INDUCED SYNCHROTRON RADIATION OF ELECTRONS IN CAVITY RESONATORS

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Induced synchrotron radiation of electrons moving along helical trajectories in a homogeneous magnetic field, or along trochoidal trajectories in crossed uniform electric and magnetic fields, were treated theoretically in several papers (see, for example, [1-7]) as applied to amplifiers and generators of electromagnetic oscillations, using various electrodynamic systems: tank circuits and transmission lines with lumped parameters, ordinary waveguides and cavity resonators, and quasioptical resonators. Induced synchrotron radiation was first observed experimentally in electronic vacuum amplifiers and in traveling-wave generators [2,8,9]. Increasingly more attention has been paid recently to the interaction between helical electron beams and the vibrations of cavity resonators [10,11].

Experiment has confirmed the possibility of obtaining high power even when ordinary waveguides with cross section of the order of λ^2 (λ = wavelength) are used. Further increase in the total radiation power can apparently be attained by increasing the volume of the "active medium" (cross section of the electron beam or the volume of the nonequilibrium magnetoactive plasma), which makes it necessary, in turn, to go over to quasioptical electrodynamic systems of the "open" type. We describe below the elements of the apparatus (Fig. 1) and present some results of observation of coherent synchrotron radiation of helical electron beams in "open" cavity resonators of sufficiently large volume. The experiments were carried out at power levels higher than in [10,11].

Resonators. The self-excitation (generation) of electromagnetic oscillations at the electron gyrofrequency (magnetic field H_0 = 3200 Oe, λ = 3.4 cm) was observed in a resonator constituting a 20 cm section of rectangular waveguide (TE_{011} mode). The electron beam was introduced at the maximum of the electric field from the end, through a waveguide biased beyond cutoff. The second, open end of the cavity was connected with a large-section waveguide used to extract the energy and to serve simultaneously as a collector.

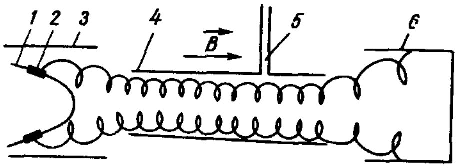

Fig. 1. Schematic diagram of oscillator using induced electron synchrotron radiation. 1 - Cathode, 2 - emitting surface, 3 - anode, 4 - resonator, 5 - high-frequency power output, 6 - collector, B - static magnetic field.

The induced synchrotron radiation of the electrons at the second harmonic of the gyrofrequency (H_0 = 4500 Oe, λ = 1.2 cm) was observed in a barrel-like open resonator (TE_{021} mode). The energy was extracted by a waveguide coupled to the resonator through an opening in the side wall.

Electron beam. The attainment of nonequilibrium electron distribution [1)] in large volumes entails as a rule considerable difficulties. In a magnetoactive plasma it is possible to use for this purpose, in particular, high-frequency heating of the electrons with subsequent compression of the magnetic field. The simplest way, however, is to use electron beams with strongly "twisted" helical trajectories in a sufficiently high vacuum. In the installation described, such a beam was produced by an axially-symmetrical electron beam with conical cathode. The smoothness of variation of the magnetic and electric static fields in the region of the gun and in the drift space ensured conservation of the adiabatic invariant $W_\perp/\omega_H$, where $W_\perp$ is the energy corresponding to the rotational motion of the electrons and ω_H is their gyrofrequency. For the electrons leaving the cathode, $W_{\perp c} = (mc^2/2)E_{c\perp}^2/H_c^2)$, where H_c is the magnetic field at the cathode, and $E_{c\perp}$ is the electrostatic field component perpendicular to it. as the electrons move in the growing magnetic field H, their rotational energy increases by a factor H/H_c.

