HIGH POWER MICROWAVE GENERATION IN VIRTUAL CATHODE SYSTEMS

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Pulsed high-power microwave generation by means of high current accelerator system has recently become an intensive area of research , the most promising among them being virtual cathode devices or vircators [1].

There are two mechanisms which lead to production of high-power microwaves in vircators [2]. The first deals with electrons , oscillating near the anode and the second with virtual cathode (VC) oscillating as a whole. Generally both mechanisms are presented, but in a given device one may dominate the other. If the anode is thick enough to absorb reflected electrons thus preventing them from reentering the diode region, the first mechanism vanished. In this paper we discuss the second mechanism, which is realized, for example, in reditron [3-4]. Anode plasma produced by high-current electron beam passing through the anode is taken into account.

The simulations were done with 2.5-dimensional fully electromagnetic and relativistic particle-in-cell code. The hollow electron beam with constant density is continuously injected into the cavity through the hole in its left side (anode of reditron). An external axial static magnetic field is imposed in all of our computer simulations. If the beam current is smaller than space-charge limiting current the VC (nought of axial electric field - E and particle density maximum - ρ) is located in the center of the cavity and no reflection of electrons occurs. When the beam current is larger than space-charge limiting current, the location of VC changes: VC moves toward anode and this distance depending upon the geometry of the cavity, external magnetic field magnitude and beam parameters. In addition to that reflected electron current appears in the cavity, its value being less than output beam current.

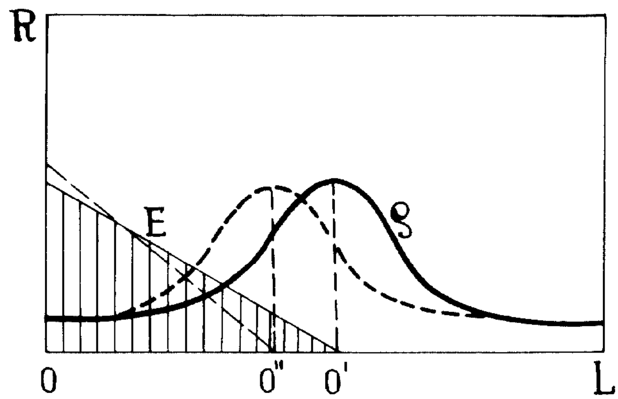

Fig.1

The mechanism of such movement can be explained by the fact, that current rise leads to increasing of potential barrier (dashed area in Fig.1), produced by cavity space charge distribution. When the kinetic energy of the particle is less than potential barrier $W < \int_0^{0'} E\,dl$, the particle is reflected from the VC and moves toward the anode. It means that VC as a whole moves toward the anode until the value of potential barrier becomes less than kinetic energy of injected particle $W > \int_0^{0''} E\,dl$.From this moment VC turns around and moves in opposite direction, oscillating around new equilibrium point. The amplitude of oscillation rise with current.

The picture varies when the beam current becomes essentially higher than space-charge limiting current. Computer simulation shows (Fig.2) that in this case VC also moves toward the anode, but the number of particles passing through the potential barrier becomes less than that of reflected ones. It leads to VC density rise up to the moment when VC practically reaches

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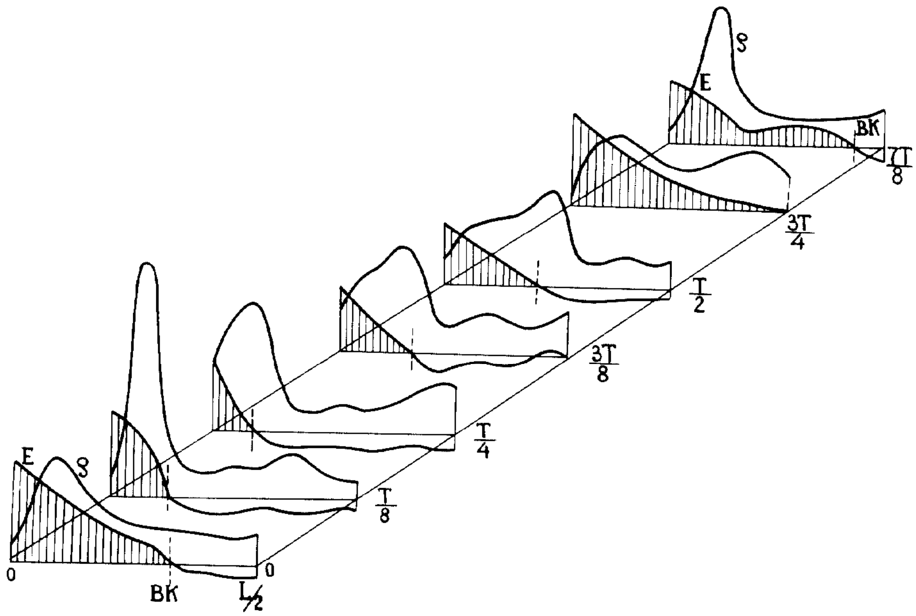

