SOME INTERACTION PECULIARITIES OF RELATIVISTIC PARTICLES WITH UHF ELECTRIC FIELD OF HIGH INTENSITY AT LARGE DISTANCES

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ABSTRACT

Interaction of relativistic charged particles with high intensity UHF electric field has been studied. Magnetic component of the field is taken equal to zero. It is shown that interaction process has some peculiarities depending on ratio between input particle energy and field intensity. In particular, an acceleration of part of monoenergetic electron beam on account of other part with simultenious energy transfer from the beam to the field is possible.

MATHEMATICAL MODEL

Mathematical model of particle movement is taken from [1]. Equation of movement:

$$\frac{dmv}{dt} = qE + q(v \times B), \qquad (1)$$

here $m = \frac{m_0}{\sqrt{1-\beta^2}}$ – mass; m_0 - rest mass of the particle; v – velocity of the particle; c – velocity of light; q – charge of the particle.

Magnetic field is equal to zero:

$$\omega \frac{dmv}{d\vartheta} = qE_0 \sin\vartheta = \frac{qV_0}{h}\sin\vartheta, \qquad (2)$$

hence

h – interaction distance, V_0 -amplitude of microwave field.

After integrating equation (2) we introduce function $A(\vartheta)$:

$$A(\vartheta) = \frac{\beta}{(1-\beta^2)^{1/2}} = \frac{\beta_e}{(1-\beta_e{}^2)^{1/2}} + \left(\frac{qV_0}{m_0c^2}\right)\left(\frac{\lambda}{2\pi h}\right)\left[\cos\vartheta_e - \cos\vartheta\right], \qquad (3)$$

where $\beta = \frac{v}{c}$, λ – wavelength, β_e, ϑ_e - are the relative velocity of the particle and initial phase (phase of the field at start of interaction).

The equation (3) governs the movement of the particle in the alternating electric field. The path traversed by the particle in this field depending on entrance phase is calculated by formula:

$$S = \frac{c}{\omega}\int_{\vartheta_e}^{\vartheta_h} \frac{A(\vartheta)d\vartheta}{\left[1 + A^2(\vartheta)\right]^{1/2}}. \qquad (4)$$

On the basic of this mathematical model a software for calculation of relativistic charged particle with UHF was developed. This software allows determination of particle energy, interaction time, description the dependence of the path traversed by the particle from the time etc., i.e. gives full description of interaction process. It can be used for a particle of any mass, energy and charge interacting with electric field of arbitrary frequency and intensity.

RESULTS AND DISCUSSION

For calculation the following initial parameters were set: frequency and intensity of the UHF electric field, energy and input phase of the electron. Varying the input phase from 0 to 360 degrees with 1 or 3 degree's step one can reveal the process of interaction with monoenergetic electron beam. To test the validity of the calculations the other problem of interaction of electron with 3-dimensional field of standing wave in rectangular waveguide was solved. The outlined problem represents the special case of 3-dimensional field. In spite of the fact that these were different problems and their solutions were performed mathematically in a different way, the results of calculations by both programs coincide within the accuracy less than 0.1%. This confirms the reliability of results.

The calculations have been performed in the frequency range 0.8-3 GHz, field intensity varying from 100 kV/m up to 100 MV/m. The input energy of electrons varied from 7 keV to 700 MeV. Fig.1 illustrates the typical dependence of maximal energy acquired by electrons from interaction distance (upper curve) and average energy acquired (or lost) by electron with input phase from 0 to 2 π (lower curve). The input electron energy was 7 MeV,

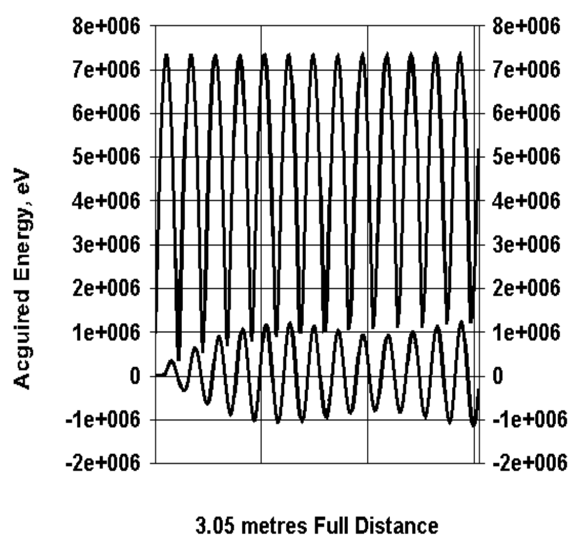

Fig.1.

field intensity (amplitude value) 100 MeV, frequency 1.3 GHz. Data analysis leads to the following conclusion:

