A RESEARCH TO THE SOLAR CORONAL INITIAL MAGNETIC DYNAMICS PRIOR A LAUNCH OF CME

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Abstract

Two dimensional magnetic-structures is developed and derived in the basic assumption line-tied condition in solar plasma. The type is two-dimensional half-circle magnetic arcade topology imbedded in photosphere dense plasma. The magnetic topology is assumed to be converted dynamically due to disturbance in magnetic fields and became a CME. Disturbance is derived from magneto-hydrostatic condition and perturbation is applied as first-order small deviation along the magnetic fields. Along the base of the magnetic arcade every disturbance is assumed to be zeroed by dense plasma and the magnetic fields of line is line-tied on photosphere. By inspecting snapshot data it is found that the derived structure is similar with solar coronal magnetic structure prior a launch of CME from coronagraph white light data.

Keywords: Half-circle arcade, dense plasma, line-tied coronal magnetic fields, CME

1. INTRODUCTION

Since the invention of solar coronagraph telescope, the more data has been compiled from the solar atmosphere in coronal level. More abundance is also gathered from satellite based coronagraph telescope. It is since thence solar physicist realized that solar corona is much more active than previously thought. The solar corona is dynamically released its huge mass into space. This is termed as the solar Coronal Mass Ejection, or CME [2].

This work is motivated by the solar coronal phenomena the CME. Such CME is thought as losing statics equilibrium and erupted as CME. It is often observed just before those phenomena to occur in the arcade type geometry frequently appears and subsequently evaporates into the region of high temperature solar corona.

Arcade models of those phenomena are based on a rapid release of magnetic energy stored in coronal currents [1]. However, the mechanisms by which the energy release is triggered vary from model to model. Some models trigger the release by a loss of magneto-hydrostatic equilibrium [3]; while others use a process such as magnetic reconnection models which invoke reconnection require the presence of a current sheet prior to the eruption of the field.

But models which are based on a magnetohydrostatic loss of equilibrium do not need examining the observational evidence for the existence of a current sheet prior to the eruption, it may be possible to determine the type of mechanism which triggers an eruption through a concept of finite disturbance in magnetic energy, that is a slow magnetic energy build up may deviates magnetohydrostatics equilibrium, and thence instability will be overwhelm the structure [4][5].

2. BASIC CONCEPT OF DISTURBANCE

Progenitor of the formulation is the basic equation which is derived from a set of magnetohydrodynamics partial differential equations that applied for static or nearly static coronal conditions, in low solar corona, when gravitational stratification is still be neglected, or when $\rho G \approx 0$.

By considering that the velocity component is virtually zero, we focus in the differential momentum equation, as written below [6],

$$\frac{\partial \rho V}{\partial t} + \nabla . \rho V V = -\nabla P + (\nabla \times B) \times B + \rho G \tag{1}$$

When velocity is zero, or $V \approx 0$, and for low solar corona, or $\rho G \approx 0$, the above equation has left to be expressed as,

$$\nabla P = (\nabla \times B) \times B \tag{2}$$

The above equation is the heart of magnetohydrostatics equation. When applying small disturbance over the magnetic fields, we may have an expression below,

$$\boxed{\nabla \delta P = -\nabla (B_0 . \delta B) + (B_0 . \nabla) \delta B + (\delta B . \nabla) B_0} \tag{3}$$

We assumed the disturbed magnetic field as small deviation δB over constant magnetic field B_0, as written below,

$$B \rightarrow B_0 + \delta B, \tag{4}$$

Where we supposed $\delta B << 1$, and as the magnetic field is disturbed, the pressure is also disturbed as

$$P \rightarrow P_0 + \delta P, \tag{5}$$

And it is meant that the pressure will deviate from its initial pressure by a pressure disturbance as $\delta P << 1$. But our scenario is to search properties of initial evolution of magnetic arcade prior a launch of CME through initially magnetic-field disturbance and then the pressure will follow the evolution according to the magnetic field disturbance.

3. DISTURBANCE SCENARIO

Following the concept for initial disturbance in a coronal magnetic arcade structure, it is introduced a strait task to concern with magnetic potential function rather than magnetic field of lines. In this way, we only concern two-dimensional magnetic potential structure rather than magnetic lines.

At very initial phase of getting unstable due to magnetic disturbance, probably we might assume as the pressure in magnetic arcade does not change much, or in an extreme state, it does change much at least along the magnetic arcade base which is laid along low solar corona. In this position, it is easier to approach the disturbance only from magnetic potential disturbance.

Mathematical relation between magnetic fields and its associated magnetic potential structure is basically may be expressed as below,

$$B = \nabla \times A, \tag{6}$$

In that above expression, B is the magnetic structure of the initial magnetic arcade, and A is the associated potential magnetic structure.

