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SATURATION OF ALFVEN 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 Alfvén 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 Alfvén 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 Alfvén 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 Alfvén 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 Alfvén 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 Alfvén 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 Alfvén waves fluctuates within the bounds of $10^{-5} \lesssim B^2/B_0^2 \lesssim 10^{-4}$, ($B$ 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 Alfvén 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 Alfvén 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 ALFVEN 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, $|\mathbf{u}| = |\mathbf{u}_i - \mathbf{u}_e| > v_{Ti}$ then there occurs the flux instability of LHO. Here v_{Ti} is the ion thermal speed. The instability is aperiodic

$$Re\,\omega \sim Im\,\omega \equiv \gamma_p \sim \sqrt{|\omega_{Be}|\omega_{Bi}} \equiv \omega_{LH}, \qquad (1)$$

where ω_{Be} and ω_{Bi} are gyrofrequencies of electrons and ions, respectively. Numerical calculations along the trajectory of the Alfvén wave propagation show that the condition $|\mathbf{u}| > v_{Ti}$ is carried out in a number of cases for the values of B^2/B_0^2 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 $\cos^2\theta \leqslant m_e/m_i$ the main non-linear process, within the framework of the weak turbulence theory, is induced scattering of LHO on electrons with characteristic time $(\gamma_s^e)^{-1}$ (Musher *et al.*, 1978).

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

$$\frac{\mathrm{d}W_k}{\mathrm{d}t} = (\gamma_p - \gamma_d - \gamma_s^e)W_k, \qquad (2)$$

$$\gamma_s^e = \frac{\omega_{Be}^2}{\omega_{LH}}\frac{W}{nT}, \quad W = \int W_\mathbf{k}\,\mathrm{d}\mathbf{k}, \quad \gamma_d \sim 0, \quad \omega_{pe}^2 \gg \omega_{Be}^2.$$

From the stationary condition we have

$$\gamma_p - \gamma_s^e = 0, \quad \frac{W}{nT} \sim m_e/m_i. \qquad (3)$$

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

$$W/nT > (kr_B)^2 m_e/m_i \qquad (4)$$

there occurs a modulational instability of LHO ($r_B = v_{Te}/\omega_{Be}$, k is the characteristic value of the wavenumber 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).

$$Q \simeq \omega_{LH}W. \qquad (5)$$

Hence,

$$Q/nT \sim \omega_{LH}m_e/m_i \sim 10^{-2}\,\mathrm{s}^{-1}.$$

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 caverns ($Q = \nu_{eff}nT$), we have from equation (5):

$$\nu_{eff} \sim \omega_{LH}m_e/m_i \sim 10^{-2}\,\mathrm{s}^{-1}.$$

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

$$\gamma_d^A W^A \simeq \gamma_p W^{LH}.$$

Using values $W^A/B_0^2 \sim 10^{-4}$, (1) and (3), we obtain $\gamma_d^A \sim 10^{-1}\,\omega_A$, where ω_A 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):

$$\gamma_p^A = \frac{A\sqrt{\pi}}{2}\mu\frac{\omega_{Bi}^3}{K_\parallel V_{Th}\omega_A},$$

where A is the temperature anisotropy of the ring current protons and μ is the relative concentration of anisotropic particles. For the relative concentration of hot particles $\mu \sim 10^{-2}$ and $V_A/V_{Th} \sim 10^{-1}$ (V_{Th} is the thermal speed of hot protons) we have $\gamma_p^A \sim 10^{-1}\,\omega_A$. Comparing γ_d^A and γ_p^A 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.

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