Mode Structure Research of a Field in the Triode with the Virtual Cathode with an Active Feedback

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Abstract – Experimental and theoretical investigations of feedback influence on the mode structure and efficiency of microwave radiation in triode with virtual cathode are presented in this paper.

There were obtained experimental results permitting to fix the interdependence between location of reflecting surfaces which forms feedback and frequency and power level of radiation. The dependence of power level from the location of this surface was established.

Theoretical investigations were executed by analytical methods with using of numerical modeling and the FEMLAB package. The eigen values of real resonance system were calculated as well as the mode structure of radiation was investigated. The impedance of resonance system was calculated and investigation of dependence of radiation efficiency from beam parameters and geometry of the system with reflectors was performed.

1. Introduction

The distinctive feature of triode with virtual cathode (VC) in compare with the other types of vircators is that the processes of forming electron beam and of transformation of beam energy to energy of microwave radiation are going by in this system in the same volume. This volume simultaneously is the electrodynamic structure where the feedback is realized. Therefore the selection of system geometry has an impact on a process of virtual cathode forming as well as on mode structure and efficiency of microwave radiation.

The results of experimental researches of feedback influence on the efficiency of generation of microwave radiation in triode with VC were presented in [1]. In this paper was shown that when the cylindrical camera, which is the electrodynamic structure of triode, is covered on the inside by radioabsorbent stuff then the reducing of radiation efficiency is observed. Thus when the reflection coefficient in working frequency band is about 3% the feedback was practically absent and the power level of SHF irradiation was reduced in several thousand times and was not more than 0.2MW.

In order to increase the generation efficiency in vircators the specially made adjustable feedback is usually used [2]. The feedback regulation permits to change in some limits the phase as well as the value of feedback by means of special devices including in the waveguide path.

The similar method of feedback regulation in the reflective triode with VC cannot be used because of its features mentioned above.

It is reasonably to use the structural features in triode for realization of adjustable feedback. In present paper the results of theoretical as well as experimental investigation of triode with VC, when adjustable feedback assured by mobile coaxial reflector are presented.

2. Experimental results

The scheme of experimental setup is shown on the Fig.1. In this construction the reflector plays a part of vacuum insulator protection from ingress of charged particles as well as ultra-violet and bremsstrahlung on it generated by oscillating electrons.. At the same time reflector is the element of electrodynamic structure. Thus it is possible to change the electromagnetic field phase in region of oscillating electron beam and VC by reflector shifting on anodeholder. Hence feedback is changing also.

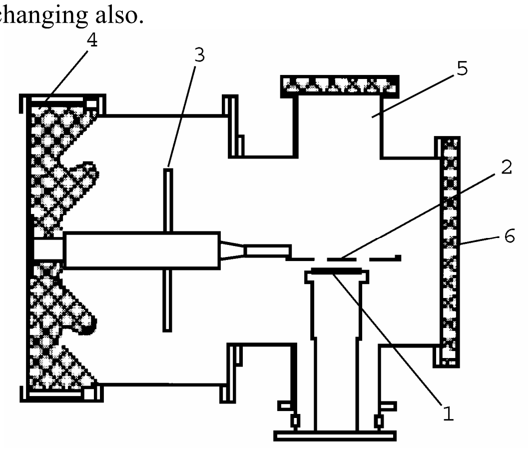


Fig. 1. The scheme of experimental setup:
1 - cathode, 2 - anode-grid, 3 - reflector, 4 - isolator of high-current electron accelerator, 5 - evacuated vessel, 6 - window for SHF-radiation output

The positive high voltage impulse with amplitude ~0.5MV from high-current electron accelerator was attached to anode- grid with diameter 20 cm and geometrical transparency 0.7. Cathode with diameter 10 cm was produced from stainless steel and was disposed coaxially with anode-grid. Experiments were realized with two cathode-anode gaps $d = 18$ and $20\ \text{mm}$ correspondingly. The distance L between the reflector and cathode axis was changed from 26.5cm to 40 cm in order to secure the vacuum isolation. Microwave radiation was putting out to free space through vacuum-dense window located on the butt-end of cylindrical camera of triode opposite of reflector. Radiation receiver [3] consisting of horn antenna, wave attenuator of polarization type and radiation frequency meter was located on the distance 3m from the window in the long-distance zone on the triode axis.

