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FORMATION OF ACTIVE REGION AND QUIESCENT PROMINENCE MAGNETIC FIELD CONFIGURATIONS.

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ABSTRACT

To investigate the formation of prominences, we have studied chromospheric mass injection into an overlying coronal dipole magnetic field using a 2-D ideal magnetohydrodynamic(MHD) numerical model. We propose that active region prominences are formed by chromospheric plasmas injected directly into the overlying coronal magnetic field and that quiescent prominences are formed by plasmas evaporated at the interface between spicules and corona.

Hence, for the simulation of an active region prominence magnetic field we inject the mass from one side, but use a symmetric mass injection to form a quiescent prominence field configuration. We try to find optimum conditions for the formation of Kippenhahn-Schuluter(K-S)type field configuration for stable support of the injected plasmas. We find that the formation of K-S type field configuration by mass injection requires a delicate balance between injection velocity, density, and overlying magnetic fields. This results may explain why a prominence does not form on every neutral line.

I. INTRODUCTION

A quiescent prominence(QP) forms along a neutral line in a quite sun region. It is imbedded in the corona at the bottom of a global coronal streamer, which is sometimes surrounded by a dark region called a coronal cavity (Tandberg-Hanssen, 1974). Active region prominences(ARP) are transient in nature. Observations show that the early stage of the formation starts with the appearance, in H-alpha, of dark strips along a neutral line. The individual dark strip appears and disappears with time scale about 10-20 minutes. If the appearance rate is higher than the disappearance rate the dark and cool dense material keeps accumulating to form an ARP(Martin, 1973). It is observed that the appearance of a dark strip is a direct chromospheric mass injection into overlying magnetic fields.

Most of past model for the formation of prominences are devided into two categories; the first assumes that prominences are formed by the condensation of coronal plasmas in (sheared) magnetic fields (Kuperus and Tandberg-Hanssen 1967; Hildner 1971; Raadu and Kuperus 1973; Chiuderi and Van Hoven 1979; Mason and Bessey 1983; Pneuman 1983; An 1985). The second is that the initial magnetic field has a dip so that plasmas in the dip are cool and condensed, and plasmas at the foot points are sucked into the dip due to pressure imbalance (Pikel'ner 1971; Priest and Smith 1979; Ribes and Unno 1980; Poland and Mariska 1986). These two approaches explain some features of prominence formation but fail to provide satisfactory answers to the following important questions. Since the total mass of a well developed prominence is about one fifth of the mass of total coronal plasmas it is hard to believe that prominence material is supplied by the condensation of coronal plasmas (Saito and Tandberg-Hanssen 1973). An important question for a prominence model to answer is then the source of prominence material. A succesful prominence model also has to answer the following questions; why does a prominence not form everywhere along a neutral line? If prominences are formed by the condensation of coronal plasmas, why does all the corona not cool to chromospheric plasmas? By what mechanism does the initial field have a dip so that plasma accumulates in it? How can we explain very transient nature of ARP but nearly steady state nature of QP? In order to answer these questions we propose that QP and ARP are formed by the plasmas supplied from chromosphere. A 2-D ideal MHD numerical model is used to simulate K-S type field configurations and to find optimum conditions for the formation.

II. MODEL

The numerical model used is based on ideal MHD. The basic MHD equations for the model are expressed in cartesian coordinate(x,y,z). These equations are the conservation laws, plus the induction equation to represent the coupling between the field and the plasma. All the equations are given by Wu, et.al(1983) and will not be reproduced here. The potential field which permeates the atmosphere can be represented by the following equations,

$$B_x = B_0 e^{-ky} \cos(kx),$$

$$B_y = -B_0 e^{-ky} \sin(kx),$$

$$B_z = 0.$$

The size of the computing domain is 8000km in height and 16000km in width. Mass is injected parallel to the field lines from the lower boundary. Mass injection is treated as a perturbation of density and velocity at the lower boundary and the characteristic method is applied to treat the initial and boundary value problem (Hu and Wu 1984). The dynamic response of magnetic field to the injected mass is studied for different injection velocities, densities, and magnetic field strength.

