ZONAL LATITUDE STRUCTURE OF THE SUN'S GLOBAL MAGNETIC FIELD EXCITED BY TURBULENT DYNAMO MECHANISM

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This study is performed on the base of the turbulent dynamo model allowed newer helioseismic measurements of the Sun's inner rotation. It is shown that the physical conditions in the deep layers of the solar convection zone in the near-pole domain are favourable for exciting of quadrupole mode of the poloidal magnetic field near maximum phase of the 23rd solar cycle.

Magnetographic observations of the poloidal field of the Sun evidence that this field may be generally described by simple magnetic dipole with antisymmetric polarity relatively to the equator. In this case the synoptic maps of the polarity distribution of large-scale surface (background) magnetic field manifest the two latitudinal zones with opposed magnetic polarity on both side of equator. However, both poles of the polar magnetic field had the same polarity during last four solar activity maximums. To interpret this observed magnetic anomaly some investigators consider the quadrupole mode, which is symmetric relative to equatorial plane, to predominate in the poloidal field at this time. Then the maps of magnetic polarity distribution must display four latitudinal zones, and two zones of opposite signs in each hemispheres. Here we try to reveal the possibility of exciting the quadrupole mode of the poloidal field in the Sun's deep layers in the frame of the main magnetic field theory with allowance for newer helioseismic measurements of the inner rotation rate.

According to the dynamo model the combination of the differential rotation and helical (hyrotropic) turbulence in the solar convection zone (SCZ) near the tachocline (a region of strong shear of the angular velocity at the base of the SCZ) produces the toroidal and poloidal components of the Sun's global magnetic field ($\alpha\Omega$-dynamo mechanism). Parker has suggested the solution of dynamo equations for global magnetic components in the form of migratory dynamo waves. Using the boundary conditions, he reduced the dynamo problem to the solution of the dispersion relations that describe the character of the dynamo-effect. Excitation thresholds of multipole modes are determined by eigenvalues of the dispersion relations, *i.e.*, numbers $K\lambda$ (K is the wave number of the dynamo wave, λ is the characteristic scale of the dynamo region). Parker [1] found by model calculation that the excitation thresholds of the periodic dipole and quadrupole modes are rather close. The wave number is determined by physical parameters of the SCZ, $K = (\alpha G/{\nu_T}^2)^{1/3}$ (α is the helicity parameter of turbulent convection, $G = r\partial\Omega/\partial r$ is the measure of the radial differential rotation $\partial\Omega/\partial r$ at the distance r from the Sun's centre, ν_T is the turbulent viscosity) and defines the scale of the magnetic field change. The direction of the dynamo-wave migration depends on a sign of the wave number. The magnetic wave travels equatorwards when $K < 0$, and polewards when $K > 0$.

Since the excitation thresholds of the periodic dipole and quadrupole modes are rather close then it is possible that the quadrupole may be excited when physical parameters (α, ν_T, $\partial\Omega/\partial r$) being changed in a some regions of the SCZ. Recently, helioseismic measurements [2, 3] have shown a strong dependence of the differential rotation on heliolatitude and depth in the SCZ. The inner regular velocity field is naturally divided in each hemisphere on two domains of the fast (near-equator domain) and slow (near-pole domain) rotation, with opposite sign of $\partial\Omega/\partial r$ in each domain. The angular velocity decreases with depth ($\partial\Omega/\partial r > 0$) in the near-equator domain, and increases ($\partial\Omega/\partial r < 0$) in the near-pole domain.