The measured dependencies of emissive power in relative units from L are represented on the Fig. 2.

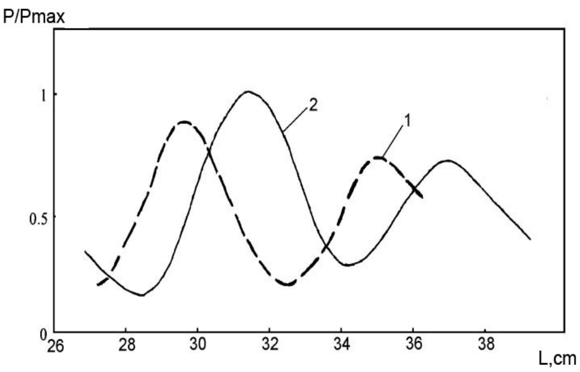
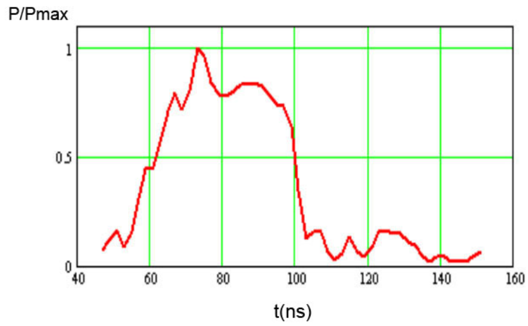


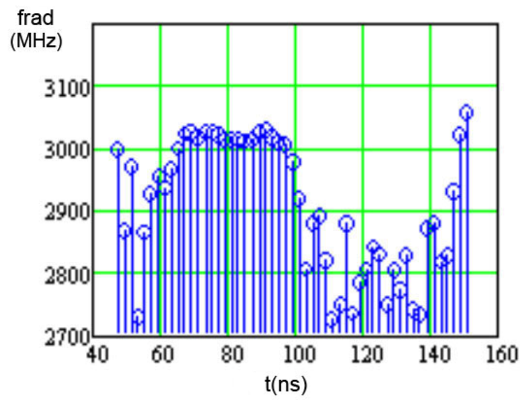
Fig. 2. The dependencies of relative radiation power from reflector location at cathode-anode gaps $d = 18\ \text{mm}$ (1) and $20\ \text{mm}$ (2)

The reflector shifting has an influence on emissive power which changing have periodical character. Radiation frequency was 3025±25 MHz at $d = 18\ \text{mm}$. The radiation frequency and character of frequency changing have nonessential deviations during the impulse at alteration of L from 28.5 cm to 35 cm. On the Fig.3 there are represented changes of relative power and radiation frequency during the high-power impulse action at location of reflector with $L = 29.0\ \text{cm}$ on the Fig.2 this location corresponds maximal power value on the curve for $d = 18\ \text{mm}$. At the $d = 20\ \text{mm}$ the radiation frequency was equal 2900±25 MHz with maximum power at $L = 31\ \text{cm}$. Radiation characteristics in that point are shown on Fig. 4.

In all experiments in question it was ascertained the increasing of radiated power during the high-power impulse action at tuning of reflector to generated frequency. The maximal general power level of triode radiation was estimated in 400 MW. In the case when reflector surface forming reflected

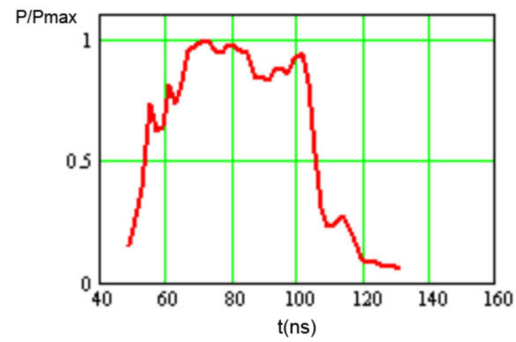


(a)

