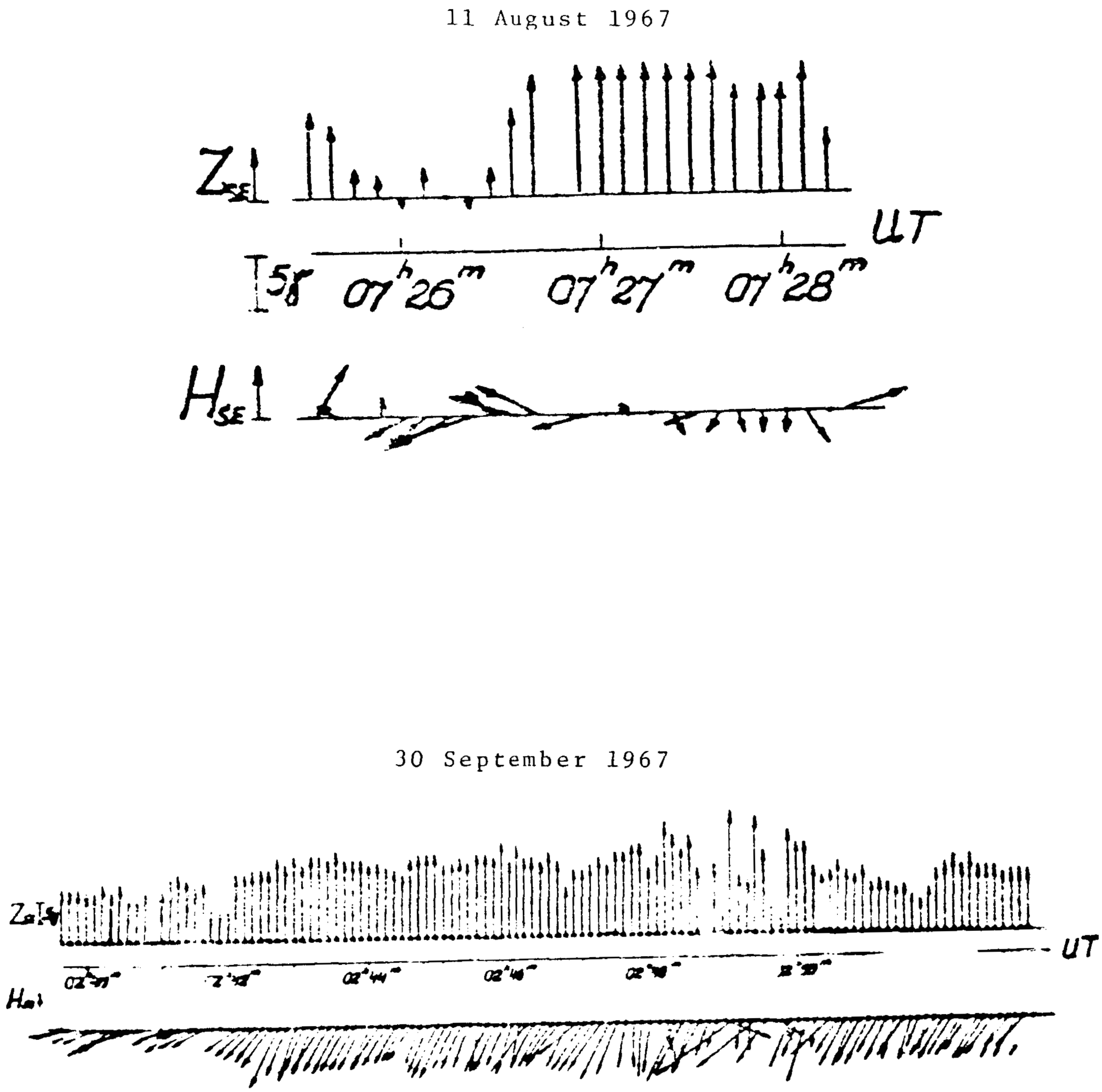


Fig. 5

Interplanetary field components during a magnetic storm.

interplanetary field.