Results. The conditions for self-excitation of electromagnetic oscillations at small longitudinal electron velocities (lower parts of the $I_{start}(V_{r-c})$ curve in Fig. 2) are in satisfactory qualitative agreement with the relation

$$I \geq I_{start} \approx \frac{2 \times 10^4}{Q} \frac{V}{\ell^3} \frac{\beta_\parallel^3}{\beta_\perp^2 n} \tag{1}$$

where I is the electron current, Q, V, and ℓ the Q-factor, volume, and length of the cavity, $\beta_\perp = v_\perp/c$ is the ratio of the electron rotational velocity to the velocity of light c (a parameter characterizing the non-isochronous nature of the rotation), $\beta_\parallel = v_\parallel/c$, $v_\parallel$ is the longitudinal electron velocity, and $n = \omega/\omega_H = 1.2$ is the ratio of the frequency of the generated radiation ω to the electron gyrofrequency ω_H. Relation (1) is valid if the frequency spectrum of the forces exerted on the electrons by the alternating field in the resonator is sufficiently narrow (width of order $v_\parallel/\ell$) so that the intensity of the induced radiation is determined essentially by the unequal spacing of their energy spectrum (non-isochronous nature of the

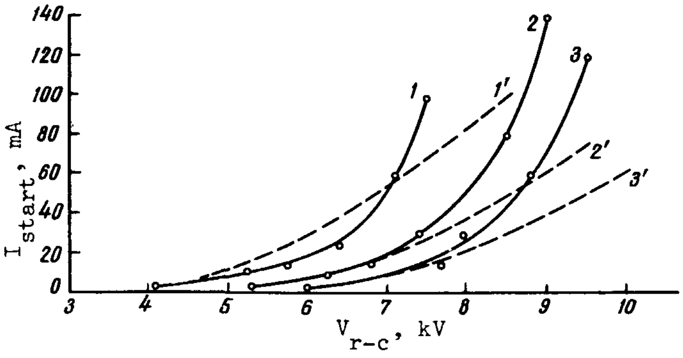

Fig. 2. Dependence of the starting current on the resonator-cathode voltage for a generator with $\omega \approx \omega_H$ (Q = 200, $V/\ell^3 = 3.5 \times 10^{-3}$) for different anode-cathode voltages: 1 - 9 kV, 2 - 10 kV, 3 - 12 kV. Solid - experimental curves, dashed - plotted from formula (1).

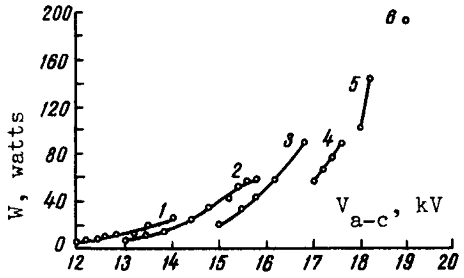

Fig. 3. Generated power vs. anode-cathode voltage for generator with $\omega \approx 2\omega_H$ at 320 mA current and resonator-cathode voltages 12 (1), 13 (2), 15 (3), 17 (4), 18 (5), and 19 kV (6).

rotation). At large longitudinal velocities, the usual "linear" induced absorption, which is not taken into account by (1), becomes significant. This explains the disparity between experiment and the curves calculated from (1) at large values of $v_{\parallel}$ (Fig. 2).

The power of the generated radiation increased monotonically in the investigated apparatus with increasing rotation electron velocity and with decreasing longitudinal velocity (Fig. 3), and also with increasing electron current. In the generator with $\omega \approx \omega_H$ the power obtained was 6 W at current 80 mA, beam voltage 8 kV, and $v_{\perp} \sim 3v_{\parallel}$, while in the generator with $\omega \approx 2\omega_H$ the power was 190 W at 320 mA, 19 kV, and $v_{\perp} \sim 3v_{\parallel}$. Further increase in power was hindered by difficulties in cooling the generators. Furthermore, a gyroresonance discharge was produced in the residual gas in the apparatus with $\omega \approx \omega_H$. The same causes kept the electron efficiency from reaching the theoretically predicted value 19% [6]. In experimental maser models with trochoidal electron beams and traveling waves, the efficiency reaches 10 - 15%.

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1) The most convenient is a δ-function distribution of the electrons with respect to the free-oscillation frequencies.

STIMULATED RAMAN SCATTERING AND PARAMETRIC PROCESSES

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We discuss in this note the feasibility of a parametric amplifier (oscillator) and frequency converter, in which the pumping is produced by non-coherent molecular oscillations