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Relativistic electron drift in overdense plasma produced by a super-intense femtosecond laser pulse

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The goal of this work is to consider the relativistic motion of free electrons induced by the super-intense laser field inside the skin layer. We assume the femtosecond duration of laser pulse in order to exclude the electron drift produced by the ponderomotive force due to spatial distribution of the laser field in the focal volume [1]. The eight-fold motion of a free electron in underdense plasma, or in vacuum produced by the plane electromagnetic wave is well known. The electron trajectories are described by simple analytic expressions in this case. But the analogous electron motion in overdense plasma cannot be described analytically and is unknown. For the sakes of simplicity we assume that the linearly polarized laser beam propagates perpendicular to the plane surface of a dense plasma. The *quiver* electron energy is assumed to be a relativistic quantity.

Relativistic electron drift along the propagation of laser radiation is produced by a magnetic part of the laser field. It remains after the end of the laser pulse, unlike the relativistic drift of a free electron in underdense plasma. As a result, the penetration depth is much larger than the classical skin depth. Of course, there are also other mechanisms for deep penetration of super-intense laser radiation into dense plasma. Hole boring by the laser beam is one of the features of laser-solid interaction [2]. From our derivations [3] the conclusion has been made that the electron *drift* velocity is a non-relativistic quantity even at the peak laser intensity of 10^{21} W/cm^2. The time at which an electron penetrates into field-free matter from the skin layer is much less than the pulse duration. We found also that the time at which an electron penetrates into field-free matter from the skin layer is much less than the pulse duration. This penetration occurs at the leading edge of the laser pulse (Fig. 1). In Fig. 2 the electron trajectory in the plane XY for the value of the relativistic field parameter $f = 2F/\omega c = 10$. The dimensionless electron coordinates are given in units of the skin layer depth c/ω_p. Finally, in Fig. 3 the dependence of the dimensionless final electron drift momentum p_x (in units of mc) along the propagation of a laser pulse inside the skin layer on the relativistic field parameter $f = 2F/\omega c$.