During the communication sessions of August 11 and September 30, 1967 (Fig.5) significant magnetic fields, respectively of 12 and 25γ, were recorded. As already mentioned, September 30 was a disturbed day (K = 5).

The increase of the field component transverse to the ecliptic plane is most unusual. It exceeds the field component H_{se}. The high values of field's scalar quantities on September 30 are confirmed by the readouts received on September 30 under storage conditions. In other words, in these cases, the special features of field orientation cannot be ascribed, for instance, to electromagnetic deviation. Field readouts received during the last direct transmission of October 11 seven days before the near-planetary session, are typical of measurements in a magnetoquiet time according to both the scalar field value and the ratio between components H_{se} and Z_{se}. It is possible that the peculiarities of orientation recorded on September 30 will find explanation in the representations on the shock front occurring during perturbations in the interplanetary medium. If the compression wave propagating in the interplanetary medium during the perturbation, should lead to an increase of the field component normal to the ecliptic plane, a clear connection between the value of the magnetic field and the K-index of magnetic activity would find its natural explanation within the framework of the Dungey model [21].

As a matter of fact, for any sign of the perturbed interplanetary field, the sign of its vertical component will be opposite to that of the vertical components of either a high-latitude geomagnetic field from the diurnal side or of a geomagnetic field in the equatorial plane. All this contributes to processes occurring in the magnetosphere tail and in the vicinity of the neutral points. Obviously, additional perturbations of the magnetic field in the transitional zone between the magnetosphere and the Earth's shock front can complicate this pattern. The magnetic field measured on October 11 (Fig.4) 7 days before the end of the session during a magnetoquiet time was found to be equal to 7γ. This makes less probabl the assumption of a systematic zero creep without, however, not excluding completely the possibility of its existence.

MAGNETIC FIELD MEASUREMENTS IN THE VICINITY OF VENUS

Magnetic field measurements during the near-planetary session began at 3117 hours UT on October 18, 1967 at a distance of $\sim 6R_V$ (from the center) on the evening side and lasted up to a distance of $\sim$ 200 km from planet's surface (see Fig.6). Magnetometer readouts were taken down every 7 sec during 1.5 hrs. In all, more

