CORONAL LOOP HEATING BY ALFVÉN WAVES

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Abstract. The excitation and dissipation of global and surface Alfvén waves and their conversion into kinetic Alfvén waves have been analyzed for solar coronal loops using a cylindrical model of a magnetized plasma. Also the optimal conditions for coronal loop heating regimes with density of dissipated power $\approx 10^3$ erg cm$^{-3}$ s$^{-1}$ by the new scheme named combined Alfvén wave resonance are found. Combined Alfvén wave heating regime appears when the global Alfvén wave is immersed into the Alfvén continuum with the condition of not-so-sharp distribution of axial current.

1. Introduction

The general coronal loop heating problem has been under consideration for many decades (Priest, 1982; Ulmschneider, Priest, and Rosner, 1991, and references therein).

In particular, a complete analysis was provided for solar loop heating regimes using global Alfvén waves (GAW) (de Azevedo et al., 1991). There are also some proposals about the possibility of coronal loop heating by surface Alfvén waves (SAW) (Priest, 1982; Ulmschneider, Priest, and Rosner, 1991; de Assis and Tsui, 1991, and references therein). These types of modes appear only in current carrying, bounded or layered plasmas. The SAW are complex type of waves (Elfimov, Kirov, and Sidorov, 1992) because they are immersed in the Alfvén continuum ($\omega_{th} = (k||v_A)_{\min} < \omega_{SAW} < (k||v_A)_{\max}$), in other words the value of the Alfvén continuum frequency ($\omega_{SAW}$) are larger than the minimum value of the Alfvén continuum frequency ($\omega_{Amin} = (k||v_A)_{\min}$), which is called here threshold frequency ($\omega_{th}$)), and smaller than the maximum frequency of the Alfvén continuum ($\omega_{Amax} = (k||v_A)_{\max}$). For these conditions, infinite amplitude of MHD waves can be found at the plasma conversion points ($r_A$) where the frequency of the wave coincides with the local shear Alfvén frequency. However, the MHD analysis of the conversion phenomenon is not very complete because the information about the wave fields in the conversion point is lost due to the simplified MHD model.

The same problem appears when the GAW is excited inside the shear Alfvén continuum, due to the flat axial profile of the current. The structure of the GAW fields is modified close to the conversion point. This type of resonance is referred to as combined Alfvén wave (CAW) resonance. This problem was discussed by Elfimov (1985) and Elfimov et al. (1989) for Tokamak conditions.

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Furthermore, in some cases, coronal loop plasmas are almost collisionless; this means that the frequency of the Alfvén wave is higher than the electron–ion collision frequency \( (\omega_A > \nu_{ei}) \) and the mean free paths of electrons are bigger than the Alfvén wavelength in the magnetic field line direction \( (\nu_{ei} < k_l v_{the}) \). Thus, with these conditions the excitation, conversion, and dissipation of the Alfvén waves must be analyzed on the basis of a plasma model with small number of collisions and taking into account the Landau and the transit-time-magnetic-pumping (ttmp) dissipations. For this purpose, it is possible to use a cylindrical model for coronal loop plasmas because the loop length \( (\pi R \gg a) \) is bigger than the minor loop radius, and the curvature of the magnetic field lines, due to the axial loop current, is stronger in comparison with the toroidal curvature. The coronal loop safety parameter is smaller than unity, \( q = r B_z / R B_\theta \approx 0.3 \), where \( R \) is the major loop radius, \( r \) is the minor radius, and \( (B_\theta, B_z) \) are poloidal and toroidal components of the magnetic field. The \( q \) factor for coronal loops is different from the Tokamak safety factor where \( q > 1 \).

Most of the papers on coronal heating by Alfvén waves, however, have used the MHD model of the plasma. Here we wish to discuss afresh the possibilities of heating coronal loops by Alfvén waves (Ionson, 1978; de Azevedo et al., 1991; de Assis and Tsui, 1991) using the one-dimensional kinetic code presented in Dmitrieva et al. (1984) and Elfimov et al. (1989), which is analogous to the one presented in Ross, Chen, and Mahajan (1982).

This paper is organized as follows. In the second section, we make an analysis of the Alfvén excitation and dissipation. In the third section, the fast magnetosonic wave (FMW), GAW, and CAW structures are discussed. In the fourth section, we discuss the dependence of the dissipated power over the frequency and find the dispersion relation of the GAW, SAW, and CAW as a function of the axial wave number \( (k = n/R) \). Here the frequencies of the eigenmodes are defined as a maximum resonance of the dissipated power, also the eigenmode field structure will be analyzed. Finally, in the fifth section, we present some possible applications of the numerical and theoretical results for the coronal loop heating problem and present conclusions.

The Gaussian system of units is used throughout this paper.

2. Alfvén Wave Excitation and Dissipation Analysis

Here we present, using a one-dimensional cylindrical numerical code, results concerning the excitation and dissipation of Alfvén waves for coronal loop conditions. The standard coronal loop parameters are used (see Hollweg, 1985; de Azevedo et al., 1991): magnetic field \( B = 5 \times 10 \text{ G} \), density \( n_i m_i = 3 \times 10^{-15} \text{ g cm}^{-3} \), temperature \( 2.5 \times 10^6 \text{ K} \), coronal loop length \( \pi R = 10^{10} \text{ cm} \), coronal loop radius \( a = 0.5 \times 10^9 \text{ cm} \), Alfvén speed \( v_A = 2.5 \times 10^8 \text{ cm s}^{-1} \), and velocity perturbation amplitude \( \delta v_{r.m.s.} = 3 \times 10^6 \text{ cm s}^{-1} \).