Available online at www.sciencedirect.com
ScienceDirect
New Astronomy 12 (2007) 479–482
New Astronomy
www.elsevier.com/locate/newast

Estimation of spicule magnetic field using observed kink waves

K.A.P. Singh, B.N. Dwivedi *

Department of Applied Physics, Institute of Technology, Banaras Hindu University, Varanasi 221 005, India

Received 4 October 2006; received in revised form 1 February 2007; accepted 2 February 2007
Available online 8 February 2007
Communicated by W. Soon

Abstract

We apply the method of MHD seismology to estimate the magnetic field in spicules using observed kink waves. We include the effects of gravitational stratification, the neglect of which leads to an error of around 30% in the estimation of the magnetic field. With stratification included, we find the magnetic field in spicules in the range of 8–16 G. We also estimate a density of 7.4×10^{-10} kg m^{-3} in spicules. The estimated values of magnetic field and density are in agreement with the available observations. Improved measurement of height, oscillation period, and plasma density in spicules will further enhance the precision of this method.

PACS: 96.50.Tf; 96.60.−j

Keywords: Spicules; Oscillations; Magnetic field

1. Introduction

Spicules are jet-like chromospheric structures in Hα line at the Sun's limb. They are short-lived (∼5–15 min). The period of observed waves is much shorter (∼70 s) with phase velocity of 50 km s^{-1} and wavelength of 3500 km. The low-β (ratio of the gas to magnetic pressure) assumption in the transition region is widely accepted. However, the low-β assumption in the corona is difficult to verify because the coronal magnetic field cannot be measured. Parenti et al. (1999) estimated $N_e = 10^{10}$ cm^{-3} and $T_e \sim 2 \times 10^5$ K in macrospicules. This means that a magnetic field of 10 G or more is needed for the low-β conditions.

Recent high-resolution observation of MHD waves in coronal loops (Nakariakov et al., 1999; Aschwanden et al., 1999; De Moortel et al., 2000; Robbrecht et al., 2001) and polar plumes (DeForest and Gurman, 1998; Ofman et al., 1999), from TRACE and SOHO, provide a unique opportunity for coronal seismology (Nakariakov and Ofman, 2001; Nakariakov, 2003). This technique is similar to helioseismology but even richer as it utilizes three modes, the Alfvén mode, slow and fast magnetoacoustic modes. From observations, we can determine the properties of coronal waves and oscillations (e.g., amplitudes, temporal and spatial spectra, typical signatures and evolution), as well as physical parameters (e.g., temperature and density structure). The MHD wave theory provides us with formulae connecting the wave properties with the measured coronal physical parameters with the unknown magnetic field, and transport coefficients (Nakariakov and Ofman, 2001).

There are now many observations of waves in the solar corona with periods of around 5 min. The source of these waves is uncertain, although global p-modes in the photosphere are an obvious candidate, given the similarity of dominant periods (e.g., De Pontieu et al., 2005). MHD waves in the corona are generated in situ either by a solar flare or magnetic reconnection, taking place nearby or through photospheric disturbances that can reach up to the corona via system of magnetic fields anchored in the photosphere. The obvious suggestion would be that the

* Corresponding author. Tel.: +91 542 2307041.
E-mail addresses: alkendra1978@yahoo.co.in, bholadwivedi@yahoo.com (B.N. Dwivedi).

1384-1076/$ - see front matter
doi:10.1016/j.newast.2007.02.001

source of observed kink waves resides in the lower part of the solar atmosphere. The cutoff period of kink waves due to stratification at the photosphere is ∼660 s. So the expected period of kink waves is well below the cutoff value. Thus the kink waves with periods of ∼35–70 s may easily propagate upwards. As the estimated frequency of the observed waves is much higher than the frequency of 5-min oscillations, this can easily be ruled out to be the source of kink waves (Kukhianidze et al., 2006). The lifetime of solar spicules is comparable to that of solar granulations, suggesting adequate energy content in photospheric motions to drive spicules (Sterling, 2000). Therefore, the only source which may excite the kink waves in the photosphere is the granulation. The photospheric granulation has been often suggested as the source of kink waves in thin magnetic tubes (Roberts, 1979; Spruit, 1981; Hollweg, 1981; Hasan and Kalkofen, 1999). Photospheric granulation is very dynamic even during the life time of one granular cell. If the magnetic tube, in which the spicule is formed, is anchored in the photosphere, then any perturbation of the granular cell will probably excite the kink waves with wavelength similar to the cell diameter. But the observed wavelength (∼3500 km) of the kink waves in the higher atmosphere is a few times longer than the mean granular diameter, which is of the order ∼800–1000 km. The discrepancy can be resolved by an increase of wave phase speed with height. Indeed, the kink speed is ∼10 km s^{-1} (or even more) in the upper atmosphere. Therefore, it is very likely that granular cells generate kink waves with a wavelength comparable to their diameter, but the wavelength increases due to increasing phase speed when waves propagate upwards. Hence, the observation of oscillatory phenomenon in the chromosphere and corona is of vital importance in understanding chromospheric and coronal dynamics. The chromospheric radiation in Hα comes mainly from spicules (Beckers, 1972).