18 October 1967

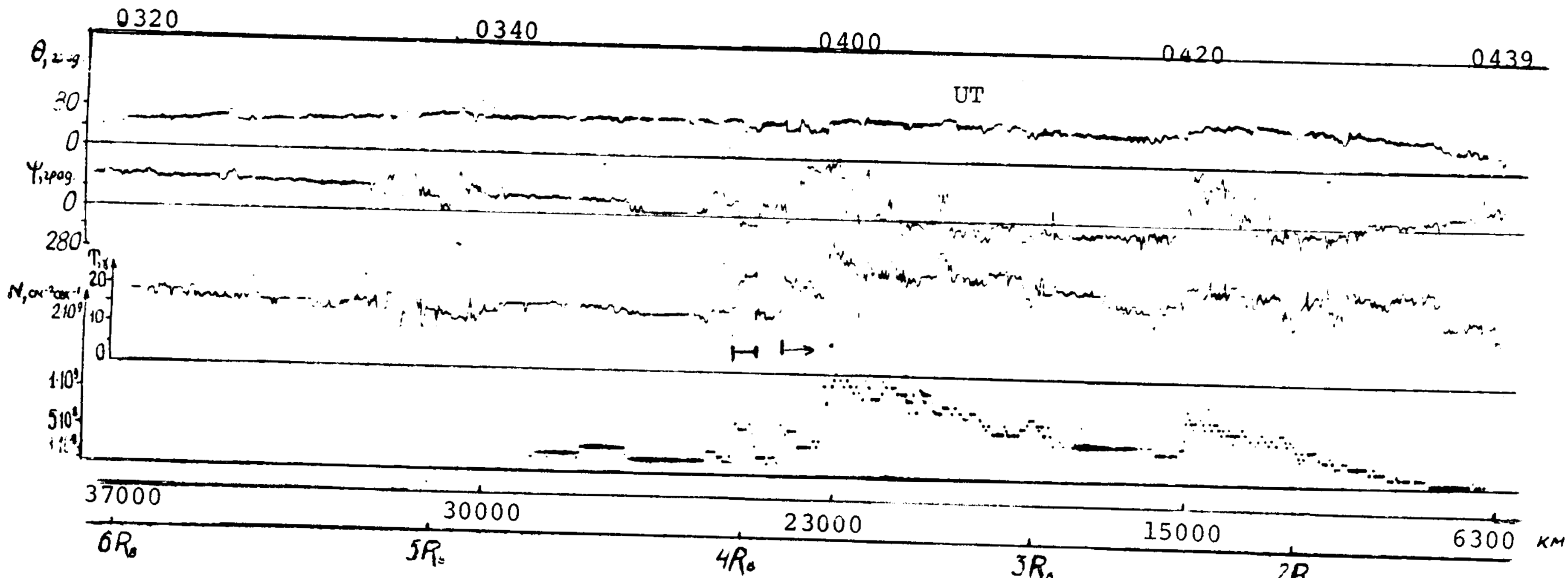


Fig. 6

Measured values during the near-planetary session. T is the total vector; Θ is the inclination angle of the total vector to the ecliptic plane ϕ is the angle between the projection of T on the ecliptic plane and the direction toward the Sun; N is the ion flux.

than 700 readouts were obtained during the near-planetary session. In the course of these measurements AIS VENERA-4 was oriented toward the Sun and toward the Earth (as in other communication sessions by means of a parabolic antenna). This orientation remained unchanged for the whole duration of the entire session. No magnetic measurements by VENERA-4 were conducted in the interplanetary space on October 16 and 17, 1967.

The magnetic data pertaining to the near-planetary session were processed on the basis of the zero-points determined on August 16, 1967. The result of measurements are shown in Fig.6 in the form of curves for the total vector T and angles ϕ and θ. ϕ is the angle between the projection of the total vector on the ecliptic plane and the direction toward the Sun. Looking from the North pole of the ecliptic it is counted counterclockwise. θ is the inclination angle of the total vector to the ecliptic plane. This angle is counted from the ecliptic plane "+" toward the North pole of the ecliptic and "-" toward its South pole. The initial data of the near-planetary session are shown in Fig.7 in the form of field components in the coordinate system of the station.

In the near-planetary portion of the trajectory the magnetic field can be clearly divided into two characteristic regions: 1) a region from 6 to $4R_V$ where the field remains almost unchanged in magnitude and direction (in this sector the RMS deviation for 1 minute intervals is either close to zero or does not exceed 1.2); 2) a region of the agitated field from $4R_V$ up to 200 km from the surface (in this region the RMS deviation is close to 5 for 1 min intervals). Over the initial sector the mean value of the total vector modulus is about 17γ, i.e. it exceeds the unperturbed interplanetary field, while in the region with increased fluctuations it is enhanced, on the average up to 25γ (in the maximum up to 35γ).

One may not exclude the assumption that in the first region of the near-planetary trajectory sector the excess of field magnitude expected in a free space at a distance of 0.7 a.u. can be connected with errors in the determination of the absolute value of the field. The significant value of the Z_{se}-component could also be linked with the same error. However, as may be seen from magnetograms of Fig.8 the field increase at a distance of $\sim 4R_V$ or closer to the planet is due mainly to the growth of Z_{se}, while field variations in this sector are clearly correlated with variations in plasma flow* (Fig.6).

A synchronous variation in the magnetic field and in the positive ion flux takes place during the transition from the quiet to the turbulent region: a simultaneous increase of the magnetic field and of the ion flux takes place within a 7 second-

* Data on plasma traps were kindly communicated to us by K.I. Gringauz.