Disturbance scenario of a perturbed coronal magnetic arcade δB is overlooked through the representation of disturb magnetic potential δA as a result of perturbed magnetic field lines inside the arcade structure. Assuming first order approximation of disturbance scenario, the relation of both quantities may be derived and be written as below,

$$\delta B = \nabla \times \delta A \tag{7}$$

The boundary conditions that are imposed for lower boundary and loop-top boundary of the arcade is relatively easy to construct since we deal only a surface magnetic parameter that is the magnetic potential A, and its disturbed quantity δA.

If we suppose that the perturbation is slowed down and stopped by dense photosphere, then the magnetic fields is tied on the photosphere. By this situation δB or δA is fixed during evolution.

Consider a half cylindrical arcade in corona. At $\phi = 0$ and at $\phi = \pi$ the disturbance δA is vanished or symbolically $\delta A \to A_0(\phi = 0)$, and $\delta A \to A_0(\phi = \pi)$, so that on the base the potential function is halted to always be at fixed value as A_0. Consequtively the magnetic field is held to always be B_0. And at the base, as quoted, the pressure balances the magnetic fields as $\delta P \to P_0 = \frac{1}{2} B_0^2$ and assumed to be held constant during evolution.

At región off the boundary for the function A may change due to the introduction of disturbance in the arcade. Let in región which is $0 < \phi < \pi$ the function A is displace in some small degree for deviation as ζ, then the value of δA may explicitly be expressed as $A + \delta A \to A(\phi + \zeta) = 0 = A_0$ when $\phi = 0$ and when $\phi = \pi$. The process is expressed as the following below,

$$\begin{aligned} A(a_0 + \zeta) &\equiv A_0(a_0 + \zeta) + \delta A(a_0 + \zeta) \\ &= A_0(a_0) + \zeta \frac{d}{dr} A_0 + \delta A(a_0) = A_0(a_0) \end{aligned} \tag{8}$$

The equation (8) is directly resulted an explicite expression for the deviation ζ as written below, as equation (9)

$$\zeta = -\frac{\delta A(a_0)}{\frac{d}{dr} A_0} = \frac{\delta A(a_0)}{B_0(a_0)} \tag{9}$$

Consecutively, the plasma pressure expression is,

$$P(a_0 + \zeta) = P_0(a_0) + \zeta \frac{d}{dr} P_0 + \delta P(a_0) \tag{10}$$

And the magnetic pressure is

$$\tfrac{1}{2} B^2 = \tfrac{1}{2} B_0^2 + B_0(a_0)\, \zeta \frac{d}{dr} B_0(a_0) + B_0(a_0)\, \delta B(a_0) \tag{11}$$

The condition becomes

$$\zeta \frac{d}{dr} P_0(a_0) + \delta P(a_0) + \zeta B_0(a_0) \frac{d}{dr} B_0(a_0) - B_0(a_0) \frac{d}{dr} \delta A(a_0) = 0 \tag{12}$$

Combining the expression in eqaution (9) and (12), one may write

$$\delta A(a_0)\frac{d}{dr}B_0(a_0)=B_0(a_0)\frac{d}{dr}\delta A(a_0) \tag{13}$$

If we further assumed

$$\delta A \rightarrow \delta A(r)\vec{z} \tag{14}$$

We may expllicitely simplify the situation for pressure disturbance δP in both directions r and ϕ

$$\frac{\partial}{\partial r}\delta P=\frac{1}{r}\frac{d}{dr}(rB_0)\frac{\partial}{\partial r}\delta A+\frac{B_0}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\delta A\right)+\frac{B_0}{r^2}\frac{\partial^2}{\partial\phi^2}\delta A \tag{15}$$

$$\frac{\partial}{\partial\phi}\delta P=\frac{1}{r}\frac{d}{dr}(rB_0)\frac{\partial}{\partial\phi}\delta A \tag{16}$$

After combining equations (16), and the conditions at the boundary, we finally have the following expression,

$$\frac{d}{dr}\left(r\frac{\partial}{\partial r}\delta A\right)+\frac{1}{r}\frac{d^2}{d\phi^2}\delta A-\frac{r}{B_0}\delta A\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}(rB_0)\right]=\frac{1}{2B_0}B_{00}^2 r\frac{d}{dr}F(r) \tag{17}$$

Simplification may also further be applied if the magnetic fields is written as,

$$B_0(r)=B_{00}r/a_0 \tag{18}$$

And the over all equation is written as

$$\boxed{\frac{d}{dr}\left(r\frac{d}{dr}\delta A\right)+\frac{1}{r}\frac{d^2}{d\phi^2}\delta A=\frac{1}{2}B_{00}a_0\frac{d}{dr}F(r)} \tag{19}$$

The last equation (19) is the equivalent with basic equation (3) in much operatioinal expression. The expression is directly used to generate a function that appropriate with initial line-tied solar coronal magnetic fields in an initial condition prior a launch of a CME.

