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Resonant absorption and the spectrum of 5-min oscillations of the Sun

II. Fine structure of the spectrum of 5-min oscillations

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Abstract. The influence of magnetic field on the spectrum of 5-min solar oscillations has been investigated. The calculations have been made within a model of the two-layer shell. The lower non-magnetized layer is characterized by linear decrease of temperature with height while in the upper layer with homogeneous horizontal magnetic field temperature increase, and reaches a coronal value at the height of about 2500km. It is shown that, accounting for resonant absorption, the spectrum of 5-min oscillations has fine structure, which is most noticeable in high - degree modes.

Key words: Sun: oscillations – Sun: chromosphere – Magnetohydrodynamics (MHD)

1. Introduction

Numerous studies (e.g. Cambell & Roberts 1989; Evans & Roberts 1990; Wright & Thompson 1992) of the influence of atmospheric magnetic field on the spectrum of 5-min solar oscillations have been carried out recently. However none of these studies took into account a possibility for the energy of 5-min oscillations to be absorbed at Alfven and cusp resonance levels.

In the previous study (Zhukov 1997a, hereafter Paper I) we made an attempt to calculate the spectrum of 5-min oscillations taking into account their resonant absorption in canopy area of the magnetic field. Calculations were made for a two-layer model of the shell consisting of the lower layer without a magnetic field with linear decrease of temperature with height and the upper layer with homogeneous horizontal magnetic field and sharp increase of temperature reaching coronal value at the height $\sim$ 2500km. In fact, we were only able to show that the resonant absorption of 5-min oscillations indeed occurs in the canopy area of the magnetic field and causes the change of eigenfrequencies of solar oscillations by a few μHz. Such a limited result was due to the fact that the calculations were made only in a very narrow range of change for k and also due to inadequate choice of model parameters.

In this study we present more detailed calculations for the spectrum of 5-min solar oscillations for large k in the framework of the two-layer model considered in Paper I. We have calculated the eigenfrequencies of 5-min oscillations only for p_1 mode. If the resonant absorption in canopy area of the magnetic field is taken into account, the eigenfrequencies turn out to increase, and the greater k is, the more they increase. A very interesting new feature of the spectrum oscillations is that in the presence of resonant absorption the eigenfrequencies of oscillations fill the whole area limited by the curves $k_{\mathrm{x}} = 0$ and $k_{\mathrm{y}} = 0$. Moreover, the eigenfrequencies increase with the growth of magnetic field.

2. Model parameters

In the present study, as in Paper I, the spectrum of 5-min oscillations is calculated for plane two-layer model of the solar shell, consisting of the lower layer without magnetic field and with linear decrease of temperature with height

$$c^2 = c_{01}^2 \left(1 - \frac{z}{z_1}\right)$$

and the upper layer with homogeneous horizontal magnetic field and sharp increase of temperature reaching a coronal value at the height of $\sim$ 2500km

$$c^2 = c_{02}^2 \left(1 + \delta \left[\tanh\left(\alpha\left(\frac{z}{z_2} - \beta\right)\right) - \tanh\left(-\alpha\beta\right)\right]\right)$$

where c – is the sound speed.

In Paper I it was assumed that at the boundary of the layers ($z = 0$):

$$c_{02}^2 = c_{01}^2$$

In this case the density in the upper layer falls down to the value of $\sim 10^{-18}\,\mathrm{g\,cm^{-3}}$ at the height of about 2000km. In order to avoid this, we adopt that there is a jump of density (and, respectively, of temperature) at the boundary ($z = 0$):

$$c_{02}^2 = c_{01}^2 \Delta$$

In the present study we have chosen the following parameters of the model:

$$c_{01} = 6.6829\,10^5\,\mathrm{cm\,s^{-1}},\ z_1 = z_2 = 500\mathrm{km},$$

$$\alpha = 3.0,\ \beta = 4.0,\ \delta = 50.0,\ \Delta = 3.2$$

Fig. 1 presents the change of density as a function of height for the parameters mentioned above. Fig. 2 presents the eigenfrequencies of oscillations of the shell calculated for $H_0 = 0$.