18 October 1967

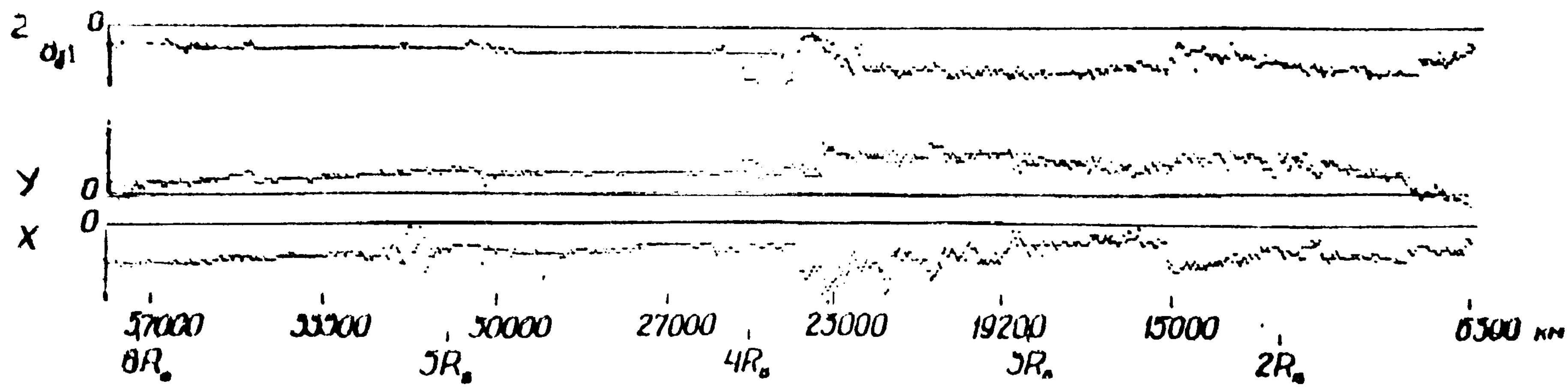


Fig. 7

Measured field components during the near-planetary session in the station's system of coordinates.

interval. Especially clearly outlined are three characteristic field and plasma bursts in the vicinity of $4R_V$. The magnetic field maxima at 3.7 R_V and 2.5 R_V are in good agreement with the maximum values of the ion flux. The clear correlation between Z_{se}-variations and the ion flux point to the reality of this field component and its involvement in the mechanism of streamline flow past the planet.

At the end of the near-planetary session a drop of the magnetic field to 15γ is observed simultaneously with a decrease of the ion flux. Let us note that at the end of the measurements the mean level of plasma trap readings is somewhat lower than at the very start at $6R_V$.

The measurements in the vicinity of Venus were carried out during a magnetoquiet period. According to the data of the Krasnaya Pakhra Observatory the K-index was mostly equal to 2 during 24 hours on October 17 and 18, and reached 3 at specific hours only.

In the most general case, and beyond possible measurement errors mentioned earlier, it is natural to assume that the observed magnetic field is a superposition of the solar wind field deformed by the planet which is an obstacle to a free flow, and of a possible field of Venus.

SHOCK FRONT IN THE VICINITY OF VENUS

As already mentioned, magnetic field intensity in the vicinity of the planet clearly differs over two portions of the trajectory. At the distance of $6\text{-}4R_V$ the field is very regular and actually varies only slightly in magnitude and direction. In the sector of $4\text{-}1.05R_V$ from the center of the planet, the field has noticeable angular fluctuations and noticeable intensity variations although it does contain a basically regular field component transverse to the ecliptic plane.

Fig.8 shows the field components in the ecliptic plane and normal to this plane along the station trajectory, averaged for separate time intervals. The position of the shock wave front for a Mach number $M_a \geqslant 7$, is shown in the same plane.

