ON OSCILLATIONS IN THE PREMODULATION DIODE OF THE VIRCATOR

O. G. Melezhik, A. V. Pashchenko, S. S. Romanov, I. M. Shapoval*

National Science Center "Kharkov Institute of Physics and Technology", 61108, Kharkov, Ukraine

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It is shown, that oscillation generation in premodulation diode of vircator caused by decelerated electron flow and two-flow instabilities.

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1. INTRODUCTION

The first vircator, that made use of the electron flow premodulation was the virtode [1]. Its action was based, first, on the property of the virtual-cathode (VC) electron flow to excite electric oscillations at a frequency close to the electron plasma frequency ω_{pe} [2] of the flow in the VC region, and, secondly, on the electron flow premodulation in the cathode region at the oscillation frequency by means of the waveguide, that transported a part of oscillation energy to the cathode gap, thereby realizing the positive feedback.

After the virtode experiment [1], further experimentation was made to use the mentioned positive feedback for performing premodulations in a specially created gap [3-5].

The key diagram of the experiment is presented in Fig.1,a.

The device made in accordance with the diagram includes the cathode gap, $0 < Z < Z_1$, the premodulation gap, $Z_1 < Z < Z_2$, and the VC gap, $Z_2 < Z < Z_3$. Whereas in the virtode [1] the feedback is realized due to the signal applied to the cathode gap from the VC, in the premodulation vircator the signal from the VC region is applied to the premodulation gap.

It has appeared, that the device based on this premodulation scheme of the electron flow has lower generation efficiency. The premodulation scheme, located in a special gap, is capable of operating in the single-mode regime only at small supercriticality of the electron flow. At high supercriticality, the generation spectrum shows the frequencies, the origin of which has not been previously interpreted unambiguously.

The present study is just intended to elucidate the situation. The appearance of frequencies, which enrich the oscillation spectrum, inhibit the realization of the single-mode operation at a high power of generation.

The generation scheme with three functional gaps also enables one to realize the "two-generator" mode of excitation of electric oscillations in the given device. We have in mind the possibility of oscillation excitation in the premodulation region because of the instability of the electron flow decelerated in the diode [9-12] (Fig.1,b), and also, the oscillation excitation in the VC gap owing to its instability. The two gaps exchange their electron flows, namely, the direct flow that goes from the cathode gap to the premodulation gap, and the flow reflected in the opposite direction. In principle, electron flows 1 and 2 may perform the feedback between the gaps as oscillation sources. It is hoped, that at certain parameters the resonance can be attained between the oscillation sources, and the required amplitude of oscillations can be provided.

The mode of this type was realized in the experiment [6, 7], where oscillations were excited both as a VC and as an electron flow oscillating around the anode grid [8].

The excitation of oscillations in the premodulation diode of the vircator has been investigated in ref. [13]. The oscillation spectra were obtained as functions of the injection current, the electron energy and the geometric parameters of the diodes.

The present paper deals with the nature of excited oscillations.

2. THE PREMODULATION-DIODE VIRCATOR

The schematic of the device is given in Figs.1,a,b. Our consideration will be carried out with the replacement of the scheme of the device by equivalent diodes [14]. In our case we shall have three diodes: the forming (accelerating) diode, the premodulation diode and the diode for VC creation. Each of the diodes presents a relatively autonomy electrodynamic region, through the boundaries of which electron flows can freely

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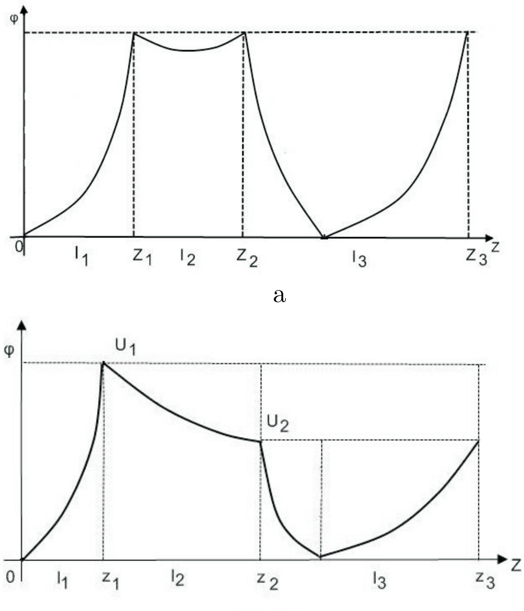
[*] Corresponding author E-mail address: shapoval@kipt.kharkov.ua

pass (or pass with the absorption coefficient f).



a

b

Fig.1. *Basic diagram of the premodulation vircator: a) without external action in the premodulation gap; b) with direct electron flow deceleration*

