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X-690-72-434

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NASA TM X-66116

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OCTOBER 1972

GSFC — GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

(NASA-TM-X-66116) THE MAGNETIC FIELD IN THE VERY CLOSE NEIGHBORHOOD OF MARS ACCORDING TO DATA FROM THE MARS 2 AND MARS 3 SPACECRAFT S.S. Dolginov, et al (NASA) Oct. 1972 18 p CSCL 03B G3/30

N73-12907

Unclas 49143

THE MAGNETIC FIELD IN THE VERY CLOSE NEIGHBORHOOD OF MARS ACCORDING TO DATA FROM THE MARS 2 AND MARS 3 SPACECRAFT*

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October 1972
(Submitted to JGR November 1972)

*Russian manuscript received by N.F. Ness on 2 Nov. 1972.

Introduction

In 1965, the magnetometer on the space probe Mariner 4 did not detect any evidence of a planetary magnetic field at a distance of 13,200 km from the center of Mars. The upper limit of any possible magnetic moment of Mars, $M_M \lesssim 10^{-4} M_E$ (where M_E is the earth's magnetic moment), was estimated on the basis of the hypothesis of intersection of the shock front by Mariner 4 at large distances, when the Sun-Mars-probe angle was 110-150° (Smith et al., 1965).

The uncertainty of the position of the shock front in the subsolar region permitted an interpretation of the origin as due to two different models of the obstacle; a magnetopause (Dryer and Heckman, 1967) and an ionopause (Spreiter and Rizzi, 1972).

The magnetometers on the spacecraft Mars 2 and Mars 3 have detected a field in the immediate vicinity of Mars, whose intensity near the orbital periapses was 7 to 10 times higher than the interplanetary field at the distance of the Martian orbit. A discussion of the nature of the observed field is the subject of the present paper.

Experimental Procedures

The spacecraft Mars 2 and Mars 3 were injected into orbit around Mars in December 1971 with initial periapses of 1100 km and apoapses of 8 R_M and 62 R_M, orbital periods of 18 hours and 12.5 days and orbital inclinations of 48° and 62°, respectively. Near the periapses of the orbits, data on the magnetic field were obtained in a limited number of transmission periods with variable information rates: 8 measurements during 1 minute, at intervals of 1.9 or 19 minutes. The spacecraft Mars 3 had a solar-stellar orientation, while Mars 2 rotated with a velocity of 0.001°-0.005°/sec about an axis close to the direction towards the sun.

The measurements of the magnetic field were performed by three component fluxgate magnetometers with a maximum range of $\pm 60\gamma$ for each component. For zero levels, the mean readings of the magnetometers at distances exceeding 10 R_M were used. Telemetry information was transmitted with a resolution of 1γ. The sensitivity was checked by the application of calibration signals.

Characteristics of the Magnetic Field

Figures 1-3 show magnetic field data from Mars 2 and 3 obtained during transmission periods with maximum frequency of measurements. In Figures 1 and 2, each data point is the average value obtained from eight measurements. Individual readings and average values of the field reveal characteristic changes which make it possible to identify regions with different physical properties.

Data from Mars 3 obtained on 21 January 1972 is shown in Figure 1. The abscissa is labeled with parameters described in the figure caption. Up to 1957 (Moscow time), indicated by the numeral (1), the characteristics of the field with respect to magnitude and components corresponds to measurements in the solar wind. In the interval bounded by (1) and (2) the magnitude of the field and the level of the fluctuations are noticably increased, just as is observed in the transition region between a shock front and the boundary of an obstacle.

Abrupt, simultaneous changes of the sign of the Y and Z components at (2) and a return to the previous directions at (3) correspond more to a magnetospheric form of the boundary than to a flow effect on the regular component of the interplanetary magnetic field in the transition region. It is known that beyond the earth's shock wave the regular component of the interplanetary field changes its sign in the morning-evening direction only during a change of the sign of the solar field. Point (4) divides the region of the transition zone from the solar wind on the nightside.

The maximum value of the field, 27γ, is observed between (2) and (3) in the periapsis region, almost at local noon. In the data obtained from Mars 2 on 8 January 1972 (Figure 2), the previously discussed characteristics of the field are also displayed, although less clearly. The maximum value, 27γ, is also observed near local noon in the region of periapsis.