1) At a relative to wavelength long distance of $\lambda/3$ electron acquires 6.45 MeV, i.e. ~80% of maximal energy which they could obtain in a permanent field of the same intensity. Average energy obtained by all electrons with input phase from 0 to 2π is close to zero. That means, the acceleration of electrons could be performed on account of other electrons of the same constant monoenergetic beam. This circumstance can be useful for superconducting resonators.
2) At the distance of $\lambda/2$ maximal accelerated are electrons with zero input phase. They obtain 64.3% from the maximal energy which could be acquired in the permanent field of the same intensity. This value is practically the same for relativistic electrons of different energies.
3) Maximum of acquired energy is repeated exactly through the distance equal to wavelength λ.
4) Minimal value of maximal electron energy is also repeated through the distance λ and has tendency to increase slowly with distance.
5) At the distance approximately equal ~5/4λ (28cm) electrons with input phase near to zero acquire energy of ~4.5 MeV whereas average energy balance shows transmission of energy from electron beam to the field. This effect could be observed only for relativistic electrons at large interaction distances. On Fig.2 the dependence of the electron energy distribution from the input phase for the 28 cm interaction distance is presented. It is seen, that maximal energy (~4.5 MeV) is acquired by electrons with input phase near zero, and ~5 MeV of energy is lost by electrons with input phase near 180°.

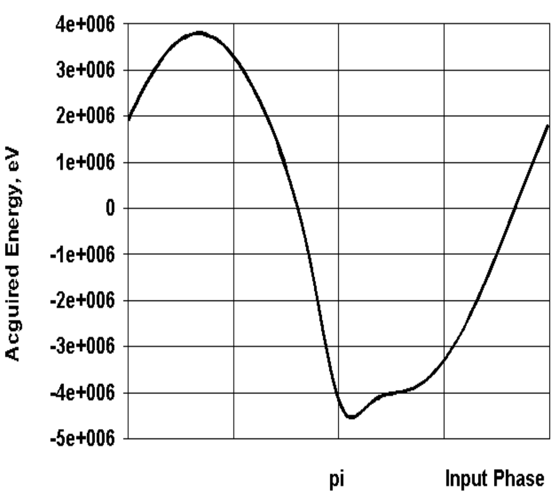

Fig.2.

6) At the distance of 31 cm electrons acquire maximum of energy 6.5 MeV without taking energy from the field.
7) On Fig.3 the input phase dependence of electron energy distribution at the distance of 3.01 m is presented. At this distance electron with input phase 0 acquire minimum of energy, whereas electrons with phase close to 180° lose totally their energy.

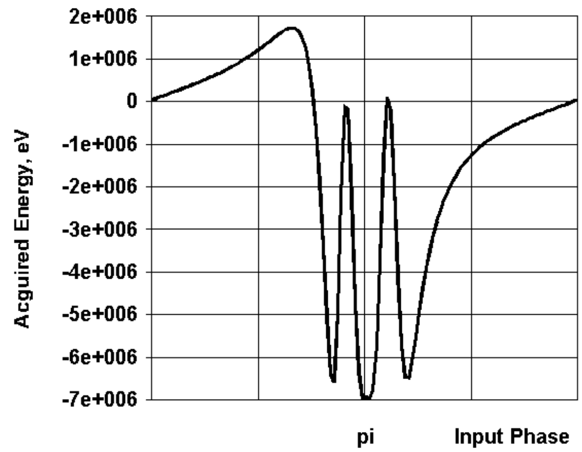

Fig.3.

8) To compare relativistic and nonrelativistic electron interaction with UHF field at large distances Fig.4 is presented. Electrons have input energy of 1 MeV, field intensity is equal 100 MV/m, frequency is equal 1.3 GHz. Special features noted above are absent on these curves.

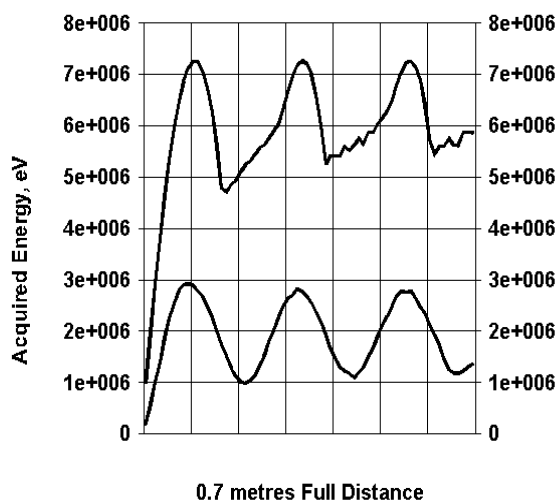

Fig.4.

CONCLUSION

The above mentioned peculiarities are specific only to relativistic electrons by definite ratios between field intensity, frequency, electron input energy. They can be used for acceleration of permanent monoenergetic electron beam with simultaneous energy transmission from beam to the field, bunched beam braking and in other cases, like movement in cosmic fields.

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REFERENCES

[1] Coleman P. D. Theory of the Rebatron - a Relativistic Electron Bunching Accelerator//N.Y.: Journal of Applied Physics. 1957. v. 28, [1] 9. p. 927–936.