SATURATION OF ALFVÉN OSCILLATIONS IN THE RING CURRENT REGION DUE TO GENERATION OF LOWER HYBRID WAVES

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Abstract—The possibility of flux generation of lower hybrid oscillations in the ring current region of the Earth's magnetosphere is suggested in this paper. The energy level of lower hybrid oscillations can exceed the modulational instability threshold, which leads to the formation of caverns. The consequences of this are qualitatively analysed. Also, an assumption is made that the flux instability of lower hybrid oscillations may limit the level of Alfven oscillations in the ring current region.

INTRODUCTION

It is common knowledge that the ring current has a significant effect on the dynamics of ionosphere-magnetosphere interactions by generating MHD waves (Galeev, 1975; Kennel and Petschek, 1966; Lyons and Williams, 1984). In this connection, while describing interactions of waves with plasma particles, there arises the need to know the spectral energy density of Alfven and fast magnetosonic waves (FMS). The concrete mechanisms of the formation of the spectra of MHD oscillations in the ring current zone (Young et al., 1981) are not yet clear. Usually, stabilization of oscillations is explained either by quasi-linear interaction or by non-linear frequency shift (see Makarenko and Tupchenko, 1988, and references therein). The present paper examines the generation of lower hybrid oscillations (LHO) by Alfven and/or FMS waves. The main consequence of this process is, in our view, the possibility of saturation of the energy level of MHD waves in the ring current zone.

Below we shall discuss the generation of LHO by Alfven waves, since the mechanism of excitation of LHO is not dependent on the type of MHD oscillations (Akhiezer, 1974). Besides, the assertion about the saturation of the energy level of Alfven waves is equally true for FMS waves. This is connected with the fact that the presence of FMS waves in the ring current zone is explained by the linear transformation of Alfven oscillations in a plasma with a small share of helium ions (Korth et al., 1984).

Experimental data (Taylor et al., 1975; Young et al., 1981) reveal that the energy density of Alfven waves fluctuates within the bounds of $10^{-5} < B^2/B_0^2 < 10^{-4}$, ($B$ is the magnetic field of the wave, $B_0$ is that of the Earth). As will be shown later, they can generate sufficiently intensive LHO. The study of this process, together with the possibility of saturation of the energy level of Alfven oscillations, is of interest in understanding a number of magnetospheric phenomena.

First of all, note that LHO have apparently been observed on Dynamics Explorer 1 near the magnetic equator (Olsen et al., 1987). Evaluations that could be made on the basis of the results given in the paper, show a fairly high level of energy density of oscillations $W/nT \sim 10^{-6}-10^{-7}$ ($W$ is the energy density of LHO; $n$ and $T$ are the concentration and temperature of the plasma). As is known, at such energy densities, LHO are unstable with respect to density modulation, which leads to strong turbulence and the collapse of individual caverns (Sturman, 1976). This means that excitation of LHO may lead to the appearance of an additional channel of energy transfer from Alfven waves to particles, may influence the formation of the plasma particle distribution function at the expense of particle acceleration at the “tail” of the distribution function during the collapse, and influence the transport processes, since there occur additional collisions of particles with caverns and particle distribution functions which are changing (Musher et al., 1986).
FLUX INSTABILITY OF LHO IN THE ALFVÉN WAVE FIELD

As is known (Akhiezer, 1974) in the field of a low frequency wave the drift of electrons and ions occurs with different velocity. If the relative velocity of electron and ion plasma components is high enough, $|\mathbf{u}| = |\mathbf{u}_e - \mathbf{u}_i| > v_{th}$, then there occurs the flux instability of LHO. Here $v_{th}$ is the ion thermal speed. The instability is aperiodic

$$Re \omega \sim Im \omega \equiv \gamma_\parallel \sim \sqrt{|\omega_{ke}| \omega_{ni} \equiv \omega_{ni}}.$$  \hspace{1cm} (1)

where $\omega_{ke}$ and $\omega_{ni}$ are gyrofrequencies of electrons and ions, respectively. Numerical calculations along the trajectory of the Alfvén wave propagation show that the condition $|\mathbf{u}| > v_{th}$ is carried out in a number of cases for the values of $B^2 \gg B^2_0$ observed in experiments in the ring current region (Taylor et al., 1975; Young et al., 1981). Let us estimate the energy density of LHO. Generation takes place in the region of angles $\cos^2 \theta \sim m_e m_i$ (θ is the angle between the wave vector of LHO $k$ and the magnetic field). At angles of $\cos^2 \theta \ll m_e m_i$ the main non-linear process, within the framework of the weak turbulence theory, is induced scattering of LHO on electrons with characteristic time $(\gamma_\parallel)^{-1}$ (Musher et al., 1978).