Magnetic field data in Figure 3 were obtained from Mars 3 on 18 April 1972. In that period, the periapsis altitude was already 1100 km higher than during the transmission period of 21 January 1972. The shock front was intersected at an altitude=2350 km. Subsequently, the spacecraft moved toward periapsis, approaching the noon meridian. With the assumption of a solar origin for the field, the maximum increase of intensity of the field is expected to occur in that region (Dolginov et al. 1968 and Bridge et al., 1967). However, in the data of 18 April 1972, neither near periapsis nor at other locations are fields of significant magnitudes observed. The maximum fields (approximately 6γ) are recorded at greater heights on the nightside. The same result is obtained on 6 April 1972.

Table 1 summarizes data related to measurements in the region of periapsis for all transmission periods: coordinates and local time of periapsis, probable level of magnetic activity at the orbit of Mars from data on the Kp index and the time shift of the events from earth to Mars and time between measurements in a transmission period.

In Table 2 are summarized data on the intersection of the shock front and magnetopause determined from magnetic field records with maximum data rates.

Plasma Data

Information on the variations of electron flux and the computed values of the electron density for the period of 1500 January 21 to 0200 January 22 (Mars 3) were kindly provided to us by K. I. Gringauz and show that

a. the electron density in the solar wind $\sim 0.4/cm^3$

b. the density near the planet was $0.6\text{-}0.8/cm^3$

c. The field maximum and electron flux maximum do not coincide in time.

The Nature of the Observed Field

The field observed close to Mars may be:

a. the field of the solar wind which is enhanced by currents induced in the ionosphere of the planet (Dessler, 1962) or heating in the transition zone between the shock front and the obstacle (Spreiter, 1970).

b. An intrinsic magnetic field of the planet which is deformed and controlled by the solar wind.

Numerical calculations on the flow of the solar wind around the Martian ionosphere (Spreiter and Rizzi, 1972; Spreiter et al., 1970) give the height of the "obstacle" as 170 km and the height of the shock front as 1400 km at the subsolar point. That does not agree with the heights of the shock front of 3400 km and 2350 km which are determined at Sun-Mars-Spacecraft angles of 22° and 31° on 6 and 18 April 1972 (Mars 3) with an average value of the height of the "obstacle" (990 km) determined by well known formulae (Obayashi, 1964) from the data on the position of the shock front and with the actually observed heights of the boundary of the "magnetosphere" given in Table 2.

The measured fields are somewhat higher than those allowed by the theoretical flow models. According to calculations (Alksne, 1967), with the angle between the velocity vector and the direction of the field of 60° in the transition zone near the earth, the interplanetary field may be enhanced by a factor of 5. Calculations conducted for Mars (Cloutier et al., 1967) yield smaller coefficients of enhancement, 1.08-3. The maximum field,

$$B = \sqrt{8\pi n_p m_p V^2}$$

on 21 January 1972 might reach 18γ.

Controversies which were presented above are easily eliminated with the hypothesis that the field observed in the region closest to periapsis is the intrinsic field of Mars which is deformed by the solar wind and controlled by it.

1. From measurements with known orientation (21 January 1972 Mars 3) the Gaussian coefficients g_1^0, g_1^1 and h_1^1 were determined. From the points at which the components of the field in the Mars centered coordinate system have the highest magnitude (they include the region of periapsis), the average values of the coefficients were determined to be $\bar{g}_1^0 = 19\gamma$, $\bar{g}_1^1 = -29\gamma$ and $\bar{h}_1^1 = 54\gamma$.

The value $H_o = \sqrt{(g_1^o)^2 + (g_1^1)^2 + (h_1^1)^2}$ characterizes the equatorial field and its multiplication with R_M^3 equals the magnetic dipole moment, M_M:

$$H_o = 64\gamma \qquad M_M = 2.47 \times 10^{22} \text{ gauss-cm}^3.$$

The average value of H_o from 20 measurements made at distances of 490-7500km from the center is 67γ.

The coordinates of the dipolar are formally determined from

$$\phi_o = \tan^{-1} \left| \frac{g_1^o}{\sqrt{(g_1^1)^2 + (h_1^1)^2}} \right| \qquad \lambda = \tan^{-1} \left| \frac{h_1^1}{g_1^1} \right|$$

$$\phi_o = 17^o \qquad \lambda_o = -61^o$$

2. With the magnetic moment $M_M = 2.4 \times 10^2$ gauss-cm^3 and the measured density of particles, the coordinates of the shock front and of the boundary of the "magnetosphere" determined experimentally agree with those calculated from the formulae of gasdynamics (Obayashi, 1964) and are illustrated in Figure 4.