Fig.1,b shows the behavior of the potential φ in the electron flow. In the cathode gap $0 < Z < Z_1$ the potential increases by the Child-Langmuir-Boguslavsky law (three-halves power law) up to the U_1 value. On exit from the gap the electron flow has the density n_0 and the velocity v_0, sufficient to form the VC in the $Z_2 \leq Z \leq Z_3$ region. In the premodulation gap the potential drops down to U_2 without forming the potential minimum in the gap. A part of the flow, R, reflects from the VC and comes back to the $Z_1 \leq Z \leq Z_2$ region. For the description of the processes in the diode gaps we shall use the quantities dimensionless by the initial values of the first flow: the velocity $\bar{V}_j = V_j/\nu_0$, the density $\bar{n}_j = n_j/n_0$, the potential $\bar{\varphi} = e\varphi/m\nu_0^2$, the coordinates $\xi = Z/l_2$, $\bar{t} = \nu_0 t/l_2$. Below the bars above the quantities will be omitted. The propagation of the flow in the premodulation gap is described by the equation of motion

$$\frac{\partial \nu_j}{\partial t} + \nu_j \frac{\partial \nu_j}{\partial \xi} = -\frac{\partial E}{\partial \xi}\,, \tag{1}$$

the continuity equation

$$\frac{\partial n_j}{\partial t} + \frac{\partial}{\partial \xi}(n_j \nu_j) = 0\,, \qquad j = 1, 2\,. \tag{2}$$

and the Poisson equation

$$\frac{\partial E}{\partial \xi} = -q_1 n_1 - q_2 n_2\,, \tag{3}$$

where $E-$ electric field, dimensionless by $m\nu_0^2/el_2$, and

$$\tilde{q} = q = \frac{4\pi e^2 n_0 l_2^2}{m\nu_0^2}\,, \qquad q_2 = Rq\,, \tag{4}$$

R – is the reflection coefficient. In ref. [13] these equations are used to describe nonlinear stationary inhomogeneous states of electron flows and also to solve linearized differential equations of the first approximation on the oscillation amplitude.

3. THE DISPERSION EQUATION AND THE OSCILLATION SPECTRUM

Relying in the solutions obtained [13], the spectrum of oscillations was found, which may arise in the gap under consideration against the background of the stationary state.

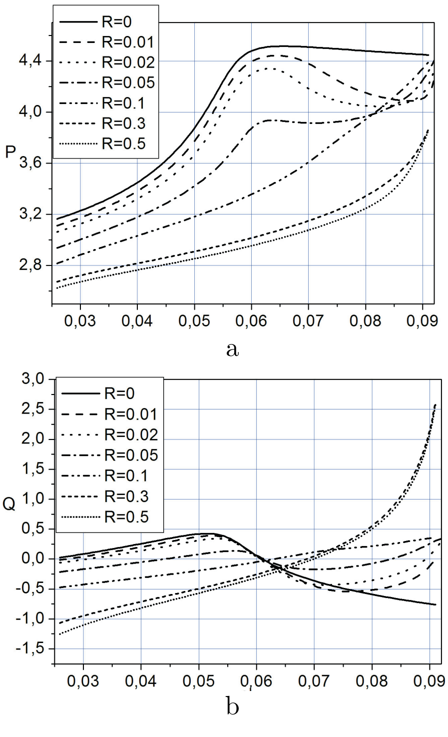
The dispersion equation (DE) that describes the spectrum has the form [12]:

$$\alpha[1+\alpha-e^{-2\alpha}(1-\alpha)-4G\alpha^3]+R+\chi(\alpha,q,V_L)=0\,, \tag{5}$$

where $\alpha = -Q + iP$, P is the frequency, Q is the increment (decrement) dimensionless by V_0/l_2, VL is the velocity of the first flow at the outlet from the premodulation diode, i.e. at the inlet of the gap with the VC. The function $\chi(\alpha, q, V_L)$ takes into account the presence of the second flow and is given in [13].

The derived DE gives the frequency and the increment of possible oscillations as functions of q, R and V_L. This DE coincides with the DE for the electron flow slowing down in the diode [9-12] at $R = 0$.

We give below the numerical solution of the DE, which gives the frequency P, the increment (decrement) Q as a function of q for the set of parameters R and V_L varying in the range from 0 to 1. As an example, Fig.2 shows $Q(q)$ and $P(q)$ at $V_L = 0.5$ and at a substantial variation of the parameter R.



a

b

Fig.2. *Dispersion characteristics of one of the harmonic oscillation modes under changes of the reflection coefficient R: a) frequencies; b) oscillation increments (decrements)*

At R=0 the solutions agree with the results from refs. [9-12].

4. THE INSTABILITY SLOWING DOWN ELECTRON FLOW

At small R ($R \leq 0.05$), just as in the single-flow case, the instability ($Q > 0$) described in refs. [9, 11] arises in the decelerated flow only if $q < 0.3$ (Fig.3).