4. RESULTS

The strategy by constructing through a definition of magnetic potential function ***A*** is the most direct way to have coronal magnetic field expression that deviate from initial topology, while we retain the magnetic line-tied geometry on the foot point af the magnetic fields. Once δA has been succesfully constructed, the new magnetic potential ***A*** at every height in the initial magnetic fields can be figure out. Except on the foot points δA is bloked to be always zero as the photospheric plasma brakes the perturbations.

Figure 1 shows the effect of a perturbation function of $F(r)=1-7r^2+9r^2$ and the dashed curve showing the initial position of the curved boundary. The field lines are moved out-wards.

The maximum effect is found at the top of the loop, and the field lines are symmetrical aperturbation about this line. If the amplitude of the perturbation is increased, its effect increases accordingly. If the perturbation is force to continue, there is a limitation on perturb geometry, and this is the signs that the CME expansion would be enter a different domain, that is the non-linear expansion.

The function that has been used for a certain function forms of equilibrium close to a cylindrically-symmetric state (with the axis of the cylinder on the photosphere) but not for others. In particular, the function ***F*** in the last equation has to be a parabolic form of r^2 solutions are can only be used that the excess of plasma pressure, integrated along the base is zero is satisfied.

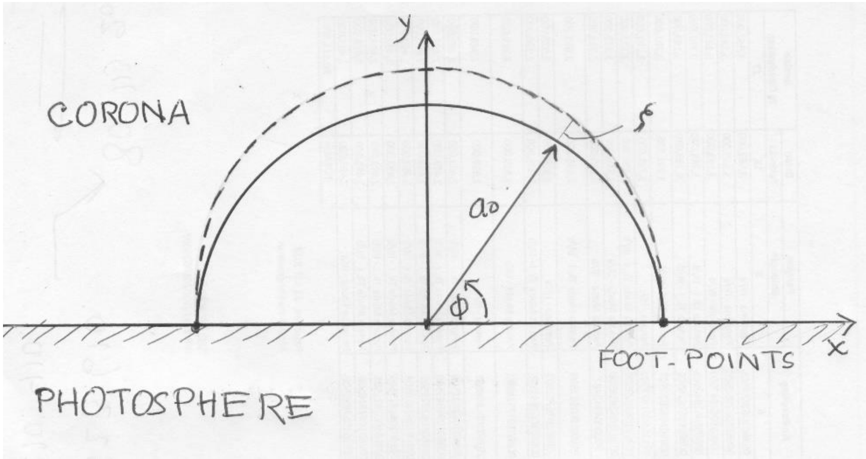

Figure 1: The initial solar coronal model with foot-points line-tied on the solar photosphere. Deviation by perturbation is represented by dash line. Perturbations along the base are kept to be zero all the time. Above photosphere is assumed the solar corona layer [6].

5. DISCUSSIOINS

The constraint might reflects that physically when the initial equilibrium with the axis on the photosphere is perturbed, there is no change in the net pressure on the curved upper surface and if global vertical equilibrium is maintained, there can be no change in the net pressure on the straight lower boundary of the semi-circle. When this constraint is not satisfied the arcade is likely either to erupt or to collapse downwards, depending on the sign of the change in the function ***F***. The eruption or collapse may perhaps continue until nonlinear effects counteract it.

6. REFERENCES

[1]. Antiochos, S.K., DeVore, R.C. (1989), The Role of Magnetic Reconnection in Solar Activity, Naval Research Laboratory, Washington, D. C.
[2]. Burkholder, B.L., Otto, A., Delamere, P.A., Borovsky, J.E. (2018), Magnetic Connectivity in the Corona as a Source of Structure in the SolarWind, Journal of Geophysical Research: Space Physics, 10.1029/2018 JA026132.
[3]. Chaowei Jiang, C., Zou P., Feng X., Hu, Q., Duan, A., Zuo, P., Wang, Y., Wei, F., (2018), Decipher the Three-Dimensional Magnetic Topology of a Great Solar Flare, arXiv:1802.02759v1 [astro-ph.SR] 8 Feb 2018.
[4]. Li, C., Sun, L.P., Wanf, X.Y., Dai, Y. (2013), Coronal magnetic topology and the production of solar impulsive energetic electrons, A&A 556, L2 (2013), DOI: 10.1051 /0004-6361/201322072.

[5]. Malandraki, O.E., Sarris, E.T., 1, Tsiropoula, G. (2003), Magnetic topology of coronal mass ejection events out of the ecliptic: Ulysses/HI-SCALE energetic particle observations, Annales Geophysicae (2003) 21: 1249–1256.
[6]. Sujito, Wisodo, H., Setiahadi, B. (2017), Comparison of Magnetohydrodynamics Simulation And Observasional Result to Solar Coronal Helmet Streamer, IOP Conf. Series: Journal of Physics: Conf. Series 846 (2017) 012004 doi :10.1088/1742-6596/846/1/012004.