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NUMERICAL MODELING OF THE GENERATION ALFVÉN WAVES BY LASER PLASMA IN A MAGNETIZED BACKGROUND PLASMA AT ALFVÉN-MACH NUMBERS LESS THAN ONE

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Abstract. The paper presents a comparison results of numerical simulation of the generation the Alfven and slow magnetosonic wave created by periodic laser plasma bunches in a magnetized background plasma in the pre-Alfvenic bunch expansion (M_A=0.2) and M_A=1. It is shown that, regardless of the mode, Alfven wave localized in a magnetic flux tube of radius R_d~1, and the efficiency of converting plasma bunches into an Alfven wave at M_A = 0.2 is several times higher than the value obtained at M_A = 1.

Introduction

The wave merging mechanism (WMM) is a method of resonant interaction of periodic laser plasma bunches with surrounding environment has been experimentally confirmed for gases [1], magnetized plasma [2] and in a magnetic field [3]. In a gas, periodic plasma bunches generate an extended wave that has characteristic frequencies in the infrasonic range. In a magnetized plasma, merging mechanism forms a low-frequency wave, the length of which linearly depends on the number of laser pulses that create the bunches.

Previously, using numerical modeling and laboratory experiments on the KI-1 facility, the relationships linking the parameters of laser plasma and surrounding background for the generation of intense and extended Alfven and slow magnetosonic waves were determined [2,4]. The main criterion of the WMM is the dimensionless repetition frequency of plasma bunches: $\omega = \frac{f \cdot R_d}{C_A} \approx \omega_R$ is approximately equal to the “resonance” value ω_R, which depends on the type of excited waves. Here f is the physical repetition frequency of the bunches, C_A is Alfven velocity, and R_d is the braking radius of the laser plasma bunches by the magnetic field, which depends on the bunch energy:

$$R_d = \left(\frac{Q}{p}\right)^{\frac{1}{3}} = \left(\frac{8\pi Q}{B_0^2(1+\beta)}\right)^{\frac{1}{3}}.$$

For low-frequency Alfven waves for different plasma expansion conditions (M_A~0.2÷1), the resonant frequency lies in the range ω_R ~ 0.2 – 0.3. To form an intense Alfven wave, the main criterion is supplemented by the following conditions:

1. The ratio of the Larmor radius of the source ions to the ion-inertial length of the background satisfies the following inequality:

$$\alpha = M_A \cdot \frac{m_i z_0}{m_0 z_i} > 5,$$

where m_i, m_0, z_i и z_0 are the mass and charge of the ions of the bunch and background, respectively. In the region α < 5, the Alfvén wave is unstable and its amplitude is small. At α > 5, the wave amplitude increases with increasing α.

2. The Larmor radius is approximately equal to the braking radius of the magnetic field: $R_L = r_l / R_d \sim 0.5 \div 1.5$, where r_l is the dimensional Larmor radius of the ions of the plasma bunches.

3. The ratio of the ion-inertial length to the dynamic radius of the plasma bunch:

$$L_{pi} = \frac{l_{pi}\,[cm]}{R_d\,[cm]} = \frac{c/\omega_{pi}}{R_d} \sim 0.1 \div 0.3.$$

At Lpi > 0.3, the amplitude of the Alfven wave decreases and whistlers predominate in the environment.

4. The ratio of the thermal pressure of the background plasma to the pressure of the external magnetic field:

$$\beta = \frac{8\pi k\big((1+Z_0)n_0\big)T_0}{B_0^2} < 1,$$

where n_0, T_0, Z_0 are the density, temperature and charge of the background plasma. Depending on the value of β, the properties of the generated waves change.

Thus, when all relations are satisfied, extended Alfven, slow magnetosonic waves and whistlers of maximum amplitude are generated in magnetized plasma, and the efficiency of converting plasma bunch into waves becomes maximum. Waves transfer energy, momentum and angular momentum [2-4]. This paper presents the results of numerical modeling for the generation of Alfven and slow magnetosonic waves by a train of laser pulses in magnetized background plasma at different Alfven Mach numbers.

