POSSIBLE MECHANISM OF SURGE FORMATION IN THE
SOLAR ATMOSPHERE

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Abstract. The possibility of surge formation as a result of plasma 'raking-up', the latter being associated with the growth of the local magnetic field in the solar atmosphere, is considered in this paper. The question is treated numerically in the MHD approximation for the case of the dipolar magnetic field. It is shown that the field growth results in the appearance of relatively dense condensations stretched along the axis of a dipole. Simultaneously the plasma acquires the upward velocity along force lines which leads to the formation of a surge. Some properties of this surge model are discussed.

1. Introduction

It is now well known that surge formation is closely connected with the structure and dynamics of local magnetic fields on the Sun. This follows already from the fact that surges, as a rule, occur in active regions (Gopasyuk and Ogir, 1963; Koval, 1965; Kiepenheuer, 1968; Kleczek et al., 1971) and surge motion both upwards and downwards follows the direction of the field lines (Schmidt, 1964; Rompolt, 1965). Moreover, according to Koval (1965) surges are formed just as the result of field variation (growth). The author comes to the conclusion that surges occur, in general, in the vicinity of spots especially during the growing phase of a spot group. Besides, it was established that if a surge was observed far from any spot group, then small spots, pores or floccules occur afterwards in place of surges, i.e., surges precede the development of the regions with a strong magnetic field.

Several models which account for surge formation were proposed. Schlüter (1957) assumed that the mechanism involved is that of the 'melon-seed'. Though the detailed calculation of the process is absent, it is still suggested that the mechanism may assure the velocities ∼100 km s⁻¹ (de Jager, 1968). However, the 'melon-seed' does not account for the observed subsequent practically free fall of the plasma along the same trajectory: plasma being pushed out as a diamagnetic body could at best only 'ooze' down slowly due to gravity.

Sweet (1958) studied the possibility of surge formation by Joule heating of plasma in the course of the reconnection of magnetic force lines. According to Parker (1964) and Petschek (1964), the required heating time is, in this case, long in comparison with the surge life-time. Besides, the surge material would have possessed a high enough temperature, which has not been observed.
The third model was proposed by Altschuler et al. (1968a, b). The gravitational fall of highly conductive material in the magnetic field was considered. It was found that the interaction of the current induced in falling plasma with the magnetic field may produce, under definite conditions, upward eruptive motions of a part of the falling gas with the Alfvén velocity, i.e., to the rise of a surge. The deficiency of this model is, in our opinion, the assumed downward motion of a great coronal mass. The mass involved would have essentially exceeded that of a surge, the latter being enormous in itself (Kiepenheuer, 1968).

Platov (1973) studied the surge dynamics using the filter and spectral observations in the Ha line. He assumed that surges rise by the raking-up of plasma due to the growth of the local magnetic field. The mechanism of surge formation resulting from the raking-up of plasma will be considered below.

The case of a strong dipolar magnetic field was theoretically studied by Syrovatskii (1969) and Somov and Syrovatskii (1972). The main idea is that a strong time-dependent magnetic field tends to remain force-free or merely potential as in the simplest high symmetry cases (e.g., the dipolar field). In frozen conditions plasma moves together with the force lines in the transverse direction and by inertia along the magnetic field.

It is assumed below that the magnetic field is that of a vertical or inclined dipole, disposed on the surface of the Sun. This assumption, being rather rough, enables one to understand easily the mechanism of the phenomena discussed. Consideration of a more complicated field structure gives no principally new results, the calculations being more difficult.

Our aim is to account for the exponential height distribution of density in the solar atmosphere. Cases of vertical and inclined direction of the dipole axis are considered. The latter case is probably realized when surges are formed in the direct vicinity of the rising solar spots. Considering the rise of a solar spot as due to the addition of new magnetic force tubes we can approximate each of the latter by a small rising dipole adjacent to the spot boundary. This mechanism helps us to understand the often observed surge formation at the boundary of the rising spots.

We shall neglect the effect of gravity, for the latter is of secondary importance not only principally, but also numerically in the process of surge formation. Indeed, the motions observed have upward directed accelerations which at the stage of surge formation often numerically exceed the acceleration of gravity. Since the latter is directed downwards, the mechanism provides the accelerating force which is at least twice as great as gravity. The raking-up process being complete, further motion is fully effected by the forces of pressure and gravity. However, the latter phase is outside the scope of this paper.

2. Calculations

Syrovatskii (1969) obtained an analytical solution of the linearized problem of plasma motion in the strong dipolar time-dependent magnetic field. The solution is valid on condition that the variation of the dipolar moment and, correspondingly, the density