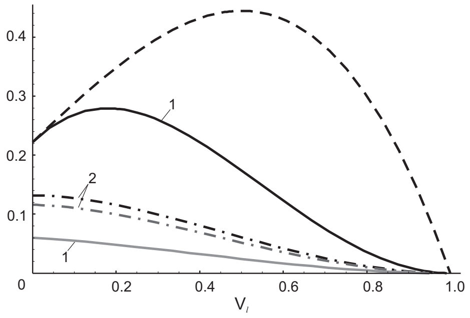


Fig.3. *Excitation regions of the first and second frequency bands. 1 - excitation region boundaries of the first frequency band; 2 - excitation region boundaries of the second frequency band; the dashed curve shows the boundary, below which the mode of electron flow deceleration is realized*

A strong dependence of the boundary curve of instability excitation on the parameters V_L is noticeable.

Below we give an example of the device operation for the VL=0.5 case, where, as seen from Fig.2, the variation range is $q < 0.1$. The related issue whether at this q the virtual cathode arises in the third gap ($Z_1 \leq Z \leq Z_2$) of the premodulation vircator [4,5] is studied into [13].

5. THE TWO-FLOW INSTABILITY

As R increases, i.e. with increasing role of reflected flow, the instability in the region of low disappears. However at high $Q \geq 0.08$ the two-flow instability manifests itself, having the increments as the reflection coefficient R gets high.

That in this case (with an increase at comparatively high q) the mechanism of two-flow instability acts, can be understood on the bases of the local analysis of the system (21) presented in [13]. In that analysis consideration is given to the wave solutions, where all the quantities are proportional to $e^{-i(\omega t-kz)}$, where k- is the wave vector on the coordinate- dependent coefficients of the system (21) (from [1]) are replaced by the values at the point under consideration.

Taking account of the terms in the coordinate expansions of stationary values gives small corrections to this result. In this analysis, consideration is given to the wave solutions, where all the sought quantities are proportional to $e^{-i(\omega t-kz)}$, where k is the wave vector, and the coordinate-dependent coefficients of the system (21) (from [1]) are replaced by their values at the point under consideration. A further simple analysis leads to the dispersion equation

$$\frac{1}{(W-1)^2} + \frac{R}{(W+1)^2} = h\,, \tag{6}$$

where $W = \omega / k\nu_1^0$ is the ratio of the local phase velocity of the wave to the local velocity of the first flow, and $h = k^2(\nu_1^0)^3/q$ The analysis of this DE suggests the conclusion about the threshold character of the instability. On the threshold, the quantities h0 and R_0 are related as

$$4h_0 = (1 + R_0^{1/3})(1 + R_0^{2/3})\,. \tag{7}$$

At $R > R_0$, the two-flow instability takes place [2]. By that

$$W_0 = \frac{-1 + R_0^{1/3}}{1 + R_0^{1/3}}\,. \tag{8}$$

The instability increment Q near the bordure has form

$$Q = \frac{2\sqrt{3}}{3} \frac{R_0^{-1/6}\sqrt{R - R_0}}{(1 + R_0^{1/3})^{1/2}}(kV^0)\,, \tag{9}$$

where V^0- stationary velocity of electron flow in the points of premodulation gap, and reflection coefficient R is related with parameters of neighborhood diode gaps by the formulae from [15]:

$$R = \left\{ 1 = \left[\frac{1}{9q_3(1 + \sqrt{1 + 9q_3})} \right]^2 \right\}^{1/2}\,, \tag{10}$$

where $q_3 = q_2(l_3/l_2)(1/V_L^3)$, q_3 and l_3 -Bursian parameter of diode with VC, q_2 and l_2 - premodulation gap parameters.

6. CONCLUSIONS

The nature of oscillations, which arise in the premodulation diode of the vircator, has been investigated.

It has been demonstrated that if the injected flow slows down in the diode, a specific instability of the decelerated electron flow is excited in the diode even in the presence of the reflected flow, however only at small reflect coefficient R.

The analysis has shown that the two-flow instability takes place in the premodulation diode of the vircator also in the case when the injected flow is not decelerated there by external voltage.

The oscillations excited in the premodulation diode of the vircator can be used for organizing both the beam and the wave feedbacks.

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О КОЛЕБАНИЯХ В ПРЕДМОДУЛЯЦИОННОМ ДИОДЕ ВИРКАТОРА

О. Г. Мележик, А. В. Пащенко, С. С. Романов, И. Н. Шаповал

Показано, что в предмодуляционном диоде виркатора генерация колебаний происходит благодаря неустойчивости тормозящегося электронного потока и двухпотоковой неустойчивости.

ПРО КОЛИВАННЯ У ПРЕДМОДУЛЯЦІЙНОМУ ДІОДІ ВІРКАТОРА

О. Г. Мележик, А. В. Пащенко, С. С. Романов, І. М. Шаповал

Показано, що у передмодуляційному діоді віркатора генерація коливань відбувається завдяки нестійкості потоку електронів, що гальмується, та двопотоковій нестійкості.