SOLITARY PRECURSOR OF LARGE AMPLITUDE

A.M.Egorov, V.I.Maslov, I.N.Onishchenko
NSC KIPT, Kharkov, Ukraine

INTRODUCTION

In this paper the results of investigations of properties of solitary perturbation of large amplitude, propagating with light velocity at small angle to strong magnetic field in plate plasma-filled waveguide, are presented. This solitary perturbation is the hollow of electric potential. The hump of electric potential can be excited as a wake-field by electron bunch, but the hollow of electric potential, considered in this paper, is excited as a precursor of electron bunch. Because this hollow forms the positive spike of electron density, it can be excited as a precursor of laser pulse.

The velocity of the solitary precursor grows with amplitude growth. At large amplitude the velocity of the solitary precursor in the nonrelativistic case can exceed more than two times the velocity of electron bunch, which excites this precursor.

The electron bunch, which excites solitary precursor, deforms the shape of this precursor and the latter becomes nonsymmetric.

PROPERTIES OF THE SOLITARY PRECURSOR

Main attention in [1] at research of excitation of the plasma wake-fields is given to process of electromagnetic soliton formation, which can not been described in approximation of envelope. The soliton is formed in wake of electromagnetic pulse. The soliton is the nonlinear superwide in frequency space electromagnetic pulse. Last years the papers, devoted to solitary wave pulses and their applications are published (see, for example, [2, 3]).

At large intensities of laser radiation qualitative change of interaction of such radiation with plasma can take place. In particular, there is a capability of formation of solitary perturbations. Really, the experiments demonstrate, that if there is in dispersion law of excited oscillations linear interval, then solitary perturbations can be excited.

There were many attempts of obtaining of the analytical solution as soliton, propagating with light velocity in unlimited plasma (see, for example, [2]). In this paper similar solitary perturbation is investigated analytically, propagating in plasma-filled waveguide.

Solitary perturbation, propagating with velocity $V_c \approx c$ under angle θ to the magnetic field $H_o \to \infty$ in plane metallic waveguide filled by plasma, is investigated analitically.

This solitary perturbation is the hollow of electric potential. The properties of small amplitude solitary perturbation one can obtain from equation

$$\Delta \vec{E} - \left(\vec{V}_c\nabla\right)^2 \vec{E}/c^2 + 4\pi e[\nabla n - \left(\vec{V}_c\nabla\right) n\vec{v}/c^2] = 0$$

Using $E_z = -\partial \varphi/\partial z$, we have

$$\varphi'' = \frac{\varphi\left[k_\perp^2 - \frac{\omega_p^2 \cos^2\theta}{V_c^2}\left(1 - \frac{V_c^2\cos^2\theta}{c^2}\right)\left(1 - \frac{1{,}5e\varphi\cos^2\theta}{m_e V_c^2}\right)\right]}{\left(1 - \frac{V_c^2}{c^2}\right)}$$

"`" is the space derivative. Integrating the latter we have equation for the solitary perturbation shape

$$(\phi')^2 = \phi^2\omega_p^2\left[\frac{k_\perp^2}{\omega_p^2} + \frac{1}{c^2} - \frac{\cos^2\theta}{V_c^2} + \frac{\phi k_\perp^2}{\omega_p^2}\right],$$

$$\phi = e\varphi\cos^2\theta / m_e V_c^2 .$$

From this equation at $\phi'\big|_{\phi=-\phi_o} = 0$ we have nonlinear expression for solitary perturbation velocity

$$V_c \approx \frac{c\cos\theta\left[1 + \phi_o c^2 k_\perp^2 / 2\left(c^2k_\perp^2 + \omega_p^2\right)\right]}{1 + \frac{c^2k_\perp^2}{\omega_p^2}}$$

From equation for the solitary perturbation shape one can find the width of the perturbation

$$\Delta\xi = \frac{\left(2m_e/e\varphi_o\right)^{1/2} 2c\omega_p\left(c^2k_\perp^2 + \omega_p^2\sin^2\theta\right)^{1/2}/k_\perp}{k_\perp\left(c^2k_\perp^2 + \omega_p^2\right)} .$$

From here at $\sin\theta << ck_\perp/\omega_p << 1$ follows

$$\Delta\xi \approx 2c^2\left(2m_e/e\varphi_o\right)^{1/2}/\omega_p .$$

There are three parameters for control of the solitary perturbation properties: $k_\perp, \omega_p, \theta$.