We calculated numbers $K\lambda$ for the SCZ model by Stix [5] (on the depth 175,000 km) using our estimation of helicity parameter [4] and the values of the radial gradient of angular velocity obtained from newer helioseismic measurements near the maximum phase of the 23rd solar cycle (May 1995 – November 1999) [3]. It was found that the calculated value $K\lambda$ is to be about -7 at low latitudes $\theta = 0° - 40°$ in domain-1 (where $\alpha < 0$ and $\partial\Omega/\partial r > 0$) near tachocline. The value obtained is close to the eigenvalue of -7.43 by Parker [1] which is necessary for dipole exciting. The radial gradient of angular velocity changes its sign on opposite at the latitudes higher then 50° so the value $K\lambda$ also changes its sign in the near-pole domain-2 ($\alpha < 0$ and $\partial\Omega/\partial r < 0$): here $K\lambda$ amounts to $\approx +8$ that is close to eigenvalue $+7.43$ necessary for quadrupole exciting.

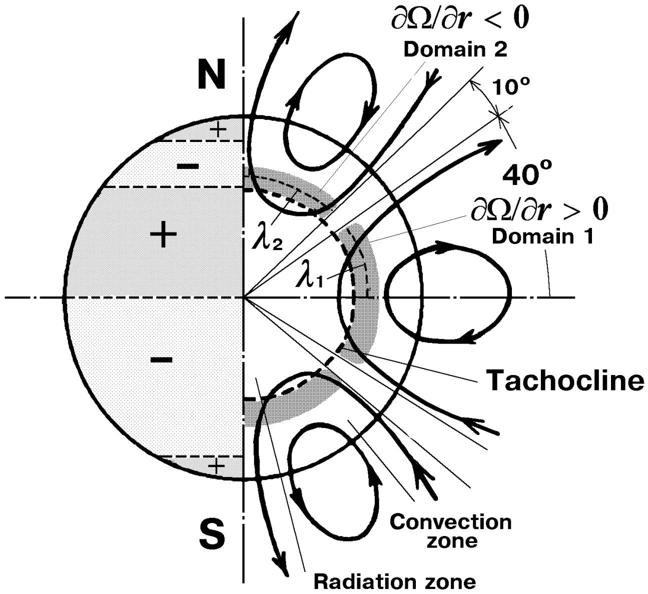

Figure 1: Dipole and quadrupole modes of the poloidal magnetic field excited by $\alpha\Omega$-dynamo mechanism in the SCZ near tachcline near maximum phase of 23rd solar cycle. Right hemisphere: force lines of the dipole ($\theta^* < 40°$) and quadrupole ($\theta^* > 50°$); left hemisphere: corresponding latitudional zones with positive (+) and negative (–) polarities of observed large-scale surface (background) magnetic field

Thus, during rising phase of the 23rd solar cycle the turbulent dynamo mechanism in the near-equator domain in the vicinity of tachocline produces the dipole mode of the poloidal field (migrated equatorwards since $K < 0$); while near-pole domain conditions are more favourable for exciting the quadrupole mode (migrated polewards, $K > 0$). As a result, the maps of polarity distributions of the observed large-scale phothosheric magnetic field in the northern hemisphere display three latitudinal zones with intermittent polarity, and two latitudinal zones in the southern hemisphere. In this case the both near-polar zones should have the same magnetic signs. This gives a possibility to explain the surface polar field magnetic symmetry relative to equator at the solar cycle maximum.

REFERENCES

[1] *Parker E. N.* The generation of magnetic fields in astrophysical bodies. IV. The solar and terrestrial dynamos // Astrophys. J.–1971.–**164**.–P. 491–510.

[2] *Tomczyk S., Schou J., Thompson M. J.* Measurement of the rotation rate in the deep solar interior // Astrophys. J. Lett.–1995.–**448**, N 1.–P. L57–L60.

[3] *Howe R., Christensen-Dalsgaard J., Hill F., et al.* Dynamic variations at the base of the solar convection zone // Science.–2000.–**287**.–P. 2456–2460.

[4] *Krivodubskyj V. N.* Rotational anisotropy and magnetic quenching of gyrotropic turbulence in the solar convective zone // Astron. Rep.–1998.–**42**, N 1.–P. 122–126.

[5] *Stix M.* The Sun.–Berlin, 1989.–200 p.