According to [23], in a gas-dynamical analogy, the shock front in the frontal part of a spherical obstacle lags at a distance $\gamma_* = 1.24r_0$ for $\gamma = 2$ and $r_* = 1.18r_0$ for $\gamma = 5/3$, where r_0 is the obstacle's radius and γ is the adiabatic exponent. In other models $r_* = 1.5r_0$ [24]. The distance to the stopping point in the frontal part of the shock front in the vicinity of Venus was chosen equal to 1.2 R_V. As maybe seen in the figure, for $M_a \geqslant 7$ the boundary between the "regular" and "agitated"

18 October 1967

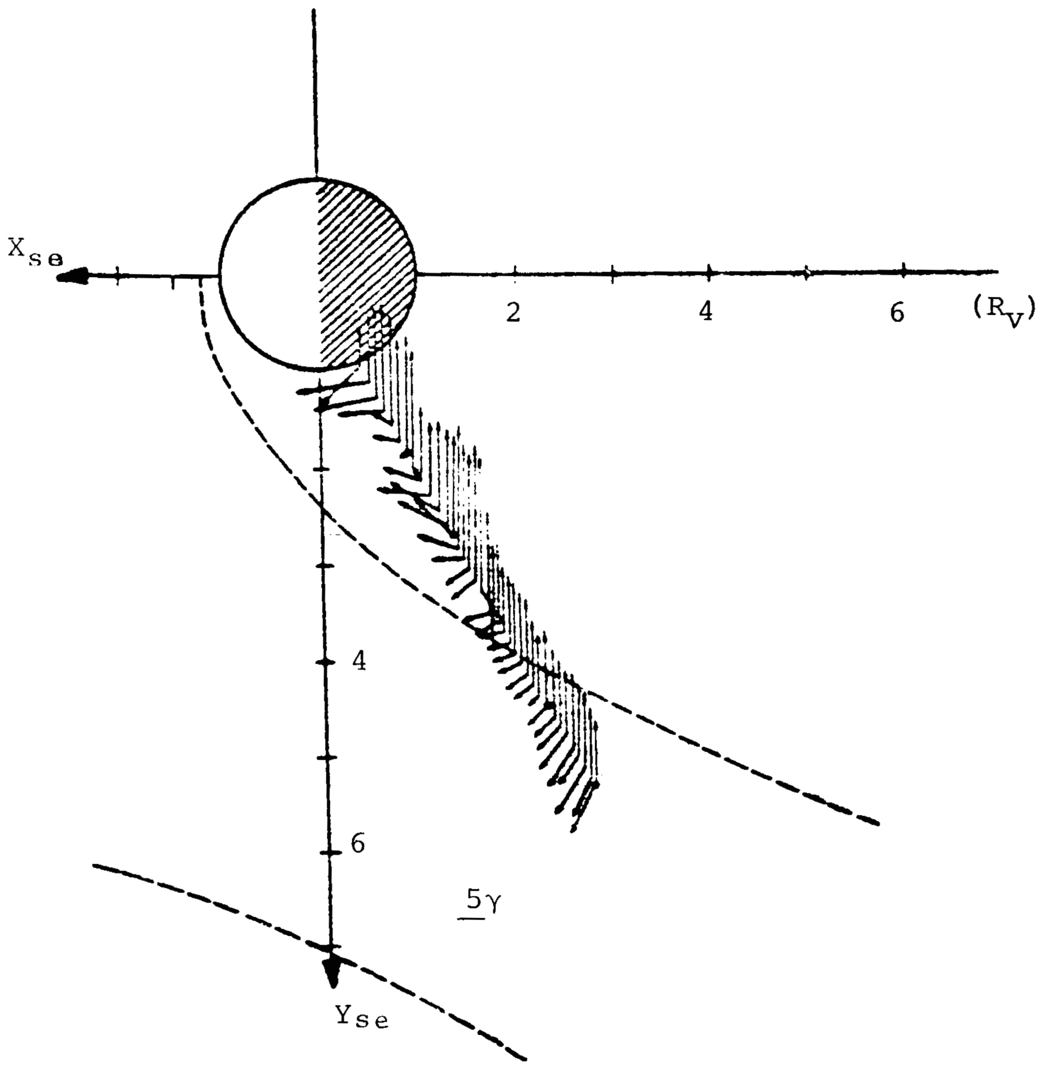


Fig. 8

Mean values of field components in station's system of coordinates. The vertical vectors are the Z_{se} component the H_{se} component is plotted in the ecliptic plane. The trajectory of MARINER-2 is shown beneath by a sharp dashed curve parts of the field passes very close to the shock wave front. The given pattern does not contradict the concept of the station crossing the shock wave front at a distance of 23,000 km, Another important factor in favor of this representation is the positive correlation between the magnetic field intensity and the positive ion flux registered by charged particle traps [22]. In the $4R_V$ - 1.05 R_V sector, these curves repeat each other in notable details. This peculiarity is typical of an oscillatory process [25-26]. On the other hand, if one compares this situation with that in the vicinity of the shock front of the Earth's magnetosphere and with some theoretical criteria, one can not overlook specific contradictions:

1) In spite of the theoretical requirements [10], the normal magnetic field components Hn_1 and Hn_2 to the right and to the left of the shock front surface show an inequality. Let us note, however, that this condition of equality of normal components is not always fulfilled for the shock front in the vicinity of Earth either [27].

2) The magnitude and direction of the field differ notably from those of the quiescent interplanetary magnetic field already over the $6R_V$ to $4R_V$ segment. This is in contradiction with the known representations on the shock wave front. The Z_{se} - component, which is normal to the ecliptic plane, has its highest value over the entire near-planetary sector, thereby marking a noticeable difference from the unperturbed interplanetary space where the component in the ecliptic plane exceeds the normal component.

