The interaction of oscillations in Crossed-Field Devices

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Abstract: There were observed two models of crossed-field devices. The interaction between fundamental, ion and space charge oscillations caused to spectrum enrichment and chaotization. The comparison both theoretical and experimental results had good congruent.

Keywords: crossed-field device, synergetic effect, magnetron, magnetron diode, microwave device, motion equation, nonlinear equation

Introduction

The crossed-field devices are ones of the first and widespread microwave oscillators where electrons moving in crossed static electrical and magnetic fields and interacted with RF electromagnetic field.

It is well known the crossed-field devices are very effective. On the other hand these devices have many outland oscillations. Now these oscillations' nature is not understand. Such behaviour was described different mechanisms. Early [1 – 4] it were proposed such oscillations as ion, space charge and resonant structure.

The ion oscillations were caused by residual gases in vacuum electron devices [2]. The space charge oscillations were caused by electron emission and outer magnetic field [3]. The resonant oscillations were caused by form and geometric parameters of crossed-field devices' resonant structure [4].

Thus we can assume that these oscillations interact in operation device due to nonlinear effect in interaction space. The nonlinearity was caused the spectrum enrichment.

This work purpose is the description of synergetic effects due to oscillations' interaction in nonlinear environment of crossed-field electron devices.

Main part

To research we used two theoretical models: magnetron diode (magnetron with smooth anode) and magnetron with vane slowwave structure. The space motion equations in polar coordinates s, φ for electron moving in interaction space are

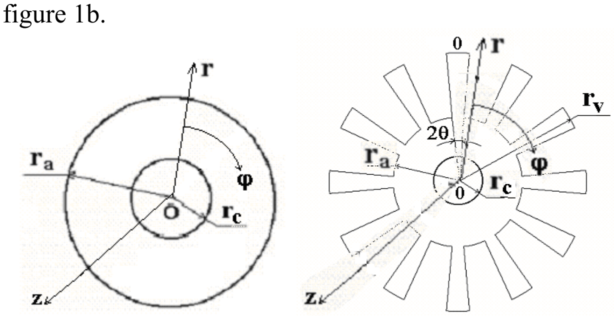
$$\begin{cases} \dfrac{d^2 s}{dt^2} - \left(\dfrac{d\varphi}{dt}\right)^2 s = \eta \dfrac{\partial U}{\partial s} - \omega_H s \dfrac{d\varphi}{dt} \\ s\dfrac{d^2\varphi}{dt^2} + 2\dfrac{ds}{dt}\dfrac{d\varphi}{dt} = \eta \dfrac{\partial U}{s\partial\varphi} + \omega_H \dfrac{ds}{dt} \end{cases} \qquad (1)$$

and initial conditions

$$s(0) = 1;\ \left.\frac{ds}{dt}\right|_{t=0} = 0;\ \varphi(0) = \varphi_0;\ \left.\frac{d\varphi}{dt}\right|_{t=0} = 0,$$

where $\eta = e/m$; $\omega_H = \eta B$.

The general view of the interaction space of magnetron diode is shown in figure 1a, and magnetron is shown in figure 1b.



a b
Figure 1. Interaction space
a – magnetron diode; b – magnetron

Potential U from (1) consists of four components: electrostatic, space charge, ion plasma and RF.
The electrostatic potential distribution in interaction space for magnetron diode is described by the following expression

$$U(s) = U_a \frac{\ln s}{\ln s_a},$$

and for magnetron [2, 3]

$$U(s,\varphi) = \frac{U_a}{\dfrac{N\theta}{\pi}\ln\dfrac{s_v}{s_a} + \ln s_a}\left\{\ln s - \right.$$

$$\left. - 2\ln\frac{s_v}{s_a}\sum_{n=1}^{\infty}\frac{\sin Nn\theta sirs^{Nn}\cos Nn\varphi}{(Nn\theta + \sin 2Nn\theta)(sirs_v^{Nn} - sirs_a^{Nn}) + \pi sirs_a^{Nn}}\right\}$$

where U_a – anode potential; $s = r/r_c$; $s_a = r_a/r_c$, $s_v = r_v/r_c$; N – number of resonators; 2θ – resonator angle.