The idea of MHD seismology was suggested long ago (e.g., Uchida, 1970; Roberts et al., 1984). Analysing flare-generated oscillations of coronal loops observed by TRACE, Nakariakov and Ofman (2001) developed a new tool of coronal seismology to estimate the magnetic field in the corona. However, they did not include the effects of stratification. In the present work, we apply the method of MHD seismology including the gravitational stratification to estimate magnetic field and density in spicules, using observed kink waves. Propagation of kink waves in spicules can be modeled as a vertical thin magnetic flux tube embedded in a field-free environment which obeys the Klein-Gordon equation. Interpretation of the observation as propagating kink waves allows us to connect the period at different heights with spicule magnetic field.

2. Propagating kink waves in spicules

Kukhianidze et al. (2006) have reported the observational signature of propagating kink waves in spicules. Using 53-cm coronagraph and universal spectrograph at the Abastumani Astrophysical Observatory, they have obtained the line spectra in Hα at different heights above the photosphere with an instrumental resolution of 0.04 Å and dispersion 1 Å/mm with an exposure of 7 s to each height series. They found that nearly 20% of the measured height series showed a periodic spatial distribution in Doppler velocities. This spatial periodicity in Doppler velocity has been interpreted as propagating kink waves in spicules. The wavelength was found to be ∼1000 km at the photosphere which indicated a granular origin of the waves. The period of waves was estimated to be 35–70 s which may carry photospheric mechanical energy into the corona. Thin elastic magnetic flux tubes in spicules may support the propagation of kink waves (Nikolsky and Platova, 1971). Kink waves cause the displacement of the tube axis. As a result, propagation of kink waves can be traced either by direct observation of the tube displacement along the limb (Nikolsky and Platova, 1971) or by the Doppler shift of spectral lines. Measurement of Doppler velocity shift measurement is possible when the velocity of the kink wave is polarized in the plane of observation. Periodicity in their spatial distribution has been detected by Khutsishvili (1986). Magnetic flux tubes support transverse kink waves that can be generated in photospheric magnetic flux tubes through buffeting action of granular motions (Roberts, 1979; Hollweg, 1981; Spruit, 1981; Hasan and Kalkofen, 1999). The photospheric granular motion can impart the magnetic flux tubes and inject several pulsations, causing the disturbance to move in the form of waves along the intense magnetic flux tubes mainly with kink speed (Kalkofen et al., 2003).

Propagation of kink waves in vertical thin magnetic flux tube of density ρ_0 embedded in a field-free environment obeys the Klein–Gordon equation (Roberts, 2004)

$$\frac{\partial^2 \xi}{\partial t^2} = \frac{B_0^2}{\mu_0(\rho_0 + \rho_e)} \frac{\partial^2 \xi}{\partial z^2} + \frac{(\rho_0 - \rho_e)}{(\rho_0 + \rho_e)} g \frac{\partial \xi}{\partial z} \tag{1}$$

where $\xi = \xi(z, t)$ is the transverse displacement of a tube radius that not only moves the matter but also roughly an equal mass of the surrounding fluid density ρ_e and g is the acceleration due to gravity. The first term on the right-hand side of Eq. (1) arises from the magnetic tension force generated in the bent tube, and the second term arises from the buoyancy force on the tube. Eq. (1) can be rewritten as

$$\frac{\partial^2 \xi}{\partial t^2} = C_k^2 \frac{\partial^2 \xi}{\partial z^2} + \frac{(\rho_0 - \rho_e)}{(\rho_0 + \rho_e)} g \frac{\partial \xi}{\partial z} \tag{2}$$

where $C_k = \left(\frac{\rho_0}{\rho_0+\rho_e}\right)^{\frac{1}{2}} C_A$ is the kink speed in the tube and C_A is the Alfvén wave speed. If we neglect the gravitational stratification, we get a dispersion relation as

$$C_k^2 k_z^2 = \omega^2 \tag{3}$$

where k_z is the vertical wave number and ω is the frequency of kink waves. Using the observed wavelength of kink waves, one can estimate the magnetic field in spicules by