Figure 4 explains also the differences between the data of 6 and 18 April 1972 and the data of 21 January 1972 and other periods. On 21 January 1972 the periapsis of the orbit was within the magnetosphere with n = 0.5 and n = $1/cm^3$. The periapses of the orbits on 6 and 18 April 1972 lie at the boundary of the magnetosphere, assuming a density of particles in the solar wind of n = $0.5/cm^3$. With n = $1/cm^3$ the satellite can immerse itself in the magnetosphere by 200 km at only 1 point. During both periods, the periapses were at the noon meridian. Exactly at noon on 6 and 18 April 1972, the boundary of the "magnetosphere" appeared to be lower than the periapsis height; the field of the planet is bounded on the day side.

3. Moreover, discrepancies between the field maximum and maximum of electron fluxes do not give evidences in favor of the model of an enhanced field of solar origin. This follows from the theory and observations of the transition zone near earth and Venus (Dolginov et al., 1968; Bridge et al., 1967).

Thus the combined data on the position of the shock front, the boundary of the "obstacle", the topology and magnitude of the field, and the intensity of the solar wind are most naturally interpreted by the hypothesis that the planet Mars has an intrinsic magnetic field with a dipole moment equal to 2.4×10^{22} gauss cm^3, with an intensity at the magnetic equator of about 60γ. Such a small dipole moment can be understood assuming that the observed field is an ancient field, being a trace of a magnetic dynamo existing in the past or that the magnetic field of Mars is undergoing a period of polarity reversal in its cosmic evolution. In any case, it can be expected that on the surface of Mars, regions with fields of high intensity can exist.

The three component fluxgate magnetometers on the spacecraft Mars 2 and Mars 3 were designed in the Special Design Office of the Ministry of Geology of the USSR. A. M. Amelkin and L. G. Kadenskaya participated in the preparation of this instrumentation. The authors express their thanks to the organizations and personnel who prepared the experiment. We acknowledge; V. V. Migulin, S. I. Braginskii, P. E. Eliasberg, P. P. Ignataev, K. I. Gringauz, V. A. Troitzky, I. A. Zhulin, and A. N. Pushkov for collaboration in the conduct of the work and for useful discussions.

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Satellite	Date	Periapsis ϕ	Periapsis λ	Periapsis h(km)	Local Time (°)	Level of Probable Activity Time Shift (days)	Kp	Measured Maximum Magnitude (gamma)	Time Interval Between Successive Measurements
Mars 2	14 December 1971	-28°	189°	1094	63°	+1.5	1	30	10
Mars 2	18 December 1971	-37°	167°	1224	21°	+1.6	2	46	10
Mars 2	21 December 1971	-21°	251°	1251	66°	+1.7	2	16	20
Mars 2	8 January 1972	-22°	155°	1074	31°	+2.2	3	27	2
Mars 3	21 January 1972	-40°	131°	1136	34°	+2.7	5	27	2
Mars 3	6 April 1972	-39°	284°	2055	0	+5.1	2	3	2
Mars 3	18 April 1972	-37°	7°	2263	355	+5.6	4	3	2

TABLE 1

Satellite	Date	Shock Front Intersection Moscow Time	S-M-S Angle	h(Km)	Magnetosphere Boundary S-M-S Angle	h(Km)	S-M-S Angle
Mars 2	8 January 1972	1956	77°	4770	60°	3173	-44°
Mars 2	8 January 1972	--	--	--	43°	1183	- 9°
Mars 3	21 January 1972	1957	111°	13800	69°	2845	-59°
Mars 3	21 January 1972	2259	99°	7900	60°	1960	+ 3°
Mars 3	6 April 1972	0620	22°	3400	--	--	--
Mars 3	18 April 1972	1914	31°	2350	--	--	--