Fig.2

the anode, electrons strike it and get absorbed. The VC particle density and value of potential barrier fall down sharply and injected particles pass through it easily thus resulting in VC (particle density maximum and nought of axial electric field) moving toward the center of the cavity until the potential barrier will rise enough to stop the particles. After that the process is repeated, producing VC oscillations and strong modulation of transmitted electron current (Fig.3). This mechanism can be used for strong modulation of high-current electron beams.

Simulation shows that radiation frequency generated by electron beam is in good relation with transmitted beam frequency modulation.

In one-dimensional model VC oscillation frequency is given by [5] :

$$F = 10.2\sqrt{J/\beta\gamma} \cong 2.5\, f_p \,, \qquad (1)$$

where f-frequency in GHz , J-current density in kA/cm^2,f_p-plasma frequency.Computer simulation gives the value of frequency less then that in (1) , which can be explained by the fact that in reality transverse movement isn't frozen;this makes VC particle density value less than that of one dimensional model.

When high current electron beam passes through the anode , plasma is formed in anode region. Anode plasma density can be greatly changed during the beam pulse depending on beam and system parameters . We have studied the influence of anode plasma density on VC formation mechanism.When plasma density approximately equals injected beam density vircator's main characteristics (value of frequency and power generated) are practically unchanged.If plasma density is in order of magnitude higher than beam current , VC oscillation amplitude and microwave radiation frequency decrease.Since anode plasma density changes during the beam pulse,it can lead to differential changes of microwave radiation frequency and power.

Let us evaluate beam generated power in vircator.According to [6] microwave radiation power of oscillating electron is given by

$$P = \frac{1}{12}\,\frac{e^2c}{a^2}\left(\frac{E}{m\,c^2}\right)^3 f(y) \,, \qquad (2)$$

where $f(y)$-normalized spectral function, a-amplitude of oscillation, E-total energy.In relativistic case power, generated by the electrons, oscillating around the anode or VC oscillating as a whole can be calculated from

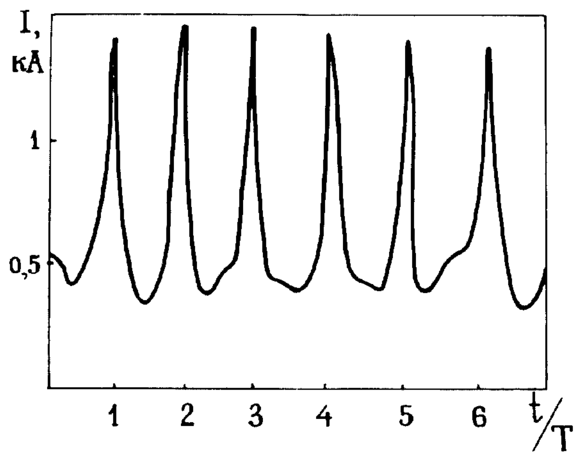

Fig.3

$$P = \frac{1}{12}\frac{e^2c}{a^2}\left[\frac{E}{m\,c^2}\right]^3 N^2 f(N)\ , \qquad (3)$$

where N-number of oscillating electrons, $f(N)$ - coherent parameter. Defining current as $I=\frac{eNc}{a}$ for cavity with finite Q-factor we obtain:

$$P \cong 2.10^{-3}\gamma^3 Q\ I^2 f(N), \qquad (4)$$

where P-power generated in GW, γ-relativistic factor, I-current in kA. For typical vircator with parameters I = 10kA and γ = 2 we have in case $f(N)$=1

$$P \cong 1.6\ Q\ ,\mathrm{GW}\ . \qquad (5)$$

Thus we obtain output power of GW level the electron beam current being I = 10kA and Q = 1 and P~10GW if I = 100kA or Q = 10.

Radiation spectral analysis from eq.(2) showed, that besides the main harmonic, whose frequency equals electron oscillating frequency near the anode or $f \sim f_p$,higher number harmonics do appear in spectrum. Their radiation power decreasing with their number increase, the radiation is concentrated in two cones with small angular spread.

Experiments of Phys. Int.Comp. have confirmed such character of angular distribution of the relativistic vircator radiation [7]

Hence we can make the conclusion that vircator is a source of powerful microwave oscillation not only of cm but also mm and sub-mm ranges.

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