III. RESULTS

The study of mass injection from one side has been performed in order to understand the formation of ARP. In the following we will discuss under what conditions a K-S type field configuration forms. Since active region field stength is about a hundred gauss and temperature and density of chromospheric plasma are about 10^4 K and $10^{12} cm^{-3}$ respectively β is much less than 1. Therefore, we take results of β =0.1, which is the smallest value of β we use, for the study of ARP. Fig.1(a, b, c)show how sensitively magnetic structure depends on injection velocity and density. Fig.1(a) shows field evolution for injection density ratio(the ratio of injection to ambient density) 1.2 and velocity 3.5km/s. Within a time scale comparable to the ARP life time (about 20 min.), the field line does not show any pit resulting in no stable accumulation of injected plasmas. If injected velocity increases to 20km/s with the density ratio 1.2 (see Fig.1(b)) the magnetic field lines on the injection side(left side) move up higher than the right side. Due to gravity the field lines at and below the injection region fall down forming an asymmetric pit or a flat top on each field line. Injected plasma at the asymmetric pit may not accumulate on the field lines, while the plasmas at the flat top may accumulate but the stability is not certain. Note that the density ratio is unrealistically low but the velocity is realistic for chromospheric mass injection.

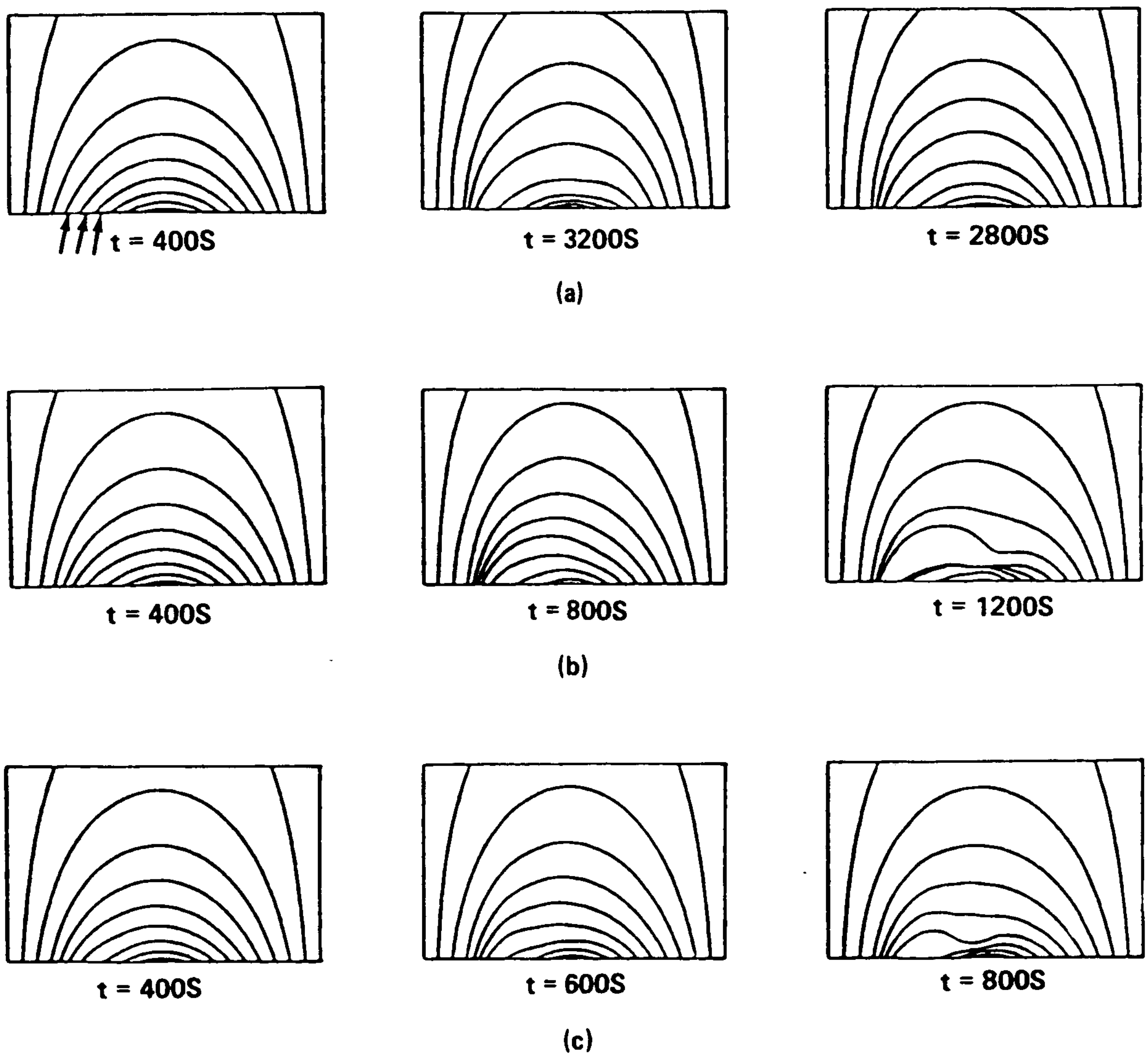
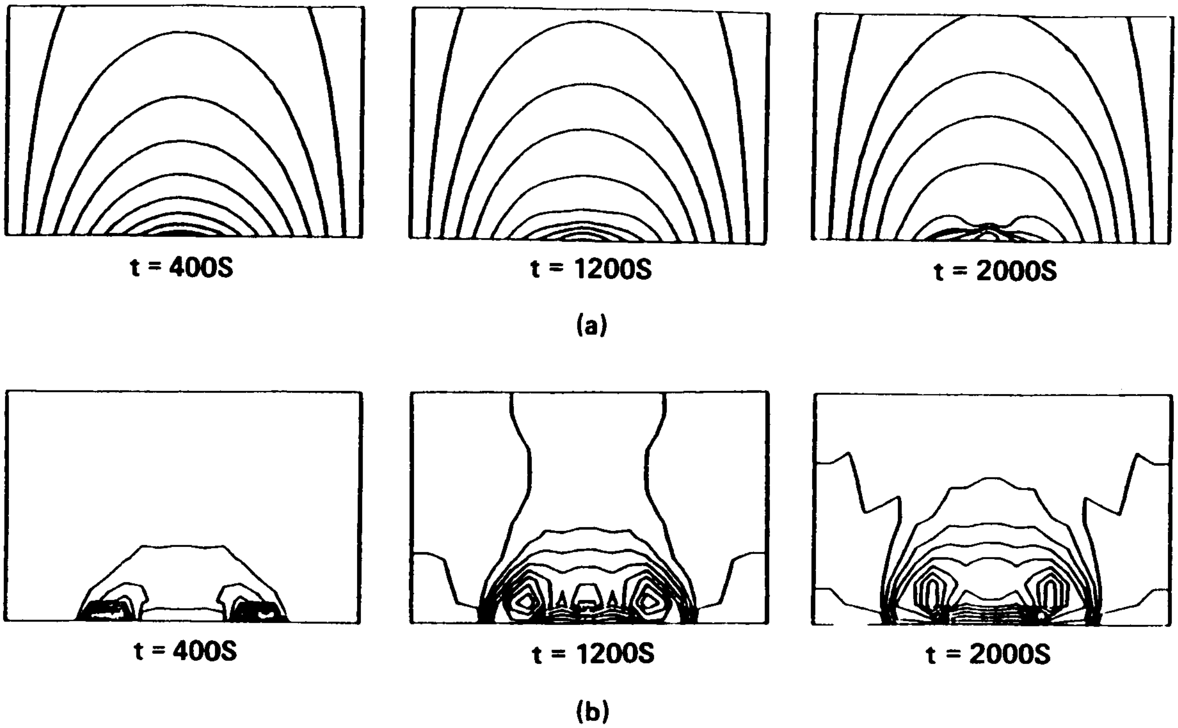


