THE ENERGY CONVERSIONS AND ENHANCEMENT CAUSED BY THE UNSTEADY PLASMA MOTION IN THE ACTIVE REGION

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ABSTRACT. In this paper,The author has discussed the coupling processes between the magnetic field and the unsteady plasma motion,and analysed the features of the energy storage and conversions in the active region.

The magnetic configuration is all the force-free field in the active region.The force-free condition is

$$\nabla \times \underline{B} = \alpha(t,\underline{r})\underline{B}, \qquad (1)$$

where $\alpha(t,\underline{r})$,the force-free factor,depends on both the time t and place coordinates $\underline{r}$.The induction equation of the magnetic field is

$$\partial \underline{B}/\partial t = \nabla \times (\underline{V} \times \underline{B}). \qquad (2)$$

The condition of zero divergence of magnetic field is

$$\nabla \cdot \underline{B} = 0. \qquad (3)$$

Now we set up a cylindrical coordinate system to the axial-symmetric force-free magnetic field.According to $\nabla \cdot \underline{B}=0$,we may introduce the magnetic potential function A as

$$B_r = (1/r)(\partial A/\partial z), \qquad B_z = (-1/r)(\partial A/\partial r). \qquad (4)$$

Hence,we may reduce Eqs.(1)—(4) to the following forms

$$rB_\varphi = G(A,t), \qquad \alpha = -\partial G(A,t)/\partial A, \qquad (5)$$

$$\Lambda(A) = \left(\frac{\partial^2}{\partial r^2} - \frac{1}{r}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2}\right)A = -G(A,t)\left[\partial G(A,t)/\partial A\right], \qquad (6)$$

$$\partial A/\partial t + u(\partial A/\partial r) + w(\partial A/\partial z) = 0, \qquad (7)$$

$$\partial G(A,t)/\partial t + (\partial u/\partial r - u/r + \partial w/\partial z)G(A,t)$$

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$$= -(\partial v/\partial z)(\partial A/\partial r) + (\partial v/\partial r - v/r)(\partial A/\partial z). \qquad (8)$$

$$\underline{B}\cdot[\partial \underline{V}/\partial t + (\underline{V}\cdot\nabla)\underline{V} + \nabla p/\rho] = 0, \qquad (9)$$

where $\underline{V}=(u,v,w)$, is the velocity field in the cylindrical coordinates.To study the evolution of kinematical force-free field,that is whether the processes might be described by the solutions of Eqs.(4)—(9) or not.

Some authors,Barnes,C.W.(1972),Ma,Y.(1981) and Svetska, Z.(1977) have calculated the quantitative relationship between the static force-free field connecting the magnetic field and the twisting processes.They pointed out that the potential magnetic field without the current may be twisted into the force-free field with the enhancing current produced by the plasma rotation.They thought that it may be a process of the storage energy in the active region.Latterly, Li,Z.(1982,1984) and Hu,W.R.(1983) have pointed out that the processes should be unsteady,and essentially, it should not be a static process.They have also pointed out that the discussion about the energy storage by the pure azimuthal motion in the solar active region is not a perfect approach. Svetska,Z.(1977),Athay,G.(1981),Hu,W.R.(1983) and Li,Z. (1985) have suggested that the poloidal plasma motion should play an important role besides the plasma rotation.

Both Eq.(7) and Eq.(8) show that the toroidal velocity may magnify the toroidal magnetic field,and the poloidal velocity may change the poloidal magnetic field.Their linear condition is

$$G(A,t)[\partial G(A,t)/\partial A] = \alpha_1(t)A + \alpha_2(t)/2. \qquad (10)$$

In this case,the force-free factor may correspondingly be written as

$$G(A,t) = \pm[\alpha_1(t)A^2 + \alpha_2(t)A]^{1/2}. \qquad (11)$$

$$\alpha = \mp [\alpha_1(t)A + \alpha_2(t)/2] \Big/ [\alpha_1(t)A^2 + \alpha_2(t)A]^{1/2}. \qquad (12)$$

Substituting (10) into (6),we may get the following force-free equation and boundary conditions

$$\Lambda(A) + \alpha^2(t)A = 0, \qquad (13)$$

$$A(r,0,t) = f_1(r,t), \qquad A(r,L,t) = f_2(r,t), \qquad (14)$$

$$A(0,z,t) = 0, \qquad A(\infty,z,t) = 0, \qquad (15)$$

where "α" and "A" are all the functions of time t.

