THE SOLAR HIGH LATITUDE MAGNETIC FIELD REVERSAL

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ABSTRACT It is suspected that the existence of 3-fold magnetic field reversals in one of the solar hemispheres is a result of two types of variations in the background magnetic field. The first type is the Hale 22-year cycle, the second is a quasi biannual cycle. In the first approximation, the background magnetic field evolution may be described by diffusion equations corrected for meridional circulation and a periodically changing source. In the case of multiplicity of the frequencies and with a definite relation between intensities of these periods, it appears that the existence of 3-fold polarity reversals take place in even cycles (on the Zurich numeration).

Theory of the turbulent dynamo gives us a possibility to explain the nature and behaviour of the solar magnetic field and to understand the main regularity of the solar cycle - the 22-year magnetic field reversal, Hale and Spörer laws, Gnevyshev-Ohl’s rule, the Maunder minimum (Parker 1955, Stix 1976, Ivanova and Ruzmaikin 1977, Makarov et al. 1987, Pudovkin and Benevolenskaya 1985).

However, one of the significant peculiarities is the 3-fold magnetic field reversal, hard to explain in the frame of the dynamo theory. From the analysis of the Hα synoptic charts 3-fold magnetic field reversals (for the last 120 years) have been observed during all even 11-year cycles, beginning with 12th cycle. At first, a 3-fold magnetic field reversal takes place in the southern hemisphere (cycles 12 and 14), then in the northern hemisphere (16, 18 and 20th) (Makarov and Sivaraman 1989a, b).

Single magnetic field reversals have taken place in the odd cycles beginning with the 11th cycle (except the 19th). This means that the 22-year solar magnetic cycles begin with a cycle in which a 3-fold reversal is observed in one of the hemispheres. According to modern concepts (Parker 1979), solar magnetic fields are generated by helicity and the differential rotation of the solar convection zone. The toroidal magnetic field ($B_\phi$ - component) formed in the convection zone shows up as sunspots on the surface. The background magnetic field ($B_r$ - component) is in turn transferred poleward due to diffusion
and meridional circulation (Wang et al. 1989). From the nonlinear theory, stable frequencies with a period shorter than 22 years may occur (Hoyng 1990).

We assume that the existence of a 3-fold magnetic field reversal in one of the hemispheres is a manifestation of two types of variations in the solar magnetic fields. The first is the 22-year Hale cycle (\( \omega_c = 2\pi/22 \)), and the second, high-frequency (\( \omega_d \)) is a multiple, \( \omega_d = k\omega_c \) (Benevolenskaya and Makarov 1990). The width of the zones of alternating polarities corresponds approximately to the period of the field order 1.5 to 2.5 years. Similar periods take place in the indexes of the solar activity: Wolf number, sunspot area, etc. (Akioka et al. 1987). Generation of the poloidal and toroidal fields is described by a system of differential equations. However, in the first approximation, the background magnetic field evolution may be described by a diffusion equation corrected for meridional circulation and a periodically changing source.

\[
\frac{\delta B_d(\mu,t)}{\delta t} = S(\mu,t) - \frac{1}{R} \frac{\delta}{\delta \mu} \left[ v(\mu) B_r \sqrt{1 - \mu^2} \right] + \frac{1}{T_D} \frac{\delta}{\delta \mu} \left[ (1 - \mu^2) \frac{\delta B_r}{\delta \mu} \right]
\]

\( \mu = \cos \theta \)

\( v(\mu) \) – velocity of the meridional circulation

\( 1/T_D \) – turbulent diffusivity

\( S(\mu,t) \) – source of the background magnetic field are represented at appearance

\( B_r \) – field in time on the solar surface from toroidal field in the convection zone.

From the distribution of the bi-polar sunspot on the solar surface, we can interpret eruptional toroidal magnetic field as a two axisymmetrical bands in each hemisphere (Figure 1a). Such toroidal magnetic field distribution gives us the distribution of the \( B_r \) - field shown in Figure 1b.

![Fig. 1. Distributions of the toroidal (a) and poloidal (b) magnetic field on the Sun.](image)

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Fig. 2. Model's distribution of $B_r$ - field for the case where (a) $V = 0.02$, and (b) $V = 0.03$ in dependence with latitude ($\theta$) and time, ($t$ in years); +1 G (solid line), -1 G (broken line), and zero (dot and dash line).

Therefore, the source of the $B_r$ - field are represented:

$$S(\mu, t) = \frac{B_c \sin 4\theta}{\Delta t} \sin \omega_c t - \frac{B_s \sin 4\theta}{\Delta t} \sin \omega_s t$$

$\omega_c$ - frequency of Hale’s cycle

$\omega_s$ - high-frequency component of the background field

$B_c, B_s$ - amplitudes, $A = B_c/B_s$
If the frequencies are multiple, i.e. $\omega = k \omega_c$ and $k$ is an integer, for $k = 8$ and $A = 2.5$, the behaviour of the $B_\phi$ - field is shown in Figures 2a and 2b.

The velocity of the meridional circulation, $v(\mu)$, is described as a function different from $v(\mu) = v_\phi \sin \theta$ that is accepted by DeVore (1987). $v(\mu) = -v_\phi R_{d\mu}$ in the northern hemisphere, $v(\mu) = v_\phi R_{o}$ in the southern hemisphere, $v(\mu) = 0$ at both the poles and the equator.

$v_\phi = 0.02$ corresponds to real velocity and equals 2 m/s (Figure 2a) and $v_\phi = 0.03$ corresponds to 3.5 m/s (Figure 2b). From Figures 2a and 2b, it follows that a polar magnetic field reversal from $-$ to $+$ forms zones of the alternating polarities. Such a situation takes place on the Sun in the northern hemisphere in the even cycles from solar cycle 16. We can see that a small decrease of velocity in the meridional circulation can result in a situation where there are processes of under-reversal (Figure 2a).

From experimental data, we know the velocity of the poleward moving neutral line toward the poles is 10-30 m/s during the solar maximum compared with 2-5 m/s in other periods (Makarov et al. 1989).

From our calculations, it follows that a large increase in the velocity of the neutral line (10-20 times) is connected not only with the restructuring of the meridional circulation, but also with turbulent diffusion, generation of the $B_\phi$ - field. The presence of zones of the alternating polarity depends on the relationship of amplitudes and phases of high-frequency and low-frequency component of the background magnetic field. The combination of the phase and the growth of the amplitude $B_\phi$ can result in a situation in which such zones formed during the period when the solar field reverses from $+$ to $-$, which actually took place in solar cycle 19-th. Therefore, a 3-fold solar magnetic field reversal and the formation of the alternating polarity zones can be interpreted as an interaction between two frequency sources of the magnetic field corrected for turbulent diffusion and meridional circulation.

REFERENCES

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