Numerical model

To study the generation of low-frequency Alfvén and slow magnetosonic waves, the electron MHD model is used in calculations. Its detailed description is given in [5], so below we will give a brief main point. The model is three-fluid, the first fluid describes the source ions, the second – the background plasma ions, and the third – the common electrons. The source of disturbances is periodic bunches of laser plasma with ions having mass mi and charge z_i. Each plasma bunchs expands and interacts with the background plasma and the external magnetic field. The background is considered as a collisionless, magnetized and completely ionized plasma with its own concentration, masses m_0 and charges z_0. The parameters of the problem were normalized to the concentration of the background plasma, magnetic field and Alfvén velocity. The dynamic radius was used as a characteristic spatial scale of the problem. The geometry of the problem is cylindrical.

The expansion of plasma bunches leads to the displacement of the magnetic field and the formation of a cavity, which creates an electric field, which in turn sets the ions of the background plasma in motion. Then, the background plasma interacts with the plasma of bunches due to the adhesion of liquids through the Lorentz force and twists, compressing along the axis of symmetry, which leads to an increase in pressure and the outflow of plasma along the magnetic field lines. In a periodic process formed a plasma flow, containing Alfven and slow magnetosonic waves, which propagate along the magnetic field lines. The waves transfer energy and momentum (magnetosonic waves), as well as the angular momentum (Alfven waves). The formation of extended and intense waves occurs due to the resonant interaction of periodic plasma bunch with the background plasma and magnetic field.

Results

Figure 1 shows the spatial structure of low-frequency waves generated by N=5 laser plasma bunches in the pre-Alfvenic expansion mode of bunches propagating in magnetized hydrogen plasma. As was shown in [6], Alfven wave consists of two parts: the front part (1), which is formed after the bunches cease to act, and extended tail formed by radial pulsations of the bunches. A slow magnetosonic wave (3) propagates behind the Alfven wave, containing the main share of the source energy.

Figure 1. Spatial structure of waves in the M_A=0.2 mode: 1 - Alfvén wave; 2 - extended "tail" of Alfvén wave; 3 - slow magnetosonic wave; 4 – source that generates a sequence of laser plasma bunches.

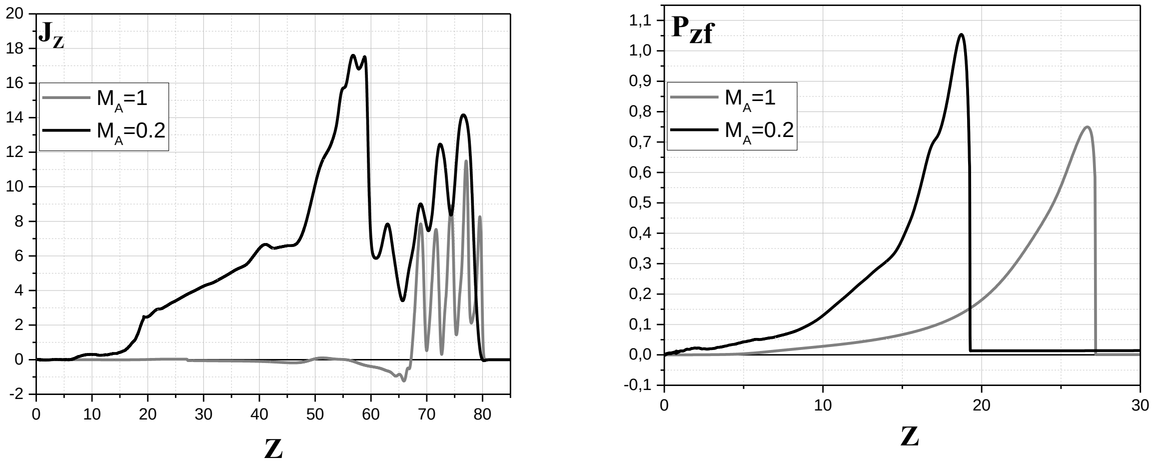

Figure 2. Distribution of the longitudinal current Jz of the Alfvén wave (left) and longitudinal pulse of the slow magnetosonic wave (right) for the Alfvén-Mach number M_A=0.2 and 1.