TABLE 2

List of Figures

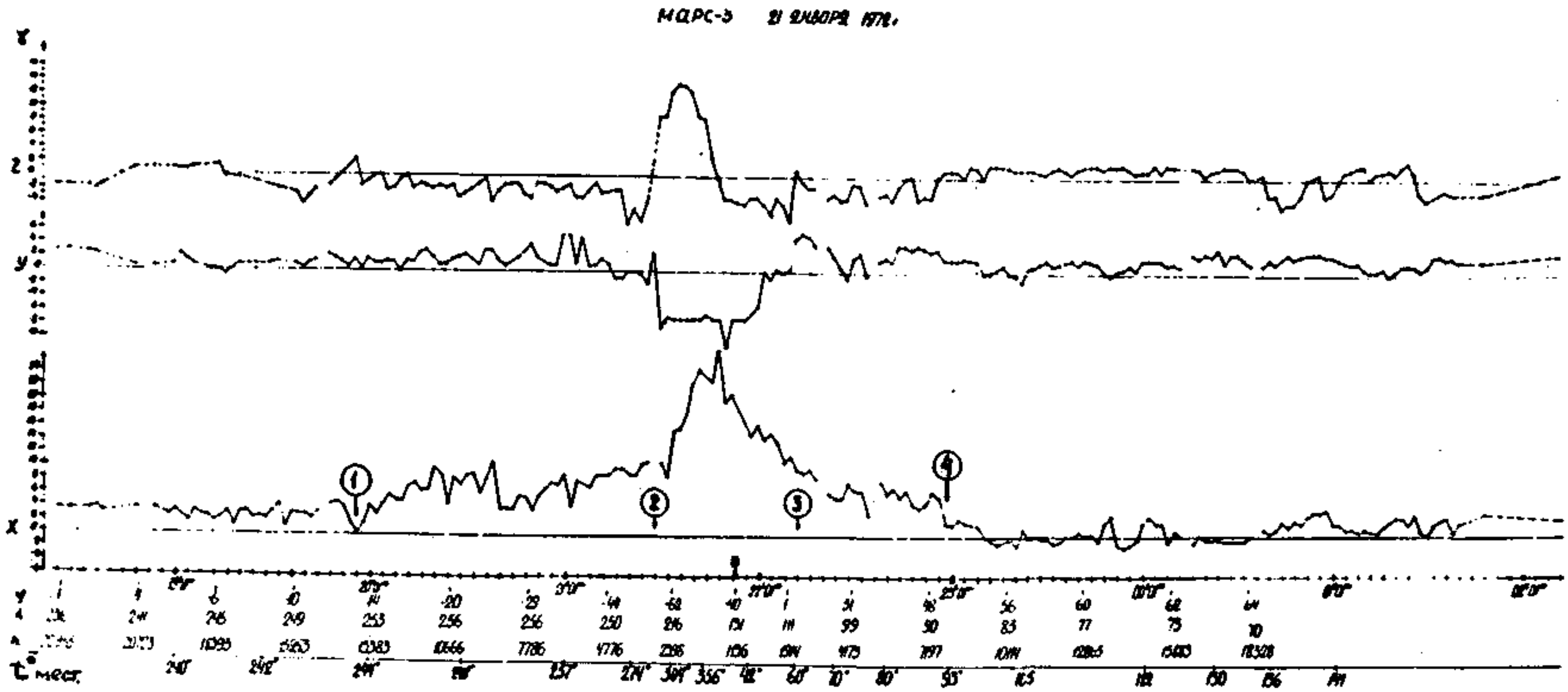


рис. 1

