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NONLINEAR DYNAMICS OF ELECTRONS IN THE ROTARY ELECTROMAGNETIC FIELD

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The paper is devoted to investigation of exchange of energies between an electron and an electromagnetic wave, both rotating in the azimuth direction inside a high-quality coaxial resonator with radial electrostatic field. It is shown that the wave mostly acquires the potential energy of the electron. The results depend insignificantly on the ordinal number of azimuth mode of the resonator proper wave.

The nonlinear effects in microwave amplifiers and generators, whose operation is based on interaction of the rotating electrons with rotary electromagnetic fields, have been described in literature in detail [1–5]. Since the deceleration of the waves of the millimeter and submillimeter range presents considerable difficulty [6], particular attention has been given to devices free of complex slow-wave systems. A simple design is inherent in devices of the orbitron type [7], in which the electrons are retained in orbits, close to circular ones, by the electric field of a thin charged thread, which forms the inner cylinder of the coaxial resonator. Moreover, the electrons may be non-relativistic, because in the charged thread field they represent non-isochronous oscillators, which is necessary for grouping the electrons. The mechanism of perturbation amplification in the orbitron is related to the azimuthal grouping of electrons in the logarithmic potential. The electrons are biased against the acting azimuthal force. Because of this, the pushing-apart forces, arising due to fluctuation in the electron contraction, lead, as time goes on, not to expansion of the bunch but to its compression (the effect of negative mass).

In nonlinear analysis of operation of gyroresonant devices and those with centrifugal electrostatic focusing (CEF), the efficiency and gain factors are calculated as functions of the longitudinal coordinate of the resonator or waveguide [1–5]. The reason is that in such systems the “exhausted” electrons are removed from the interaction space due to their longitudinal (drift) velocity. By contrast, in the orbitron the electrons escape the interaction space because of settling to the charged thread. In this case the longitudinal velocity of electrons V_z is close to zero. Hence, we must analyze the efficiency factor as a function of the azimuth angle. In [8–12] we proposed a linear theory of instability of a cylindrical layer of electrons in the orbitron type devices. The present work is devoted to analysis of the nonlinear stage of development of instabilities in the conditions of amplification of proper waves in the coaxial resonator when the electrons are rotating in the field of a positively charged thread.

Since the density of the electron cloud in the orbitron is low (the respective plasmic frequency is less than the generated wave frequency by an order [7]), we may limit ourselves by the kinematic approximation, i.e., neglect the space charge field. Consider a high-quality coaxial cylindrical resonator of infinite length in the z-axis direction (here we use the cylindrical system of coordinates r, φ, z). The inner radius of the resonator outer cylinder equals r_2 while the radius of the thread — r_1 ($r_1 \ll r_2$). The latter creates a radial electrostatic field $E_0(r) = 2Q/r$ (Q is the charge density per unit length). According to experimental data [7], the electron trajectories are close to circular. Because of this, assume that in the absence of the high-frequency field the electrons are moving along the circle line of radius r_0. Their velocity does not

REFERENCES

1. V. A. Zhurakhovskii, Nonlinear Oscillation of Electrons in Magnetically Directed Flows [in Russian], Naukova Dumka, Kiev, 1972.

2. A. A. Kurayev, Microwave Devices with Periodic Electron Flows [in Russian], Nauka i Tekhnika, Minsk, 1971.

3. S. V. Kolosov and A. A. Kurayev, Radiotekhnika i Elektronika, Vol. 18, No. 12, pp. 2558–2566, 1973.

4. T. F. Dikun, A. A. Kurayev, B. M. Paramonov, and A. K. Sinitsyn, Radiotekhnika i Elektronika, Vol. 28, No. 8, pp. 1624–1632, 1983.

5. A. A. Kurayev, Power Microwave Devices [in Russian], Radio i Svyaz', Moscow, 1986.

6. Z. I. Taranenko and Ya. K. Trokhimenko, Slow-Down Systems [in Russian], Tekhnika, Kiev, 1965.

7. I. Alexeff and F. Dyer, Phys. Rev. Lett., Vol. 45, No. 5, pp. 351–354, 1980.

8. V. V. Dolgopolov, M. V. Dolgopolov, and Yu. V. Kirichenko, Izv. VUZ. Radioelektronika, Vol. 40, No. 12, pp. 16–22, 1997.

9. V. V. Dolgopolov, Yu. V. Kirichenko, and I. F. Kharchenko, Izv. VUZ. Radioelektronika, Vol. 42, No. 2, pp. 33–40, 1999.

10. Yu. V. Kirichenko, ZhTF, Vol. 69 Iss. 6, pp. 112–114, 1999.

11. Yu. V. Kirichenko, ZhTF, Vol. 70, Iss. 8, pp. 141–142, 2000.

12. Yu. V. Kirichenko, Izv. VUZ. Radioelektronika, Vol. 43, No. 3, pp. 52–58, 2000.

13. N. S. Ginzburg, I. A. Man'kin, V. Ya. Polyak et al., Capture of particles by a synchronous wave as a method for improvement of microwave device efficiency, in coll.: Relativistic high-frequency electronics [in Russian], Iss. 5, Institute of Applied Physics at AS USSR (city of Gor'kii), pp. 37–77, 1988.

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