Using Hankel transformation,it is possible that we try to get the solutions of Eqs.(13)—(15).In Hankel transformation,the time t will be used as a parameter.In order to finalize to make Eq.(13) into Bessel Equation, first we have to suppose

$$A_1(r,z,t) = A(r,z,t)/r, \tag{16}$$

thus, (13)—(15) become

$$\frac{\partial^2 A_1}{\partial r^2} + \frac{1}{r}\frac{\partial A_1}{\partial r} + \frac{\partial^2 A_1}{\partial z^2} + (\alpha^2 - \frac{1}{r^2})A_1 = 0, \tag{17}$$

$$A_1(r,0,t) = f_1(r,t)/r, \quad A_1(r,L,t) = f_2(r,t)/r, \tag{18}$$

$$A_1(0,z,t) = 0, \qquad A_1(\infty,z,t) = 0. \tag{19}$$

Now we make a Hankel transformation. Given:

$$\tilde{A}(z,t) = \int_0^\infty rA_1(r,z,t)\, J_1(\beta,r)\, dr, \tag{20}$$

then, (17)—(19) may be reduced to

$$(\partial^2\tilde{A}/\partial z^2) + [\alpha^2(t) + \beta^2]\tilde{A} = 0, \tag{21}$$

$$\tilde{A}(0,t) = F_1(\beta,t), \qquad \tilde{A}(L,t) = F_2(\beta,t), \tag{22}$$

where

$$F_i = \int_0^\infty f_i(r,t)\, J_1(\beta,r)\, dr, \quad i=1,2. \tag{23}$$

It is not very difficult thing to get the solution of (21) and (22), we can obtain it and it is

$$\tilde{A} = c_1 \exp[(\alpha^2 + \beta^2)^{1/2} z] + c_2 \exp[-(\alpha^2 + \beta^2)^{1/2} z], \tag{24}$$

where

$$c_2 = \frac{F_1(\beta,t)\exp[(\alpha^2 + \beta^2)^{1/2}\cdot L] - F_2(\beta,t)}{2\,\mathrm{sh}(\sqrt{\alpha^2 + \beta^2}\cdot L)}, \tag{25}$$

$$c_1 = \frac{F_2(\beta,t) - F_1(\beta,t)\exp[-(\alpha^2 + \beta^2)^{1/2}\cdot L]}{2\,\mathrm{sh}(\sqrt{\alpha^2 + \beta^2}\cdot L)}. \tag{26}$$

Using the inversion of Hankel transformation, the following form can, therefore, be arrived at:

$$A_1(r,z,t) = \int_0^\infty \left\{ F_1(\beta,t)\frac{\mathrm{sh}[\sqrt{\alpha^2 + \beta^2}\cdot(L-z)]}{\mathrm{sh}(\sqrt{\alpha^2 + \beta^2}\cdot L)} + F_2(\beta,t) \times \frac{\mathrm{sh}(\sqrt{\alpha^2 + \beta^2}\cdot z)}{\mathrm{sh}(\sqrt{\alpha^2 + \beta^2}\cdot L)} \right\} \beta J_1(\beta,r)\, d\beta. \tag{27}$$

Thus, the solution of Eqs.(13)—(15) is

$$A(r,z,t) = rA_1(r,z,t). \tag{28}$$

Substituting (28) into (11), and according to (5), we can get $G(r,z,t)$ and $B_\phi(r,z,t)$; thus, we may discuss the evolution of the toroidal magnetic field with time t. For example,we analyse a brief condition in which $\alpha_2(t)=0$. In this case, we may have

$$G(r,z,t) = r\alpha\left\{\int_0^\infty\left[F_1(\beta,t)\frac{sh\left[\sqrt{\alpha^2+\beta^2}\cdot(L-z)\right]}{sh(\sqrt{\alpha^2+\beta^2}\cdot L)} + F_2(\beta,t)\times \times\frac{sh(\sqrt{\alpha^2+\beta^2}\cdot z)}{sh(\sqrt{\alpha^2+\beta^2}\cdot L)}\right]\cdot\beta\cdot J_1(\beta,r)\cdot d\beta\right\} . \quad (29)$$

Then, the density of the toroidal magnetic energy is

$$W_\theta = B_\theta^2/8\pi = G^2(A,t)/8\pi r^2 . \quad (30)$$

In terms of the discussion ,hence,we may obtain a kinematical form.Due to the poloidal plasma motion,the kinetic energy and the internal energy of the plasma under the lower levels may be transfered to the upper levels of the active region.The coupling process between the magnetic field and flow field will cause the enhancement of the force-free factor α with time t.The enhancing α will impel the increase in the toroidal magnetic field.If the plasma rotation is also existing at the same time,the toroidal magnetic field can even more be increased.In this case, the energy may be stored up in the active region.Due to the continued enhancement of W_θ ,it will be able to become possible that the active region goes to the unstability and even eruption.

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