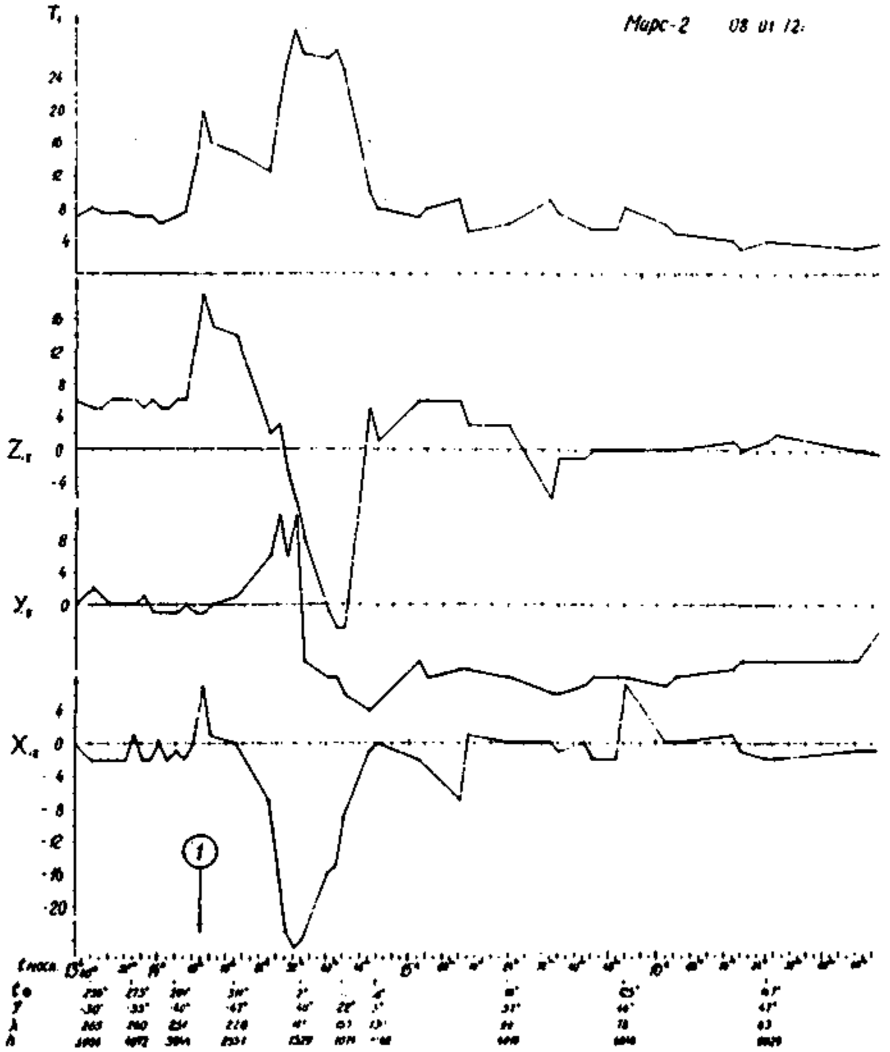
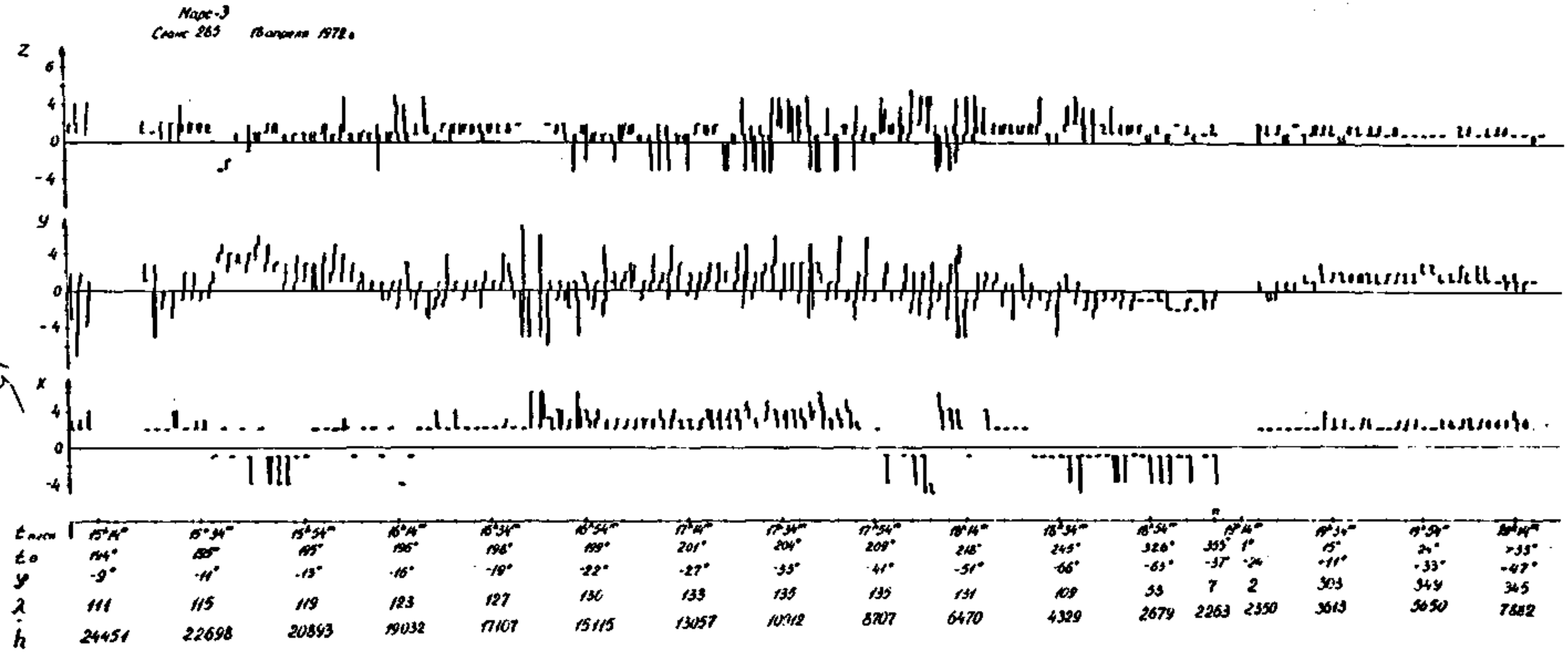