The solitary perturbation shape is described by expression

$$\phi = -\phi_o/ch^2\left[\xi\left(\phi_o\eta\right)^{1/2}/2\right],$$

$$\eta = k_\perp^2\left(c^2k_\perp^2 + \omega_p^2\right)/\left(c^2k_\perp^2 + \omega_p^2\sin^2\theta\right).$$

For the excitation of this perturbation by electron beam one can derive equation

$$\partial_t^3\phi = -(n_{bo}/2n_o)V_o^3\phi''' ,$$

$$\phi(z,t) = \phi_o(t)\mu[z - \int_{-\infty}^{t} d\tau\,\delta V_o(\phi_o(\tau))],$$

$$\mu(z) = 1/ch^2(z\sqrt{2}/\Delta z(\phi_o)) .$$

From here expression for growth rate of perturbation’s amplitude follows

$$\gamma \approx \omega_p(n_{bo}/2n_o)^{1/3}(1{,}5e\phi_o/mV_o^2)^{1/2} .$$

Thus, the interaction of the electron beam with solitary perturbation leads to growth of its amplitude in a goodness with similar results, obtained in [4-10].

The hump of electric potential can be excited as a wake-field by electron bunch, but the hollow of electric potential, considered here, is excited as a precursor of electron bunch. Because this hollow forms the positive spike of electron density, it can be excited as a precursor of laser pulse.

The velocity V_c of the solitary precursor grows with amplitude growth φ_o. At large amplitude the velocity of the solitary precursor in the nonrelativistic case can exceed more than two times the velocity of electron bunch, which excites this precursor.

In relativistic case the soliton is described by equation

$$\varphi'' + 4\pi e(n - n_o) +$$
$$+ [\gamma_o^3 - (\gamma_o + e\varphi / mc^2)^3] mc^2 k_\perp^2 / 3e = 0,$$
$$n = n_o \sqrt{1 - \gamma_o^{-2}} / \sqrt{1 - (\gamma_o + e\varphi / mc^2)^{-2}},$$
$$\gamma_o = (1 - V_c^2 / c^2 \cos^2\theta)^{-1/2}$$

Its shape is determined by equation

$$(\varphi')^2 = (2mc^2 k_\perp^2 / 3e)\{-\gamma_o^3 \varphi +$$
$$(mc^2 / 4e)[(\gamma_o + e\varphi / mc^2)^4 - \gamma_o^4]\} +$$
$$8\pi e n_o \{\varphi - (mc^2 / e)[-\gamma_o +$$
$$+ \sqrt{1 - \gamma_o^{-2}} \sqrt{(\gamma_o + e\varphi / mc^2)^2 - 1}]\}$$

From condition $\varphi' \big|_{\varphi = -\varphi_o}$ follows that the maximum velocity of solitary perturbation is realized at $e\varphi_o \approx mc^2(\gamma_o - 1)$ and is determined by equation

$$\gamma_o^4 - \gamma_o^3 4/3 + 1/3 + 4\omega_p^2 / c^2 k_\perp^2 = 0$$

The electron bunch, which excites solitary precursor, deforms the shape of this precursor. The latter becomes nonsymmetric.

REFERENCES

1. S.Bulanov, T.Esirkepov, F.Kamenethz, N.Naumova. // Plasma Physics Reports, 1995. V. 21, p. 584.
2. R.W.Ziolkowski. Phys. Rev. A. 1991. v. 44. p. 3960.
3. B.I.Cohen, B.B.Afeyan, A.E.Chou and N.C.Luhmann, Jr. Computational study of ultra-short-pulse reflectometry. Preprint UCRL-JC-117947. 1994.
4. H.Schamel, Phys. Rep. 1986. V. 140. P. 163.
5. K.Nishihara, H.Sakagami, T.Taniuti, amd A.Hasegawa, Riso Nat. Lab. R. 472. 1982. P. 41.
6. V.I.Maslov, Proc. of 4th Symp. on double layers. Innsbruck. Austria. 1992. P. 82.
7. J.P.Lynov, P.Michelsen, H.L.Pecseli, J.J.Rasmussen, K.Saeki and V.A.Turikov, Phys. Scr. 1979. V. 20. P. 328.
8. H.Ikezi, P.J.Barrett, R.B.White and A.Y.Wong, Phys. Fluids. 1971. V. 14. P. 1997.
9. V.I.Maslov, Phys. Lett. 1992. V. A165. P. 63.
10. Y.Takeda and K.Yamagiwa, Phys. Fluids. 1991. V. B3. P. 288.