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# THE DYNAMICS OF SOLAR MAGNETIC FLUX TUBES SUBJECTED TO RESONANT FOOT POINT SHAKING.

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Abstract. Using local correlation tracking techniques on data obtained with the SOUP instrument on Spacelab 2, Title (1987) has measured correlated horizontal displacements of solar surface regions of much larger than granular size with a periodicity of the five minute oscillation. We investigate the time-dependent development of waves in thin magnetic flux tubes generated by this purely transverse foot point shaking. The resulting magnetic field and velocity variations, the pressure and temperature fluctuations generated by nonlinear coupling to the longitudinal wave mode, as well as the expected resonance effects are discussed.

## 1. Introduction

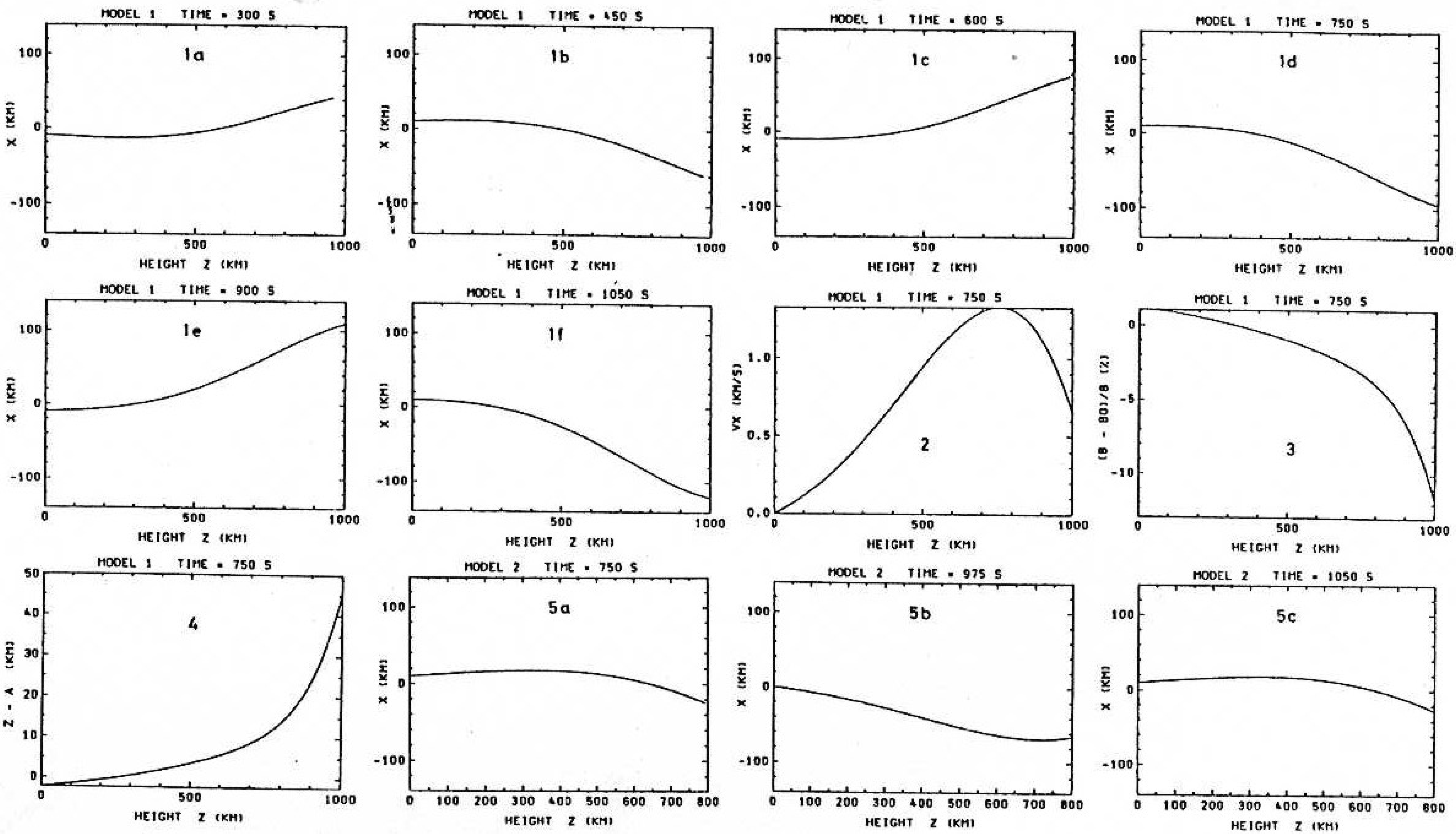
Title (1987) has shown that using data obtained with the SOUP instrument on Spacelab 2 it is possible to measure relatively small horizontal motions on the solar surface. He found that areas of much larger than granular size show correlated horizontal displacements with a periodicity of the five minute oscillation. These motions which affect granules and also presumably flux tubes, have velocity amplitudes of about 100 to 200 m/s. It is interesting to investigate what effects these transverse motions have on the magnetic flux tubes. Zähringer and Ulmschneider (1987) have studied the time-dependent development of short period longitudinal and transverse mhd waves propagating along thin magnetic flux tubes. We now want to extend this work to the long period domain and in particular study the resonance effects in tubes of various height which show similarity to the gas oscillations in an organ pipe. We aim to predict the effects of the shaking on the observable variations of the magnetic field strength, the velocity components as well as of the temperature and pressure.

