FAST VARIATIONS OF THE SOLAR ROTATION

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The rotation law of the Sun is often described by the Faye formula:

$$\xi(\varphi) = a - b \sin^2 \varphi,$$

where φ is a heliographic latitude and a and b are constants. For a long time researchers have been studying the problem in what way the constants a and b change in time and in dependence on a phase of 11-year cycles.

The results of solar rotation observations in cycle No. 19 (1955–1963) and No. 20 (1965–1973) are presented in this report.

The photoheliograms of sunspots received during a standard program were used for these investigations. The diameter of Sun in the picture was 75 mm. The measurement of φ and λ coordinates was carried out using orthographic charts 25 mm in diameter. Measuring accuracy of φ and λ coordinates was equal to $\pm 0°.5$. If during the time T the spot moved along the parallel to $\Delta\lambda$, and if the measuring error $\Delta\lambda$ does not exceed 1°, the error in measuring the rotation velocity is equal to $\Delta\xi \leq 1° \; T^{-1}$. For these investigations the sunspots in the central zone were selected. The relative distance from the centre of the disc for spots was $r/R \leq 0.7$. The interval between observations was $T = 6$ days. Consequently, the measuring accuracy of rotation velocity $\xi(\varphi)$ was about 0°.17. Real rotation velocity of spots deviated from the average one within the limits ±2°. It greatly exceeds error limits. The coefficients a and b were determined by the method of minimal squares.

General statistics for No. 19 cycle included 619 sunspots. 361 spots were situated in the northern hemisphere and 258 in the southern. General formulae of the rotation law for the cycle are as follows:

the northern hemisphere:

$$\xi(\varphi) = 14°.583 \pm 2°.708 \sin^2 \varphi$$

$$+ 0°.092 \pm 0°.496$$

the southern hemisphere:

$$\xi(\varphi) = 14°.583 - 2°.638 \sin^2 \varphi$$

$$\pm 0°.072 \pm 0°.623$$

Statistics of the cycle No. 20 included 854 sunspots. 505 spots were in the northern hemisphere and 349 in the southern.

The following formulae were obtained for this cycle:

the northern hemisphere:

$$\xi(\varphi) = 14°.610 - 1°.485 \sin^2 \varphi$$

$$\pm 0°.117 \pm 0°.989$$

Bumba and Kleczek (eds.), Basic Mechanisms of Solar Activity, 107–111.

the southern hemisphere:

$$\xi(\varphi) = 14\overset{\circ}{.}563 - 1\overset{\circ}{.}480 \sin^2 \varphi$$
$$\pm 0\overset{\circ}{.}119 \pm 1\overset{\circ}{.}245$$

The coefficients a_N and a_S, b_N and b_S coincide in the two cycles.

But we observe another picture when we take short time intervals, for example, 0.5–1 yr. Then a and especially b change significantly. These changes are not conditioned by the low number of annual selections but they have a real solar origin, because a and b variations are determined by the series of objective laws in both hemispheres.

Figure 1 shows the time course of Δb, of deviation coefficient b from the average for the cycle No. 20: a curve Δb_N for the northern hemisphere and a curve Δb_S for the south. The curve Δb_S is represented by a mirror image. It equals multiplication of Δb_S by (-1). The parallel course of curves Δb_N and Δb_S shows that the variations of rotation velocity of spots in the northern and southern hemispheres are in the opposite phase. If the rotation velocity of spots in the northern hemisphere increases, it decreases in the southern and vice versa.

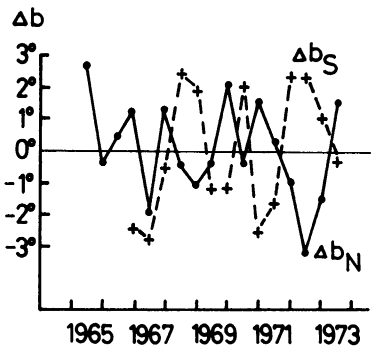

Fig. 1.