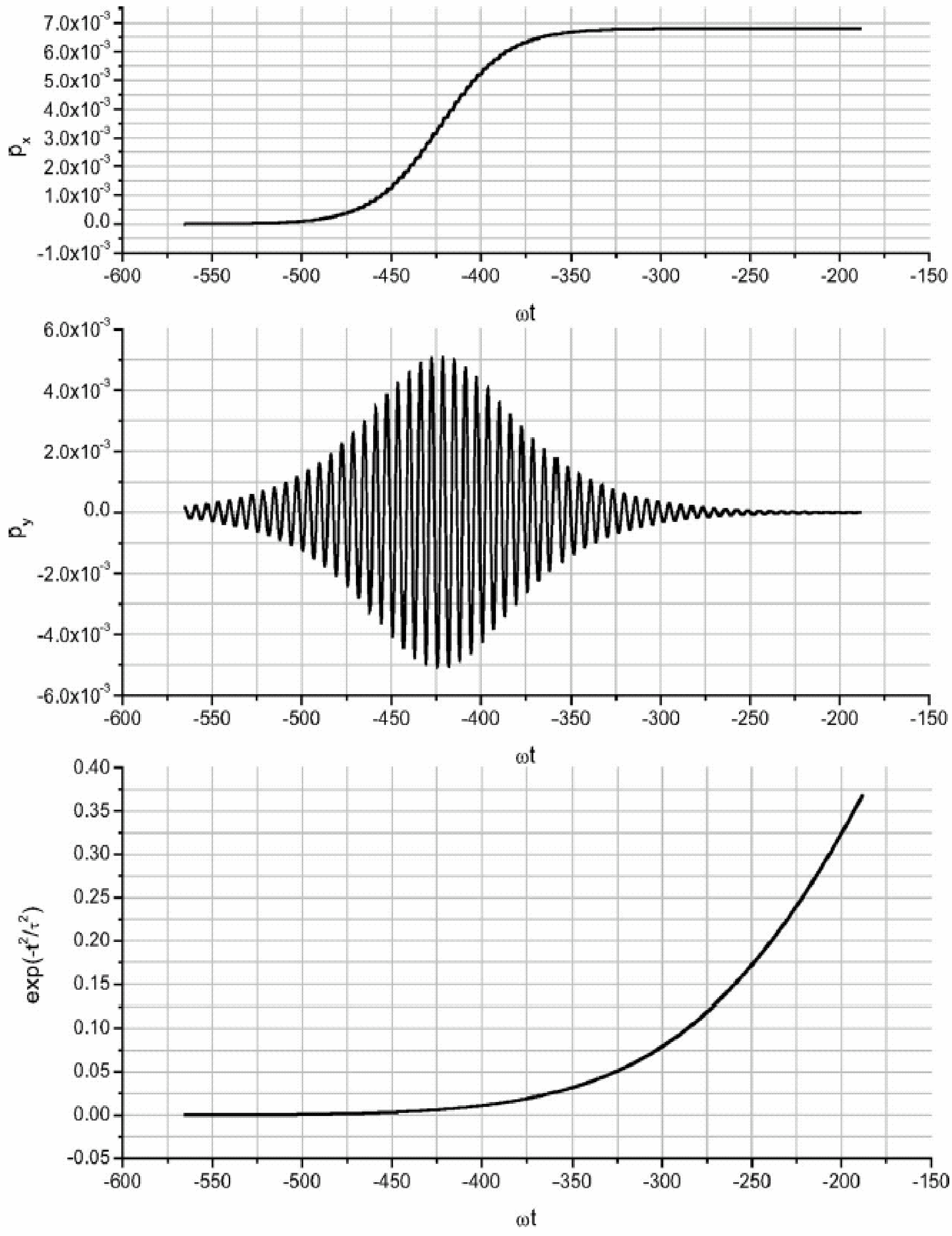

FIG. 1 . The dependences of the dimensionless electron momentum p_x and p_y (in units of mc) on the laser phase ωt at the leading edge of the laser pulse for the value of the relativistic field

parameter $f = 2F/\omega c = 10$. The lower curve demonstrates the dependence of the field strength envelope on the laser phase ωt at the leading edge of the laser pulse.