Рис. 2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t₀ 194° 195° 195° 196° 198° 199° 201° 204° 209° 218° 245° 326° 355° 1° 15° 24° 35°
φ -9° -11° -13° -16° -19° -22° -27° -35° -41° -51° -66° -63° -37° -24° +11° +33° +47°
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Рис. 3

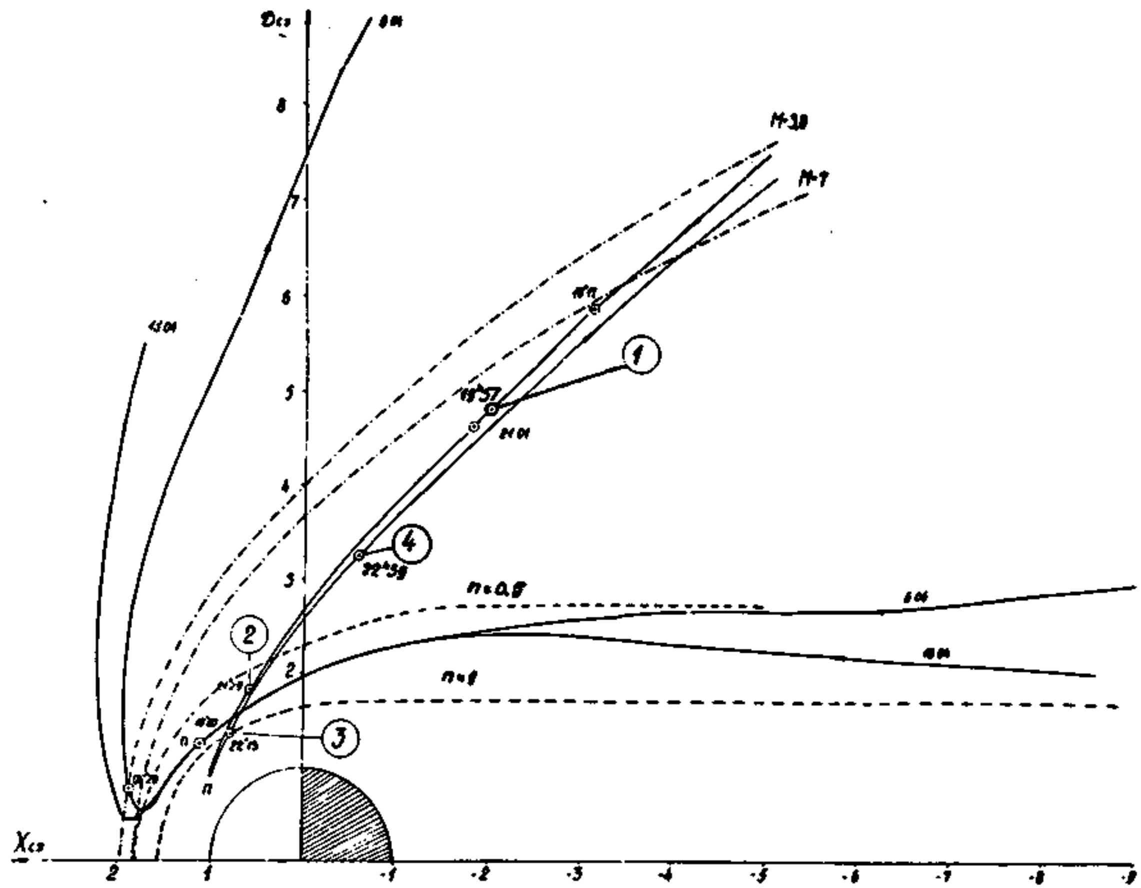

Рис. 4.