The energy density of LHO, $W_k$, can be estimated from:

$$\frac{dW_k}{dt} = (\gamma_\parallel - \gamma_d - \gamma_n)W_k.$$  \hspace{1cm} (2)

$$\gamma_d = \frac{\omega_{ke}}{\omega_{ni} n T}, \quad W = \int W_k dk, \quad \gamma_\parallel \sim 0, \quad \omega_{ke} \gg \omega_{ni}.$$  \hspace{1cm} (3)

From the stationary condition we have

$$\gamma_p - \gamma_n = 0, \quad W/nT \sim m_e/m_i.$$  \hspace{1cm} (4)

At these energy densities the plasma should not be considered weakly turbulent, since already

$$W/nT > (kr_n)^2 m_e/m_i$$

there occurs a modulational instability of LHO ($r_n = v_{th}/\omega_{ke}$. $k$ is the characteristic value of the wave-number from the LHO spectrum) (Musher and Sturman, 1975). Since at such growth rates there is no point in differentiating between low frequency and high frequency oscillations, and the dynamics of this process have not yet been studied, let us confine ourselves to the evaluation of the energy flux into the plasma (Musher et al., 1986).

$$Q \sim v_{th} W.$$  \hspace{1cm} (5)

Hence,

$$Q nT \sim \omega_{th} W, \quad m_e \sim 10^{-4}.$$  \hspace{1cm} (6)

Thus, on separate sections of the Alfvén wave trajectory, the above effect may lead to a significant heating of particles and possibly particle acceleration from the “tails” of the distribution function. The latter assumption needs additional analysis.

For the effective frequency of collisions of plasma particles with electrons ($\varphi = v_{th} n T$), we have from equation (5):

$$v_{th} \sim v_{th} n_e n_i m_e \sim 10^{-4} s^{-1}.$$  \hspace{1cm} (7)

Let us estimate the characteristic time of energy outflow from Alfvén oscillations, $(\gamma_\parallel)^{-1}$, at the expense of LHO generation. A qualitative estimate may be obtained from

$$\gamma_p W^\lambda \sim \gamma_\parallel W^{\lambda+1}.$$  \hspace{1cm} (8)

Using values $W^\lambda/B^2_0 \sim 10^{-4}$, (1) and (3), we obtain $(\gamma_\parallel)^{-1} \sim 10^{-1}/\nu_\alpha$, where $\nu_\alpha$ is the Alfvén wave frequency. The linear growth rate of Alfvén wave generation by anisotropic protons of the ring current during the cyclotron interaction has the form (Kennel and Petschek, 1966):

$$\gamma^\lambda = \frac{A_0}{2} [K_0 (\nu_\alpha)]^{-1},$$  \hspace{1cm} (9)

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where $A_0$ is the temperature anisotropy of the ring current protons and $\mu$ is the relative concentration of anisotropic particles. For the relative concentration of hot protons $\mu \sim 10^{-1}$ and $V^\lambda/V^\lambda_{th} \sim 10^{-1} (V^\lambda_{th}$ is the thermal speed of hot protons) we have $\gamma_\parallel \sim 10^{-1}/\nu_\alpha$. Comparing $(\gamma_\parallel)^{-1}$ and $(\gamma^\lambda)^{-1}$ we may assume that the considered process may serve as one of the mechanisms restricting the level of the Alfvén turbulence in the region of its generation, i.e. in the ring current region.

Let us note, in conclusion, that the present results are of a qualitative nature. To clarify the authenticity of the suggested physical mechanisms, a detailed quantitative description is required, as well as the comparison of theoretical results with experimental data.

REFERENCES


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