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Letter to the Editor

# Observation of coronal loop torsional oscillation

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**Abstract.** We suggest that the global torsional oscillation of solar coronal loop may be observed by the periodical variation of a spectral line width. The amplitude of the variation must be maximal at the velocity antinodes and minimal at the nodes of the torsional oscillation. Then the spectroscopic observation as a time series at different heights above the active region at the solar limb may allow to determine the period and wavelength of global torsional oscillation and consequently the Alfvén speed in corona. From the analysis of early observation (Egan & Schneeberger 1979) we suggest the value of coronal Alfvén speed as ~500 km s$^{-1}$.

**Key words.** Sun: corona – Sun: oscillations

## 1. Introduction

Magnetohydrodynamic (MHD) waves and oscillations play an important role in the dynamics of the solar corona (Roberts 2000). They can heat and accelerate the coronal plasma (Goossens et al. 1995) and also offer an unique tool for developing a coronal seismology (Edwin & Roberts 1983; Nakariakov & Ofman 2001). The solar corona is highly structured into narrow coronal magnetic loops which are anchored into the dense photosphere. The loops permit the propagation of three kinds of MHD waves: sausage, kink and torsional Alfvén waves. The closed boundary conditions at the loop footpoints lead to the discrete spectrum of harmonics and consequently to the formation of global oscillations.

The global MHD oscillation in the sausage mode (Roberts et al. 1984) modulate loop cross section and causes the variation of the density and emission measure of radiating plasma. Using coronal loop images obtained with the Yohkoh soft X-ray telescope (SXT), McKenzie & Mullan (1997) found the periodical modulation of the X-ray brightness, which was interpreted as the signature of global mode oscillation. The global kink oscillations can be detected as transverse displacement of spatial loop positions between fixed nodes. The typical property of recently observed kink oscillations by TRACE (Aschwanden et al. 1999; Nakariakov et al. 1999) is very short damping time. It was suggested that the oscillations may be damped either due to the phase mixing with anomalously high viscosity (Ofman & Aschwanden 2002) or due to the resonant absorption (Ruderman & Roberts 2002) acting in the inhomogeneous regions of the tube, which leads to a transfer of energy from the kink mode to Alfvén (azimuthal) oscillations within the inhomogeneous layer. Consequently the resonant absorption of global kink modes may lead to the global torsional oscillation of coronal loops.

Unfortunately, contrary to the sausage and kink modes, the global torsional oscillations do not cause neither intensity variation nor the spatial displacement of the loop position. Therefore they hardly subject to the observation in usual coronal spectral lines.

The influence of torsional waves propagating along a thin, vertical, photospheric flux tube on Zeeman-split polarized line profiles (Stokes profiles) was studied recently by Ploner & Solanki (1999). In the presence of such a wave spatially resolved Stokes profiles are found to oscillate strongly in wavelength, amplitude and blue-red asymmetry. Also observation on the Solar and Heliospheric Observatory (SOHO) showed an increase of spectral line width with height (Doyle et al. 1998; Banerjee et al. 1998) which can be interpreted as vertically propagating undamped Alfvén waves (Moran 2001). However no wave parameters (wavelength, frequency) were identified, because of the propagating pattern of waves. On the other hand, the stationary character of standing Alfvén waves in magnetic tubes (or torsional oscillations) allows to identify the velocity nodes and antinodes and thus may be used for determining the wave parameters.

We suggest that the global torsional oscillation of coronal loop can be detected by periodical broadening of spectral lines due to the periodic azimuthal velocity. The amplitude of the azimuthal velocity in the torsional oscillation is maximal at the antinodes and tends to zero at the nodes. Therefore the torsional oscillation causes the periodical variation of spectral line broadening with different amplitudes at different heights from the solar surface: the place of stronger variation corresponds to the antinode and the place of constant broadening corresponds to the node. Then the time series of spectroscopic observations at different heights above the active region at the solar limb

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may allow to determine the period and wavelength of global torsional oscillation and consequently the Alfvén speed in the coronal loops.

