DIFFERENTIAL ROTATION OF CHROMOSPHERE AND PHOTOSPHERE IN THE RISING PHASE OF N22 CYCLE OF THE SUN: TORSIONAL OSCILLATIONS

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The angular velocities of chromosphere and photosphere are calculated for 1987–1990 on the basis of heliographic coordinates of the chromospheric flares and sunspots (Solar Geophysical Data). The time resolution accepted is 0.25 year. The mean equatorial rotations of chromosphere and photosphere practically coincide. However, the differential coefficients in the chromosphere and photosphere, b, have strongly different behaviour. The value $b_{ch} - b_{ph}$ change regularly from "+" sign to "−" sign over two-year interval. Thus, the idea of a torsion like oscillations of "chromosphere–photosphere" is supported.

INTRODUCTION

Many researches have been dedicated to variations of differential rotation of the Sun, since Sheiner discovered this phenomenon in 1630. Unlike the Earth, the Sun does not rotate as a rigid body. The equatorial region rotates faster than the poles. In the photosphere, the sinodic rate of rotation w is given approximately by the Fay equation:

$$\omega = a - b \sin^2 \phi, \tag{1}$$

where ϕ is the solar latitude, a is the angular velocity at the equator, and b is the coefficient of differentiality. As a starting point, we can use the differential rotation of Eq. (1) in the form given by Newton and Nunn for the unit and recurrent sunspots; $a = 13.39°$/day and $b = 2.77°$/day [2]. Lately, for detection of the rotation rate the method of tracers like bright Ca^{+} elements, a short living X-rays elements, radio emissions, and so on is widely used [2]. To calculate the angular velocity in the active chromosphere, we suggested to use the solar flares as the tracers [1]. The flares have these advantages that they trace the position of some magnetic centre in the active region which generates the flares. Generally speaking, Eq. (1) was derived by averaging over many 11-year cycles (1878–1944). Therefore, all variations of a, b parameters with time are ruled out. Practically, all the relationships on the Sun reveal the 11-cycle phase dependence. This dependence may include the variation of rotation at the equator, $a(t)$, variation of the coefficient of differentiality, $b(t)$, and some kind of a torsion like oscillations [1, 2]. In the present study, the angular velocities of chromosphere and photosphere were calculated for the 11-year cycle N 22 (1987–1990), on the basis of heliographic coordinates of the chromospheric flares and sunspots [3]. The time resolution accepted was 0.25 year. The time behaviour of the difference of "chromosphere–photosphere" in the a and b parameters was investigated, which may reflect a torsion like oscillations of the Sun.

The data for the study were the Tables of chromospheric flares (H-alpha solar flares groups) published in Solar Geophysical Data (Comprehensive Reports, Part II [3]). The other data used were the Tables "Sunspot groups" ordered by the central meridian passage (Prompt Report, Part I [3]). We used such kinematic features as the position of flares in the Central Meridian coordinate system (CM), the time of flares maximum as the moment of flare, t_m, the coordinate of sunspot, ϕ_s, and flares, ϕ_f.

The heliographic coordinate of each flare can be transformed from central meridian (CM) system into the system related to the centre of proper sunspot following the procedure suggested in [1]. This transformation was applied to the system of "true" rotation of sunspots using the data from "Sunspot groups" tables [3]. Applying to the run of ϕ_s-sunspots and ϕ_f-flares the least-squares method [1], we obtain the mean angular velocity $<\omega>_s$ in the photosphere and chromosphere $<\omega>_f$.

RESULTS

The main parameters of our rotation mode calculation are listed in Table 1. The time points are in 1st column; the cynodic angular velocities at the equator in the chromosphere and photosphere are in 2nd and 3rd columns. The coefficients of differentiality are in 4th, 5th columns, respectively. The difference "chromosphere–photosphere" of a and b coefficients are given in 6th and 7th columns. The statistics of sunspot groups are presented in the last column. Altogether, 309 sunspot groups are used.

Table 1. List of parameters

t	a_{ph}	a_{ch}	b_{ph}	b_{ch}	$a_{ch} - a_{ph}$	$b_{ch} - b_{ph}$	N_{gr}
1	14.19	14.28	4.96	7.90	0.09	2.94	24
2	13.25	13.44	1.70	3.14	0.19	1.43	23
3	13.71	13.78	4.66	4.34	0.07	−0.32	43
4	13.57	13.41	3.35	1.89	−0.16	−1.46	55
5	13.79	13.68	5.07	3.97	−0.11	−1.1	41
6	13.5	13.42	2.64	1.76	−0.08	−0.88	35
7	13.35	13.41	2.22	0.06	0.06	−0.53	33
8	13.4	13.74	2.13	0.34	0.34	1.86	55
mean	13.60	13.64	3.11	2.80	0.05	0.24	309 (sum)

As it is seen from Table 1, the mean cynodic angular velocity at the equator in the chromosphere, 13.64 ± 0.11, is to be the same as that in the photosphere, 13.60 ± 0.11. The coefficients of differentiality show much more variations. The syderic law of differential rotation in the photosphere and chromosphere is:

$$\omega = 14.57 - 3.11 \sin^2 \phi, \tag{2}$$

$$\omega = 14.61 - 2.80 \sin^2 \phi. \tag{3}$$

As it follows from the Table 1, the solar flares rotate faster than the flocculi [2]. An attempt was made to find out the temporal variation of rotation with height. For this purpose, the difference "chromosphere–photosphere" of a and b coefficients in Eq. (1) was taken; see 6th and 7th columns of Table 1.

