RADIAL ELECTRIC FIELDS IN THE BEAT-WAVE ACCELERATOR

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ABSTRACT

The DC pondermotive force of the laser beams in the beat-wave accelerator causes a small but significant difference in the radial focusing of positive and negative charged particles.

Due to the finite width of the laser pump beams the electric fields generated in the "beat-wave accelerator"[1] will not be purely longitudinal. The effects of the radial dependence of plasma wave amplitude have been analysed by J.D. Lawson[2]. It is assumed that the longitudinal wave amplitude has a quadratic dependence on radius, r

$$E_z(r) = E_z\left(1 + \frac{r^2}{r_0^2}\right) \qquad (1)$$

where r_0 is the laser beam radius.

The radial electric field is then found to be

$$\frac{E_r}{E_z} = \frac{2r}{k_p r_0^2} \qquad (2)$$

where k_p is the wavenumber of the plasma wave. The longitudinal field E_z is given in terms of the plasma density fluctuation as

$$eE_z = m\, c\omega_p \cdot \frac{\delta n}{n} \, .$$

Thus

$$eE_r = \frac{2mc^2}{r_0^2} \cdot \frac{\delta n}{n} \cdot r \qquad (3)$$

since $\omega_p/k_p = c$

and if $\delta n/n$ is limited by detuning at large amplitude then

$$\frac{\delta n}{n} = \frac{16}{5} \left(\frac{v_0}{c}\right)^{2/3} . \tag{4}$$

The radial electric field E_r is 90° out of phase with the longitudinal field E_z so that one half of the accelerating cycle is radially focusing and one half is radially defocusing.

A second, and hitherto neglected effect is the radial field induced by the DC component of the ponderomotive force. This force results in the expulsion of plasma electrons from the intense parts of the laser beam and thus tends to focus injected negative charges and defocus injected positive charges. It introduces an asymmetry between the betatron wavelengths in the two halves of a linear collider.

The ponderomotive potential is conveniently expressed in terms of the oscillating velocity of the electrons in the laser fields

$$e = \frac{1}{4} m \left(v_{01}^2 + v_{02}^2\right) \quad ; \quad v_0 = \frac{eE}{m\omega} .$$

For conveniience we assume that $v_{01} = v_{02}$.

If the plasma potential is assumed to be parabolic and to build up at the boundary $r = r_0$ to just compensate the ponderomotive potential then

$$eE_r^{DC} = \frac{mv_0^2}{r_0^2} \cdot r . \tag{5}$$

Since the injected particles are moving close to the phase velocity of the electromagnetic waves they do not see the ponderomotive force of the pump waves, but they are affected by the potential built up by the ponderomotive force acting on plasma electrons.

The ratio of DC to AC electric fields is given by (3) and (5) as

$$\frac{E_r^{DC}}{E_r^{AC}} = \frac{5}{32\xi} \left(\frac{v_0}{c}\right)^{4/3}$$

where ξ is the ratio of $\delta n/n$ achieved in practice to the value of $\delta n/n$ given by the detuning limit. Unless ξ is very small the DC field will introduce a small, but noticeable difference in the focusing properties for positive and negative particles.

ACKNOWLEDGEMENTS

This work arose out of discussions in the media working group and thanks are particularly due to J.D. Lawson, W. Willis, B.W. Montague and P.B. Wilson.

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