Recently, strongly damped Doppler shift oscillations of hot ($T > 6$ MK) coronal loops were observed with SUMER on SOHO (Kliem et al. 2002; Wang et al. 2002). These oscillations were interpreted as signatures of slow-mode magnetosonic waves excited impulsively in the loops (Ofman & Wang 2002). It is possible that the slow magnetosonic waves (as well as the kink waves) may also cause the oscillation of Doppler broadening in given direction of propagation. However the velocity field of waves is inhomogeneous (which is necessary for the line broadening) only at wave nodes and thus may lead only to negligible effect. On the other hand, the velocity field at wave antinodes will cause the Doppler shift oscillation as was interpreted by Ofman & Wang (2002). However it is also possible that the Doppler broadening of the line is due to superimpose of several loops in the line of sight containing slow waves at different phases. But in this case the broadening must be nearly constant or it will show rather chaotic behaviour in time than the periodical one. Recently Sakurai et al. (2002) presented a time sequence over 80 min of coronal green-line spectra obtained with a ground-based coronagraph at the Norikura Solar Observatory. They found the oscillations of the spectral line Doppler shifts and interpreted them as propagating slow MHD waves. No clear evidence of the Doppler width oscillations was found. It may indicate that either they could not catch the velocity antinodes of the global torsional oscillation or the oscillations are not common in corona and they are related to the flare or mass ejection. Future space and ground-based spectroscopic observations are necessary to make the conclusion.

In the next section we briefly describe the method of observation and interpret the early observation of Eagen & Schneeberger (1979) as the global torsional oscillation of coronal loop.

## 2. Observation of the torsional oscillation

Consider a coronal loop as straight magnetic tube, the axis of which is perpendicular to the line of sight. If the tube rotates about its axis with an angular velocity $\Omega$, then the Doppler shift of the observed spectral line with wavelength $\lambda$ is $\Delta\lambda = (\lambda\Omega/c)x$, where $x$ is the distance from the tube axis in the plane perpendicular to the line of sight and $c$ is the speed of light (the expression must be multiplied by $\sin i$ if the tube is inclined with the angle $i$). The largest shift occurs at the edges of the tube and has a value

$$\Delta\lambda = \frac{\lambda}{c}\upsilon, \tag{1}$$

where $\upsilon$ is the rotation velocity at $x = R$ ($R$ is the radius of the tube). So the Doppler shifts at different $x$ from the tube axis cause the spectral line broadening by $2\,|\Delta\lambda|$. It must be mentioned that the broadening of spectral lines can be caused by thermal motion of ions and turbulent motion of gas, however here we consider only the nonthermal broadening of spectral lines caused by the azimuthal velocity of the tube.

Now suppose that the tube undergoes the torsional oscillation due to the closed boundary conditions imposed at the tube ends. For simplicity the density $\rho$ and the magnetic field $\boldsymbol{B} = (0, 0, B_0)$, directed along the axis $z$ of a cylindrical coordinate system $r, \phi, z$, are considered to be homogeneous throughout the tube. Then the velocity and the magnetic field components of the torsional oscillation can be expressed as

$$B_\phi = -B_0\alpha\cos(\omega_n t)\cos(k_n z), \tag{2}$$

$$V_\phi = V_A\alpha\sin(\omega_n t)\sin(k_n z), \tag{3}$$

where $V_A = B_0/\sqrt{4\pi\rho}$ is the Alfvén speed, $k_n = n\pi/L$ ($L$ is the length of the tube and $n = 1, 2, 3\ldots$) is eigenvalue of wave number, $\omega_n$ is the corresponding eigenfrequency and $\alpha$ is the relative amplitude of oscillations. Eigenvalues and eigenfrequencies satisfy the dispersion relation of Alfvén waves

$$\frac{\omega_n}{k_n} = V_A. \tag{4}$$

The velocity field of each $n$th mode has different amplitude of oscillation, but the same frequency $\omega_n$ along the tube: the amplitude is maximal at the antinodes ($\sin(k_n z) = \pm 1$) and tends to zero at the nodes ($\sin(k_n z) = 0$).