Figure 2 shows the distributions of the azimuthal current of the Alfven wave and the longitudinal pulse of the magnetosonic wave at M_A=0.2 and 1. At M_A=1, the Alfven wave consists only of the front part, due to the energy expenditure of the bunches not only on wave generation, but also on the plasma flow. Simulation parameters: number of pulses N=5, Mach number M_A=0.2, bunch pulsation frequency ω= 0.33, β=0.01, L_{pi} =0.1, m_i=207. The ions of the bunches and the background are ionized once. The center of the bunches is localized at the point R=0, Z=0. The spatial boundary of the computational domain along is ΔZ=0÷120, ΔR =0÷10.

Figure 3 illustrates the radial distribution of the azimuthal magnetic field of the Alfvén wave in the M_A=0.2 and 1. As in the case of M_A=1 [7], the wave localized in a magnetic flux tube of radius ~ Rd. The amplitude of the disturbances reaches of $\Delta B/B_0$~ 0.2.

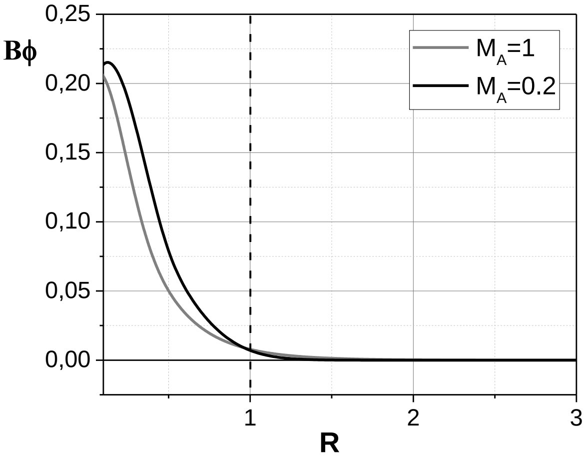

Figure 3. Radial distributions of the azimuthal magnetic field of Alfvén wave for the Alfvén-Mach number M_A=0.2 and 1.

Figure 4 shows the dependence of the thermal β efficiency of Alfvén wave generation at Mach numbers M_A=0.2 and 1. At M_A~1, the efficiency of Alfvén wave generation is approximately 7 %, while in the regime pre-Alfvénic expansion, the efficiency of converting bunches into an Alfvén wave reaches of 40 %.

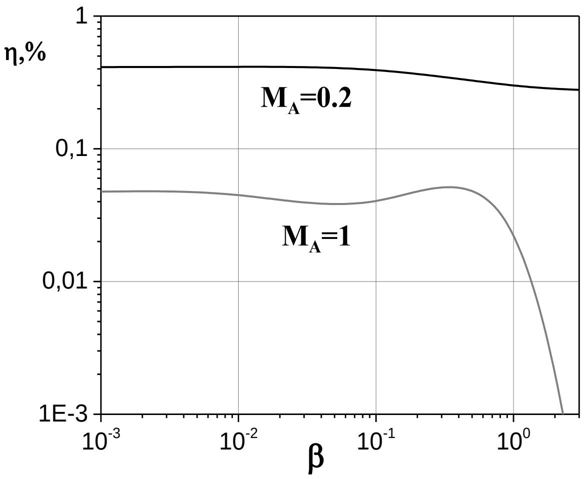

Figure 4. Efficiency of conversion plasma bunches into an Alfvén wave depending on thermal β at values of the Alfvén-Mach number M_A=0.2 and 1.

Descussions

Thus, the wave merging mechanism allows generating an extended plasma flow, Alfven and magnetosonic waves of large amplitude. In the pre-Alfven interaction plasma bunches with magnetized plasma (M_A=0.2), the Alfven wave length increases several times, and the efficiency of converting bunches into a wave reaches 40% (at M_A=1, the efficiency is ~7%). Regardless of the generation mode, the waves propagate in a magnetic flux tube of radius Rd.

Acknowledgments

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