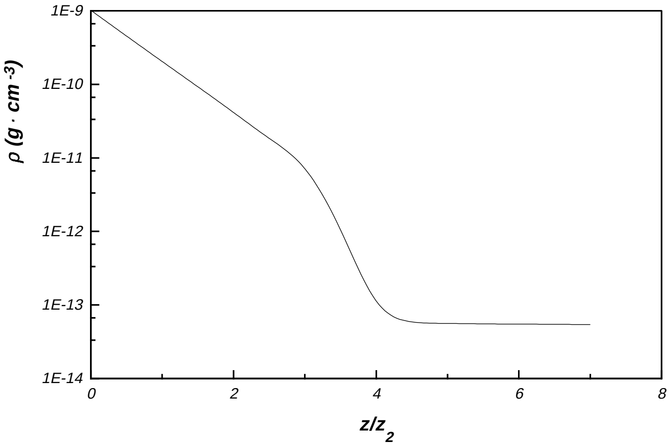

Fig. 1. Variation of density with height in the chromosphere – corona

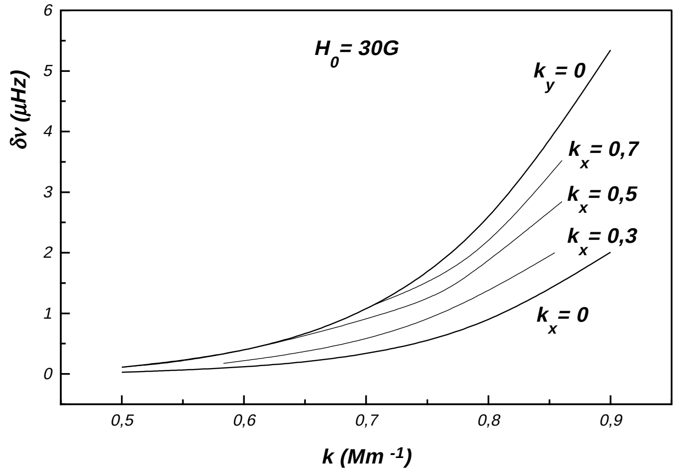

Fig. 3. Shift of the frequencies due to resonant absorption

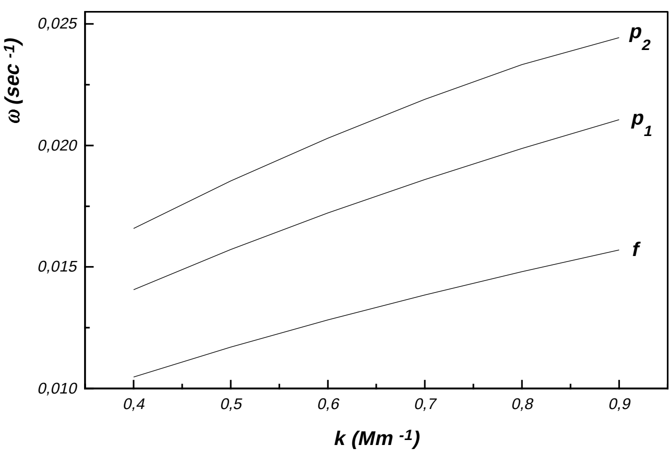

Fig. 2. The diagnostic diagram for the shell without magnetic field

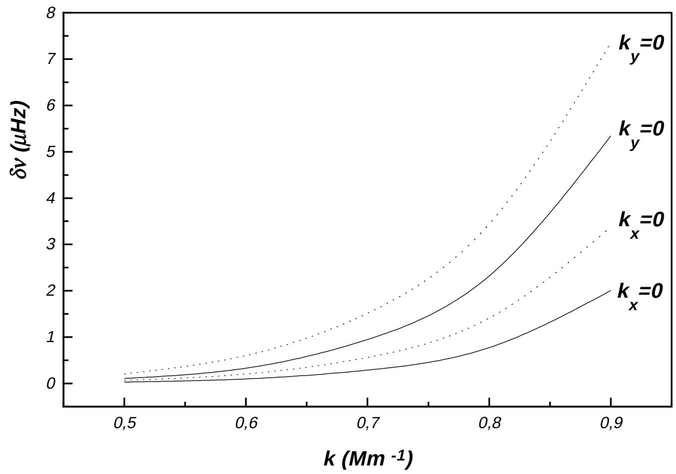

Fig. 4. Shift of the frequencies due to resonant absorption for $H_0 =$ 30G (solid line) and $H_0 = 50$G (dotted line)

3. Results of calculations

The calculations of eigenfrequencies of oscillations for the shell with homogeneous magnetic field H_0 were made only for p_1 mode. For the other p-modes the results should be similar.

The results of calculations are shown in Fig. 3. The shift of eigenfrequencies is denoted by $\delta\nu = (\omega_{\rm r} - \omega_0)/2\pi$, where $\omega_{\rm r}$ - is the real part of eigenfrequency for the shell with magnetic field H_0, and ω_0 - is the eigenfrequency for the shell without magnetic field.

For wave modes which are presented in Fig. 3 the Alfven resonance levels are located in the chromosphere at heights $z_{\rm A} \approx (2.8 \div 3.2) z_2$ and cusp levels are located within a thin layer close to $z_{\rm c} \approx 3.5 z_2$.

As is seen in Fig. 3, in the presence of resonant absorption the shift of eigenfrequencies increases with the increase of k. Moreover, the eigenfrequencies of oscillations prove to fill the whole area limited by the curves $k_{\rm x} = 0$ and $k_{\rm y} = 0$, when the resonant absorption is taken into account. Since for $k_{\rm x} = 0$ there are neither Alfven nor cusp resonances in the area $z > 0$, the curve $k_{\rm x} = 0$, in fact, gives the shift of eigenfrequencies caused only by the presence of magnetic field (without resonances). Thereby, the presence of resonances additionally increases the shift of the eigenfrequencies. As shown in Zhukov (1997b), it is obviously due to tunnel leakage of wave energy into the area of Alfven resonances.

The results of calculations of the spectrum of 5-min oscillations for two values of the magnetic field are presented in Fig 4. We can see from the Fig. 4 that the larger magnetic field is, the larger the shift of frequencies is.

4. Conclusions

Our results show that in the presence of resonant absorption the spectrum of the oscillations is continuous, since in the given model, k can have any value greater than zero. On the Sun $k = \sqrt{\ell(\ell+1)}/R_\odot$ (since on a circle of a large diameter the integer of waves should be pack up). Therefore, in the presence of resonant absorption the spectrum of 5-min oscillations is discrete; it has fine structure, observation of which will be of great importance for determination of the structure of canopy magnetic field. Moreover, the observational detection of the resonant absorption of 5-min solar oscillations will provide a reliable basis for the theory of heating of the upper chromosphere suggested in Zhukov (1992, 1997b). Some indications of the presence of fine structure in the spectrum of 5-min oscillations shown in Fig. 3 have been received by Espagenet et al. (1996).

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