Then the velocity field (3) leads to the periodical variation of Doppler width at each point $z$ along the tube axis. It means that the torsional oscillation causes the periodical variation of spectral line broadening (expressed by a half of line width, $\Delta\lambda_B$, hereafter HW) with the same frequency, but with different amplitudes along the tube. The amplitude of HW variation will be maximal at the velocity antinodes and minimal at the nodes. According to Eqs. (1) and (3) HW can be expressed by

$$\Delta\lambda_B = \frac{\alpha V_A \lambda}{c}|\sin(\omega_n t)\sin(k_n z)|. \tag{5}$$

The distance between the points of maximal variation i.e. between the velocity antinodes will be the half wavelength of torsional oscillation. Then the observed period of HW variation allows to determine the Alfvén speed from the dispersion relation (4). Also the amplitude of HW variation at the velocity antinodes (maximal value of $\Delta\lambda_B$ along the tube axis) gives the value of $\alpha$ i.e. the amplitude of torsional oscillations.

However we have to be sure that the periodical variation of spectral line broadening can be caused only by the torsional oscillations. The velocity field of other wave motions may cause the Doppler shift variations. For example, the slow magnetosonic waves propagating along an applied magnetic field may lead to this effect recently observed by SUMER in given arbitrary loop orientation (Kliem et al. 2002; Wang et al. 2002; Ofman & Wang 2002). However neither slow magnetosonic waves, nor kink waves can cause the significant periodical variation of Doppler broadening at given height from the solar surface. The velocity field of waves must be highly inhomogeneous to produce the line broadening. The velocity field of slow magnetosonic waves (as well as the kink waves) is inhomogeneous at velocity nodes, where they can produce only negligible Doppler broadening. On the other hand, they can produce the Doppler shift oscillations at antinodes where the velocity is maximal and almost homogeneous. However it is also possible that the Doppler broadening of the line is due to superimpose of several loops in the line of sight containing

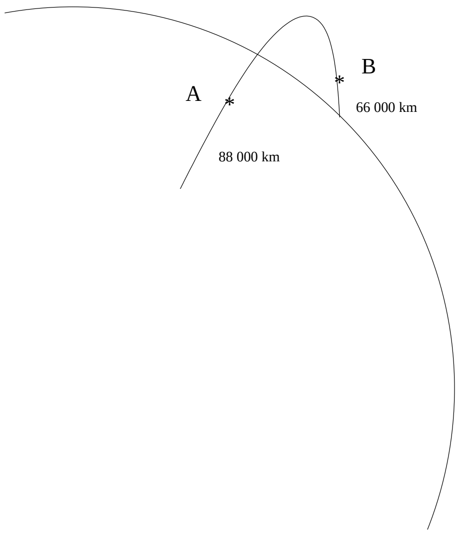


**Fig. 1.** Schematic picture of a coronal loop at the solar limb is presented. The points A and B correspond to the velocity antinodes of second mode of global torsional oscillation. Both points are located at ∼88 000 km from the surface. However only 66 000 km part is visible in the case of point B, because the footpoint is anchored into the reverse side of the solar surface.

slow waves at different phases. But in this case the broadening must be nearly constant or it will show rather chaotic behaviour in time than the periodical one. Therefore from our point of view the torsional waves are best candidates for producing the periodical variation of spectral line broadening.

Thus the observation as a time series at different heights above the active region at the solar limb may allow to determine the wavelength and the period of torsional oscillation. As an example of proposed method let analyse the observation made almost two decades ago by Egan & Schneeberger (1979). They presented the time series of Fe XIV coronal emission line spectra above both active and quiet regions at the solar limb. They found the Doppler width temporal variations with the period of 6.1 ± 0.6 min above the active region. The width fluctuations were amplified in two 5500 km long segments at heights of 66 000 km and 88 000 km above the limb. The amplitude of variation was 0.125 Å at 88 000 km, while at lowest heights it reduces to 0.04 Å. They also found a marginal evidence for 6 min intensity oscillations at these two positions. For quite region they found neither Doppler width nor intensity variations.

We suggest that this observation can be interpreted as the global torsional oscillation of coronal loop. The two regions of amplified Doppler width variation may correspond to the velocity antinodes of torsional oscillation. They likely belong to the second mode of oscillation, because it has two velocity antinodes at the middle of both footpoints, while first mode has only one at the top (the velocity antinode at the loop top hardly undergo to the observation in this spectral line because of rapidly decreasing intensity in the corona).