FIGURE 1; MAGNETIC FIELD EVOLUTION OF $\beta = 0.1$ DUE TO LEFT-SIDE INJECTION.
(a) DENSITY RATIO 1.2 AND INJECTION VELOCITY 3.5km/s.
(b) DENSITY RATIO 1.2 AND INJECTION VELOCITY 20km/s.
(c) DENSITY RATIO 10 AND INJECTION VELOCITY 20km/s.

Fig.1(c) shows mass injection of v=20km/s and density ratio 10, which is realistic for chromospheric mass injections like spicules. The figure shows a nearly symmetric pit on top of a field line at the injection region at a



FIGRE 2. SYMMETRIC MASS INJECTION FOR $\beta = 2$, DENSITY RATIO 1.2, AND INJECTION VELOCITY 3.5m/s. (a) FIELD LINES, (b) DENSITY CONTOURS.

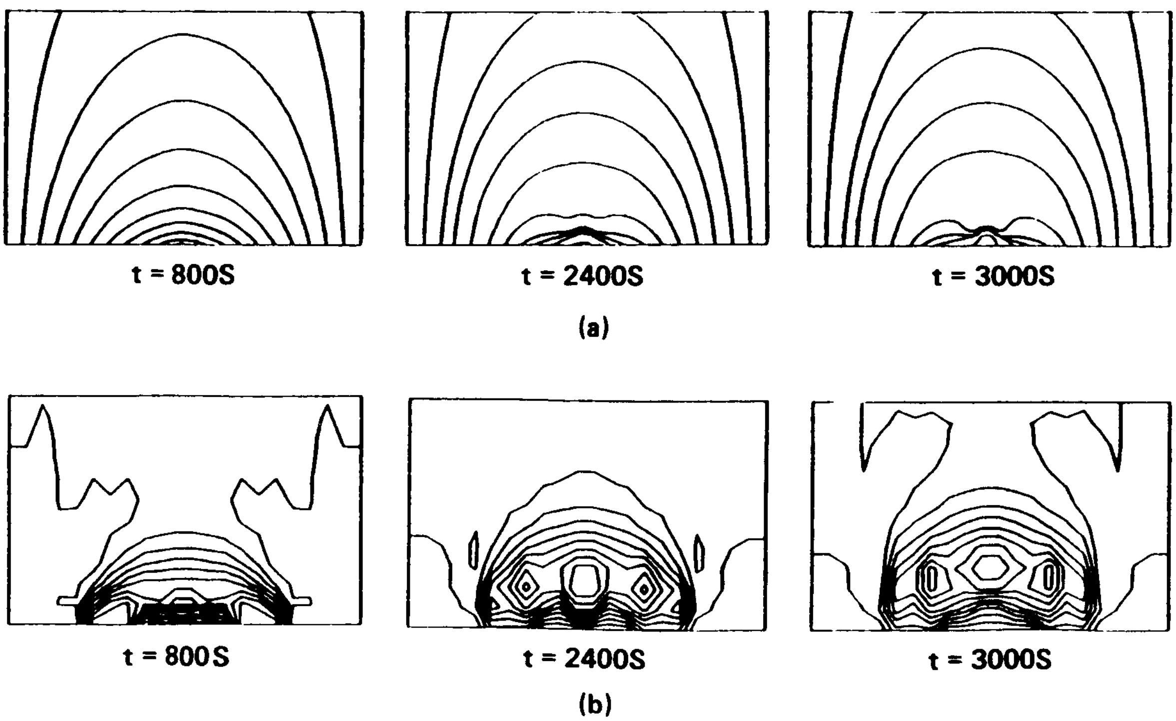


FIGURE 3. SAME AS FIG. 2 WITH $\beta = 0.5$

time comparable to the life time of an individual dark strip in an early stage of ARP formation. The injected plasmas might stably accumulate in the pit to form an ARP. The figure shows that the spicule-like mass injection is the most favorable condition for the formation of ARP. Since we have not considered sheared fields, which is an important characteristic of ARP (Tandberg-Hanssen 1974), we cannot claim that we simulate the formation. However, the results show that not only shear but also injection velocity, density, and magnetic strength should be right for the formation to precede. The reason why every neutral line does not have a prominence along it may be attributed to that only certain neutral lines have right mass injection and magnetic field for the formation.

The study of symmetric mass injection is aimed at understanding the formation of QP. Since the evaporated plasmas may have nearly the same density as ambient coronal plasmas, injection density is assumed to be 20% higher than ambient density. The injection velocity is assumed to be 3.5km/s but a realistic velocity for the evaporated plasma is not known. For the formation we need radiative cooling to have low temperature and high density plasmas which are not provided directly by evaporation. Since we do not include radiation and heat conduction in our numerical model we cannot simulate the formation at present time. However, we can understand the mechanism of forming a pit at the top of injection field lines. We believe that a necessary condition for the foramtion of a QP is the formation of a pit in a time scale shorter than condensation time scale of the injected plasmas. If the time scale of forming a pit is longer than the radiative cooling time scale, the injected plasma will condense and, due to gravity, flow down along field lines before a pit forms for a stable support. On the other hand, if the time scale of forming a pit is much shorter than the condensation time scale, the injected plasmas accumulate in the pit and condense to form a prominence. Fig. 2 and 3 show evolutions of magnetic field(a) and density(b) for β =2, 0.5 