The difference between the unperturbed magnetic field expected on Venus' orbit ($\sim 10\gamma$) and the field measured on the $6R_V$ - $4R_V$ segment is 6γ. As already mentioned, under real experimental conditions, this difference lies within the range of possible determination errors and of magnetometer zero stability. On the other hand, it may be admitted that this difference is real. A final judgement on this point is seriously handicapped by lack of information for October 16 and 17. With such an admission one must assume that in the vicinity of Venus the perturbation is of a more complex nature. The complexity of the streamline flow pattern was pointed at in [25], for example, where the existence of two Mach cones was admitted.

It must be acknowledged that a description of the observed pattern in concepts of the shock front is at the present time somewhat complicated since theoretical models for the streamline solar wind flow past planets devoid of intense proper magnetic fields are still in an initial stage of development.

EVALUATION OF VENUS' PROPER FIELD

As already mentioned, the maximum value of the field measured in the near-planetary sector at a distance of 3.7 R_V is 35γ. Since the magnetic energy density of this field is lower than the density of solar wind radiation or comparable energy, it is natural to assume that this field is controlled by the solar wind. In this connection it becomes natural to endeavour to find out whether or not the jump of the magnetic field and plasma at the distance of 23,000 km represents "the boundary of the venusian magnetosphere".

The admission of such a possibility results in a magnetic moment equal to $\sim$ 1/20 of the Earth's magnetic moment. In such a case, at a distance of 200 km from the surface of Venus, a field intensity of $\sim 1500\gamma$ should be expected on the equator. In reality, as is shown in Fig.6 on the night side of Venus the measured field magnitude at a distance of $\sim$ 200 km is 15γ. This contradiction cannot be substantially corrected by the consideration that the real position of "the boundary" may also be determined by the pressure of the plasma inside the "magnetic cavity".

At a distance of 6 - 4R_V the field magnitude remains virtually unchanged and is equal to the field at the distance of 200 km from the surface. Therefore, the absence of a noticeable decrease in the field with distance and the observed field direction do not permit to attribute the measured field to Venus. On the other hand, in a model analogy with the field of the Earth's magnetic tail, field decrease with distance was to be expected if this field belonged to Venus.

