CURRENTS IN THE SOLAR ATMOSPHERE AND A THEORY OF SOLAR FLARES

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1. Definition of the Electro-Magnetic State

The electro-magnetic state in a certain volume is defined if we know the electric field E and the magnetic field H as functions of space and time. However, because of the first Maxwell equation

$$\operatorname{curl} H = \frac{1}{c}\left[4\pi i + \frac{\partial D}{\partial t}\right] \tag{1}$$

the magnetic field variations are defined by the electric current (comprising the current density i and the displacement current $\partial D/\partial t$). Hence a description in terms of currents is possible, and often physically more interesting than a description in terms of magnetic fields. The displacement current is of importance only for frequencies of the order of the plasma frequency or higher. As in this paper we describe stationary or slowly varying phenomena, we shall neglect it.

2. Measurements of Magnetic Fields and Currents

In astrophysics no direct measurements of electric fields have yet been made. All conclusions about electric fields have been reached in an indirect way. The magnetic fields are much better known, because it is possible to measure them by means of the Zeeman effect or the Faraday rotation. However, up to quite recently it was essentially the longitudinal effects which were measured. Of the six electro-magnetic vector components only one, viz. the magnetic component along the line of sight, was measured, so no real understanding of the electro-magnetic state has been possible.

Important progress in the knowledge of solar electro-magnetic conditions was recently made by SEVERNY (1964, 1965) with systematic measurements of the transverse Zeeman effect. In active regions, including sunspots, he has sometimes found a remarkable rotation of the transverse component $H_\perp$ and a change of its magnitude from one point to another.

If the z-axis of an orthogonal coordinate system points along the line of sight we can calculate the current component i_z from

$$i_z = \frac{c}{4\pi}\left[\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y}\right] \tag{2}$$

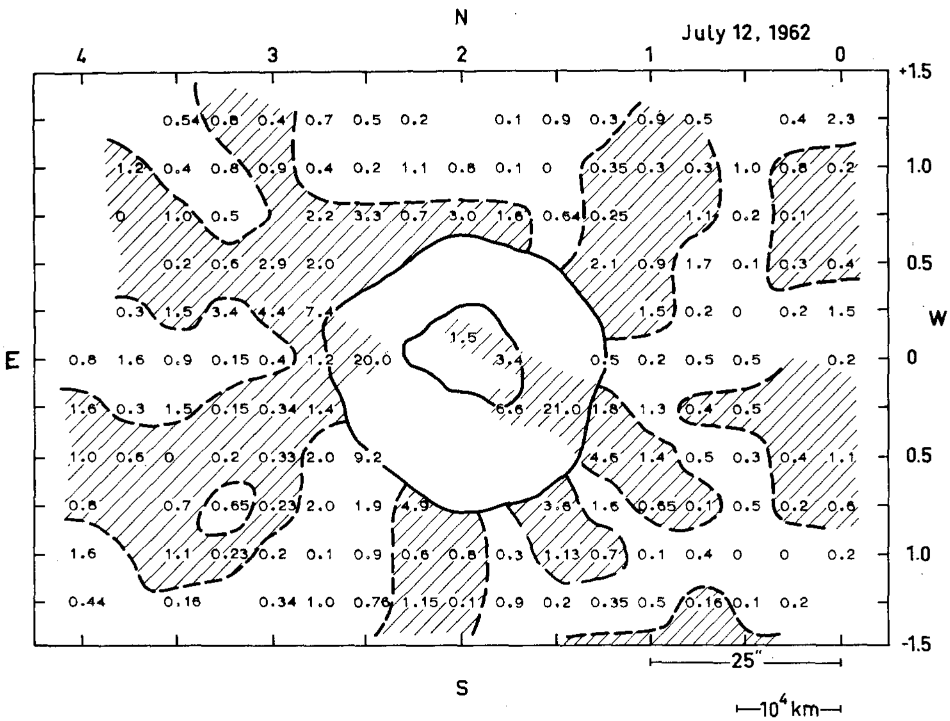

Fig. 1. Vertical electric currents in the neighbourhood of a sunspot. White areas and shaded areas represent regions with currents of opposite directions. The numbers give i_z in units of $10^4/4\pi$ amp/km^2.

Hence, if the space variation of H_x and H_y, measured by the transverse Zeeman effect, is calculated, we can find the electric current along the line of sight. Combined measurements of the longitudinal and the transverse Zeeman effect yield the current system in three dimensions.

By using methods of this kind Severny has mapped vertical currents near the centre of the solar disk. Especially in the neighbourhood of sunspots he has found small regions ($\lesssim 10^9$ cm in diameter) in which vertical currents of the order of 10^{11} amps flow, sometimes upwards, sometimes downwards. Figure 1 shows such a map, constructed by Severny, where many regions of opposite current directions are located around a sunspot. The value $(4\pi/c)i_z$ is given in units of 10^{-2} gauss/km.

3. Description of the Electro-Magnetic State by the Current System

As the advance in observational technique has given us a possibility to describe the electro-magnetic state by currents instead of magnetic fields it would be of interest to give a survey of the advantage of the current description in different respects. However, in this paper we shall confine ourselves to one important problem, viz. the theory of the solar flares and further develop ideas which earlier have been discussed by