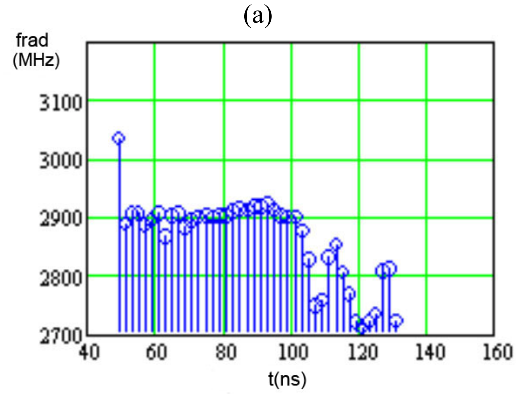


(b)

Fig. 3. The dependencies of radiation frequency changing (a) and relative power (b) during the impulse at $L = 29.0\ \text{cm}$



(a)



(b)

Fig. 4 The dependencies of radiation frequency changing (a) and relative power (b) during the impulse at $L = 31\ \text{cm}$

electromagnetic wave was covered by radioabsorbing stuff with reflection coefficient 13 dB, radiation power decrease more then in 6 times. That suggests the influence of reflector as feedback element on the generation process.

3. Theoretical results and discussions

The experimental results are well explained when the region of electrodynamic structure between cathode and reflector is regarded as half-restricted coaxial waveguide. The cylindrical camera of triode plays the role of external surface but internal conductor is anode-holder and anode-grid. The metal reflector is moving transversal waveguide face.

In such system because of high level nonlinearity of electron oscillations and fluctuation of VC synchronized with coherent oscillations of electron stream it is possible to support high level of interaction [4]. Excitation of electromagnetic oscillation is going at frequency ω which is multiple to electron oscillation frequency in potential well ($\omega \sim l\Omega_0, l = 1,2,3...$) with maximal increment

$$\zeta = \left[16\pi^2 \frac{\Omega_0 d}{c} \Lambda Z(k_z) K_x\right]^{1/2} \Omega_0 \cdot$$

Where $\Lambda = \frac{\omega_b^2}{2\pi\gamma_0\Omega_0^2}$, ω_b is plasma frequency of electron beam, γ_0 - is relative electron energy on anode, $K_x = \frac{c^2}{\Omega_0^3}\left(\frac{\partial\Omega}{\partial x}\right)_0$ - parameter of nonlinearity of electron oscillations, $x = a^2, a$ - amplitude of electron oscillations, c – is velocity of light, k_z - is longitudinal wave vector. Non-dimensional impedance $Z(k_z)$ reflects influence of geometry as well as wave type.

The numerical modeling of VC forming was carrying out in order to obtain information about distribution of beam current density in its cross-section. As a result it was fixed the dependence of current density distribution from beam radius (Fig.5). The impedance for obtained distribution of beam current density can be written as:

$$Z(k_z) = -\frac{\sin^2 k_z\Delta}{(k_z\Delta)^2}(e^{ik_z z_1} \cdot \sin k_z z_1 + \quad (2)$$
$$+e^{ik_z z_2} \cdot \sin k_z z_2)\rho_e(x_0),$$

where $z_{1,2}$ and Δ are coordinates of maximum of current density along Z-axis and maximum width correspondingly, $\rho_l(x_0)$ - describes the influence of electric field distribution along triode camera cross-section on impedance.

Let us regard the most probable types of oscillations which can be efficiently excited in that electrodynamic system. It are TEM-mode and H_{11} mode waveguide cross section field distribution for which is shown on Fig. 6,7, where A - anode, C - cathode.

In the beginning let us dwell on the of TEM-mode (Fig. 6.). In such a case the standing wave is formed between electron stream and reflector. The nods of this wave are situated on the distance $nc/2f_{\text{rad}} = n\lambda_{\text{rad}}/2 = n\pi/k_z$, $n = 0,1,2,...$ from reflector, $f_{\text{rad}} = \omega/2\pi$, and λ_{rad} – are frequency and radiation wave length.