If, nevertheless, one assumes that the observed field belongs in part to Venus and that its proper field is strongly distorted as a result of some complex deformations, one should then admit that since measurements were taken on the night side, the proper field is weaker than the observed field. It is well known, that the Earth's field is enhanced on the night side.

Thus, it may be assumed that the possible magnetic dipole moment of Venus is lower than that of the Earth by a factor of 3000.

The absence on Venus of a substantial dipole field is a result expected only up to a certain degree. The angular rotation velocity of Venus is low. At the present time, there is every reason to consider as definitely established that there exists no proportionality between the angular rotation velocity of a planet and its magnetic moment. Had such proportionality existed the field on the Venus' surface could have reached 200γ.

As is well known, the majority of magnetic dipole models base the explanation of the field generation mechanism or of its peculiarities on planet rotation. It is also supposed [28] that an asymmetric velocity distribution of matter in the depths of the planet plays an essential role in field generation. It is, for instance, assumed [29] that the existence of transverse dipole components (dipole inclination) and its eccentricity, which are accurately determined for the Earth and are supposed to exist on Jupiter, i.e., the two planets possessing magnetic fields, are not casual but are directly connected with the field generation mechanism. On the other hand, low rotation velocities produce, for instance, a tendency to maintain azimuthal asymmetry. Therefore, they behave as if they were a nonlimiting factor for the generation mechanism. At the same time, the concept that rotation contributes to field regulation of individual current vortices if either generation mechanism has in some measure led to their formation, is in no way inconsistent with any magnetic dynamo-model. However, orderliness in a magnetic field can also take place at lower angular rotation velocities provided the direction of planet's angular rotation remains unchanged. If one attributes the virtual absence of a magnetic field on Venus to its much lower angular rotation velocity as compared to Earth, it becomes necessary to assume the existence of a certain "critical" angular rotation velocity, below which all other conditions being identical, the generation and maintenance of a general magnetic field is impossible.

The fact that Mars, whose angular rotation velocity is close to that of the Earth, has a very small magnetic field or is even devoid of it, indicates that the internal structure of Mars is essentially different from that of the Earth and that probably Mars does not have a conducting liquid core. It is well known that the general models of the internal structure of planets of the terrestrial group are based on the closeness of their mean densities. There is a good reason to attribute this to Venus where the analogy was extended also to dimensions and masses. The absence of a substantial magnetic field of Venus makes it possible to assume that the analogy between the Earth and Venus does not extend beyond similarities of masses, dimensions and mean densities. Finally, it cannot be excluded that Venus is at one of the stages of cosmogonic development when the magnetic field is small, as was the case for the Earth in the past according to paleomagnetic data.

CONCLUSION

The submitted experimental materials make it possible to arrive to the following conclusions:

1. Planet Venus is devoid of a substantial field of dipole

nature. Its magnetic moment is smaller than that of the Earth by a factor of 3000. This result is important in connection with considerations regarding the internal structure of Venus and the magnetic dynamo theory.

2. When solar wind flows past the planet, it exerts a perturbing action. The observed pattern of field and plasma distribution is not inconsistent in a number of main peculiarities with the concept that VENERA-4 crossed the shock front at a distance of $\sim$ 23,000 km from the center of the planet.

3. At the same time, the observed magnetic field pattern on the near-planetary sector is far from trivial and requires further studies in the light of theoretical models.

4. To formulate a judgement on field distribution by magnitude and sign in the near-planetary sector as being either a permanent singularity or variable as a function of interplanetary magnetic field polarity and activity, will be possible only after prolonged observations in planet's vicinity. These observations must also be carried out on the diurnal side. They obviously may yield valuable data on the internal structure of Venus and on the interaction mechanism between the magnetized solar plasma and the celestial bodies.

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