Let us use a dimensionless parameter $\Delta\xi/\bar{\xi}$, where $\bar{\xi}$ is the average rotation velocity of the spots in the latitude for the cycle (in agreement with the Faye formulae), and $\Delta\xi$ is the deviation from the average velocity. Thus we shall be able to obtain the characteristics of solar rotation independent from the latitude for the short intervals of time, for example a month.

A time course $\Delta\xi/\bar{\xi}$ for the spots of the northern (the solid line) and the southern (dashed line) hemispheres is given in Figure 2. A curve $\Delta\xi/\bar{\xi}$ for the southern hemisphere is turned round the horizontal axis. The mean value of its coordinate was multiplied by (-1).

Figure 2 shows sharp variations of the solar rotation in an annual period on the ascending branch of cycle No. 20 (1965–1969). After the cycle maximum (at the beginning of 1970) the variation $\Delta\xi/\bar{\xi}$ had the smallest amplitudes and has lost its regular, almost harmonic character. The parallel course of both the curves in Figure 2

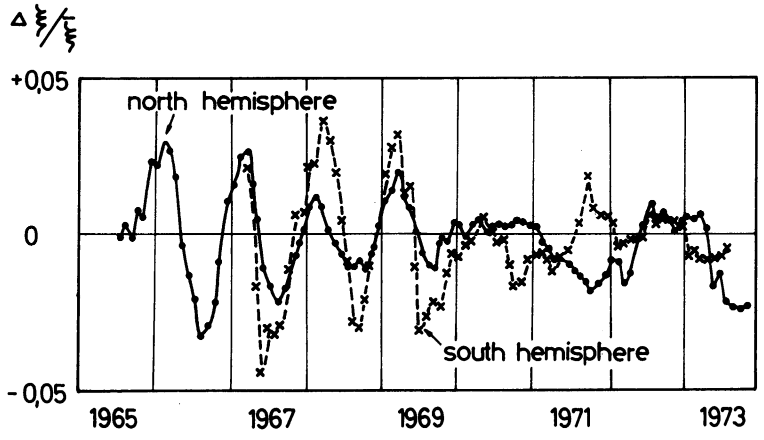

Fig. 2.

indicates that there are variations of parameter $\Delta\xi/\bar{\xi}$ for the northern and southern hemispheres in opposite phase. In other words, this result shows the alternation of acceleration and retardation of the rotation in the northern and southern hemispheres. Investigations show that the rapid variations of rotation velocity of the spots are accompanied by rapid variations of meridional velocity of motion. These are shown in Figure 3. Here, the continuous curve shows time variations of the average velocity of the meridional motions in the northern hemisphere and the dashed curve in the south. The curve $\Delta\varphi/\Delta t$ for the northern hemisphere is turned round the horizontal axis. The parallel course of both the curves on Figure 3 shows that the motions of the spots along the latitude have a global character. At a given moment the spots on the solar surface are moving in the direction of one of the solar poles. This situation changes in time.

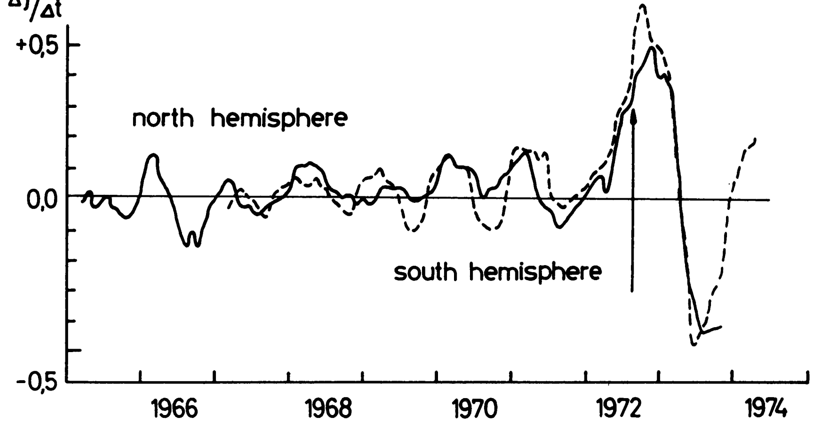

Fig. 3.