Figure 1 shows the time-run of differences "chromosphere–photosphere" of a and b coefficients. It is seen that the variations of $a_{ch} - a_{ph}$ are in the limit of error, $\Delta a = 0.05 \pm 0.06°$/day. At the same time, variations of $b_{ch} - b_{ph}$ in six time points exceed a mean error of 0.57°/day. It is remarkable that there a positive correlation between the two coefficients (a, b) of order of 0.77 exists. This means that the changes of sign in a, b are someway synchronized in time (Fig. 1). This change of sign from "+" to "–" and vice versa seems to indicate the torsion like oscillations between the chromosphere and photosphere. This may be called like the torsion oscillations of the "degree of differentiality" with height.

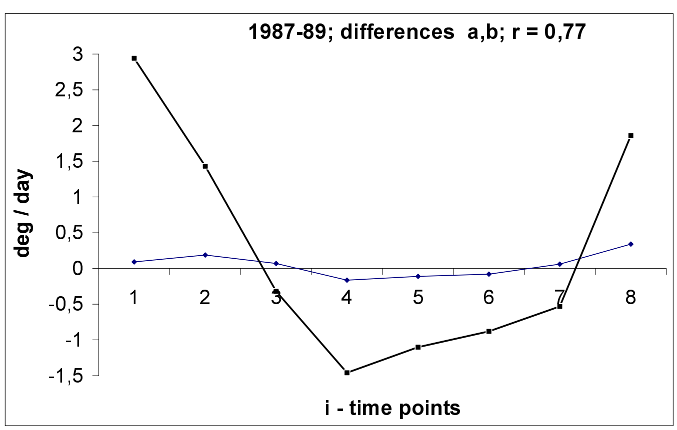

Figure 1. The time-run of rotation parameters (a, b) of the "chromosphere–photosphere" for 1987–1990

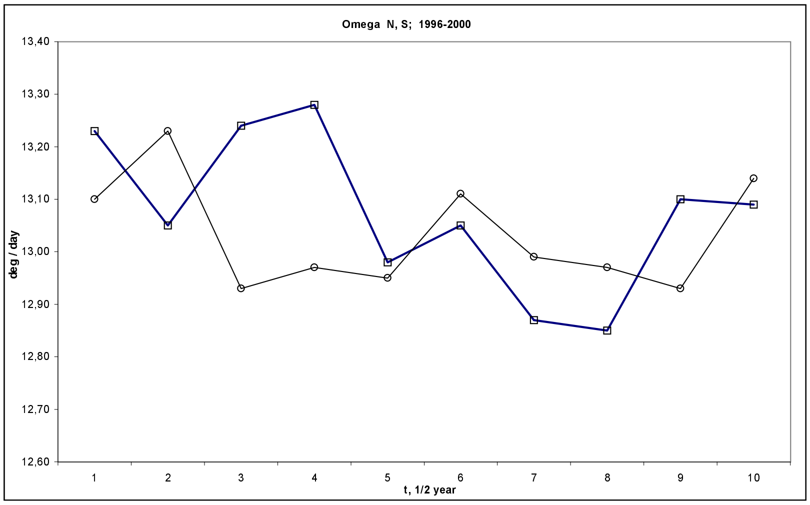

Figure 2. Variations of the mean angular velocity for N and S hemispheres in the photosphere for 1996–2000

An attempt was made to find out the temporal and spatial variations of rotation in the northern (N) and southern (S) hemispheres. For this purpose, we take the mean daily rotation over all sunspots in each hemisphere separately. The derived mean rotations $<\omega(N)>$ and $<\omega(S)>$ are presented in Fig. 2.

Figure 2 shows superimposed variations of the mean angular velocity of N and S hemispheres in the units of $^\circ$/day for 1996–2000 with a 1/2-year time resolution. Correlation of this graphs shows that there are "in phase" as well as in "anti-phase" fluctuations of $<\omega(N)>$ and $<\omega(S)>$. The relative fluctuation $(<\omega> /\omega)$ is of order of 3%. When smoothed over nine rotations (240 days), there exists slight tendency onto the anti-phase fluctuation of rotation of the opposite hemispheres. This tendency may be considered as the sign of torsion-type oscillation of "hemisphere–hemisphere". So, we reveal two possible types of torsion like oscillations possible on the Sun. The first is connected with rotation-velocity fluctuations of north–south hemispheres as a whole. The second one is more peculiar. It reveals itself as the variations of "differentiality" of the law of rotation in the chromosphere and photosphere.

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[2] *Obridko V., Shelting B.* Differential Rotation of the Sun // Issled. po Geomagnet. Aeronomii i Phizike Solntza.–1988.–**83**.–P. 3–24.

[3] Table "H-alpha solar Flares", Part II; Table "Sunspot Groups", Part I.–Solar Geophysical Data, NOAA, Boulder, Colorado, 1987–2000.–PII, PI.