As the observations were performed off the solar limb it is reasonable to suppose that the antinodes were located at ∼88 000 km height from the photosphere, but the second footpoint was anchored at the reverse invisible side of the Sun, so that only 66 000 km part of footpoint was visible (Fig. 1). Then the wavelength of global torsional oscillation can be

$$\lambda = 4 \times\ 88\,000\,\mathrm{km} \approx 352\,000\,\mathrm{km}. \tag{6}$$

The period of torsional oscillations will be ∼12.2 min i.e. double of observed period. Then we easily calculate the Alfvén speed in corona (here the constant Alfvén speed is assumed along the loop, however in real conditions it may be inhomogeneous which complicates the problem)

$$V_\mathrm{A} \sim 500\,\mathrm{km\,s^{-1}}. \tag{7}$$

If the regions of amplified Doppler width oscillations belong to two different loops, then the similar calculation for the loop with velocity antinodes at 66 000 km gives

$$V_\mathrm{A} \sim 360\,\mathrm{km\,s^{-1}}, \tag{8}$$

which is below the expected value of the Alfvén speed in corona. Also it seems unreal that the two different loops have the same periods of global mode. On the other hand, the global oscillation of coronal loop in other wave mode may not cause the periodic oscillations of Doppler width. Only the temperature changing due to the nonadiabatic slow MHD waves may lead to this variation. But it seems again unreal that the nonadiabaticity leads to the variation of line broadening with ∼25%. Therefore we suggest that the torsional oscillation of one loop can be the reason for the observed phenomenon.

We also easily calculate the amplitude of torsional oscillation for Fe XIV ($\lambda$5303) spectral line from Eq. (5)

$$\sim 7\,\mathrm{km\,s^{-1}}. \tag{9}$$

This result is calculated when the loop axis is perpendicular to the line of sight. The amplitude of oscillation will be even greater in the case of loop inclination.

Evaluated Alfvén speed, as well as the amplitude of torsional oscillations, have the suggestive values for the low corona. This gives the idea that the observation of Egan & Schneeberger (1979) may be interpreted as the global torsional oscillation of coronal loop. Observed intensity oscillations can be interpreted as the density perturbations caused by the nonlinear magnetic pressure acting at velocity antinodes of torsional oscillations.

Another problem is that the amplitude of the Doppler width oscillations in the paper of Egan & Schneeberger (1979) is comparable or below the instrumental spectral resolution. Therefore the validity of the observation is unclear. On the other hand, Sakurai et al. (2002) could not find clear periodical variation of the line width. It may indicate that either they could not catch the velocity antinodes of the global torsional oscillation or the oscillations are not common in corona and they are related to the flare or mass ejection like the transverse loop oscillations (Schrijver et al. 2002). Therefore the future observations are necessary for making the final conclusion. Also analysis of recent space based spectroscopic observations on SOHO and TRACE may reveal more precise data which can test the validity of this method.

## 3. Conclusion

We suggest that the global torsional oscillation of the coronal loop, axis of which is not parallel to the line of sight, can be observed by the periodical variation of spectral line width. The amplitude of the variation must be maximal at certain regions which correspond to the velocity antinodes of torsional oscillations. Then the period of variation will be the half of oscillation period and the distance between the regions with maximal variations will be the half of wavelength. The spectroscopic observation as a time series at different height above the active region at the solar limb may allow to determine the wavelength and the period of the torsional oscillation. Then the Alfvén speed can be calculated which is very important for determination of magnetic field strength in corona. The observation of the spectral lines with larger wavelengths will be more successful, because of their sensitivity to the Doppler shift. Both, ground based coronagraphs and space based instruments can be used. The analysis of early observation (Egan & Schneeberger 1979) give the values of Alfvén speed and the amplitude of torsional oscillations as $\sim$500 km s$^{-1}$ and $>$7 km s$^{-1}$ respectively.

We hope that the observation of torsional oscillations after the damping of coronal loop kink oscillations will provide the clue for the damping mechanism and consequently for the coronal heating (Ruderman & Roberts 2002).

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