The following general picture of motions is observed on the Sun. If the spots of the northern hemisphere rotate faster than the average velocity, the meridional streams are directed to the south, and vice versa. The connection of the meridional motions of the spots with the velocity of their rotation shows that there is a large-scale circulation in subphotospheric layers. The alternation of rotation acceleration of spots in the north and the south indicates that there is an interchange of motion quantity between these hemispheres.

Such a kind of rotation variations reminds us of torsional variations.

Since there are variable meridional streams, whose direction alternately changes to the north and to the south, the coefficient a in the Faye formula formally indicating the velocity of equatorial rotation, should be considered as a kind of kinematic characteristics of the sunspots zone. A diagram of dependence of coefficients a and b for the cycle No. 19 (points) and for the cycle No. 20 (crosses) is given on Figure 4.

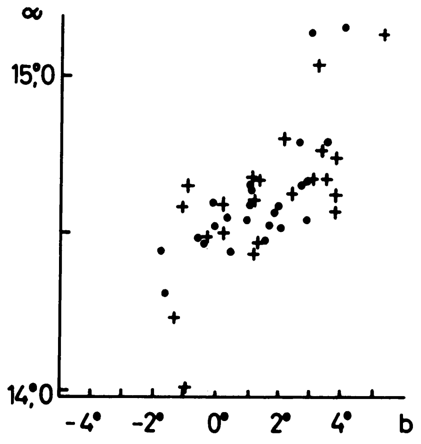

Fig. 4.

We can see the proportionality of a and b values. It has a simple sense: increasing rotation velocity in the equatorial belt is accompanied by decreasing rotation velocity in higher latitudes. The larger scatter of spots on the diagram indicates the influence of other factors.

One of these factors may be the connection of a with a phase of an 11-year cycle. For cycle No. 19 values a were the biggest at the beginning and at the end of the cycle and smallest in the period of the cycle maximum. Variations a_S may have developed with the retardation by 1.5 yr in respect to the variations a_N in the sunspots cycle No. 20. The same retardation by 1.5 yr was observed in spots formation of the southern hemisphere in comparison with the spots formation in the northern hemisphere.

In conclusion we would like to point out one interesting possibility to investigate the solar rotation. Spectrographic methods permit us to register the rotation velocity of the surface layers of the solar atmosphere. As a rule we assume that spots originate in deeper layers. Consequently, the rotation of the sunspots should reflect the peculiarities of these deeper layers. For the large time interval the law of the solar rotation determined by motion of the sunspots and by the spectral methods is described by Faye formulae. But in this case the rapid rotation variations are not explained. That is why it would be interesting to find the differences in the rapid variations of the rotation between the surface and the deeper layers.

DISCUSSION

Gilman: The units on your figure are degrees per day. The magnitudes of the coefficient b seem very large.

Chistyakov: The unit along the vertical axis is 1° per day. The rotational velocity of sunspots changes from +3° (per day) to −3°. Those deviations are averaged over a short time interval, 0.5–1 yr.

Howard: Do I understand from your first slide that the $\Delta\beta$ is the average at times for a whole year larger than b, so that for negative $\Delta\beta$ there is an equatorial deceleration instead of acceleration?

Chistyakov: Yes. In practice we meet the following occurrence: Δb is positive and Δb is negative. If Δb is negative then the rotation law is described by the formula:

$$\xi = a + b \sin^2 \varphi .$$

Howard: I have measured rotational velocities from sunspots only for a two-year interval, but I am surprised at the magnitude of the effect.

Chistyakov: We established such a situation for the two 11-year cycles, i.e. No. 19 and No. 20.