respectively. The figures show that a pit starts to form at t=1500s for β =2 and at t=2000s for β =0.5. The field lines of β =2 cannot support the injected plasmas in the pit but collapse in t=3000s. On the other hand, the field lines of β =.5 can support the plasmas against gravity up to t=6000s at which the calculation terminates. In order for the field lines to support the injected plasmas, the magnetic field strength should be high-but too high a field strength cannot form a pit in radiative cooling time scale in which the injected plasmas accumulate. Therefore, a narrow range of field strengths may be required for the formation of a QP. Observations(Nikolsky, et.al 1984; Leroy 1977; Tandberg-Hanssen 1970; Kim, et.al 1982) show that there is an optimum magnetic strength for the formation, which may be explained by the above argument. The formation may also depend on the degree of symmetry of the injection. As an extreme example, one sided injection requires a delicate balance between injection velocity, density, and magnetic strength for the formation of a pit.

IV. CONCLUSIONS.

We have generated magnetic field configuration similar to the K-S model through symmetric and one side mass injection for quiescent and active region prominence formation respectively. Since we do not have radiation and heat conduction in our numerical model and use a computational domain that is smaller than the dimension of observed prominences, we do not intend to make direct comparision of the results with observations. However, we obtain very important results for understanding the formation of K-S model field configurations. The study shows that the formation requires a delicate balance between injection density, velocity, and magnetic field strength, implying that a prominence should not be expected to form on every neutral line. The result also implies that there is an optimum field strength for the formation. The formation of an ARP by direct chromospheric mass injection and a QP by evaporated plasmas may explain the transient nature of ARP and nearly steady state nature of the global configuration of a QP respectively. We have discussed the ideal MHD aspect of prominence formation without considering plasma heating which may play a crucial role for the formation (Davis and Krieger 1982). Since the heating mechanism is not known, a quantitative study of it's effect on the formation is out of scope of this study. The future study of mass injection with sheared field and with more realistic dimensions will provide the optimum condition for the formation of prominences along a neutral line. Including radiation, heat conduction, and heating will be major improvements over the present model for better understanding the process of prominence formation.

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