The space charge potential distribution in interaction space both magnetron diode and magnetron is described by the following expression

$$U_{SC}(s) = A_{SC} cors^2 \cos \omega_{SC} t,$$

where

$$\omega_{SC} = k\omega_H \frac{\ln s_a \left(1-\sqrt{1-h^2}\right)\left(2-\sqrt{1-h^2}\right)}{2+\ln s_a \left(1-\sqrt{1-h^2}\right)\left(2-\sqrt{1-h^2}\right)},$$

$$h = \frac{\sqrt{\dfrac{8U_a \ln s_a}{\eta\left(\ln s_a + \dfrac{\theta N}{\pi}\ln\dfrac{s_l}{s_a}\right)}}}{Br_a\left(1-\dfrac{1}{s_a^2}\right)}.$$

The space charge oscillations stretched in hundred megahertz domain.

The ion plasma oscillation's potential distribution in interaction space both magnetron diode and magnetron is described by the following expression

$$U_i = A_i\left(\frac{s_a^2-1}{\ln s_a}\ln s - s^2 + 1\right)\cos\omega_i t.$$

The ion oscillations stretched from some megahertz to dozen megahertz.

The field structure of RF oscillations both magnetron diode and magnetron is described by the following expression

$$E_s = \frac{2E_1 \sin\gamma\theta\, cors^{\gamma}}{\pi s r_c sirs_a^{\gamma}}\sin(\gamma\varphi - \omega t)$$

$$E_{\varphi} = \frac{2E_1 \sin\gamma\theta\, sirs^{\gamma}}{\pi s r_c sirs_a^{\gamma}}\cos(\gamma\varphi - \omega t).$$

These oscillations stretched from some gigahertz to dozen gigahertz.

Here we discussed investigations' results of synergetic effect of interactions between different nature oscillations.

The principal output spectrum such systems is shown in fig. 2. In this figure we can see fundamental oscillation (f_0) and space charge oscillation.

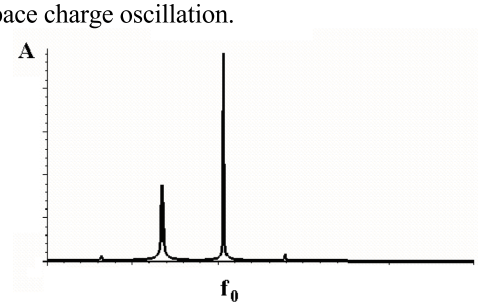


Figure 2. Principal output spectrum

Using theoretical model it was calculated output spectrum. The spectral lines were broaden due to interaction between ion oscillations and fundamental and space charge oscillations. Next increasing of ion oscillations' magnitude drive to breakdown of resonant structure oscillations and jump to chaotic operational regime. Output spectrum for such operational regime is shown in fig. 3. These results were according to experimental ones absolutely.

Oscillations' chaotization was a result of destroy the structure of negative space charge cloud by space charge of positively charged residual gases' ions.

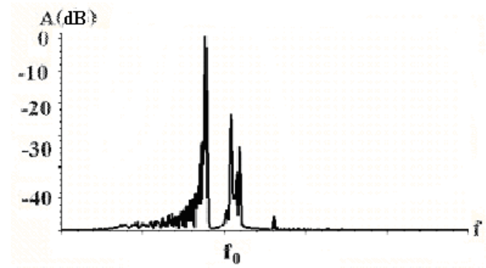


Figure 3. Chaotic oscillations

Conclusion

It is shown that possible the theoretical investigations of interaction processes of different nature oscillations in crossed-field systems. The comparison both theoretical and experimental results had good congruent.

Thus it is possible to simulate oscillations' interaction of different nature in crossed-field system.

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