CORRELATION BETWEEN MAGNETIC SHEAR AND MAGNETIC TENSION IN A SOLAR ACTIVE REGION

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Abstract. The difference between the magnetic tension and magnetic shear was calculated for four vector magnetograms of NOAA AR 4474. It was seen that this difference between the two independent angular measures of magnetic stress is less than 18° for more than 50% of the pixels. Magnetic tension is thus found to be fairly well correlated with magnetic shear for AR 4474.

1. Introduction

Flares are believed to be produced when magnetic fields in the solar corona relax from a highly stressed configuration to one with smaller stress. The amount of energy available for flaring is generally considered to be the excess of magnetic energy over that in a potential field having the same distribution of magnetic flux as the observed field. For force-free fields, the vector magnetic field measured at any given height level in the atmosphere is sufficient to calculate the excess energy in the region above the layer by means of the virial theorem (Molodensky, 1974; Low, 1985). For more general field configurations, one has to resort to indirect methods. One such way is to measure the so-called 'magnetic shear' of the field, defined as the angle between the observed transverse field and the transverse component of the potential field (Hagyard et al., 1984). This parameter was found to have large values at the sites of flares on the polarity inversion lines of bipolar active regions (Hagyard et al., 1984; Hagyard and Rabin, 1986; Hagyard, Venkatakrishnan, and Smith, 1990).

A physical basis for the correlation between shear and flares was suggested in terms of the loss in magnetic tension caused by the 'shearing' of the field line (Venkatakrishnan, 1990a, b). A basic assumption made in that suggestion was that large magnetic shear corresponded to low magnetic tension. This assumption cannot be theoretically justified in general. An attempt is made therefore to check the validity of the assumption in practice using data from four vector magnetograms of NOAA AR 4474 obtained with the Marshall Space Flight Center vector magnetograph (Hagyard et al., 1982) in April 1984. In Section 2, we develop a definition for an angular measure of magnetic tension to enable direct comparison with magnetic shear. In Section 3 we present the results of such a comparison. In Section 4 we discuss the implications of these results.
2. Angular Measure of Magnetic Tension

The Lorentz force is given by

\[ F = \frac{(\nabla \times B)}{4\pi} \times B, \]  

(1)

where \( F \) is the force and \( B \) is the field. The right-hand side of Equation (1) can be split as

\[ F = \frac{(B \cdot \nabla)B}{4\pi} - \frac{\nabla(B \cdot B)}{8\pi}. \]  

(2)

The first term in the right-hand side of Equation (2) is the tension and the second term is the magnetic pressure. The \( z \)-component (vertical component) of Equation (2) reduces to

\[ F_z = \frac{\partial (B_z^2)}{\partial z} = \frac{\partial (B_T \cdot \nabla_T) B_z}{4\pi} - \frac{\partial (B^2)}{8\pi}, \]  

(3)

where

\[ B_T = (B_x, B_y) \quad \text{and} \quad \nabla_T = \left( \frac{\partial}{\partial x}, \frac{\partial}{\partial y} \right). \]

At the polarity inversion line, \( B_z = 0 \) and therefore the first term on the right-hand side of \( z \)-component of Equation (2) is identical with the first term in the right-hand side of Equation (3). Thus, at the polarity inversion line, the vertical component of tension \( T_z \) can be written as

\[ T_z = \frac{(B_T \cdot \nabla_T) B_z}{4\pi}. \]  

(4)

We can thus define an angular measure of tension as

\[ \Theta = \cos^{-1} \left( \frac{4\pi |T_z|}{|B_T| \cdot |\nabla_T B_z|} \right). \]  

(5)

Note that by taking the absolute value of \( T_z \) we avoid the 180° ambiguity in the measured transverse field azimuth. Likewise, we will always choose the acute angle solution of Equation (5) for the definition of the tension angle. For force-free fields, \( F_z = 0 \) in Equation (3). Thus the two terms in the right-hand side of Equation (3) must balance each other. Therefore any decrease in the first term in the right-hand side necessitates a decrease in the second term. This means that \( B_T^2 \) becomes distributed less steeply with height and therefore implies a vertical extension of the field. Thus, even for \( B_z \neq 0 \), we will continue to call \( \Theta \) (as defined by Equation (5)) as the tension angle in the sense that \( \Theta \rightarrow 90° \) indicates a large vertical extension of the transverse field. In any case, large values of the 'tension angle' off the polarity inversion line serve to denote a lower vertical gradient of the transverse field (in the case of force-free field) or alterna-