## 2. Method

The equations for the treatment of time-dependent longitudinal and transverse mhd tube waves valid for applications in thin magnetic flux tubes have been described by Zähringer and Ulmschneider (1987). These authors discuss the boundary conditions and the initial vertically oriented flux tube model which is also employed in our present work. The flux tube spreads with height according to horizontal pressure balance. At the top a transmitting boundary condition is used both for the longitudinal and the transverse wave. At the bottom where the tube has a diameter of 100 km we prescribe for the transverse component a sinusoidally oscillating velocity with a period of $P = 300$ s and an amplitude of 200 m/s while for the longitudinal velocity component we assume a transmitting boundary condition.

## 3. Results and discussion.

Fig.1 shows six consecutive phases of the horizontal deviation $\Delta x$ of the tube axis versus height z for an adiabatic wave calculation in our Model 1. The phases are separated in time by $P/2 = 150$ s starting at time $t = 300$ s. The height (1000 km) of tube Model 1 was chosen to be about 1/4 of the wavelength $\lambda$. From e.g. Fig. 1c it is seen that the swaying amplitude of the transverse oscillation increases from bottom to the top from $\Delta x$=9.5 km to 80 km. Comparison of similar wave phases (e.g. Figs 1a, 1c, 1e) shows that the swaying amplitude increases with time. We attribute this to a



Figs. 1 to 5: Variations with height of physical variables at different phases (time indicated in s) of transversely excited 300 s period waves in Models 1 and 2, extending to 1000 and 800 km height respectively.

resonance situation produced by our $\lambda/4$ choice of the tube height. At the top the amplitude increases in one wave period from $\Delta x$ = 44 km in Fig. 1a to 78 km in Fig. 1c, and to 114 km in Fig. 1e. Calculations of later phases show that this amplitude growth continues. However, a realistic increase of this swaying amplitude can only be computed if radiative damping effects are taken into account. The transverse velocity $v_x$ for the phase of Fig. 1d is shown in Fig. 2. It is seen that the amplitude of $v_x$ increases with height to a value of about 1.6 km/s. At the top at phase P = 825 s the velocity $v_x$ reaches 2.1 km/s and at phase P = 1125 s $v_x$ = 2.6 km/s. This shows that the transverse velocity associated with the resonant swaying increases rapidly in time.

The deviation of the flux tube by about 7.5° (Fig. 1f) from the vertical direction leads to magnetic field oscillations with amplitudes of about 13 percent for the $B_x$ and 0.8 percent for the $B_z$ component. The decrease of the magnetic field strength $\bar{B}$ seen in Fig. 3 is a secular phenomenon and is due to the with time increasing mass flow towards the top which increases the gaspressure at great heights in the tube. This generation of secular mass outflow is also shown by the height difference z-a (Fig. 4) which gives the displacement of the gas elements which at time t=0 were at height a. The topmost mass element e.g. is lifted from 970 km height in Fig. 1a to 1065 km in Fig. 1f. We attribute this effect to centrifugal forces generated by the swaying. The lifting occurs only in the upper parts of the tube and is smaller than in our short period wave calculation which comes from different initial and boundary conditions and the smaller amount of bending at low height. The purely transverse excitation generates longitudinal waves with half the wave period (150s). The velocity amplitude of this longitudinal wave is 800 m/s at the top of the model at phase P = 1050 s which corresponds to a wave flux of about 1.2 $10^5$ erg $cm^{-2}s^{-1}$. The temperature and pressure fluctuations are associated with the induced longitudinal wave and thus also oscillate with half the wave period. Their magnitude is consistent with the flux of the wave. In addition the strong lifting of the upper parts of the tube results in adiabatic cooling which increases secularly with time and leads to temperatures as low as 1700 K at the top in Fig 1f. Here for realistic situations computations which include radiation damping should be carried out.

Figs. 5 show a wave calculation in Model 2 employing the same excitation. Model 2 is identical to Model 1 except that the height is reduced to 800 km. This decreases the height below the $\lambda/4$ value. It is seen by comparing Figs. 5a and 5c with similar phases of Figs. 1d and 1f of Model 1 that the increase of the swaying amplitude with time is much smaller. This shows that the tube height plays a critical role for the occurrence of resonances in the shaking amplitudes which is expected from the analogy with the gas oscillations in an organ pipe. For realistic situations it is not clear what the choice of different tube height means. It is true that the canopy height can be widely different in active and quiet regions. Clearly flux tubes go to infinity but the present work shows that the height over which it can be considered a single entity plays an important role.

## 4. Conclusions

We have seen that foot point shaking of magnetic flux tubes due to small horizontal motions induced by the five minute oscillation generates transverse swaying of the tube with horizontal velocity amplitudes of up to 3 km/s which leads to vertical magnetic field oscillations of about 0.8 percent. At 1000 km height the tube axis sways horizontally by up to 130 km. Centrifugal forces are generated which lead to a lifting and adiabatic cooling of the upper parts of the tube. These oscillations show a resonance character by depending strongly on the height of the tube. Due to the nonlinear coupling a longitudinal wave is generated at the top of the tube with energy fluxes of about 1 $10^5$ ergs $cm^{-2}$ $s^{-1}$. More realistic calculations however should include radiative effects.

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