As $z_2 - z_1 \sim \lambda_{\text{rad}}$, (Fig. 5) for the beam current distribution then it is needed for getting optimal excitation level to locate cathode axis in the node of standing wave and to make current distribution maximum more sharp. According to calculations the node of standing wave located on the distance 31.03cm for radiation frequency 2900 MHz and $n = 6$. The maximal power level of microwave radiation was obtained in experiments with cathode-anode gap 20 mm, when reflector was located in this very position. When cathode-anode gap is 18 mm, radiation frequency is 3050 MHz and $n = 6$, the node of standing wave must be located on the distance 29.5cm. It is in agreement with experiment also.

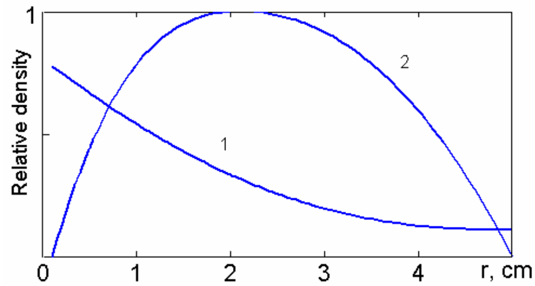


Fig. 5. Electron beam density distribution along beam radius. 1 – inside diode gap, 2-across the anode

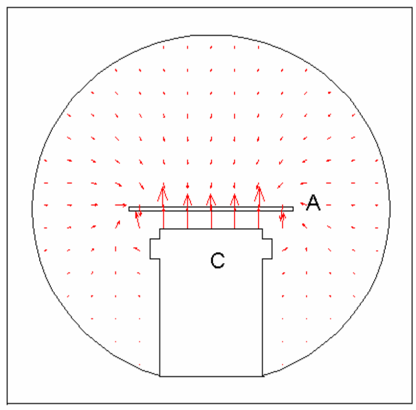


Fig. 6. Electric field of TEM mode

As it is shown by numerical calculations, the transversal wave vector for H_{11} mode in electrodynamic structure of triode with VC is situated between 0.1 and 0.11 cm^{-1}. It has a weak influence on k_z value in our frequency band. The conditions of excitation

H_{11} mode are found sufficiently similar to obtained above for TEM-mode.

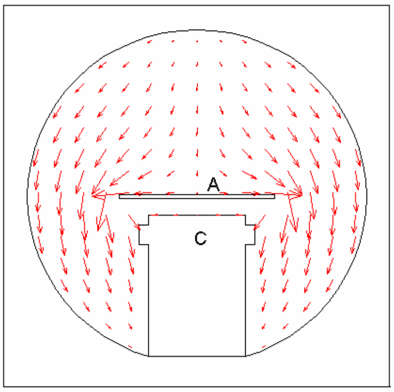


Fig. 7. Electric field of H_{11} mode

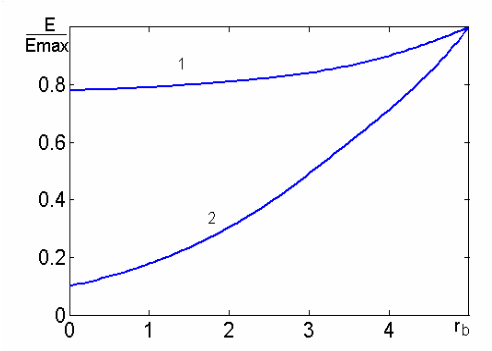


Fig. 8. Electric field distribution along beam radius. 1- TEM, 2 – H_{11} mode

Therefore it is possible to excite H_{11} mode in triode changing the beam parameters and the diode gap. The typical beam cross section electric field distribution of TEM-mode and H_{11} mode is given on Fig.8 for comparison.

4. Conclusion

Realized investigations show that

1. The regulable feedback in triode with VC can be successfully realized by means of moving reflector located on anode-holder axis.
2. The changing of reflector location brings to changing of radiation power level. That changing has the circulating character which period connected with radiation frequency.
   The period is decreasing with increasing of radiation frequency. Ratio of maximum and minimum of power level can be differing in 5 and more times.
   The most high radiation power level is observed at reflector location on the distance from cathode centre which is equal to integer number of half-waves.
3. The regulable feedback in triode with VC permits to realize the single-mode radiation.

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