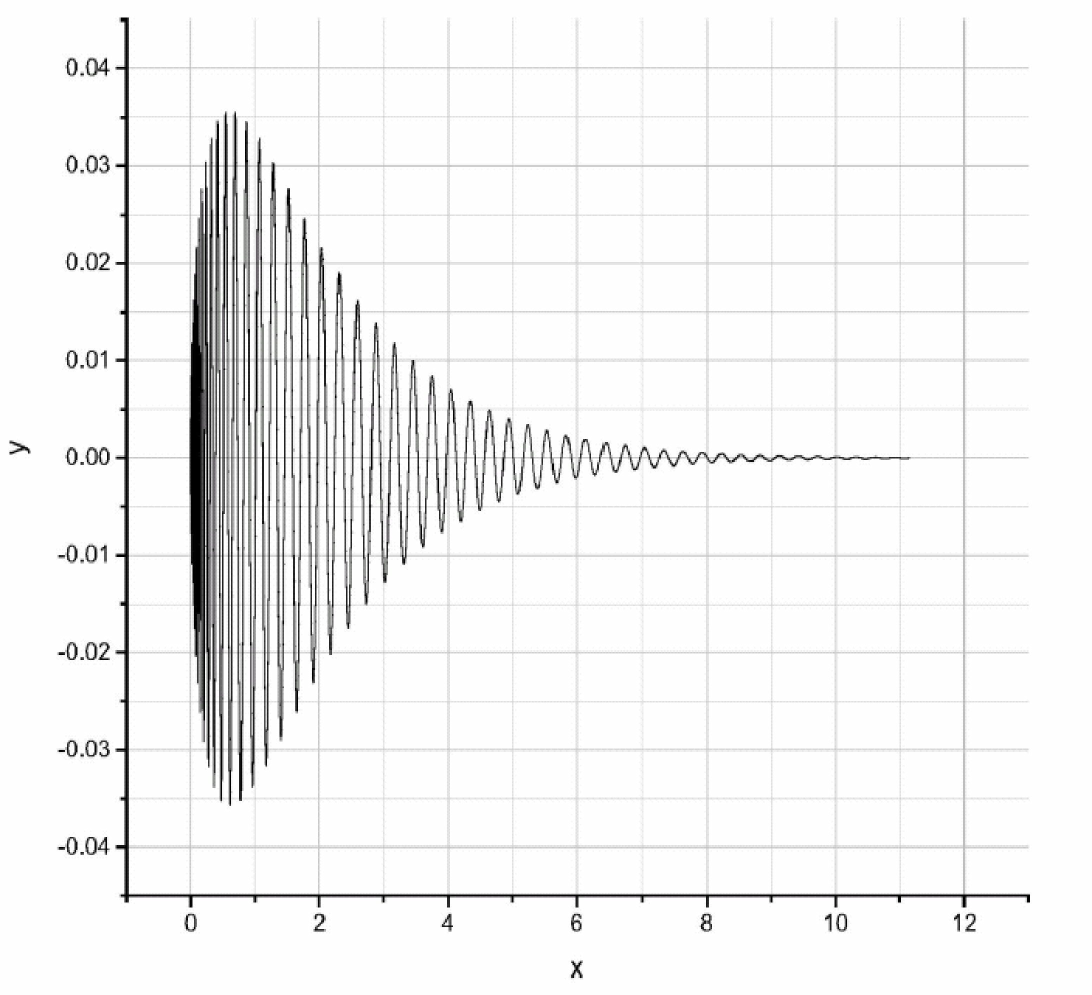

FIG. 2. The electron trajectory in the plane *XY* for the value of the relativistic field parameter $f = 2F/\omega c = 10$. The dimensionless electron coordinates are given in units of the skin layer depth c/ω_p.

It is seen that the amplitude of electron oscillations in the transverse direction *Y* is much less than its drift motion in the direction *X* of the pulse propagation. It is concluded that an electron penetrates many skin layers into field-free matter even before the laser pulse reaches its maximum.

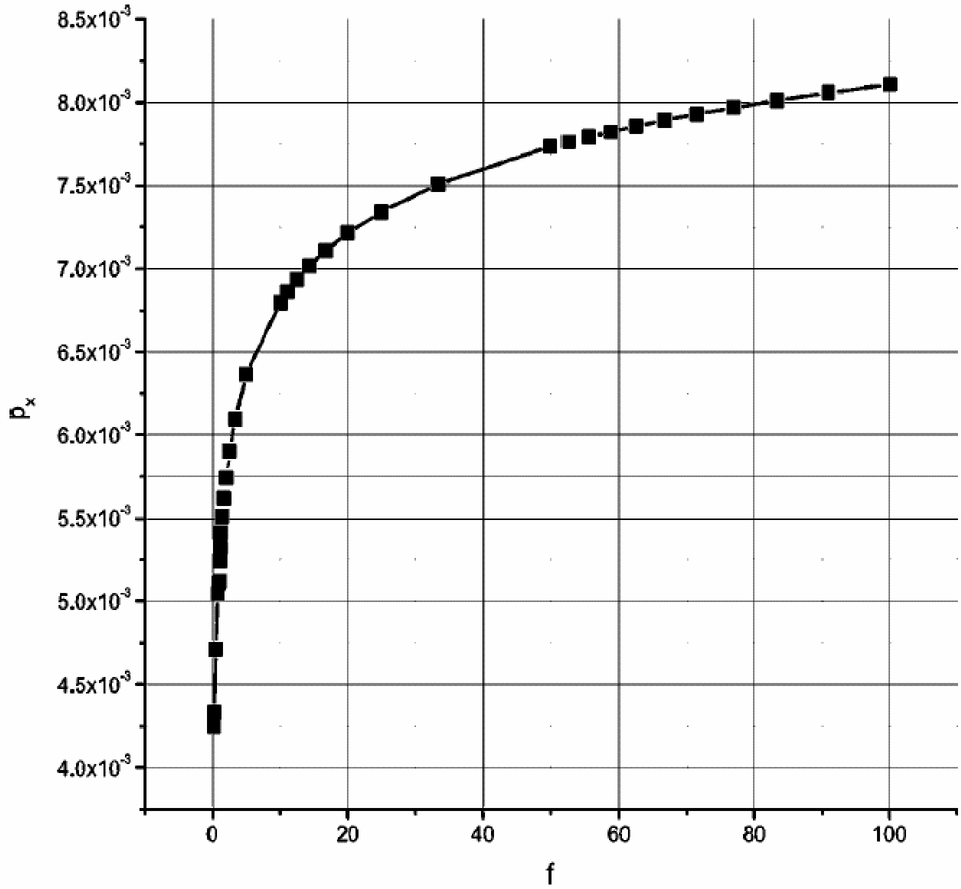

FIG. 3. The dependence of the dimensionless final electron drift momentum p_x (in units of mc) along the propagation of a laser pulse inside the skin layer on the relativistic field parameter $f = 2F/\omega c$.

Thus, the relativistic electron drift in overdense plasma along the propagation of laser radiation remains after the end of the laser pulse, unlike the relativistic drift of free electrons in underdense plasma. The following deep penetration of electrons into field-free matter takes place until collisions stop this motion.

[1] A. Pukhov, Rep. Prog. Phys. **66**, 47 (2003)

[2] A. Pukhov and J. Meyer-ter-Vehn, Phys. Rev. Lett. **76**, 3975 (1996)

[3] V.S. Rastunkov and V.P. Krainov, Phys. Rev. E **69**, 037402 (2004)